Heat Transfer Enhancement of Solar Air Heater By Using Artificial Roughness double inclined ribs

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Abstract - Artificial roughness applied on the absorber plate is the most acclaimed method to improve thermal performance of solar air heaters at the cost of low to moderate friction penalty. Providing an artificial roughness on a heat transferring surface is an effective passive heat transfer technique to enhance the rate of heat transfer to fluid flow. The objective of this experimental study, by using different artificial roughness elements to enhance the heat transfer rate in range of Reynolds no 3000-12000, relative roughness height (e/Dh) of 0.022 and angle of attack of flow (α) of 30̊ for a fixed relative pitch of 10. Results have also been compared with those of smooth duct under similar flow conditions to determine the enhancement in heat transfer coefficient

Keyword- rectangular duct, heat transfer enhancement, Convective Heat Transfer Coefficient

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. Solar energy is available abundance on earth in the form of radiation. Solar energy is used for heating application and converts it into thermal energy. Solar air heater is the cheapest way of converting solar energy into thermal energy. Thermal performance of solar air heaters is comparably poor from solar water heaters. Thermal performance may be increased by increasing convective heat transfer coefficient. There are two way for increasing heat transfer coefficient either increase the area of absorbing surface by using fins or create the turbulence on the heat transferring surfaces.

HEAT TRANSFER ENHANCEMENT TECHNIQUE

Heat transfer inside flow passages can be enhanced by using passive surface modifications such as rib tabulators, protrusions, pin fins, and dimples.These heat transfer enhancement techniques have practical. Application for internal cooling of turbine airfoils, combustion chamber liners and electronics cooling devices, biomedical devices and heat exchangers. The heat transfer can be increased by the following different Augmentation Techniques.

They are broadly classified into three different categories:

(i) Passive Techniques

(ii) Active Techniques

(iii) Compound Techniques.

MECHANISMS OF AUGMENTATION OF HEAT TRANSFER

The mechanisms of heat transfer enhancement can be at least one of the following.
1. Use of a secondary heat transfer surface.
2. Disruption of the unenhanced fluid velocity.
3. Disruption of the laminar sub layer in the turbulent boundary layer.
4. Introducing secondary flows.

5. Promoting boundary-layer separation.
6. Promoting flow attachment/reattachment.
7. Enhancing effective thermal conductivity of the fluid under static conditions
8. Enhancing effective thermal conductivity of the fluid under dynamic Conditions
9. Delaying the boundary layer development.
10. Redistribution of the flow.

CONCEPT OF ARTIFICIAL ROUGHNESS

Thermo hydraulic performance of a solar air heater can be improved by providing artificial roughness on the absorber plate. The artificial roughness has been used extensively for the enhancement of forced convective heat transfer, which further requires flow at the heat-transferring surface to be turbulent. However, energy for creating such turbulence has to come from the fan or blower and the excessive power is required to flow air through the duct. Therefore, it is desirable that the turbulence must be created only in the region very close to the heat transferring surface, so that the power requirement may be lessened. This can be done by keeping the height of the roughness elements to be small in comparison with the duct dimensions.

The key dimensionless geometrical parameters that are used to characterize roughness are:

1. Relative roughness pitch (p/e): Relative roughness pitch (p/e) is defined as the ratio of distance between two consecutive ribs and height of the rib.

2. Relative roughness height (e/d): Relative roughness height (e/d) is the ratio of rib height to equivalent diameter of the air passage.

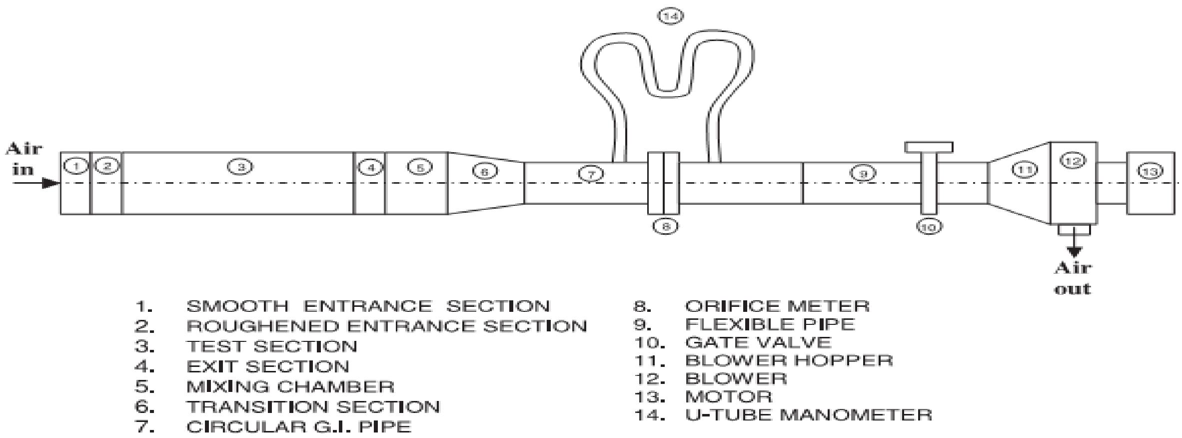
3. Angle of attack: Angle of attack is inclination of rib with direction of air flow in duct.

4. Shape of roughness element: The roughness elements can be two-dimensional ribs or three-dimensional discrete elements, transverse or inclined ribs or V-shaped continuous or broken ribs with orwithout gap. The roughness elements can also be arc-shaped wire or dimple or cavity or compound rib-grooved. The common shape of ribs is square but different shapes like circular, semi-circular and chamfered have also been considered to investigate thermo hydraulic performance.

5. Aspect ratio: It is ratio of duct width to duct height. This factor also plays a very crucial role in investigating thermo-hydraulic performance.

II. THE EXPERIMENT

A. The apparatus



An experimental set-up has been designed and fabricated to study the effect of 30̊ double inclined ribs on heat transfer and fluid flow characteristics of flow in rectangular duct and to develop correlations for heat transfer coefficient and for the range of parameters decided on the basis of practical considerations of the system and operating conditions. The experimental duct consists of channel of 2.8 m long and 0.2 m wide which includes five sections, namely, smooth entrance section, roughened entrance section, test section, exit section and mixing chamber as Duffie and Beckman [21]. An G.I sheet of $1.5\times0.2m^2$ size was used as an absorber plate and the lower surface of the plate provided with artificial roughness in the form of double inclined copper wires. An electric heater plate of identical di-mensions as those of absorber plate was used to provide a uniform heat flux up to a maximum of 1500 Wm^{-2} to the absorber plate. The power supply to the heater plate assembly was controlled through an ACvariac.

B. **Roughness geometry**

The optimum parameter has been used in the present experiment as was discussed in the literature sandeep at al. (2015) . Relative roughness pitch (P/e) =10mm, angle of attack (α) =30̊, wire diameter (e)=1mm, width of absorber plate (W)=200mm, length of absorber plate(L)=1500mm. The arrangement of ribs on surface in square channel is shown in figure.

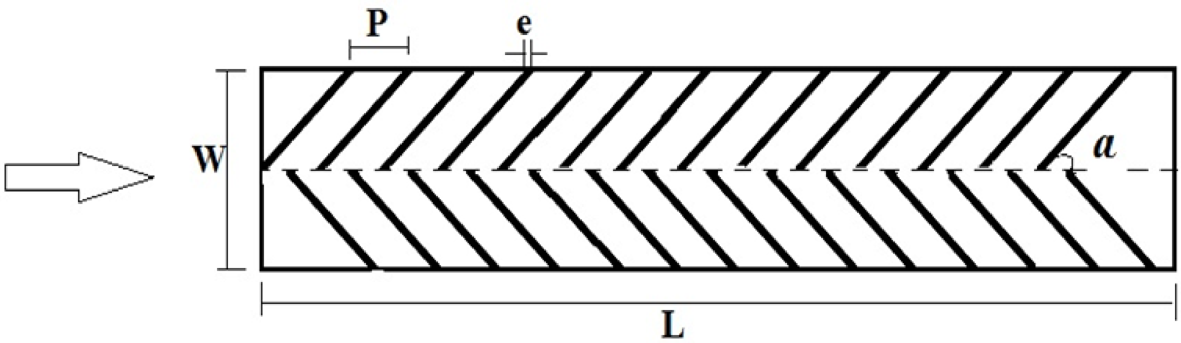


Fig :- Schematic diagram of double incline ribs

C. Experimental procedures

The air is sucked through the rectangular duct by means of a blower driven by a 3-phase, 440 V, 3.0 kW and 2880 r.p.m, AC motor. It sucked the air through the duct and a gate valve has been used to control the amount of air in the duct. The air is thoroughly mixed in the mixing chamber before the exit temperatures were recorded and baffles were provided for achieving thorough mixing of the air. The duct was covered with thermocole (foamed polystyrene) from the three sides and upper side of the duct was covered with the ther-mocole and black insulating material, to ensure that all the heat flux which is supplied from the heater plate is transferred to the duct and also to minimize the losses to the surroundings. The other end of the duct is connected to a circular pipe via a rectangular to circular transition section.

The flow rate of air in the duct was measured by means of a flange type orifice meter calibrated by using a pitot tube, and the values of the coefficient of the dis-charge were obtained and used for calculating the flow rate of the air. Pressure drop across the orifice meter was measured by an inclined U-tube manometer with Spirit as manometric fluid.

D. Data Reduction

Steady state values of the plate and air temperatures in the ductat variouslocations were obtained fora given heat flux and mass flow rate of air. Heat transfer rate to the air, Nusselt number and friction factor have been computed from the data. These values have been used to investigate the effect of various influencing parameters viz., the flow rate, the relative roughness height and the angle of attack of flow on the Nusselt number.

The following equations have been used for the evaluation of relevant parameters:

$$q = m \times C_p \times (\overline{t_o} - \overline{t_i}),$$

$$h = q/[A_c \times (\overline{t_p} - \overline{t_f})],$$

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

III Result and discussion

Table :-1

Table shows the result of smooth absorber plate

S no	Mass flow rate (kg/s)	Velocity (m/s)	Reynolds no	Qair (W)	Nusselt no
01	0.00854	1.500	4019	99.3	11.21
02	0.01202	2.116	5658	129.5	17.01
03	0.01707	2.981	8032	160.5	24.19
04	0.02100	3.656	9882	179.6	28.53
05	0.02509	4.340	11809	189.4	32.95

Table:- 2

Table shows the result of double inclined ribs with30 degree

S no	Mass flow rate (kg/s)	Velocity (m/s)	Reynolds no	Qair (W)	Nusselt no
01	0.00866	1.47	4141	102	15.38
02	0.01227	2.078	5887	143.6	21.55
03	0.01742	2.93	8393	177.5	29.388
04	0.02149	3.583	10417	190.24	34.2
05	0.02555	4.274	12355	204.27	36.56

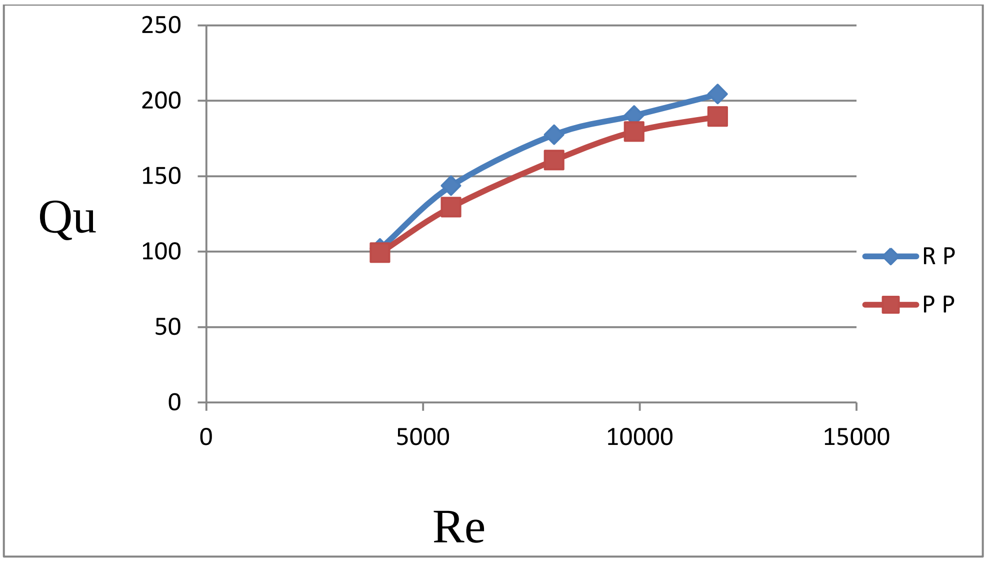


Fig.1. Variation of Qu with Reynold's No

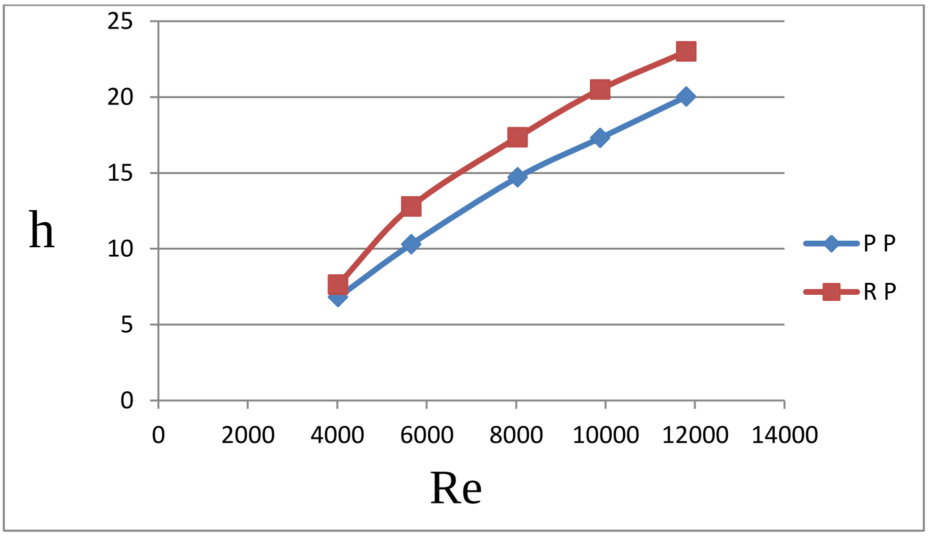


Fig.2. Variation of h with Reynold's No

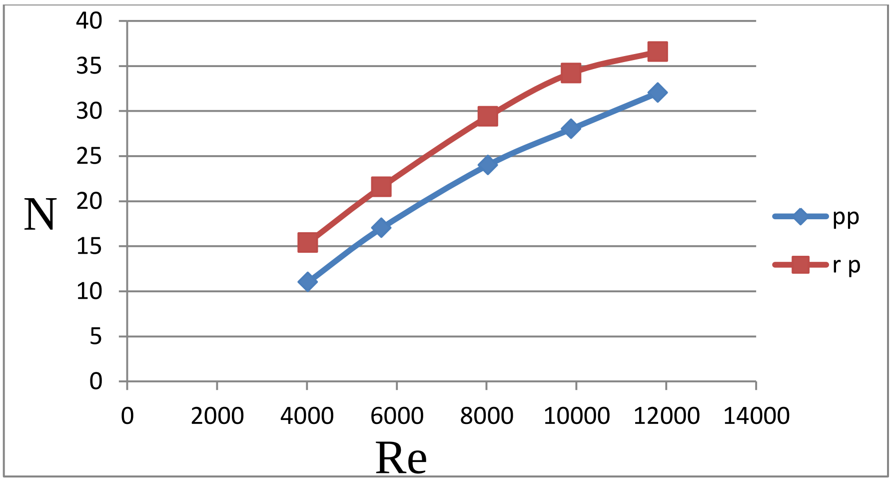


Fig.3. Variation of Nusselt No. with Reynold's No

IV. Conclusions

The following conclusions can be drawn from this work:

1. It was observed that the rate of increase of Nusselt number with an increase in Reynolds number this appears due to the fact that at relatively higher values of relative roughness height, the reattachment of free shear layer might not occur and the rate of heat transfer enhancement.
2. The thermo-hydraulic performance parameter improves with increasing the angle of attack of flow and relative roughness height.

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