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Conjugate Heat Transfer Analysis Of A Rectangular Cooling Channel With Different Orientation Of Ribs

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ABSTRACT

Heat transfer enhancement using transverse ribs inside a rectangular channel is investigated numerically in the present study. Six different angular orientation of ribs at constant flow velocity of 0.0085 m/s has been considered. Water is used as the working fluid. Turbulence k-epsilon model is used for the analysis. The results in the present paper are presented in the form of velocity and temperature contours. A maximum enhancement in the working fluid temperature is obtained at 55^o angular orientation. This is due to high turbulence intensity and development of secondary flow over the ribbed surface which result in extensive mixing of fluid element which led to enhance heat transfer.

Keywords- Transverse ribs, Heat transfer enhancement, Heat transfer, CFD

1. INTRODUCTION

Heat transfer enhancement is become the necessity due to high demand of energy and depleting energy resources. To overcome the problem related to energy conservation, demand of energy efficient equipment is raised all over the world. Heat transfer improvement can be accomplished in two ways: Active methods and Passive methods[1]. The use of vortex generators to improve heat transfer is a passive way[2]. In industrial applications, the use of vortex generator arrays to improve heat transfer is becoming increasingly important.The vortex generators act as the obstruction in the fluid flow field which disturbs the boundary layer and promotes the secondary flow as a result of which turbulence is increase which led to higher heat transfer rate[3]. The convection heat transfer and fluid flow dynamics of tube type heat exchanger have been studied using a variety of experimental and numerical methods.

However, since the majority of the experimental ranges were minimal and the correlations were caused for specific geometries, the applicability of these correlations was limited.Numerical simulation, on the other hand, is more widely applicable for thermohydraulic analysis due to wide range of data availability.

There are a few ways to improve the heat dissipation capability of forced convection by installing fins and baffles, modifying the duct geometry using ribs or dimples, jet impingement, etc. Prasad et al. [4] conducted CFD based evaluation for enhanced heat transfer rate in an solar air heater with triangular transverse ribs and reported triangular ribs enhance the convective heat transfer rate. Ligrani et al.[5] compared many forms of heat transfer augmentation strategies and observed that dimples outperform pin–fins, rib turbulators, and other surface roughness's in terms of overall efficiency.Sahu and Bhagoria[6] employed transverse broken ribs of different pitch, height, and aspect ratio to evaluate their influence on the thermal and flow performance of solar air heater and reported enhancement in the performance of the solar air heater when ribs are employed.Wang et al. [7] evaluated the thermal and flow performance of solar air heater employed with S-shaped ribs with gap. The gap is provided between the ribs to reduce the influence of friction factor. The thermal efficiency of solar air heater with artificial roughness was increased by 13– 48% under various conditions as compared to a smooth channel. Hans et al. [8] performed an experimental investigation to evaluate the thermal and flow performance of solar air heater with multiple v-ribs and developed correlations for Nusselt number and friction factor. Aljibory et al. [9] investigated the heat transfer and pressure drop inside a circular duct with annular ribs for turbulent flow and a comparison was done based on temperature and velocity profile between duct with and without ribs.Tanda[10] evaluated the performance of ribs in an rectangular channel and found that rib roughened channel performs better over plain channel. Jin et al. [11] carried out simulation study to evaluate the influence of V-shaped ribs on the thermal and flow performance and evaluate the optimal parameters for maximum thermal efficiency. Bhattacharyya et al. [12] performed computational evaluation to report on the influence of ribs and rib angle on the inner surface of a circular channel on the thermal and flow performance. Gawande et al. [13] numerically evaluated the influence of inverse L-shaped ribs on the thermal and flow performance inside a solar air heater duct and reported a significant enhancement in thermal performance factor for same pumping power. Singh et al. [14] reported on the heat transfer enhancement in a solar air heater using the square, circular, trapezoidal and saw tooth ribs which acts as the turbulence promoter in the fluid flow field and reported that

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maximum Nusselt number was reported with saw tooth ribs while the friction factor remains minimum when compared with other geometries. Promvonge et al. [15] investigated the combined impact of delta winglets as well as ribs on the thermohydraulic of solar air heater for Reynolds number 5 000 to 22 000. The Nusselt number and friction factor values for combined rib and delta winglets are far higher than those for ribs and delta winglets acting alone.Thakur et al. [16] reported on the influence of hyperbolic ribs on the thermal and flow performance characteristics of solar air heater.

On the basis of the above, it can be inferred that having ribs within a channel enhances thermal performance.The geometry, height, pitch, and angle of a rib have a direct impact on thermo-hydraulic activity.Furthermore, it has been discovered that the configuration of ribs in a conduit, whether transverse or inclined, continuous, or separated, inline, or staggered, has a considerable impact on performance.The heat transfer and pressure drop characteristics are regulated by the flow patterns developed over the rib. Hence in present paper, the influence of inclination angle of rectangular ribs fitted inside a rectangular channel heated from the bottom while keeping the other three walls smooth will be evaluated numerically using ANSYS 18.1.

2. NUMERICAL ANALYSIS

For numerical analysis of rib roughened rectangular channel, ANSYS 18.1 is employed. The k-epsilon model is used to analyses the turbulent flow.

2.1 Computational Domain

The computational domain used for CFD analysis is shown in Figure 1. The computational domain has a length of 200mm, width of 20mm and height of 20.mm. The ribs used for the investigation has the height of 2mm, width of 2 m and thickness of 2mm. Only lower surface is roughened with the ribs while other three side of computational domain remain smooth. A uniform heat flux is given to roughened surface while other side of channel remain well insulated to contains heat loss. Material properties are considered constant, and effect of buoyancy and viscous heating is neglected. Uniform inlet velocity condition is applied while no slip condition is assumed at all the solid surfaces. 5% of turbulent intensity at the inlet will be given to the fluid.

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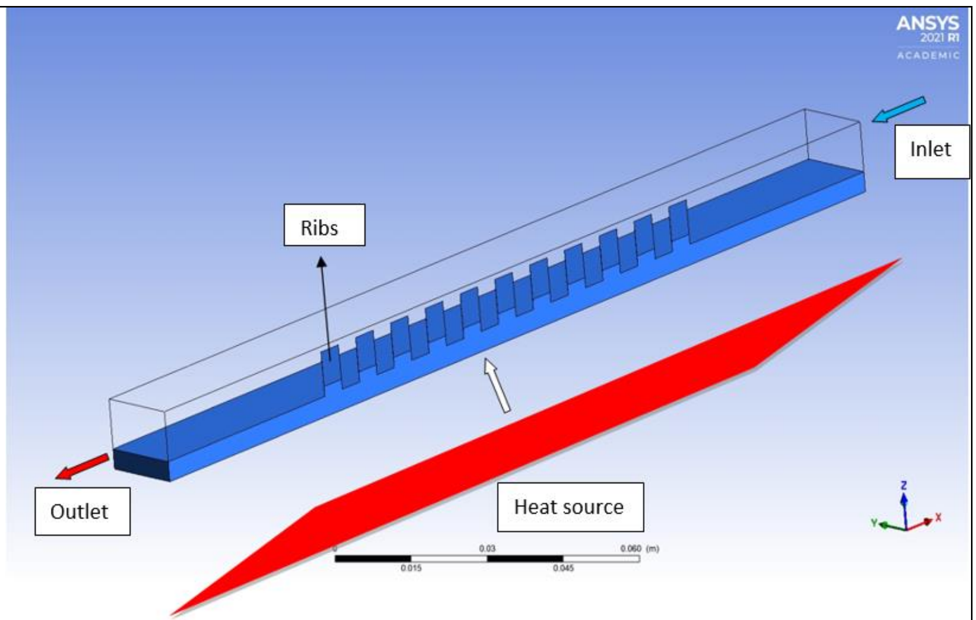

Figure 1- Schematic representation of geometry used for analysis.

2.2 Governing Equations

The basic governing equations will be given as-

(i) Conservation of Mass

$$\frac{\partial(\rho u_j)}{\partial x_j} = 0 \qquad (1)$$

(ii) Conservation of Momentum

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) + \mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \qquad (2)$$

(iii) Conservation of Energy

$$\frac{\partial u_i T}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\left(\frac{\mu}{\mathrm{Pr}} + \frac{\mu_t}{\mathrm{Pr}_t}\right)\frac{\partial T}{\partial x_i}\right] \qquad (3)$$

where ρ, and $\mu$are the density and viscosity of working fluid, respectively.
The expression for turbulent kinetic energy and turbulence dissipation rate are given by equation 4 and 5, respectively.

$$\frac{\partial(\rho k u_i)}{\partial x_i} - \frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right) - G_k + \rho\varepsilon = 0 \quad (4)$$

$$\frac{\partial(\rho k u_i)}{\partial x_i} - \frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right) - G_k + \rho\varepsilon = 0 \quad (5)$$

The turbulent kinetic energy generation is presented by $G_k C_{1e}, C_2, C_{3e}, \alpha_e$ and α_k are the constants.

$$\mu_{eff} = \mu_f + \mu_t = \mu_f + \rho C_\mu \frac{k^2}{\varepsilon} \quad (6)$$

$$R_s = \rho \frac{\varepsilon^2}{k} \frac{C_\mu \eta^3 (1 - \eta/\eta_0)\varepsilon^2}{1 + \beta\eta^3} \quad (7)$$

where μ_f and μ_t are the effective turbulent viscosity and turbulent viscosity and dynamic viscosity.

2.3 Mesh Generation

The mesh has been conducted in commercial software ANSYS Meshing. Grid independency test has been conducted for decreasing the computational time and memory. During the grid independency test at the element number 84004 the results do not effect increasing the element or fine mesh is further not required. The Mesh QualityMinimum Orthogonal Quality is maintained 9.61813e-02 which is acceptable and further analysis can be conducted.

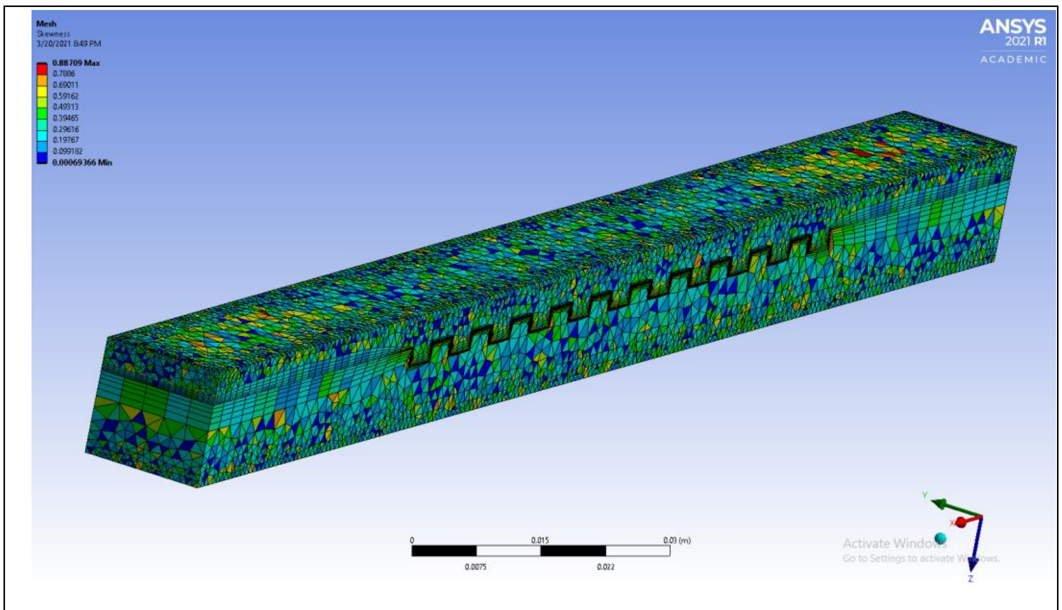

Figure 2- Meshing

2.4 Boundary Condition

At the inlet and exit of the numerical domain, velocity and pressure boundary conditions are used, respectively.The mean inlet velocity of a fluid flow is determined using the Reynolds number. Water enters the channel at 298 K temperature and 1 bar pressure condition. At the roughened side of the channel, a steady heat flux boundary state is maintained. The heat flux will be maintained at 12500 J/m^2.No slip condition is maintained between the fluid and the roughened surface inside the channel. The other three walls remain insulated to maintain the adiabatic condition.

3. RESULT AND DISCUSSION

The effects of the rib angle are considered into account during the numerical investigation. Six angular position from 35° to 60° for the ribs are considered while keeping the ribs geometry fixed. Owing to the presence of a low static pressure area behind the ribbed wall, the movement in the vicinity of the ribbed wall accelerates. The flow becomes stagnant around the rib tip on the upstream face of the rib, forming the high static pressure area

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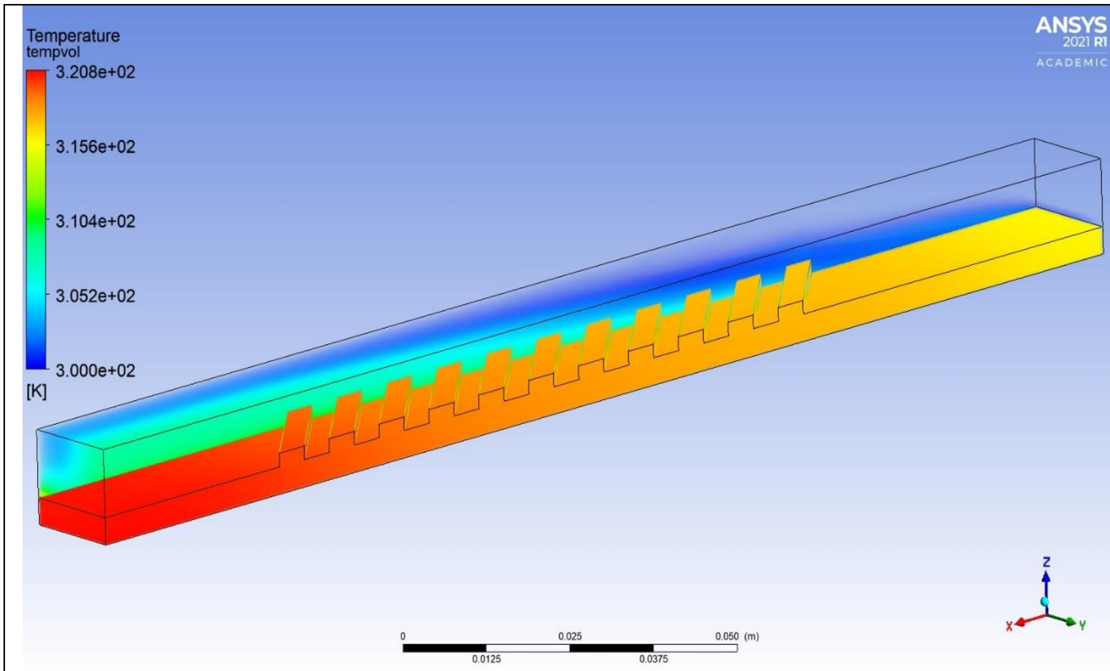
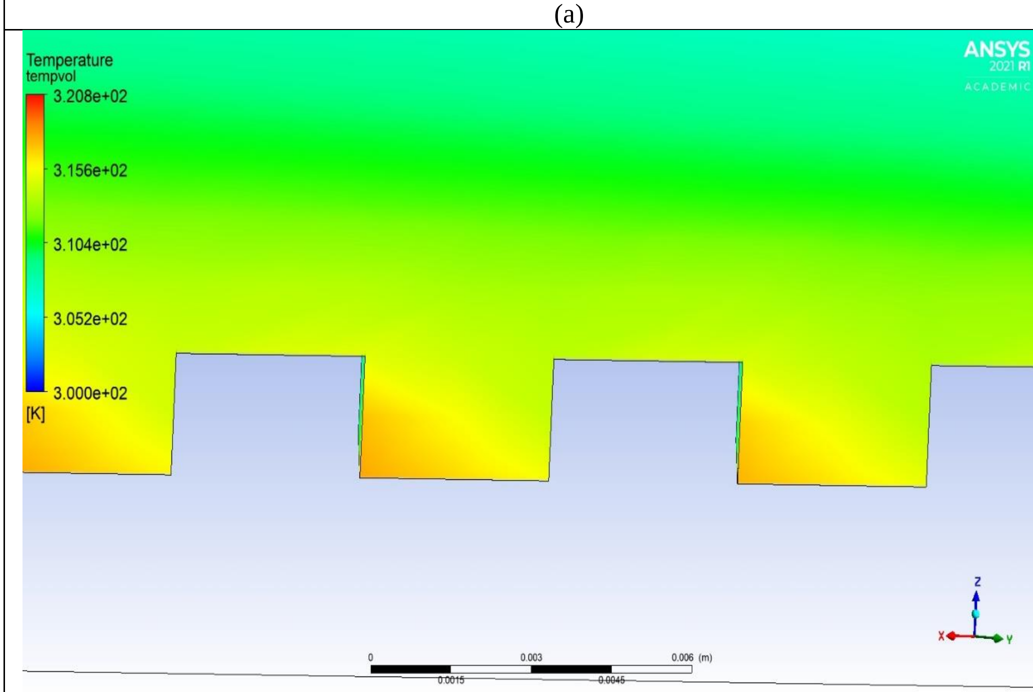
labelled with high pressure in front of the rib.The flow around the rib tip goes in a different direction, resulting in a secondary flow. For lower value of angle, this secondary flow remains weak while increase in angle of orientation result in higher heat transfer due to heavy spinning secondary flows.Owing to the flow interference and external flow separations at the rib tips, turbulence intensity is strong over a large area around the rib tips.

Figure 3 (a) shows the temperature distribution in the fluid domain. It clearly depicts that the working fluid carrying more heat along with it when it passes over the ribs. This is due to the intense mixing of fluid elements over the ribbed surface. The ribbed surface increases the turbulence intensity which result in heavy spinning movement of fluid. Figure 3 (b) shows the close view of temperature distribution along the ribs.



(a)



(b)

Figure 3- Temperature distribution over the fluid domain.

Figure 4 (a) shows the velocity distribution along the fluid domain. It depicts that the velocity increases over the ribbed surface. This is because of reduced flow area and enhanced turbulence intensity over the ribbed surface. This accelerated the flow over the rib, which result in high flow mixing and local turbulence. Increase in the

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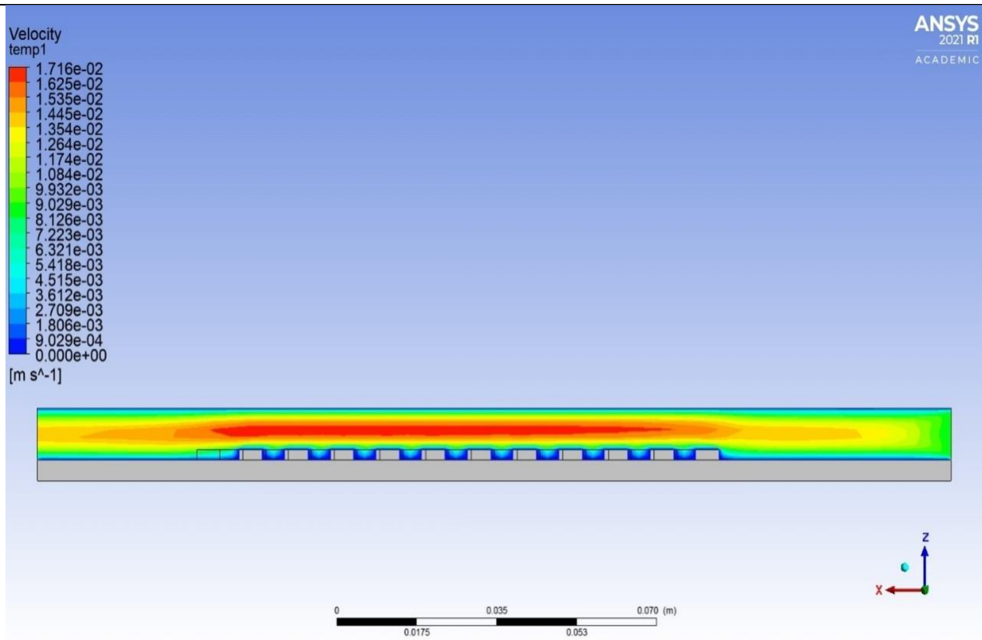
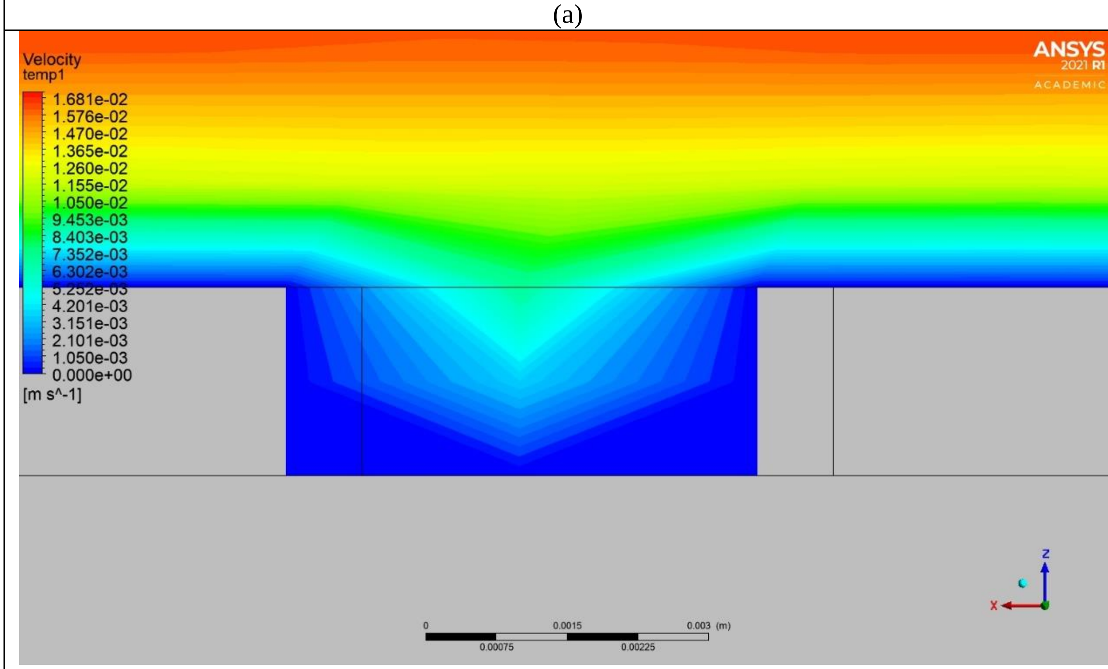
angle of ribs also result in higher heat transfer rate. Figure 4(b) shows the close view of velocity distribution over the ribs.

Figure 5 shows the maximum temperature achieved by working fluid with various angle of orientation of ribs. It is visible from the graph that maximum fluid temperature was achieved with 55° angle ribs. Further increase in the orientation angle result in decreased temperature. The high temperature result in high heat transfer rate of working fluid.



(a)



(b)

Figure 4- Velocity distribution along the fluid domain.

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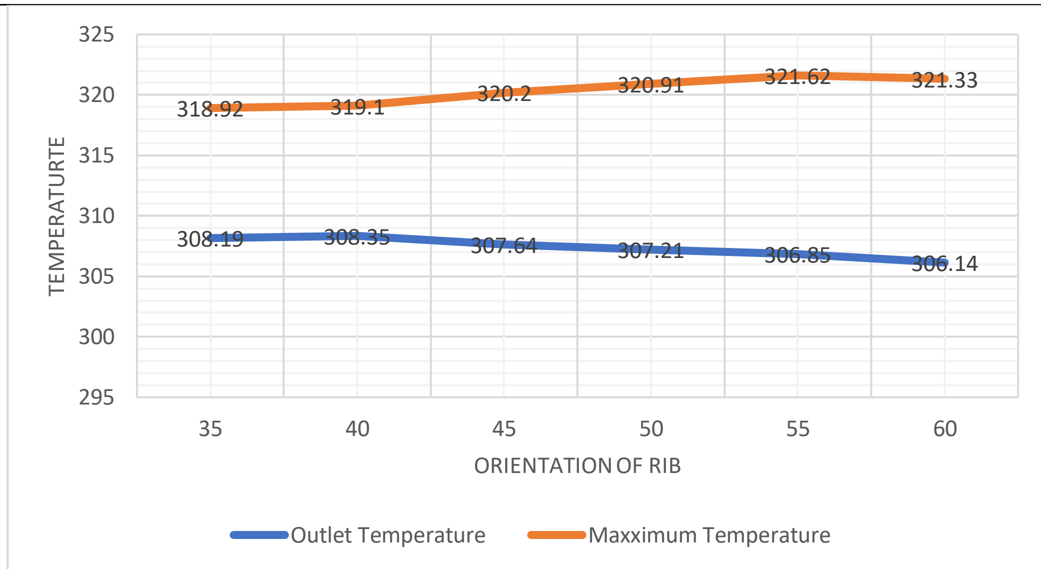

Figure 5- Temperature versus Rib orientation

4. CONCLUSION

In this paper, a ribbed channel with rectangular geometry with 6 orientation angles has been analysed by means of ANSYS FLUENT. A continuous heat flux heats the ribbed walls, while maintaining the adiabatic condition at other three walls, and the flow regime is turbulent. The velocity of flow is also kept constant at 0.00835 m/s. Simulations show that maximum fluid temperature is detected with 55° orientation ribs. Owing to the presence of a low static pressure area behind the ribbed wall, the movement in the vicinity of the ribbed wall accelerates. This result in higher turbulence intensity which result in better mixing of fluid because of which heat transfer rate increases. The flow around the rib tip goes in a different direction, resulting in a secondary flow which further enhance the heat transfer rate.

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