Performance Analysis of Solar Air Heater in Rectangular Channel With Double Inclined Ribs with Gap

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Abstract-The efficiency of solar air heater is incredibly low. So in order to increase the efficiency of solar air heater we can create the geometry on the solar absorber plate. The heat transfer from surfaces might normally be increased by enhancing the heat transfer coefficient in between a surface and its surroundings, and by increasing the heat transfer area of the surface, or by both. In most of cases the heat transfer coefficient is worries with the appliance of artificial surface roughness techniques as a create turbulence for convective heat transfer improvement.

An experimental study has been conducted to research heat transfer, and thermo-hydraulic performance characteristics of flow in an exceedingly rectangular duct artificial roughened on one side with 75̊ double inclined ribs with gap. The rectangular duct used had aspect ratio of 5 and the Reynolds number based upon the mass flow rate of air at inlet of the duct ranged from 4000 to 12000. The rib pitch(P) 10, rib height-to-hydraulic diameter (e/Dh) ratio 0.0337 and angle of attack (α) 75̊ while, gap width (g) 2,3,4, one number of gap (n) on both side of the inclination were used as fixed parameters during the experimentation.

Keyword- rectangular duct, heat transfer enhancement, convective heat transfer coefficient

1. Introduction

Solar air heaters are very simple in design and construction. They're wide used as collection devices having applications like crop drying and space heating. Efficiency of smooth plate solar air heater is low as aresult of low convective heat transfer coefficient between absorbent plate and flowing air that enhancing the absorber plate temperature, leading to higher heat losses to environment. Low value of heat transfer coefficient is due to presence of laminar sub-layer that can be broken by creating artificial roughness on heat transferring surface. Efforts for enhancing heat transfer coefficient have been directed toward artificially disturbing this laminar sub-layer.

Artificial roughness in kind of ribs and in varied configurations has been used to produce turbulence close to wall or to interrupt laminar sub-layer. Artificial roughness results in high frictional losses resulting in additional power demand for fluid flow. Thus turbulence has got to be created in region very near to heat-transferring surface for breaking laminar sub-layer. Core fluid flow should not be unduly disturbed to limit increase in pumping demand. This is often done by keeping height of roughness elements little as compared to duct dimensions. Application of artificial roughness in solar air heater owes its origin to many investigations carried out for enhancement of cooling of turbine blades' passage. Many investigations are administered to check result of artificial roughness on heat transfer and friction factor for 2 opposite roughened surfaces by Han [3,4], Han et al. [5-7], Wright et al. [8], Han and Park [15], and correlations were developed by completely different investigators.

Saini and Saini [23] , Karwa et al. [24], Bhagoria et al. [26], Aharwal et al. [33], Saini and Verma [35] and Saini and Saini [36] have administrated investigations on artificial rib roughened absorber plate of solar air heater that has only one roughened wall and three plane walls. Correlations for heat transfer coefficient have been developed for such systems. Saini and Saini [23] investigated performance of dilated metal mesh geometry by varying relative short way length and relative long way length of mesh. Karwa et al.[24] investigated effect of rib chamfer angle(ϕ) and duct aspect ratio on heat transfer coefficient and friction factor using integral chamfered ribs. Chamfer angle of 15gave highest Stanton number as well as highest friction factor. Bhagoria et al. [26] investigated wedge shaped transverse integral rib roughness. Maximum heat transfer coefficient occurred for relative roughness pitch of 7.57. Wedge angle of 10gave maximum enhancement of heat transfer. Karwa [28] investigated effect of transverse shaped ribs, inclined ribs, continuous V and discrete V pattern ribs on heat transfer enhancement. V pattern ribs were tested pointing upstream and downstream to flow. Based on equal pumping criteria V-down ribs arrangement gave best heat transfer performance. Sahu and Bhagoria [29] investigated using 90̊ broken transverse ribs on solar absorber plate of solar air heater. Plate with relative roughness pitch of 20 mm gave maximum efficiency of 83.5%. Aharwal et al.[33] investigated heat transfer enhancement due to relative roughness gap in inclined continuous rib arrangement for square cross-section rib. They reported maximum increasing in Nusselt number and friction factor to be 2.87 and 2.59 times to that of plane duct respectively. Saini and Verma [35] investigated performance of solar air heater using dimple shape roughness element. Investigation covered range of Reynolds number (Re) from 2000-12000, roughness height from 0.018-0.037 and roughness pitch from 8 to 12.

They reported that large value of Nusselt number corresponded to roughness height of ribs are 0.037 and roughness pitch of 10. Small value of friction factor corresponded to relative roughness height of 0.0289 and relative roughness pitch of 10. Saini et al. [36] investigated that performance of solar air heater using arc shaped wire as artificial roughness. Although analytical tools are available for studing heat transfer problems, however due to complex nature of governing equations and issues in getting numerical solutions, researchers have focused heighest attention on experimental investigation. According to literature survey it has been found that Han et al. [5] investigated effect of rib shape, angle of attack and pitch to rib height ratio (p/e) on heat transfer and friction factor characteristics of rectangular duct with two side roughened walls. They reported that large value of heat transfer and friction factor occurs at relative roughness pitch of 10 and for ribs oriented at 45angle when compared to ribs at 90angle of attack or when compared to sand-grain roughness. There after focus of rib turbulators shifted to investigation of high performance ribs. Han et al. [7] investigated square channel with V, parallel (angled) and crossed ribs. Results reported that 60 deg (or 45 deg) V-shaped rib have better performed than 60 deg (or 45 deg) respectively parallel rib and also better than 60 deg (or 45 deg) crossed rib and 90 deg rib. V-shaped rib gave maximum heat transfer augmentation while L -shaped rib generated greatest pressure drop. Crossed ribs produced minimum heat transfer enhancement and smallest pressure drop penalty.

Studies of Han et al. [5 e7] , Wright et al. [8], Lau et al. [9 e11] and Taslim et al. [12,13]have not covered wide range of relative roughness and operating parameters that would be required for selection of roughness parameter to be used in solar air heaters. Most of the study carried out so far have applied artificial roughness on two opposite walls within all four walls being heated. But in case of solar air heater, roughness elements are applied to heated wall while rest three walls are fully insulated. Heated wall consists of absorber plate and is subjected to uniform heat flux. This makes flow of fluid and heat-transfer characteristics distinctly different from those found in case of two roughened walls and four heated wall channel. Literature survey reveals that inclined and V-ribs give significant increasing in heat transfer as compared to plane absorber plate. Secondary flow generated in above two cases has been crated as the main cause. In case of V-ribs four secondary vortices are generated. If the number of vortices is increased then theoretically it should increase heat transfer. However effect on friction needs to be investigated experimentally to evaluate its feasibility. Hence the present study has been taken up with objective of experimentation on W-shaped ribs as artificial roughness attached to inner side of one broad wall of duct, to collect data on heat transfer and fluid flow characteristics. Data is available in form of Nusselt number and friction factor plots as a function of geometrical parameters of artificial relative roughness and thermo-hydraulic performance plots to bring out clearly effect of these parameters and enhancement in heat transfer coefficient achieved as result of providing artificial roughness.

2. Experimental program and procedure

Experimental procedure and program an experimental set up has been designed and fabricated to study effect of double inclined ribs with gap on heat transfer and fluid flow characteristics in rectangular channel for range of parameters selected on the basis of sensible concern of system and operating conditions. Experimental duct consists of wood channel that has five sections, namely roughened entrance section, smooth entrance section, test section, exit section and mixing chamber as out lined by Duffie and Beckman [37]. G.I sheet of 20 SWG of $1.5\times0.2\ m^2$ size has been used as an absorber plate and lower surface of plate has been provided with artificial roughness in form of double inclined with gap ribs copper wires. An electric heater of dimensions identical to that of absorber plate has been used to provide uniform heat flux to absorber plate up to maximum of 900 Wm^2. Power supply to heater has been provided through variable transformer. Transformer enables heat flux applied to absorbent plate to be varied as desired. Schematic diagram of experimental set up Fig. 1. W-shaped roughness elements were fixed below the absorber plate and fast drying epoxy has been applied for gluing roughness elements. Relative roughness pitch (p/e) value has been selected as 10, based on optimum value of this parameter reported in literature[5,27].

II. THE EXPERIMENT

A. The apparatus

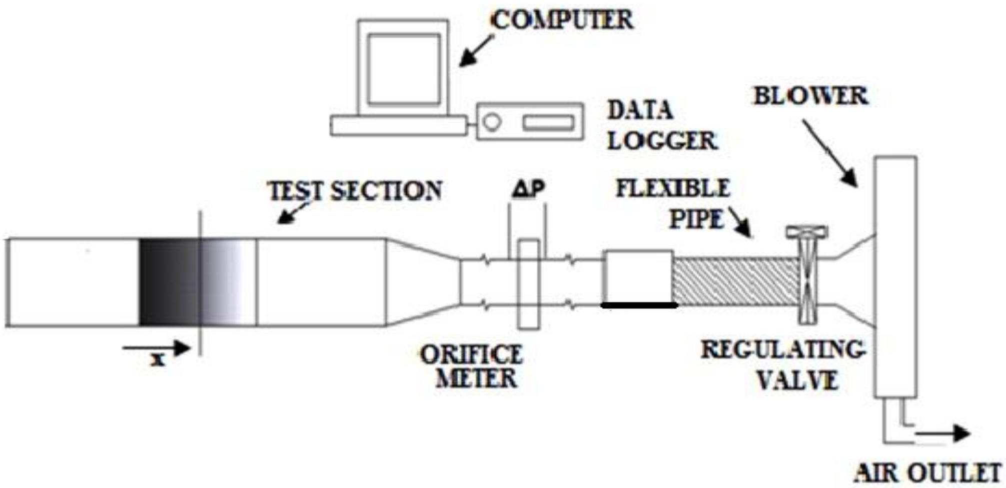

Fig 1:- Schematic diagram of experimental setup

In this experimental work an experimental setup has been designed and fabricated figure to measure the Nusselt number of smooth surface and artificial roughened surface. Fig (1) shows the schematic diagram of experimental set-up. It consists of heating element, test section, blower, data logger and computer. Test section was a rectangular channel with aspect ratio 8 and length 1.5m and made of G.I sheet. The upper plate of the test section made of G.I sheet. A surface heater with temperature sensing element was used to warm up incoming air. Fine-gauge T-type thermocouples were used inside the duct and directly exposed to the airflow, also at several locations of the duct wall. T-type thermocouples were used to measure the mean air temperature at the section inlet and outlet. A data logger was used for temperature recording.

B. Roughness geometry

The optimum parameter has been used in the present experiment as was discussed in the literature sandeep et al. (2015). Relative roughness pitch (P/e) =10, angle of attack (α) =75°, relative gap width (g/e) =2. The arrangement of ribs on surface in square channel is shown in figure. Effect of gap position and gap width was examined in this work.

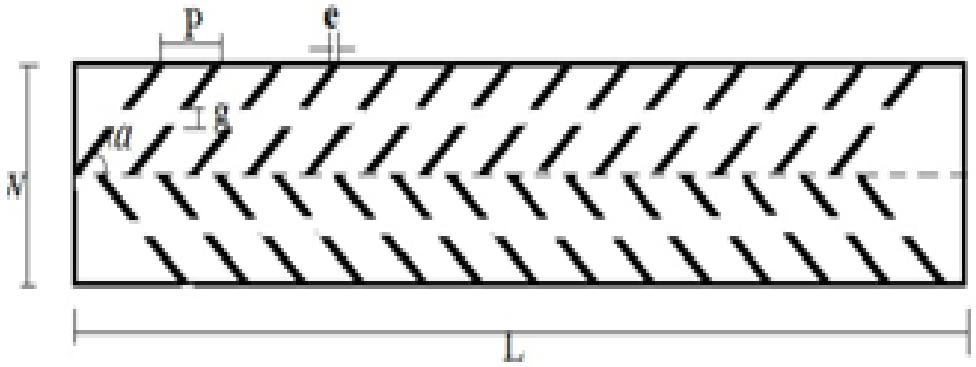

Fig 2 :- Schematic diagram of double incline ribs with gap

On the enhancement of heat transfer and friction factor, the relative gap position (d/W) in discrete rib was kept 2 of the width of the duct. Gap position for consequently broken rib is kept in pattern. The relative gap width (g/e) was 1. The range of Reynolds number is 4000 -14000 and relative roughness height (e/D) has been chosen 0.03

C. Experimental procedures

In the test surface for measuring temperature distributions in duration of transferring heat from hot air by using thermocouple. After the copper wire had been set in the desired pitch over the surface of G.I sheet and the airflow velocity had been adjusted by valve to a prescribed velocity. Initially test model must be kept at constant temperature. At the time when the temperature of the air was maintained constant at the event temperature. The thermocouple readings were recorded by use of data logger. Data were recorded to measure the temperature distribution over the surface. Flow is adjusted by valve for different Reynolds no and take reading for different Reynolds no.

D. Data Reduction

The semi infinite transient technique has been employed in this study. The convective heat transfer coefficient is determined by using following relationship.

$$\frac{T(t) - Ti}{Tb - Ti} = 1 - exp\left(\frac{h^2 \alpha t}{k^2}\right) erfc\left(\frac{h\sqrt{\alpha t}}{k}\right)$$

Where Ti is the initial temperature of the surface, Tb is the bulk mean temperature of hot air in the channel, T(t) is the transient temperature distribution, h is the heat transfer coefficient, α and k are the thermal diffusivity and conductivity of the wall material, respectively. The Nusselt and Reynolds number were explained by following formula

$$Nu = h\, D_{ch}/k$$

$$Re = (\dot{m} D_{ch}) / (\mu A_{ch})$$

Where ṁ is the mass flow rate, Ach is the flow area offered by the rectangular channels without ribs, Dch is the hydraulic diameter of the rectangular channel. Thermal conductivity k and dynamic viscosity μ of air were calculated at the film temperature.

III Result and discussion

S. no	Mass flow rate (kg/s)	Velocity (m/s)	Reynolds no	Qair (W)	Nusselt no
1	0.00863	1.48	4099	106.99	14.33
2	0.01221	2.09	5798	153.33	24.92
3	0.01727	2.95	8222	185.67	38.57
4	0.02126	3.62	10136	204.94	49.37
5	0.02535	4.31	12114	212.57	54.79

Table 1:- shows the result of 75̊ double inclined ribs with 2mm gap

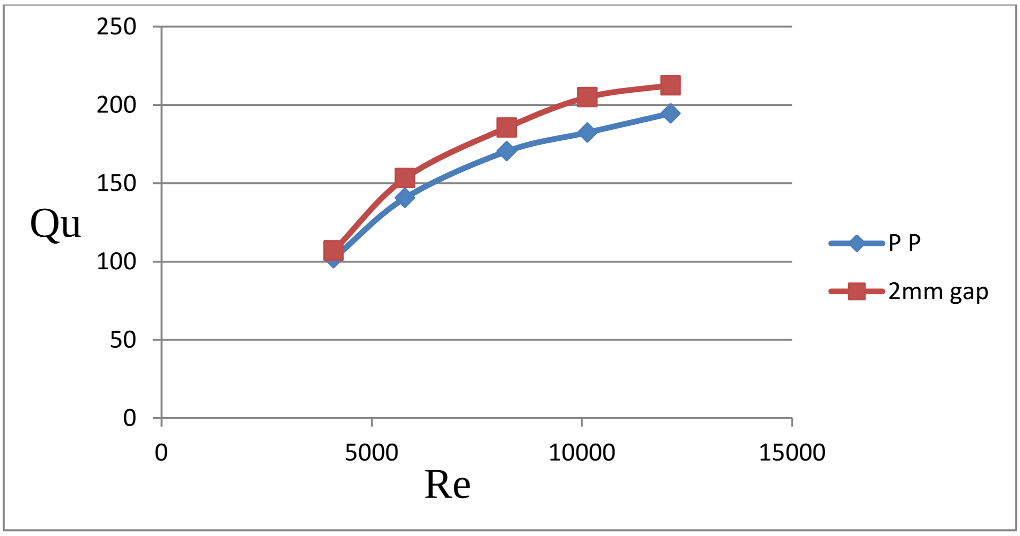

Fig 3 :- Variation of Qu with Reynold's No

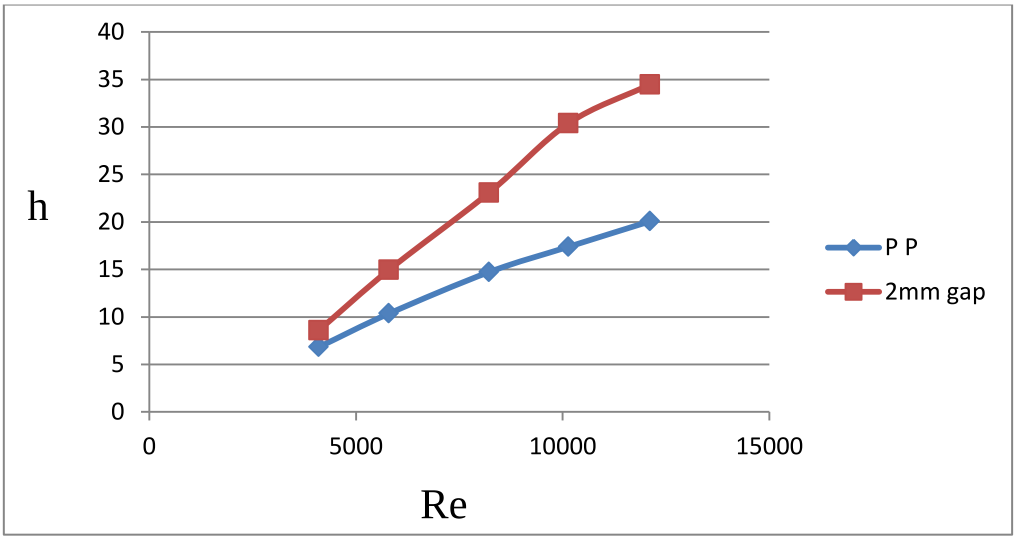

Fig 4 :- Variation of h with Reynold's No

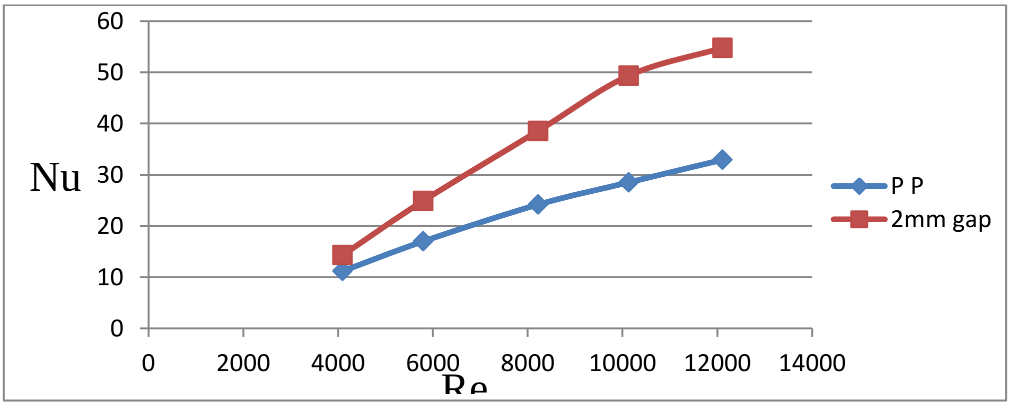

Fig 5 :-Variation of Nusselt No. with Reynold's No

IV. CONCLUSIONS

In this paper new double inclined discrete rib roughness geometry has been investigated for the enhancement of heat transfer. This roughness arrangement gap position was kept middle to both on the inclined the side wall in alternate fashion with consecutive ribs roughness. Experimental tests were performed with the technique for the selected design parameters of rib roughness geometry to find the average Nusselt number. It is observed that the enhancement of heat transfer for proposed double inclined discrete rib roughness arrangement is better as compared to that of the smooth plate.

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