# Thermo Hydraulic Performance of Solar Air Heater by Using Double Inclined Discrete Rib Roughened Absorber Plate

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## Abstract

As it is well known, heat transfer coefficient of a solar air duct can be increased, by providing artificial roughness on the heated wall. An experimental investigation has been carried out to study of thermo hydraulic performance of solar air duct with various types of artificial roughness geometries at the absorber plate. The experiments were performed to collect thermo hydraulic performance for forced convection flow of air in solar air heater rectangular duct with one broad wall roughened by double inclined ribs. Characteristic performance parameters, investigated for the heat transfer has been presented. The performance evaluation in Terms of thermo hydraulic performance has been carried out for various value of Reynolds number for some selected artificial roughness geometries, in the absorber plate of solar air heater duct.

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

## Introduction

The energy demand is growing continuously and rapidly, and it is impossible to meet the future demand with the presently available exhaustible energy sources. So, the technology is focusing on harnessing new and renewable sources of energy. Furthermore, the conventional energy sources are causing an alarming health hazard to the planet life. The use of solar energy is an intelligent option for the use of mankind which is available free of cost, in abundant and is a clean source for various applications. The solar energy can be used directly or indirectly by converting it into thermal energy. Instead of direct use of solar energy, it is more useful when converted in to thermal energy. Solar air heater is such a device, which converts solar energy into thermal energy. It can be used for various applications like the heating of building, wood seasoning, drying of crops of fruits and vegetables , chicken brooding as well as curing of industrial products. It has many advantages like low fabrication, installation, and operational costs, and can be constructed by using cheaper and lesser amount of material. However, its efficiency is poor. The lower efficiency of solar air heater is attributed to poor heat transfer characteristics of air, and also the air cannot be used as storage fluid due to low thermal capacity. The low efficiency of the solar air heater can be increased either by increasing the surface area of the absorber plate or by using certain artificial geometries on the absorber plate with some adverse effect of the increase in frictional loss inducts which is needed to be taken care of by using proper, geometrical parameters and flow conditions. The use of artificial roughness rib elements on the absorber plate is one of the effective ways which enhances the heat transfer coefficient of the air, thus increasing the heat transfer rate . These roughness rib elements breaks up the boundary layers and induces turbulence which results in heat transfer enhancement. These roughness elements being smaller in height as compared to duct size causes turbulence in the laminar sub layer adjacent to the wall without affecting the main turbulent zone in the flow. Several attempts have been ma de by various researchers in their experimental work to achieve the heat transfer enhancement through these solar air heaters by using different roughness elements on the surface of absorber plate . The researchers have used several geometries of artificial rib roughness elements with different parameters and material still now. But still this area of research has large opportunity for doing novel work to achieve the heat transfer enhancement with new geometry with different parameters.

# Heat transfer enhancement through artificial roughness

Arti fi cial roughness and different obstruction used in the path of air passage in solar air heaters are used to increase the heat transfer rate either by breaking the laminar sub-layer or by increasing the turbulence in duct passage for air flow. Artificial roughness solves the first purpose and obstructions in the form of baffles, and winglets solve the second purpose. However, this increase in the thermal performance is gained at the cost of the increase in the pressure drop which requires pump or blower to supply energy to the fluid. The important phenomenon which helps to increase the heat transfer by using roughness elements in solar air heaters are (a) reattachment of flow, (b) formation of secondary flow, and (c) formation of vortices. These elements help in increasing the heat transfer performance characteristics of solar air heaters and also increase the friction loss. The maximum heat transfer occurs at the reattachment point which is due to the separation of flow. The geometrical parameters of the roughness elements as well as the duct, such as rib to channel height ratio ( e/D or e/D h); pitch to the rib height ratio ( P/e); duct aspect ratio, AR ( W /H); angle of attack of rib (α ); relative gap width ( g /e); relative roughness length ( B /S ) etc. greatly affect the thermo-physical behaviour of the duct.

# Parameters affecting the flow patterns

**1. Rib height (e)**

Ribs of certain height and alignment affect the flow by obstructing it and separating it from the main flow. Secondary flow can be seen along the ribs and its mixing with the main flow. Vortices are also generated in the downside of flow behind the roughness element which causes turbulence, thus enhancing the heat transfer from the surface. For some types of ribs, the flow separation, free shears layer formation and vortices formation. In addition to that the frictional loss as well tends to occur due to vortices formation. The rib height is approximately 15% of the plate separation distance.

**2. Rib pitch (P)**

As the rib height and pitch changes there is a change in the flow pattern also. Due to the height, the flow in the downstream side of the roughness element is separated and if the pitch is not maintained properly reattachment of the flow does not occur. The reattachment of the shear layer does not occur for pitch ratio less than 8, and it will result in poor heat transfer from the surface. Maximum heat transfer occurs at the reattachment point. The local heat transfer coefficients in the separated flow region are larger than those of an undisturbed region [7]. W hen the relative roughness height ratio(e/D h) is kept constant then also reattachment can be achieved by reducing the relative roughness pitch (P/e ). As P /e increases from its lowest value, the friction factor and the heat transfer also increases. The maximum value of P/ e occurs at about 10.

**1. Effect of rib alignment (p)**

Rib alignment in the surface affects the performance of the solar air heater; the friction factor falls rapidly as the angle of attack decreases from 90̊ to 15̊. Secondary flow is generated along the rib surface which helps in increasing the heat transfer. However, it also increases the friction factor. Fluid vortices are generated in the upstream and downstream side of rib. The two vortices meet the main stream at the tail end while

moving along the rib surface. These moving vortices mix up with the cold stream of air thus increasing the temperature of leading edge. The rib alignment has a very modest effect on the friction factor and the heat transfer.

Many type of artificial roughened geometries over the duct had been investigated by many authors in the last few decades. Aharwal et al. (2008) experimentally investigated the heat transfer enhancement due to a gap with in an inclined (α=60°) continuous rib arrangement in rectangular duct of solar air heater and observed the optimal performance of relative gap width of 1 and at relative gap position of 0.25. Sandeep et al.(2015) investigated the effect of breaking inclined ribs was orientations on the local heat transfer distributions and pressure drop in rectangular duct. a comparative study of overall thermal and hydraulic performance with previously tested continuous ribs roughness was conducted. It was found that the discrete rib had better overall performance in the high Reynolds number range. Sandeep et al.(2015) also investigated the Transient heat transfer from a transverse ribbed roughned rectangular duct, by using the LCT (Liquid Crystal thermography) technique. the transient Nusselt number for roughned surface is almost four times than that of the smooth surface for beginning time duration for fixed value of Reynolds number .

## II. THE EXPERIMENT

### A. The apparatus

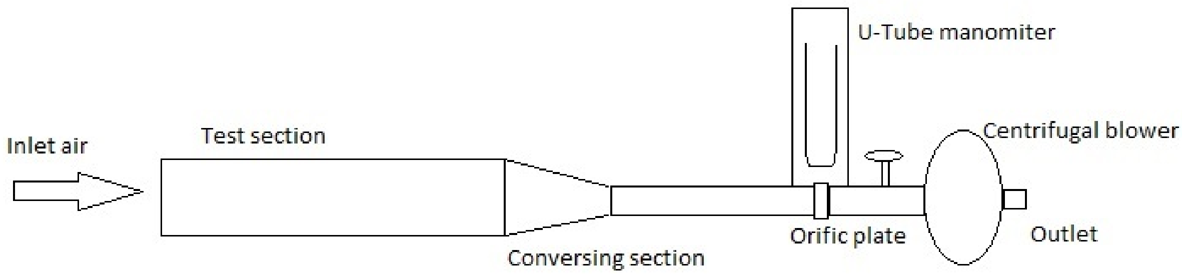



Fig:1 schamatic diagram of experimental setup

In this experimental work an experimental setup has been designed and fabricated figure to measure the Nusselt number of smooth surface and artificial roughned 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(0.025m height and 0.2m wide) and length 1.5m, made of G.I sheet. the upper plate of the test section made of G.I sheet. A 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 at al. (2015) . Relative roughness pitch (P/e) =10, angle of attack (α) =60°, relative gap width (g/e) =2.5 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.

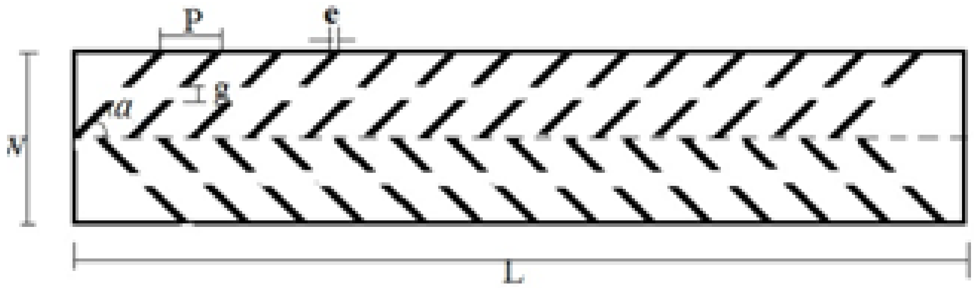



Fig:- Schematic diagram of double incline ribs with gap

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 3000 -10000 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 ribs 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

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

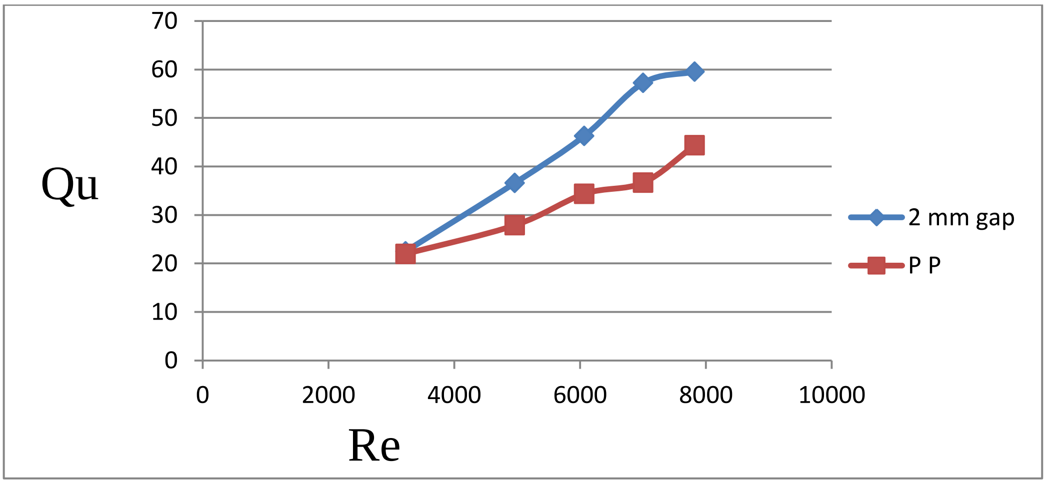
$$Re = (\dot{m} D_{ch}) / (\mu A_{ch})$$

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

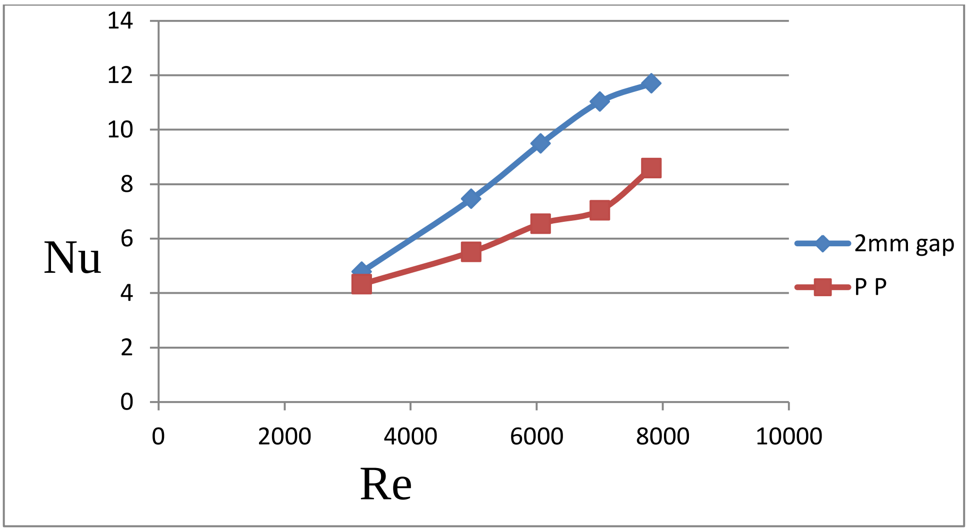
### III Result and discussion

| S no | Mass flow rate (kg/s) | Velocity (m/s) | Reynolds no | Nusselt no | Qair (W) |
|---|---|---|---|---|---|
| 01 | .007408 | 1.28 | 3528 | 4.79 | 22.52 |
| 02 | 0.01048 | 1.8 | 4964 | 7.46 | 36.6 |
| 03 | .01282 | 2.21 | 6070 | 9.016 | 46.32 |
| 04 | 0.0148 | 2.55 | 7004 | 11.03 | 57.20 |
| 05 | 0.01654 | 2.86 | 7823 | 11.7 | 56.87 |

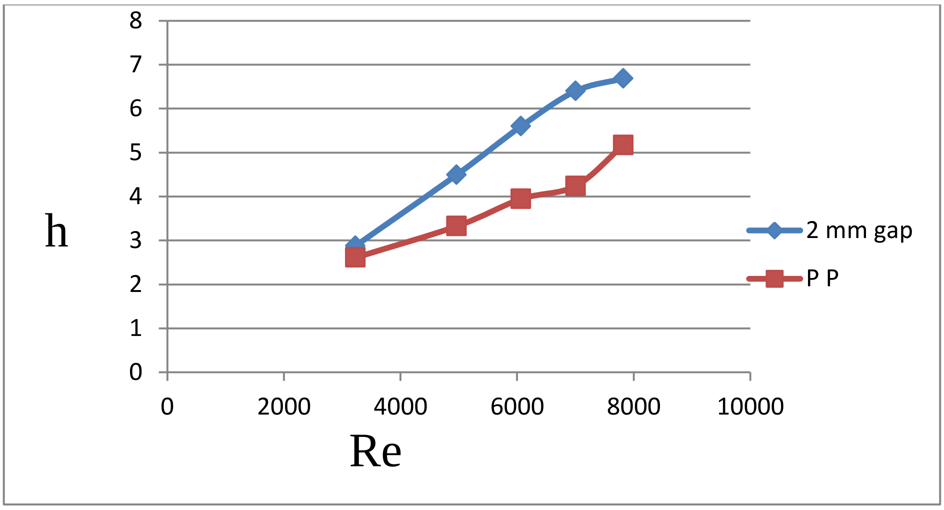
Table shows the result




Variation of Qu with Reynold's No




Variation of Nusselt No. with Reynold's No




Variation of h 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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