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Numerical Investimation of Heat Transfer in A Rectangular Channel with Triangular Vortex Generators in the Channel at Blade Angle 30° for Reynolds no. of 1500, 2000

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Abstract: The compact heat exchanger is widely used in fields such as automobile industry, heating and air conditioning, power system, chemical engineering, electronic chip cooling and aerospace, etc. The subject of heat transfer enhancement is of significant interest in developing compact heat exchanger to meet the desire of high efficiency and low cost with the volume as small as possible and the weight as light as possible.

The use of ribs/baffles placing in the cooling channels or channel heat exchangers is one of the commonly used passive heat transfer enhancement technique in single-phase internal flows. Periodically positioned ribs/baffles in the channels interrupt hydrodynamic and thermal boundary layers. Downstream of each rib/baffle the flow separates, recalculates, and impinges on the channel wall and these effects are the main reasons for heat transfer enhancement in such channels.

the effect of vortex generators in the spanwise averreged nusselt number. The comparison between the plots of spanwise avereged Nusselt number with and without vortex generators shows that there is a considerable increase in Nusselt number near the vortex generator region and this effect decreases as we move far from the vortex generator region in the stream wise direction.

Keywords: Vortex Generators, Reynolds Number, Nusselt Number, rectangular channel

I. INTRODUCTION

There are two different methods for heat exchange enhancement: active vortex method and passive vortex method. The active vortex method is used to actively control the secondary flow and pressure drop so as to meet the required heat transfer rates even at the cost of increased pumping power. There is little known use of this method in heat exchangers since the operating cost is very high. A few examples of active vortex method are the use of jets at different angles from the heat transfer surface into the boundary layer, and the generation of a secondary flow through acoustic excitation, and Electro hydrodynamics (EHD) which is the process of producing an electric field to create electric body force in the flow. Using longitudinal or latitudinal vortex generators for heat exchange enhancement is known as the passive vortex method.vortex generator (VG) can be regarded as a special kind of extended surface, which can be stamped on or punched out from the fin. A large amount of investigations have been carried out in this area since 1960s .Although the heat transfer surface area may not be changed before and after the set up of VG, the fluid flow can be strongly disturbed because of the generation of vortex when fluid flows over it. In the conventional point of view, vortex generator not only disturbs the flow field, disrupt the growth of the boundary layer, but also makes fluid swirl and causes a heavy exchange of core and wall fluid, leading to the enhancement of heat transfer. The vortex may be divided into transverse vortex (TV) and longitudinal vortex (LV) according to its rotating axis direction. The axes of TVs lie perpendicular to the main flow direction, while LVs have their axes parallel to the main flow direction, thus they are also called stream wise vortices. In general, the LVs have been reported to be more efficient than TVs for heat transfer enhancement.

II. LITERATURE REVIEW

type longitudinal vortex generators and conclude that local enhancement of heat transfer coefficient increases by a factor of three compared to its value in awing less channel. Fiebig et al. (1991)carry out an experimental comparison of delta wings, delta winglets, rectangular wings and rectangular winglets. Biswas and Chattopadhyay (1992)study heat transfer and skin friction characteristics in a channel with built-in wing-type vortex generators at angle of attack (β) of 26°and Reynolds number of 500.

They conclude that combined spanwise average Nusselt number shows increase of 34% even at the exit of along channel. Deb et al. (1995)study heat transfer and flow structure in laminar and turbulent flows in a rectangularchannel with longitudinal vortices.Biswas et al. (1996)carry out numerical and experimental study of flow structure and heat transfer effects of longitudinal vortices in a fully developed channel flow. They define a performance equality factor which indicates heat transfer enhancement for a given pressure loss penalty. Based on the value of this factor, they conclude that the performance of the winglet is best for β of 15°. Same trend is observed by Biswas et al.(1994), when the performance evaluation is done taking into account the energy transfer and the losses due to the thermodynamic irreversibilities.Sohankar and Davidson(2003)attempt unsteady three-dimensional Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES)of heat and fluid flow in a plate-fin heat exchanger with thick rectangular winglet type vortex generators at Reynolds and Prandtl numbers of 2000 and 0.71, respectively. In the numerical investigations, except for the study of Sohankar and Davidson (2003),

III. COMPUTATIONAL FLUID DYNAMICS

Computational Fluid Dynamics also generally called CFD is an important branch of fluid mechanics and it uses numerical methods and algorithms to analyze and solve fluid flow problems. It has become popular since the previous methods, experimental and theoretical are either very expensive, time consuming, or involve too much labor. In CFD, computers are used to solve the algorithms that define and analyze the fluid flow.

Due to the increase in the computational capabilities over time and better numerical solving methods, most experimental and theoretical work has been done using CFD. CFD is not only cost effective but it helps one analyze and simulate complex geometries, heat transfer, and shock waves in a fluid flow. It also helps solve partial differential equations (PDE) of any order in a fluid flow. CFD mainly helps analyze the internal or external fluid flow. The use of CFD has become increasingly popular in branches of engineering such as Aerospace to study the interaction of the propellers or rotors with aircraft fuselage, Mechanical to obtain temperature distribution of a mixing manifold, Bio-medical engineering to study the respiratory and circulatory systems. There are a few simple generic steps that must be followed for CFD analysis. The following scales and non-dimensional variables are used,

$$x^* = \frac{x}{L},$$

$$u^* = \frac{u}{V},$$

$$P^* = \frac{p}{\rho V^2},$$

$$\frac{\delta}{\delta x^*} = \frac{1}{L}\frac{\delta}{\delta x^*},$$

$$Re = \frac{VL}{\Theta} = \frac{V^2/L}{\Theta V/L^2},$$

$$T^* = \frac{T - T_{in}}{T_w - T_{in}}$$

The continuity equation in a non-dimensional form for a steady state flow is given by,

$$\frac{\delta u^*}{\delta x^*} + \frac{\delta v^*}{\delta y^*} + \frac{\delta w^*}{\delta z^*} = 0$$

The momentum equation in a non-dimensional form for a steady state flow is given by,

$$u^*\frac{\delta u^*}{\delta x^*} + v^*\frac{\delta u^*}{\delta y^*} + w^*\frac{\delta u^*}{\delta z^*} + \frac{\delta P^*}{\delta x^*} = \frac{1}{Re}\left(\frac{\delta^2 u^*}{\delta x^{*2}} + \frac{\delta^2 u^*}{\delta y^{*2}} + \frac{\delta^2 u^*}{\delta z^{*2}}\right)$$

$$u^*\frac{\delta v^*}{\delta x^*} + v^*\frac{\delta v^*}{\delta y^*} + w^*\frac{\delta v^*}{\delta z^*} + \frac{\delta P^*}{\delta y^*} = \frac{1}{Re}\left(\frac{\delta^2 v^*}{\delta x^{*2}} + \frac{\delta^2 v^*}{\delta y^{*2}} + \frac{\delta^2 v^*}{\delta z^{*2}}\right)$$

$$u^*\frac{\delta w^*}{\delta x^*} + v^*\frac{\delta w^*}{\delta y^*} + w^*\frac{\delta w^*}{\delta z^*} + \frac{\delta P^*}{\delta z^*} = \frac{1}{Re}\left(\frac{\delta^2 w^*}{\delta x^{*2}} + \frac{\delta^2 w^*}{\delta y^{*2}} + \frac{\delta^2 w^*}{\delta z^{*2}}\right)$$

The energy equation in a non-dimensional form for a steady state flow is given by,

$$\frac{\delta(u^*T^*)}{\delta x^*} + \frac{\delta(v^*T^*)}{\delta y^*} + \frac{\delta(w^*T^*)}{\delta z^*} + \frac{\delta P^*}{\delta z^*} = \frac{1}{Re\ Pr}\left(\frac{\delta^2 T^*}{\delta x^{*2}} + \frac{\delta^2 T^*}{\delta y^{*2}} + \frac{\delta^2 T^*}{\delta z^{*2}}\right)$$

IV. GEOMETRIC MODEL

Meshing (also called grid generation) is the process of splitting flow domains into sub domains which are primarily composed of triangles or quadrilaterals for 2D geometry or tetrahedral or hexahedra in 3D geometry. Governing equations are discretized and solved in every single sub domain. The sub domains are called cells or elements. Combined, they are collectively called mesh. Grids are normally classified as structured, unstructured, or mixed. Grids are generated in Pointwise, Gambit, or ANSYS Workbench. In this study ANSYS Workbench 12.0.1 was used to mesh the geometry that was imported from Creo Parametric 2.0. The Finite Volume Method (FVM) is the most common approach used for obtaining CFD simulation. As the name suggests, the governing equations are solved over discrete control volumes. This method reforms the governing partial differential equations, especially the Navier-Stokes equation in a conservative form and then discretizes the new equation. The Finite Element Method (FEM) is commonly used in the structural analysis of solids. In FEM, the problem is divided into very small elements which are related to one another. FEM is more stable than FVM and, at times, can require more memory than FVM. The Finite Differential Method (FDM) is a method for approximating solutions to differential equations.

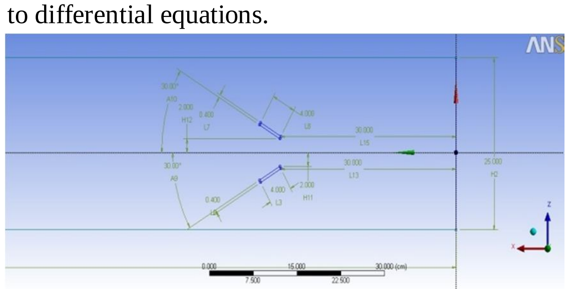

Fig. 4.3 Geometric model with angle b/w vortex generators 30° showing the dimensions (in cm)

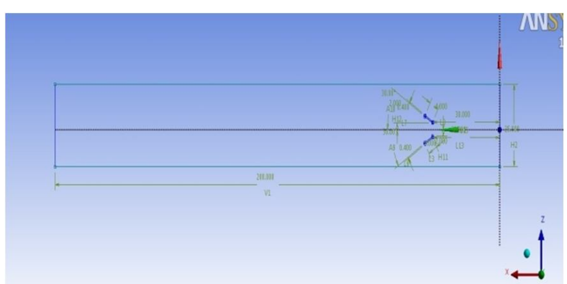

Fig. 4.4 Geometric model with angle b/w vortex generators 30° showing the dimensions (in cm

A. Grid Generation

In this study ANSYS Workbench was used as a meshing tool. The structured non uniform grid was generated. The fig. 4.5 shows the fine meshing near the vortex generators. Fine meshing is needed near the wall region to capture the boundary layer on the wall. The whole fluid domain has all the elements as hexa elements. Mapped Face Meshing option from the ANSYS Workbench meshing tool was used to generate this kind of structured non uniform meshing. Bias factor of 10 was used to make the grids near the wall and the vortex generators fine to capture the boundary layer effects

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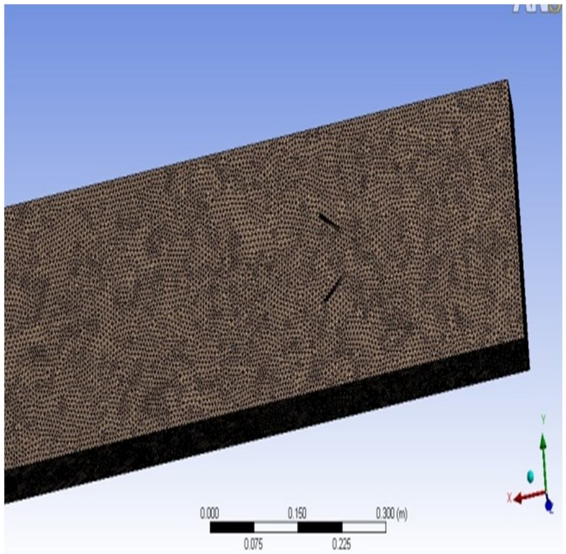


Fig. 4.7 Tetrahedral messing view of the fluid domain meshing

B. FLUENT Setup

In this study ANSYS Workbench was used as a meshing tool. The structured non uniform grid was generated. The fig. 4.5 shows the fine meshing near the vortex generators. Fine meshing is needed near the wall region to capture the boundary layer on the wall. The whole fluid domain has all the elements as hexa elements. Mapped Face Meshing option from the ANSYS Workbench meshing tool was used to generate this kind of structured non uniform meshing. Bias factor of 10 was used to make the grids near the wall and the vortex generators fine to capture the boundary layer effects.

A temperature of 373K is applied on the surface of the heated section which is the bottom surface of the rectangular channel and all the surface of the vortex generator. The inlet has been given an inlet temperature of 300 K and a specific velocity based on the Reynolds number corresponding to the chosen Reynolds number. The outlet has zero pressure thus implying ambient condition. The walls of the whole channel, as well as surfaces of the vortex generator, have been given the no slip boundary condition. A second order upwind discretization method has been used for energy and momentum. Convergence is based on the absolute criteria of continuity, x velocity, y velocity and z velocity equal to 10^{-4} and energy equal to 10^{-8}. This means the solution will converge once the residuals reach the above mentioned mark. The model is computed from the inlet surface and 1000 iterations were given for the solution to converge.

C. Grid Independency Validation

Fig.a shows that due to vortex generators the formation of vortices takes place in which the clockwise and counterclockwise vortex is generated. The magnitude of velocity is greater towards the bottom wall. These opposite vortex generator cause the mixing of the fluid due to which the convection coefficient at the bottom wall increases and hence the Nusselt number increases. With increase in Reynolds number the strength of the vortex are increased which cause greater increase in the Nusselt number. The vortex formation also prevents the thickening of velocity boundary layer on the bottom wall that cause enhanced heat transfer.

Fig.b shows that vortex strength is maximum near the vortex generators and decrease continuously in stream wise direction. So the mixing near the vortex generators cause the greater heat transfer from the bottom wall.

Table 4-2.

Table 4-2

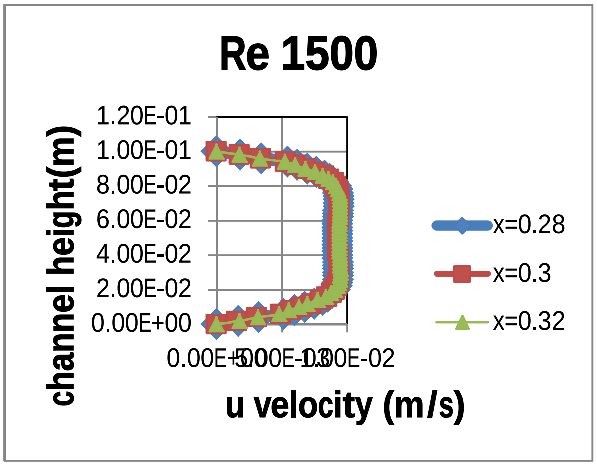
Geometry	Element Numbers
β= 30°	1731773

V. RESULTS AND DISCUSSION

Numerical simulation of the flow in the channel with heated bottom wall has been carried out. In this chapter feature of the flow at a blade angle 30° at different Re are discussed in detail.

1) Analysis of performance of vortex generator with 30° blade angle Reynolds no. 800, 1200.

Fig. 5.1 to 5.16 shows the velocity profile of u velocity at Reynolds no.1500 and 2000. at β= 30



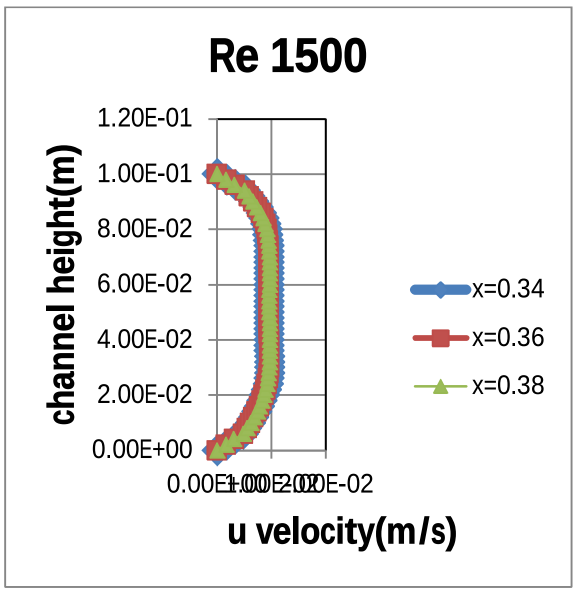


Figure 5.2: Velocity Profile at different planes with x varying from 0.34m to 0.38m for Re=1500

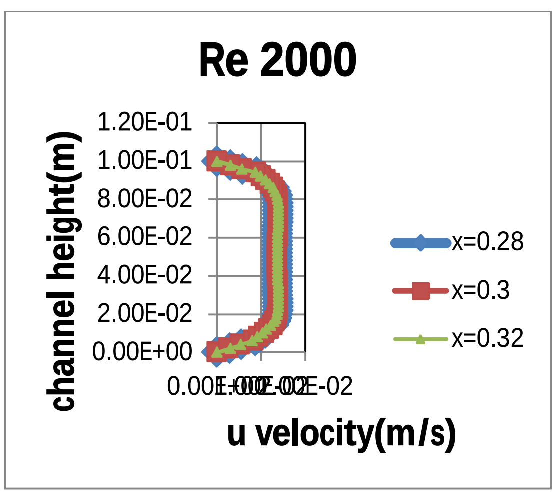


Figure 5.4: Velocity Profile at different planes with x varying from 0.28m to 0.32m for Re=2000

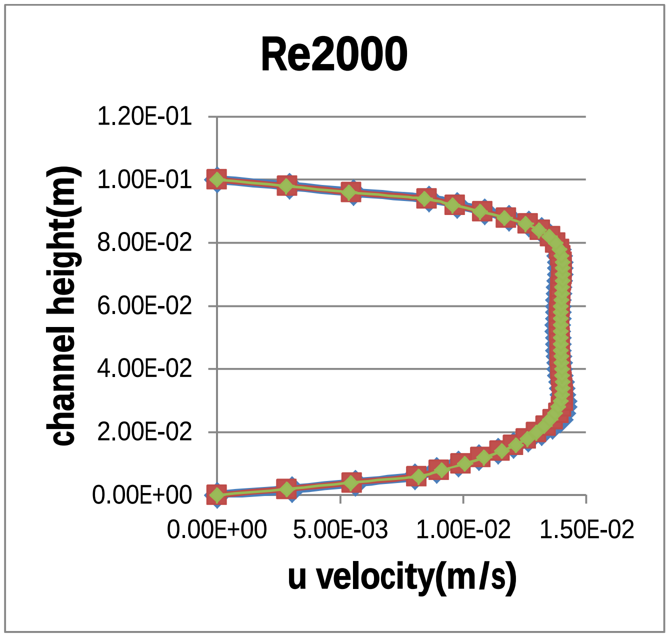


Figure 5.3: Velocity Profile at different planes with x varying from 0.34m to 0.38m for Re=2000

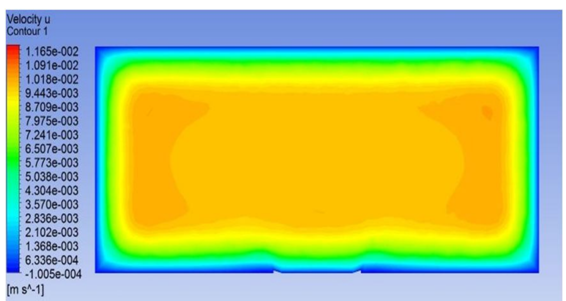


Fig. 5.8 Contour of u velocity, Re 2000, β = 30° (yz plane, x=30cm)

2) Flow structure

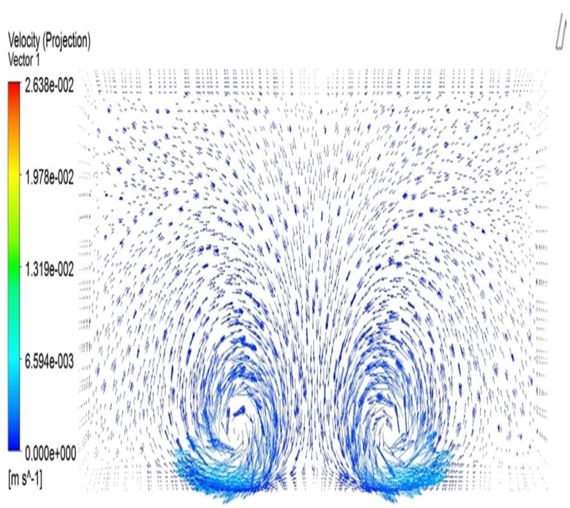
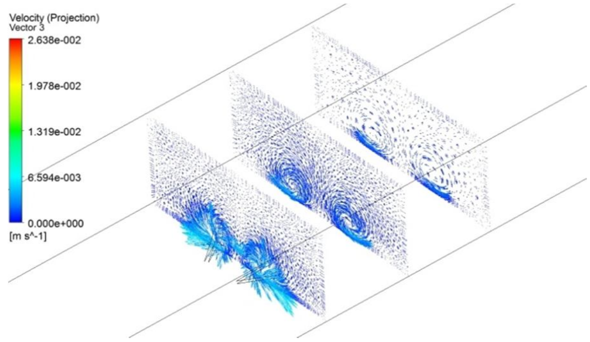


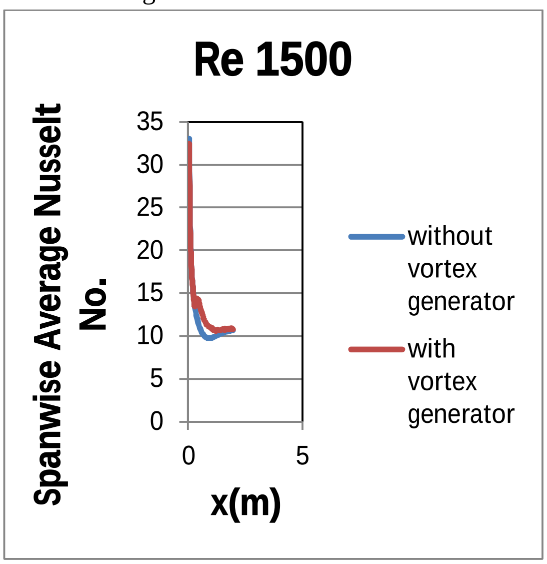
Fig. a Formation vortices on yz plane at x=42cm,R 2000,β=30°

Fig.b shows that vortex strength is maximum near the vortex generators and decrease continuously in stream wise direction. So the mixing near the vortex generators cause the greater heat transfer from the bottom wal



VI. HEAT TRANSFER

The variation of span wise averaged Nusselt number was calculated at different values of x at Reynolds number of 800, 1200. We considered parametric studies between channel without winglet and with winglet pair. It shows that the span wise averaged Nusselt number increase with the increment of Reynolds no. at particular x. Fig. 5.a to 5.d show the behavior at these Reynolds no with blade angle 30°. The increment in the span wise averaged Nusselt no. can be observed from these figures.



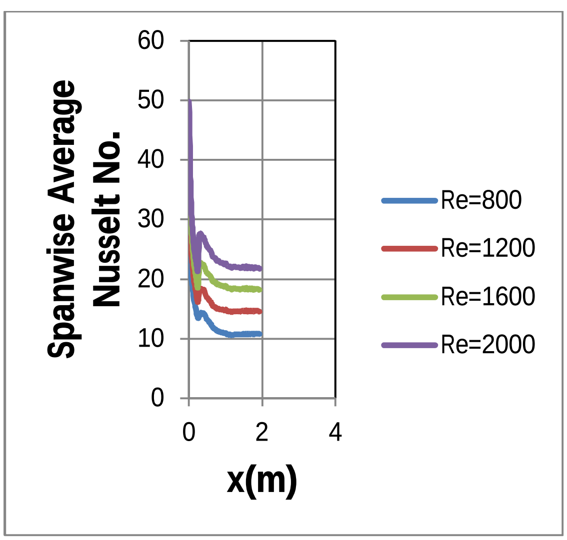


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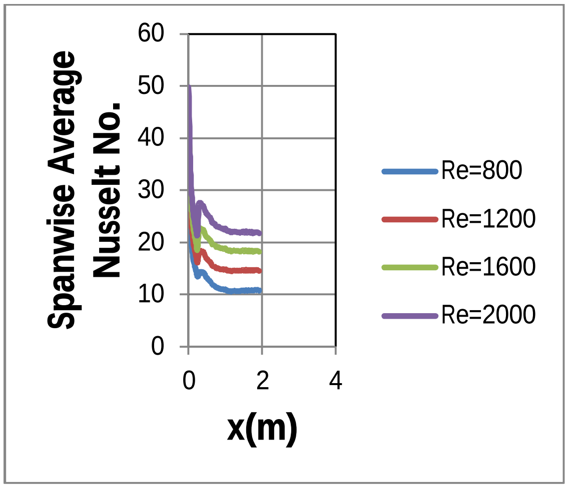
Fig.5.e shows the combined plot for all the cases dicussed. The plot shows that with increase in Reynolds number the span wise avereged Nusselt number increase for the particular x. It is also observed that with increase in the Reynolds number the rate of increase in span wise avereged Nusselt number near the vortex genreator region high,means the vortex generators are more effective at higher reynolds number and causes greater heat transfer from the bottomwall



Above figures show the comparison between the previous work (S.R. Hiravennavar, E.G. Tulapurkara, G. Biswasb 2019) and the present work. The curve behavior is observed same. The difference between the values of Nusselt number is due to difference in the channel and vortex generators dimensions**.**

Table below shows the improvement of heat flux (in percentage) from the bottom wall by the use of vortex generators

Table 5-1

Reynolds No.	β = 30°
1500	8.841
2000	7.262

VII. CONCLUSIONS

show the effect of vortex generators in the spanwise averreged nusselt number. The comparison between the plots of spanwise avereged Nusselt number with and without vortex generators shows that there is a considerable increase in Nusselt number near the vortex generator region and this effect decreases as we move far from the vortex generator region in the stream wise direction.

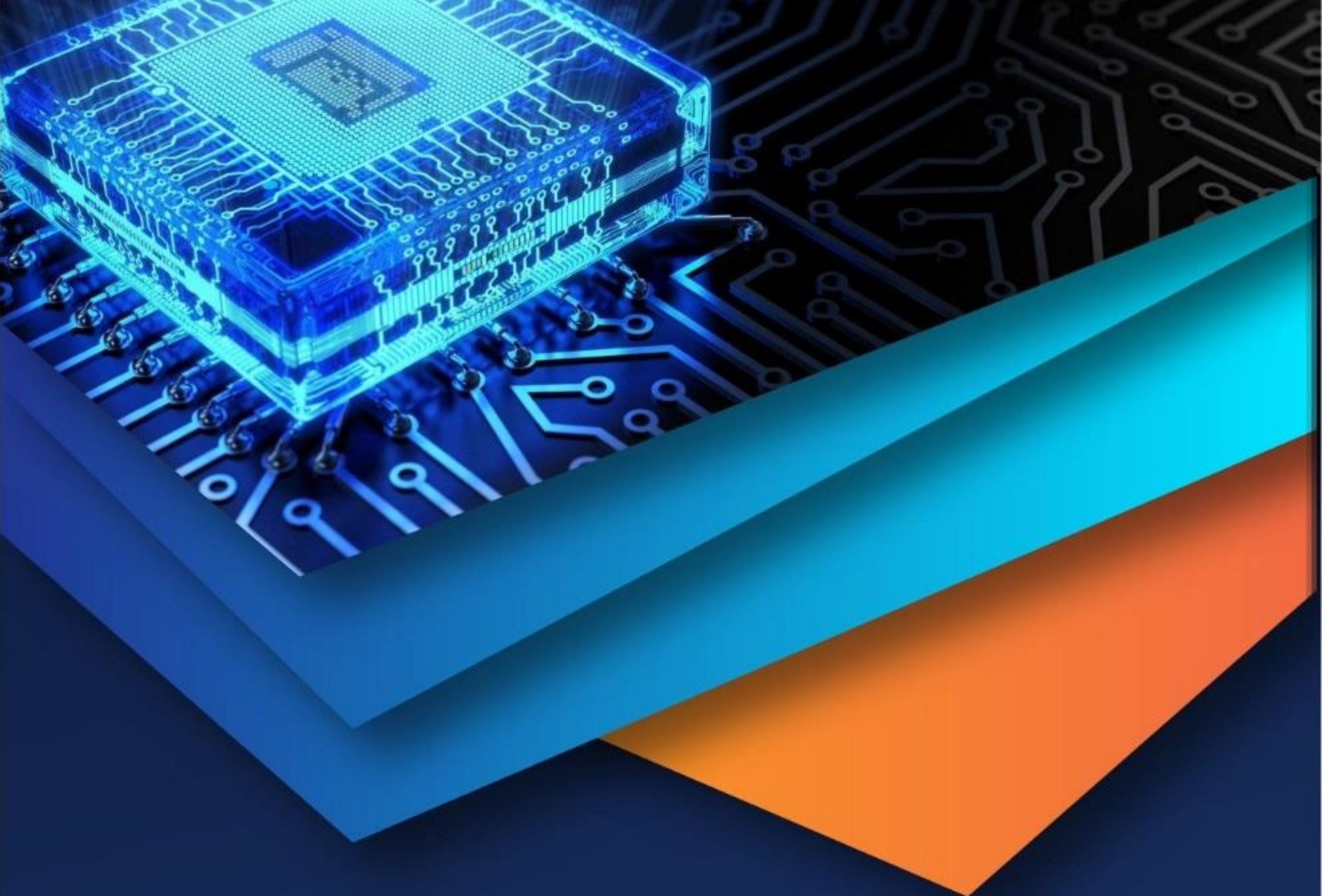
VIII. SCOPE FOR THE FUTURE WORK

Based on this study, a great deal of work can be done for heat transfer enhancement using vortex generator in the future. Here are a few ways to improve the performance enhancement factor or average surface Nusselt number:

1) The effect of placing more than one pair of vortex generators i. e. an array of VGs along the flow direction at particular distance between them can be studied.
2) The effect of varying the height of the vortex generators on the heat transfer can be studied.
3) Other shapes of vortex generators (rectangular, trapezoidal,cube,cylinder,prism,hemi- sphre etc.) can be studied.

REFERENCES

[1] The first use of longitudinal vortex was mentioned by Schuauer and Spangenberg [2012]
[2] A delta winglets pair kept at an angle of attack is very effective [2015].
[3] Laminar channel flow (Fiebig et al., 2018). In the case of the heat exchangers the flow on gas side is usually laminar
[4] Edwards and Alker (1974) find that the delta winglets provided a higher overall heat transfer enhancement, com-pared to cubes placed on a flat plate.



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