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Performance Evaluation of Solar Air Heater by Using W-Discrete Rib Pattern

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Abstract

Solar air heater effectiveness enhancement is the major criterion today. For the enhancement of efficiency of solar air heater relative roughness pitch plays a very important role. An experimental investigation has been performed to know about heat transfer rate, thermo hydraulic performance and friction factor of W-Discrete ribs in the form of artificial roughness of solar air heater. The relative roughness pitch (p/e) of the ribs was taken as 6 and 10 to studies its effect.

Keywords: W-discrete ribs; Reynolds number; Heat transfer enhancement rate; Solar air heater.

1. Introduction

Artificial surface roughness is one of the active techniques of augmenting forced convection heat transfer. For the higher heat transfer rate the flow must me made turbulent at heat transferring surface. For the turbulent fluid flow some sort of external device is needed that may be in the form of fan, blower and compressor. But excessive turbulence leads to excessive power requirement for the proper supply of air through the duct. So it is desirable that the turbulence must be created only in the region very close to the heat transferring surface that is in the laminar sub layer only because it is the proper place of heat exchange but the fluid flow should not be unduly disturbed in order to avoid excessive friction losses. In solar air heater important parameters are shape of the roughness element, roughness element height (e) and pitch (p).

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The above mention parameters are usually specified in terms of dimensionless parameter called as relative roughness height (e/D) and relative roughness pitch (p/e). Friction losses can be reduced by keeping relative roughness pitch within a certain limit. Reattachment point that is responsible for the enhancement of heat transfer rate for varying relative roughness pitch.

Results shows that thermo-hydraulic performance of W-discrete rib for p/e as 10 are better than for p/e as 6.

2. Literature Review

Bhagoria and his colleagues [1] worked on wedge shaped rib with parameter of p/e, e/D and ϕ of different dimensions. Sahu and Bhagoria [2] investigated on transverse broken rib with parameter of p/e, e/D and α. Prasad and Saini [3] worked on rib geometry of transverse continuous rib of parameter p/e and e/D. Varun and his colleagues [4] worked on rib geometry of combination of inclined and transverse rib with parameter of p/e and e/D. Momin and his colleagues [5] investigated on V-shaped rib geometry with parameter of p/e, e/D and α. Singh and his colleagues [6] worked on discrete V-rib with another different parameter i.e d/W , g/e, p/e, e/D, α. Karwa and his colleagues [7] investigated on geometry of chamfered rib with p/e, e/D and ϕ. Saini and Saini [8] investigated on expanded metal mesh with e/D, S/e, L/e, α. Lanjewar and his colleagues [9] worked on W-shaped rib with p/e, e/D and α. Bopche and Tandale [10] worked on U-shaped rib with p/e, e/D and α. Saini and Verma [11] studied on Dimpled shaped rib with parameters p/e, e/D. Jaurker and his colleagues [12] worked on Rib-groove with parameter of p/e, e/D and g/p. Karmare and Tikekar [13] worked on metal grit rib with p/e, e/D and α. Saini and Saini [8] worked on Arc shaped rib with e/D and α. Literature reveals no study has been done on W-discrete rib and is worth exploring.

3. Experimental Set-up

An experimental set up is designed and fabricated to study effect of artificial roughed heat transfer and fluid flow characteristic in rectangular duct for range of parameters decided on the basis of practical considerations of system and operating conditions for different relative roughness pitch. The line diagram of experimental setup is shown in Fig.1. Experimental duct consists of wooden channel that includes five sections, namely smooth entrance section, roughened entrance section, test section, exit section and mixing chamber as outline by Duffie and Beckman [14]. G.I sheet of 20 SWG of 1.5 x 0.2 m^2 size is used as an absorber plate and lower surface of plate is provided with artificial roughness in form of discrete W-shaped copper wires.

An electric heater of dimensions identical to that of absorber plate is used to provide uniform heat flux to absorber plate up to maximum of 1500 W m^{-2}. Power supply to heater is provided through variable transformers. Transformer enables heat flux applied to absorber plate to be varied as desired relative roughness pitch (p/e) is varied. Range of Reynolds number and relative roughness height (e/D_h) is chosen based on requirement of solar air heater. Parameters to be tested are Reynolds number and relative roughness pitch for given angle of attack and relative roughness height. The experimental result will be plotted as function of operating parameter like Reynolds number, relative roughness pitch. Roughened plate shown in Fig. 2 and Fig.3.

4. Result and Discussion

Variation of Nusselt number and friction factor for of relative roughness pitch of 6 and 10 is shown in Fig. 4 and Fig. 5

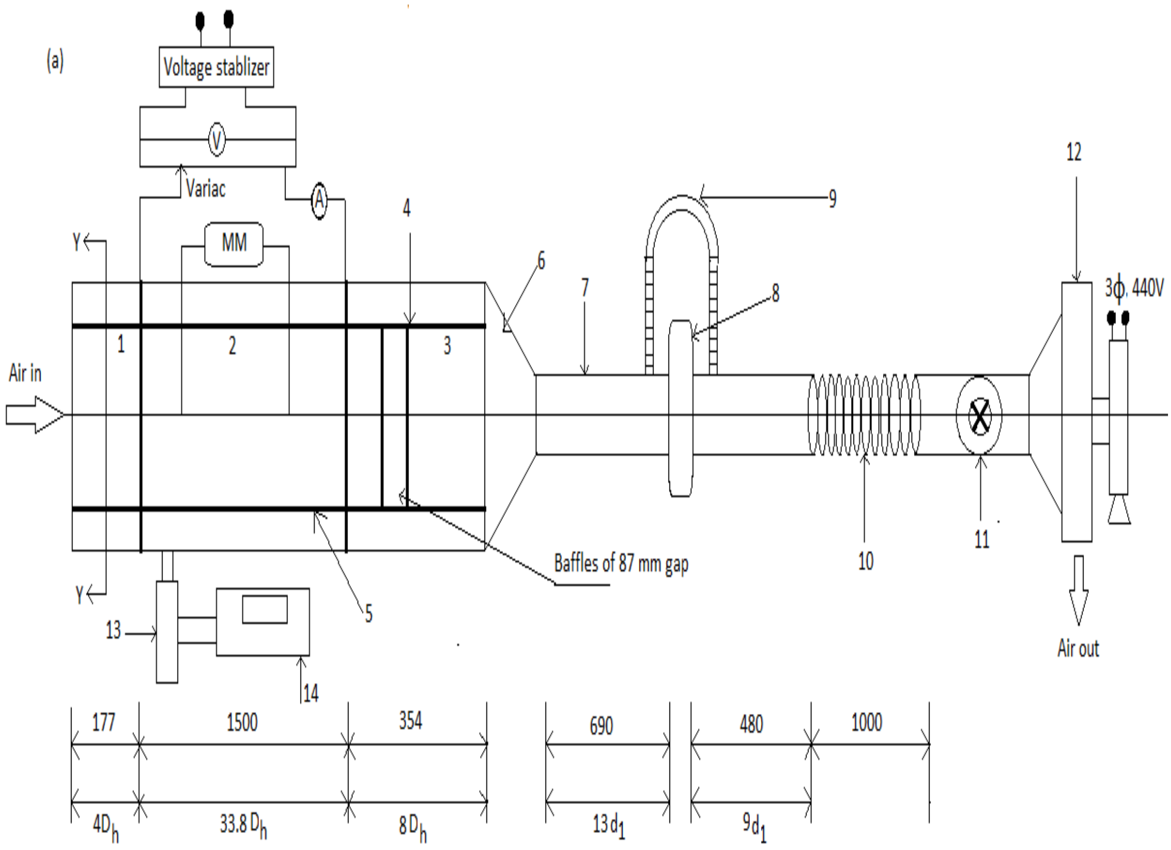

Figure 1: Experimental Set-up

Figure 2: Photograph of W-discrete ribs roughness plate

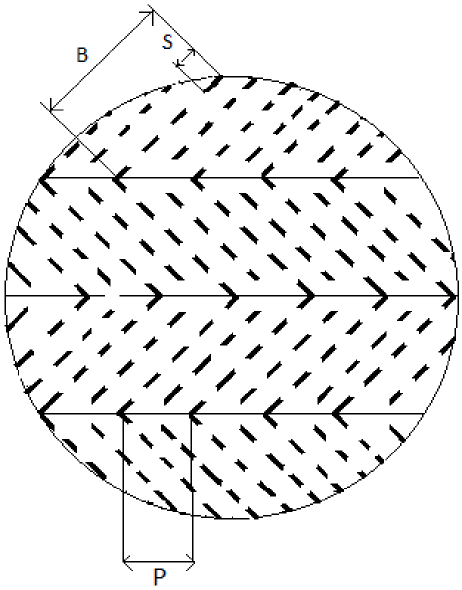

Figure 3: Enlarged view of cross-section of roughness plate

Table 1: Roughness Parameters

S.NO.	PARAMETERS	VALUES
1	Relative roughness height (e/D_h)	0.03375
2	Relative roughness pitch (p/e)	6, 10
3	Relative roughness length ratio(B/S)	6
4	Relative roughness staggering ratio (p'/p)	0.6
5	Relative roughness segment ratio (S'/S)	1
6	Plate length, L (m)	1.5
7	Reynolds number (Re)	4000 - 14,000
8	Angle of attack (α)	60^o
9	Rib height (e)	1.5 mm
10	Duct aspect ratio (W/H)	8
11	Hydraulic diameter, D_h (m)	0.044

Nusselt number increases with increase in Reynolds number due to progressive breaking of laminar sub-layer. Friction factor decreases with increasing Reynolds number due to increase in pressure drop. Heat transfer enhancement is accompanied with increase in pressure drop it is necessary to evaluate thermo-hydraulic performance. Thermo-hydraulic parameter is plotted against Reynolds number in Fig.6. Figure shows that thermo-hydraulic performance for p/e 10 is greater than thermo-hydraulic performance for p/e 6. Above results are in accordance with the literature as optimum value occur for p/e 10 for rib roughness due to reattachment point considerations.

5. Conclusion

In this paper an attempt has been made to report heat transfer and friction characteristics of artificial roughened duct of solar air heater. It is observed that artificial roughness is a good option to enhance the thermal performance of solar air heaters. After experimental investigation the successful results concluded are as follows:

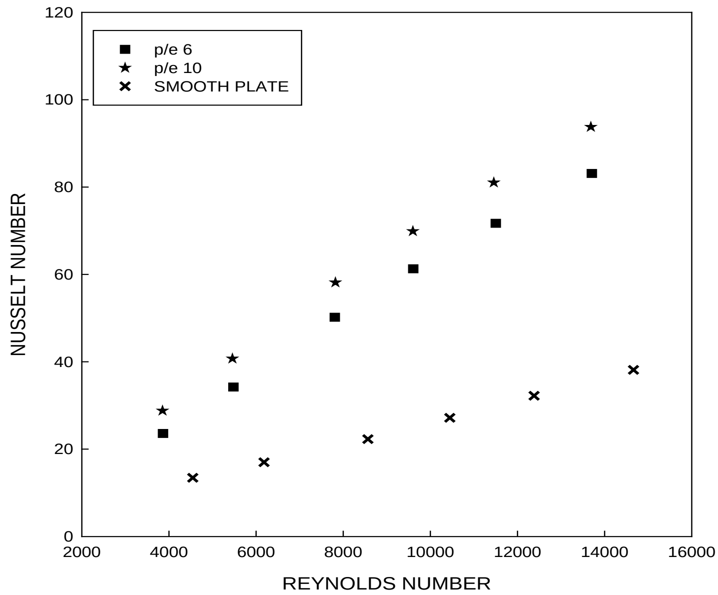

Figure 4: Effect of Reynolds on Nusselt number with variation of relative roughness pitch as compare to smooth duct for W-discrete ribs flow arrangement.

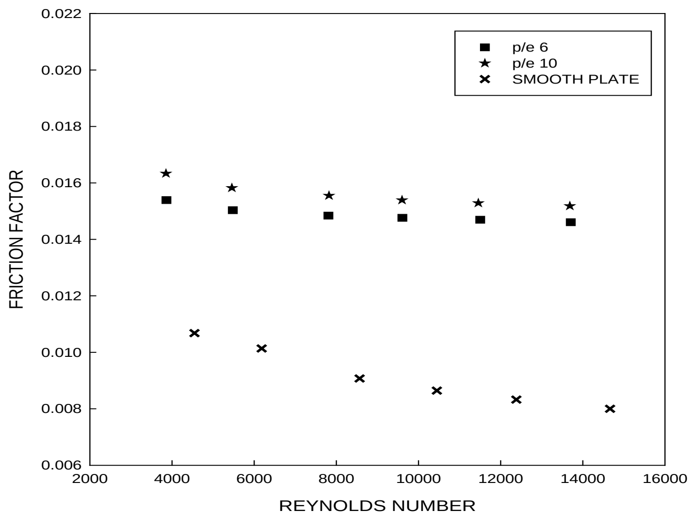

Figure 5: Effect of Reynolds on friction factor with variation relative roughness pitch as compare to smooth duct for W-discrete ribs flow arrangement.

1. Maximum thermo-hydraulic parameter with W-discrete rib is found with relative roughness pitch of 10.

2. It has been found with increase of Reynolds number the value of Nusselt number also increases. Maximum value of Nusselt number found for relative roughness pitch of 10.

3. Friction factor decreases with increase in Reynolds number. Maximum value of friction factor also occurs for relative roughness pitch of 10.

4. Thermo-hydraulic performance increases and attained maxima and then decreases. Thermo-hydraulic performance is higher for relative roughness pitch of 10 as compare to relative roughness pitch of 6.

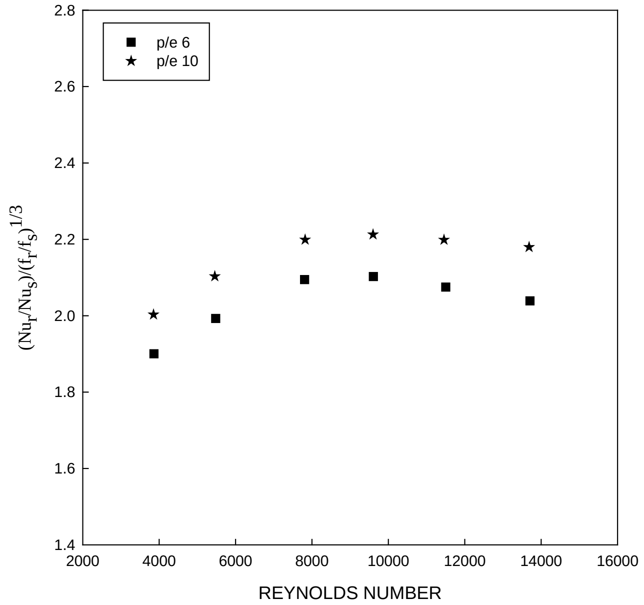

Figure 6: Effect of Reynolds number on Thermo-hydraulic parameter for relative roughness pitch as compare to smooth duct for W-discrete ribs flow arrangement.

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Appendix 1: Nomenclatures

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 (^{o})

p Rib pitch, m

e Rib height, m

f Friction factor

f_r Friction factor of roughened duct

f_s Friction factor of smooth duct

H Depth of duct

L Duct length, m

m Mass flow rate, kg/s

Nu Nusselt number

Nu_r Nusselt number of roughened duct

Nu_s Nusselt number of smooth duct

Re Reynolds number

Dimensionless parameters

e/D_h Relative roughness height

p/e Relative roughness pitch, dimensionless

B/S Relative gap width

S'/S Relative roughness segment ratio

p'/p Relative roughness staggering ratio

Greek symbols

α Angle of attack (^{o})