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Developing Heat Transfer in Rectangular Channels with Rib-Turbulators

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Abstract: The thermal performance has been examined computationally for the stationary duct with rib turbulators. Ribs were placed on bottom surface and the heat transfer coefficient and frictional losses has been calculated. The thermal performance has been measured by calculating the Nusselt number and frictional factor as well as thermo-hydraulic performance parameter. Square and trapezoidal ribs of different chamfering angles (0, 15, 30, 45 deg) were considered for investigations for Reynolds number range of 30,000 to 60,000. It is found that heat transfer characteristics along with underlying flow mechanism in the inter-rib region are strongly affected by rib shape. The rib with larger trapezoidal angle in the flow direction has shown better overall performance.

Keywords: Heat transfer coefficient; Nusselt number; CFD; Chamfer angle; Reynolds number.

I. INTRODUCTION

One well-known method of enhancing heat transfer on a surface is to roughen the surface by the use of repeated ribs. Generally the Ribs are employed in internal cooling passages of turbine blades to augment heat transfer with cooling air flowing through the internal ribbed passages. To increase the efficiency of a gas turbine, the common approach is to increase the turbine inlet temperature. In order to allow the gas turbine designers to increase the turbine inlet temperature advanced cooling methods are developed.

The ribs break the laminar sub layer and create local wall turbulence due to flow separation and reattachment between the ribs, which greatly enhances the heat transfer. Developing and fully developed turbulence heat transfer and friction in ducts with rib turbulators on the walls of the duct have been extensively studied. The angled ribs provide better heat transfer performance than the transverse ribs because of the secondary flow induced by the rib angle, in addition to breaking the laminar sublayer and producing local wall turbulence. The rib angle effect decreases in the wide aspect ratio ducts because the ribs on two opposite walls are too close to each other, which retards the rib angle induced secondary flow. The effects of rib angle orientation on the local, regionally averaged heat transfer distributions and pressure drop in a square duct with two opposite ribbed walls were recently re-examined (Han et al., 1991; Han and Zhang, 1992).

Dipprey and Sabersky [1] developed a friction similarity law and a heat momentum transfer analogy for flow in rough tubes. Webb and Eckert [2] developed the heat transfer and friction factor correlations for turbulent air flow in tubes having repeated rib roughness. Han [3] carried out an experimental study for the fully developed turbulent airflow in square ducts with two opposite rib roughened walls. Liou and Hwang utilized a real time Laser Holographic Interferometry [LHI] to measure the local as well as average heat transfer coefficient and compared the performance of square, triangular and semi-circular ribs and showed that the square ribs give best heat transfer performance among them. Zhang et al [4] reported that the addition of grooves in between adjacent square ribs enhance the heat transfer capability of the surface considerably with nearly same pressure drop penalty. Most of these investigations have been conducted for a turbine blade cooling design to optimize the ridge geometry in order to obtain the best heat transfer coefficients for either a given cooling rate or an available pressure drop across the cooling passage. Prasad et al. [5] and Gupta et al. [6] carried out studies on rectangular duct with protrusion of circular wire roughness on the heated wall. Karwa et al. [7] experimented on integral chamfered rib-roughness on the heated wall. They reported that chamfer angle of 15 gives maximum heat transfer. It is reported by Webb and Eckert [8] that square ribbed surface having relative roughness pitch (P/e) less than 8 does not reattaches the free shear layer. While Zhang et al. [9] observed that deploying of groove in between the ribs enhances the turbulences as well as reattaches the free shear layer nearer to the rib. Prasad and Saini [10] attempted to optimize flow and roughness parameters so that they could increase heat transfer while keeping in mind minimum friction factor. They investigated the concerned properties in a range of parameters and found that for optimum thermo-hydraulic condition, a particular roughness Reynolds number always existed. They found that the Nusselt number augmented with the increment in Reynolds number whereas reverse trend was observed in case of friction factor results. They further concluded that optimal conditions were obtained when the roughness height was slightly more than the thickness of transition sublayer. They constructed basis design curves that yielded parameters at which optimal thermos-hydraulic performance could be expected.

This paper basically describes the characteristics of the heat transfer and friction in a rectangular duct where various-shaped ribs are placed transversely to the main stream direction on one wall. The objectives of this research are to fulfill different aspects; i.e., to assess the occurrence of hot spots on the rib roughened wall by investigating the effects of rib shapes on the local heat transfer; to provide detailed information of local heat transfer results for prediction of the flow and heat transfer characteristics in ribbed passages, and to compare the thermal performance of the five types of ribbed duct.

II. GOVERNING EQUATIONS

A. The Navier-Stokes Equations

1) General Form

2) Continuity Equation

$$\frac{\partial \rho}{\partial t} + \vec{\nabla}.(\rho\vec{u}) = 0$$

3) Momentum Equation

$$\frac{\partial u}{\partial t} + (\vec{\boldsymbol{u}}.\vec{\boldsymbol{\nabla}})\,\vec{\boldsymbol{u}} = -\frac{\boldsymbol{\nabla p}}{\boldsymbol{\rho}} + \boldsymbol{g} + \boldsymbol{\vartheta}(\boldsymbol{\nabla}^2\vec{\boldsymbol{u}})$$

The SST k−ω turbulence model is used with enhanced wall functions for the near-wall.

B. Geometry

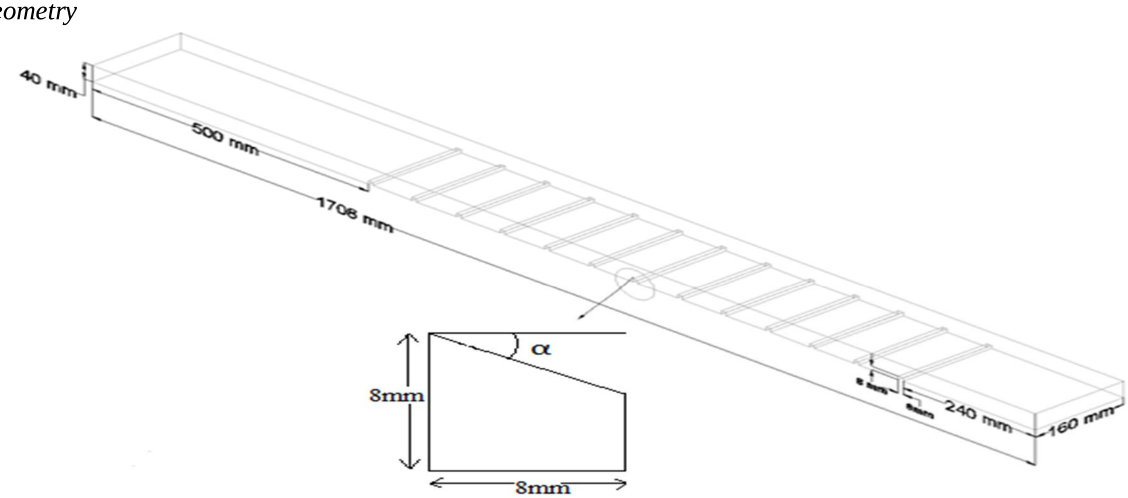


Fig.1. Geometry

The configuration of various-shaped ribs used in this study is shown in Fig. 1. The rib height-to-hydraulic diameter ratio, e/Dh, is 0.125 and rib pitch-to-height ratio, P/e, is 10. The effects of these various-shaped ribs on Local Heat Transfer are studied. The computational domain consists of a 500 mm long smooth section followed by a rib-roughened section of 1708. In this the hydraulic diameter D_h of 64mm. The whole computational domain including both long smooth section and rib-roughened section is meshed with more cells near the ribs and near the bottom wall. This fine mesh size will be able to provide good spatial resolution for the distribution of most variables within the duct..

C. Meshing

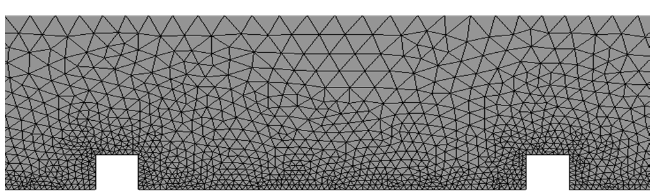


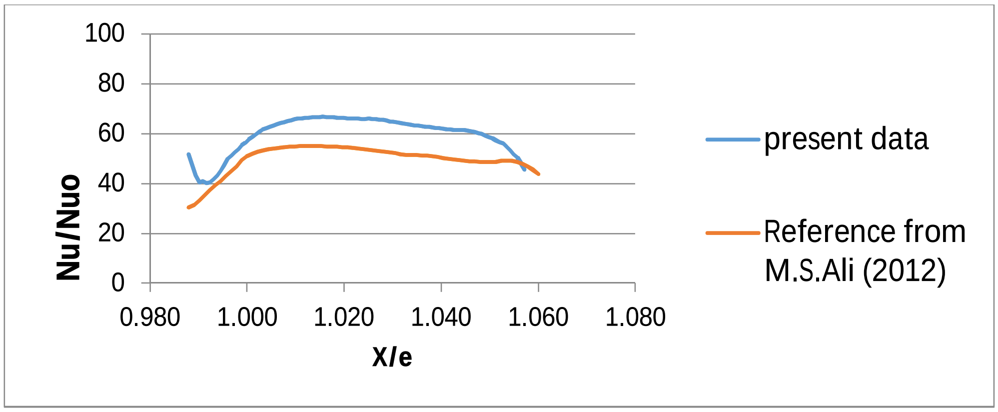
Fig.2. Mesh

The geometry is meshed by keeping the relevance to 100 and by selecting a size function to Proximity and curvature. In sizing relevance centre is kept as fine. Moreover in sizing Max face size is kept to1.0 mm and Max face size and Max text size is kept to 500.0 mm.

D. Boundary Conditions

The working fluid in all cases is air. The inlet temperature of air is considered to be uniform at 300 K. The Reynolds number is 60,000 at the inlet. No-slip conditions for velocity in solid surfaces are assumed. Except bottom wall (excluding the rib) all other wall are assumed to be adiabatic. To the bottom wall Uniform heat flux is applied.

E. Validation



III. RESULTS AND DISCUSSION

A. Streamlines

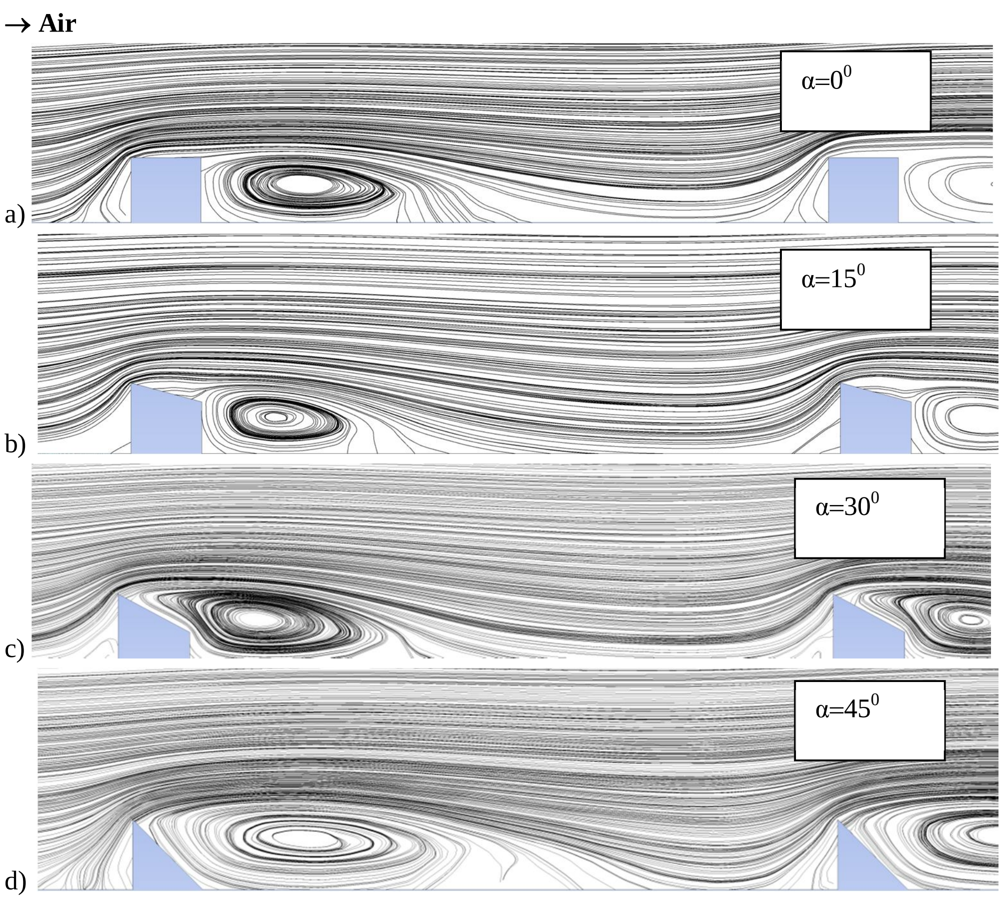


Fig.3. Streamlines for p/e=10 at Re = 60,000 (a) 0^0 rib (b)15^0 rib (c) 30^0 rib (d) 45^0 rib

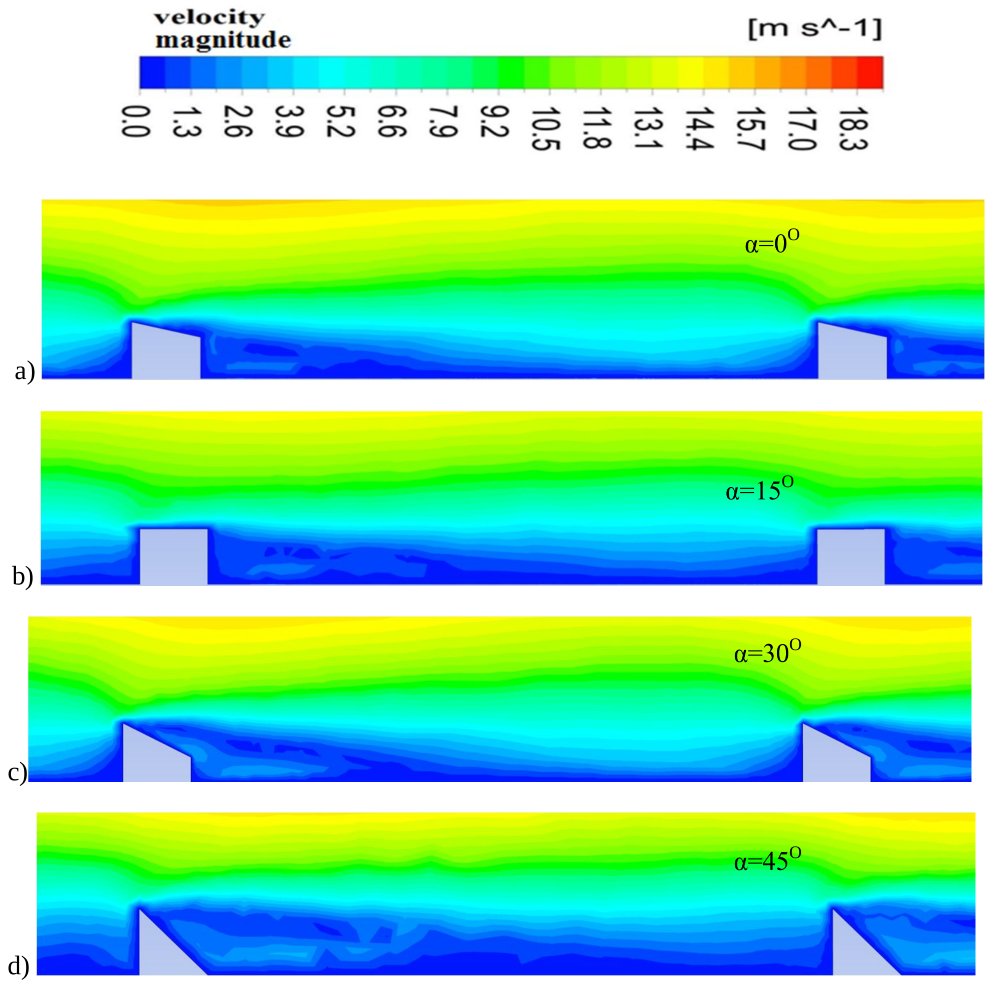


Figure 4. Velocity magnitude for p/e=10 at Re =60,000 (a) 0^0 rib (b)15^0 rib (c) 30^0 rib (d) 45^0 rib

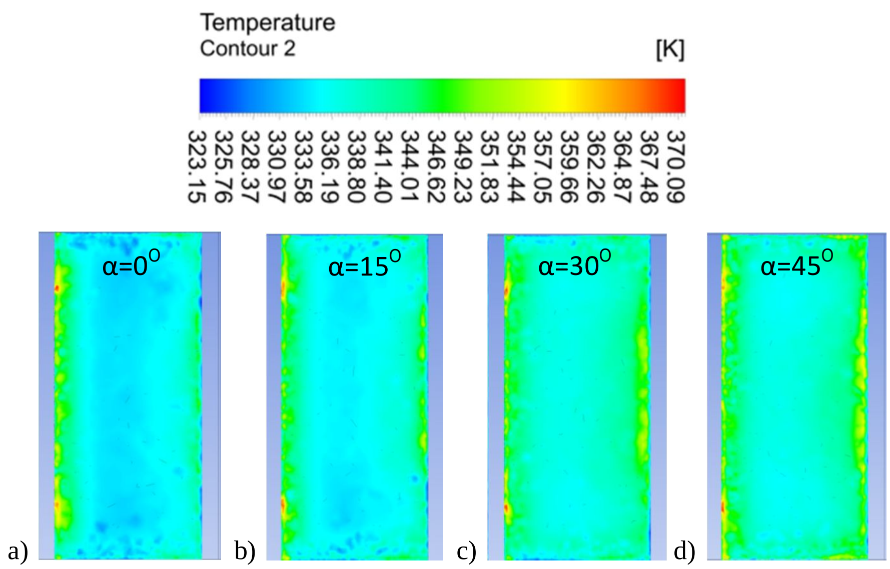


Fig.5. Temperature contours of (a) 0^0 rib (b) 15^0 rib (c) 30^0 rib (d) 45^0 rib

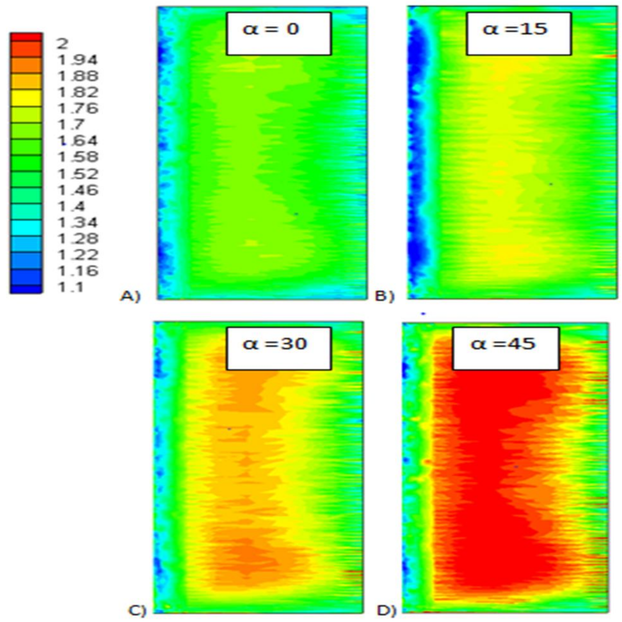


Fig.6. Augmentation Nusselt number between two consecutive ribs for Reynolds number 60,000.

The surface augmentation Nusselt number (Nu/Nu_o) distribution behind trapezoidal ribs of different chamfering angles (0, 15, 30, 45 deg) at 60,000 has been shown in figures, where Nu_o is the Nusselt number for smooth test surface. Imprints of separation and reattachment of the shearing layer, and the flow recirculation are clearly visible in these figures. Typical span wise variation of augmentation Nusselt number indicates the two-dimensionality in the flow field. The heat transfer coefficient distribution seems to be axisymmetric, and no conclusive outcome can be inferred about the effect of change in chamfering angle on the surface augmentation Nusselt number, once inlet flow conditions were laminar.

In the present work a square rib and trapezoidal rib with variable downstream chamfering angle and the effects trapezoidal rib on heat transfer and fluid flow characteristics have been investigated for all the five ribs at the Reynolds number 60,000. The effect of rib configurations on local heat transfer characteristics has been assessed by examining the enhancement in surface heat transfer and with respect to that in smooth surface (i.e., augmentation Nusselt number,Nu/Nuo).

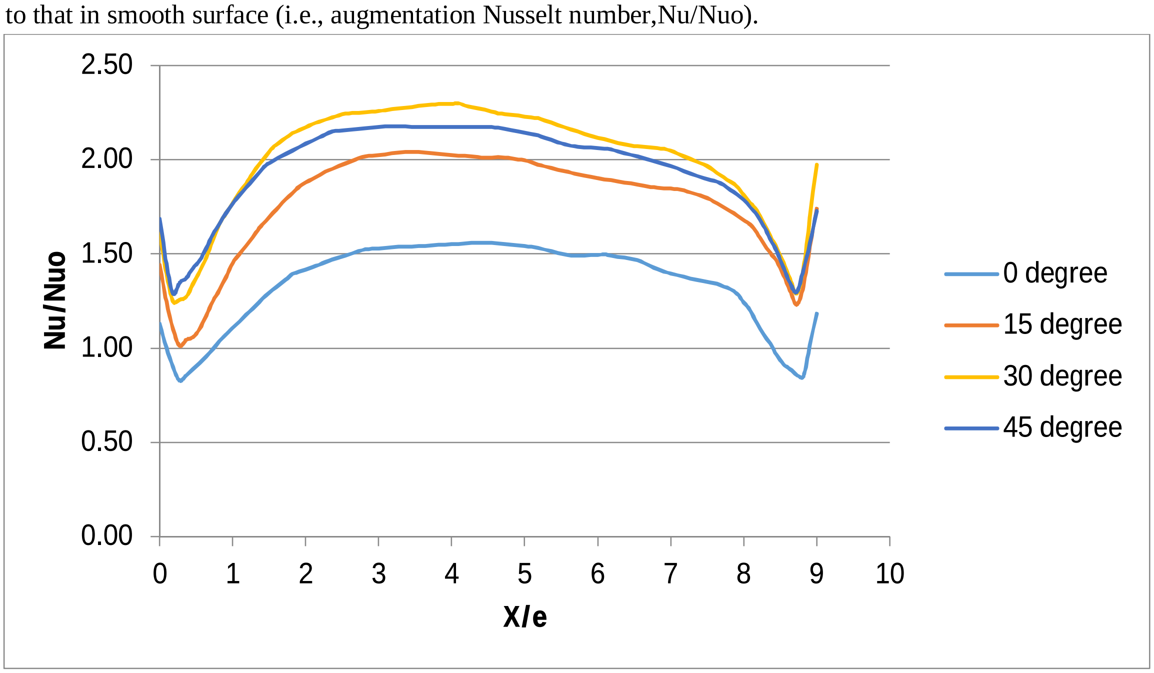


Fig.7. Normalized Nusselt number by Numerical vs. dimensionless distance between two successive ribs.

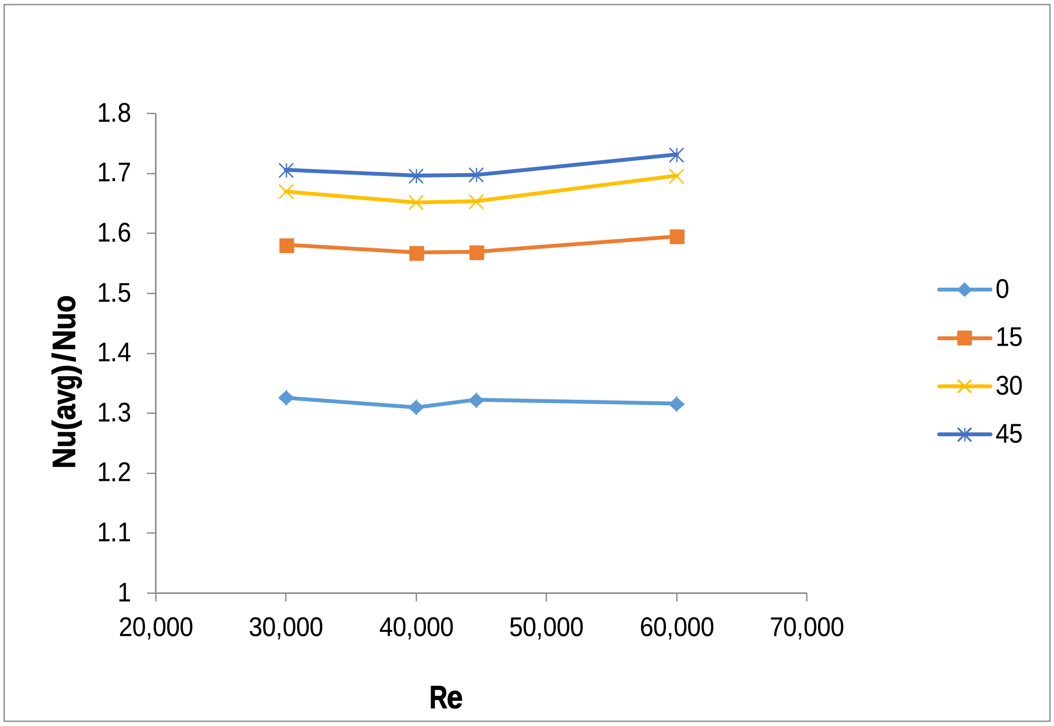


Fig.8. Normalized Nusselt number by Numerical Nusselt number.

First, the effectiveness of trapezoidal rib configurations on mixing/heat transfer enhancement has been studied by investigating the surface- and spanwise-averaged heat transfer distribution and the overall heat transfer augmentation in the presence of a rib. In this investigation, an attempt has been made to analyze the basic heat transfer parameters and the turbulence quantities together in the immediate vicinity as well as in far downstream region of the rib, under a variety of flow and geometrical conditions. Furthermore, the role of turbulence flow structure on the detailed surface HTC distribution has been explored in the wake region of the rib.

The vertical thick black lines on the Nu/Nu_o contours indicate the existence of ribs, not the magnitude and it clearly shows that Nu/Nuo distribution in the inter-rib region is strongly dependent on rib configuration, p/e, and Re. The behaviour of local augmentation Nusselt numbers in the developing flow regions for different rib configurations are distinctly different. A repeated nature of Nu/Nuo are found to be generated after 7^{th} 8^{th}rib at p/e equal to 9 respectively, for each configuration. The flow region is generally termed as repeated flow region, in which periodicity in Nu/Nuo has been observed.

It has been observed that the flow separates at upstream edge of the first rib for all configurations. A minimum heat transfer zone is observed just behind downstream of each rib. Typical chamfering angle 20degrees shows highest heat transfer enhancement at the Reynolds number of 60,000.It has been observed that reattachment takes place at p/e equal to 3.

The velocity is very low and heat transfer dominantly occurs by conduction where corner eddies are present in the downstream direction, higher heat transfer just before the next rib is observed, which can be linked with the existence of possible separation bubble caused by the adverse pressure gradient.

Overall, the streamline patterns are in compliance with the expected global flow features downstream the rib such as separation, recirculation, and reattachment of shear layer. A region of high heat transfer enhancement occurs just behind the rib and Low heat transfer region exists at the end of the rib the maximum heat transfer is seen at p/e=3 the flow with a minimum at far end of the rib, and reason can be attributed to the wall effect of the duct.

IV. CONCLUSION

The detailed heat transfer and friction factor characteristics of five different rib configurations deployed periodically on the heated bottom surface of the duct are investigated. Based on the Reynolds-averaged Navier–Stokes equations coupled with a turbulence model that resolves near wall and flow is able to successfully capture the essential features of the flow over the surface with two-dimensional ribs. It is found that features of the inter-rib distribution of the heat transfer coefficient are strongly affected by the rib shape. The trapezoidal shaped rib with decreasing height in the flow direction has the highest value of heat transfer.

REFERENCES

[1] D.F. Dipprey, R.H. Sabersky, Heat and momentum transfer in smooth and rough tubes at various Prandtl numbers, Int. J. Heat Mass Transfer 6 (1963) 329–353.

[2] R.L. Webb, E.R.G. Eckert, R.J. Goldstein, Heat transfer and friction in tubes with repeated rib roughness, Int. J. Heat Mass Transfer 14 (1971) 601–617.

[3] J.C. Han, Heat transfer and friction in channels with two opposite rib-roughened walls, ASME/J Heat Transfer 106 (1984) 774–781]

[4] T.M. Liou, J.J. Hwang, Effect of ridge shapes on turbulent heat transfer and friction in a rectangular channel, Int. J. Heat Mass Transfer 36 (1993) 931–940

[5] Y.M. Zhang, W.Z. Gu, J.C. Han, Heat transfer and friction in Rectangular channel with ribbed or rib

[6] B.N. Prasad, J.S. Saini, Effect of artificial roughness on heat transfer and friction factor in a solar air heater, Solar Energy 41 (1988) 555– 560.bed-grooved walls, ASME/J. Heat Transfer 116 (1994) 58–6

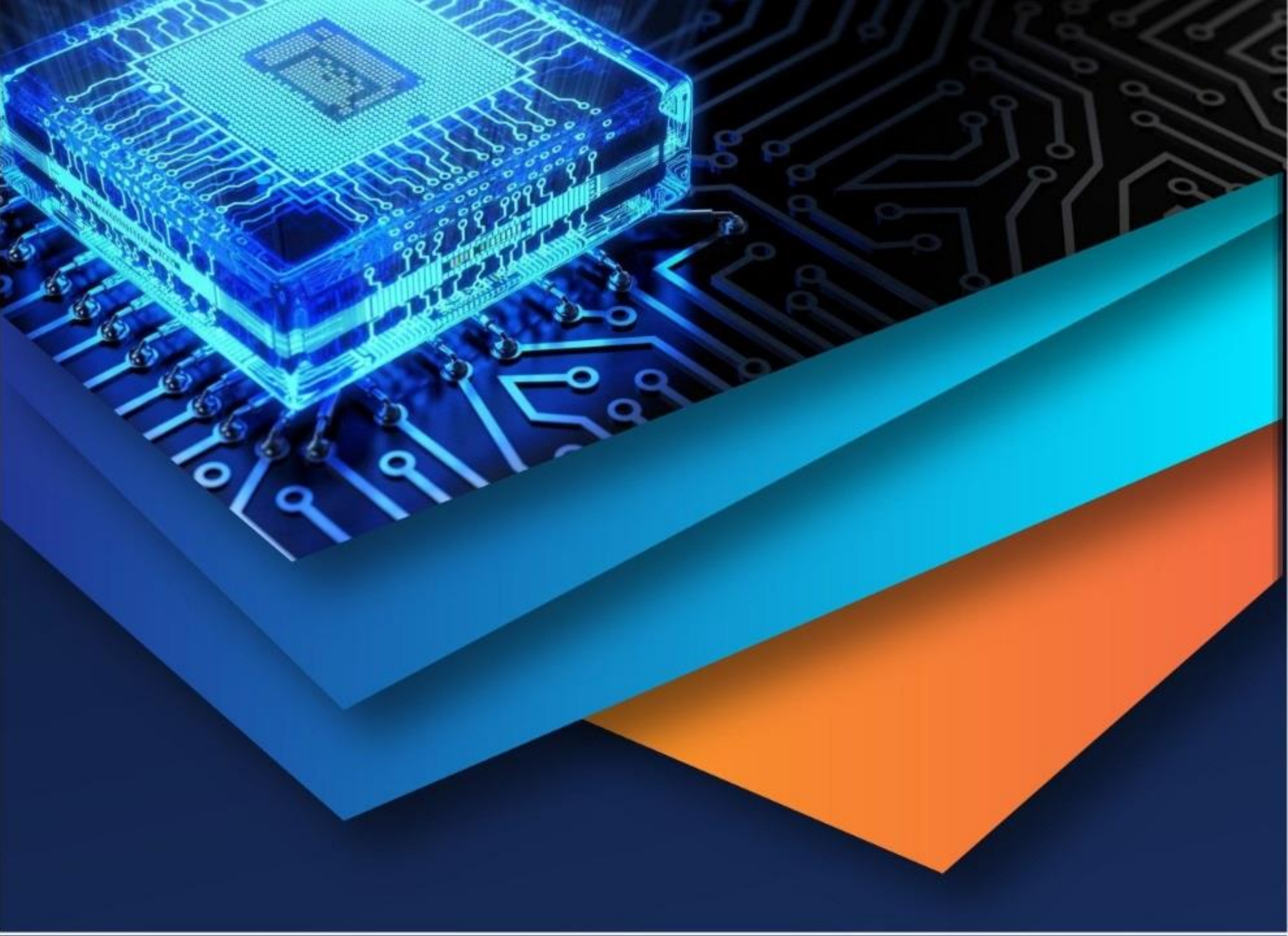
[7] D. Gupta, Investigations on fluid flow and heat transfer in solar air heaters with roughened absorbers, Ph.D. Thesis, University of Roorkee, Roorkee, India, 1993.

[8] R. Karwa, S.C. Solanki, J.S. Saini, Heat transfer coefficient and friction factor correlations for the transient flow regime in ribroughened rectangular ducts, Int. J. Heat Mass Transfer 42 (1999) 1597–1615.

[9] Heat Transfer and Friction in Rectangular Channels with Ribbed or Ribbed-Grooved Walls .Y. M. Zhang, W. Z. GU, J. C. Han. 1994.

[10] Prasad B. N. and Saini J. S., 1991, Optimal thermo-hydraulic performance of artificially roughened solar air heaters, Solar Energy, 47(2): pp. 91-96.

[11] R. Kamali, A.R. Binesh, The importance of rib shape effects on the local heat transfer and flow friction characteristics of square ducts with ribbed internal surfaces, International Communications in Heat and Mass Transfer 35 (2008) 1032-1040.



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