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Numerical and Experimental Investigation Of Thermo Hydraulic Performance Of Combination Of Punched Triangular and Rectangular Winglets

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Abstract

Many researchers had done research on increasing the heat transfer rate by using vortex generators of different geometry. Till date very few researcher had taken test on combined geometries. In this work we are going to use the rectangular and triangular winglets with punch at center, fitted on plate. These tests are going to conduct under different conditions by changing parameter like velocity, angle of attack, heat input and aspect ratio. These tests will be taken on four different plates one with flat plate, another with only triangular, next with only rectangular and last with combined. In all the cases heat transfer rate will be calculated and it compared with each other. Average convective heat transfer on the top and bottom surfaces of a plain plate and four plates with a pair of delta winglet longitudinal vortex generator punched directly from the plates at attack angles of 15°, 30°, 45°and 60°respectively. Test is conducted by varying Reynolds number Re =9000 -24000 and velocity V= 1 – 4 m/s. At the last we are going to do analysis of flow in different conditions with the help of CFD software.
Keywords: *The Longitudinal vortex, Punched holes, Heat transfer enhancement, Experimental study, Numerical simulation.*

1. Introduction

The improvement of high performance thermal systems has increased interest in methods to enhance heat transfer rate. The study of improved heat transfer is referred to as heat transfer enhancement, augmentation or intensification. The performance of conventional heat exchanger can be developed by a number of enhancement techniques. A great deal of research effort has been devoted to developing apparatus and performing experiments to define the conditions under which an enhancement technique will improve heat transfer. Heat transfer enhancement technology has been widely applied to heat exchanger applications in refrigeration, automobile, process industries etc. The aim of enhanced heat transfer is to accommodate high heat fluxes. This causes reduction of heat exchanger size, which generally leads to low capital cost. Another benefit is the reduction of temperature driving force, which reduces the entropy generation and increases the second law efficiency. In addition, the heat transfer enhancement enables heat exchanger to operate at low velocity, but still obtain the same or even higher heat transfer coefficient. This indicates that a reduction of pressure drop, corresponding to low operating cost, may be achieved. All these advantages have made heat transfer enhancement methods attractive in heat exchanger applications.Furthermore as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more usual for heat exchangers used in chemical and marine industries. In this case the heat transfer rate can be developed by introducing obstructions in the fluid flow by different enhancement technologies (breaking the viscous and thermal boundary layer).

For well over a century, efforts have been made to create more efficient heat transfer devices by applying various methods of heat transfer enhancement. The study of enhanced heat transfer has got serious momentum during recent years, however, due to increased demands by industry for heat exchange equipment that is less expensive to build and operate than standard heat exchange devices. Savings in materials and energy use also provide strong motivation for the development of improved methods of enhancement. Enhancement equipments are necessary for the high heat duty exchangers found in power plants (i. e. air-cooled condensers, nuclear fuel rods). These applications, as well as numerous others, have led to the improvement of various enhanced heat transfer surfaces. The development in the performance of the heat transfer equipments have attracted many researchers for a long time as they are of great technical, economical, and not the least, ecological importance. Performance improvement becomes essential particularly in heat exchangers with gases because the thermal resistance of gases can be 10 to 50 times as large as that of liquids, which requires large heat transfer surface area per unit volume on gas side. Generally, enhanced heat transfer surfaces can be used for three purposes:

1. To produce heat exchangers more compact to reduce their overall volume, and its price.
2. To bring down the pumping power need for a given heat transfer process.
3. To improve the overall heat transfer coefficient value of the heat exchanger.

Nomenclature

A =total surface area of the heated plate,m2
cp=specific heat of air, J/kg K
H=channel height, m
h=average heat transfer coefficient/m2 K
K=thermal conductivity of air, W/m K
LV= longitudinal vortex
LVG= longitudinal vortex generator
LVs=longitudinal vortices
Nu=average Nusselt number

2. Litertrature Review

Assadour Kantian et al [1],the generation of secondary flow that are added to the main flow to fluid exchange between hot and cold regions in the system to increase convective heat transfer coefficient. In this experiment, results are related to laminar convection heat transfer in a rectangular channel which bottom wall which is connected with rectangular winglet pair vortex generators. They have studied the effect of the generators' roll-angle on the heat transfer and characteristics. The roll angle β used in this case study is in the range of 20^0 to40^0, while a constant angle of attack (α =30°) was maintained for all the cases. At the end, from research all over the world, it found that the optimal values of the roll-angle, determined for each Reynolds number is not necessarily to be 90° thatis used mostly as an optimum configuration.

S.Caliskan et al.[2], combines new punched triangular vortex generators (PTVGs) and punched rectangular vortex generators (PRVGs) developed. Both triangular and rectangular vortex generators are directly punched from the longitudinal winglet at attack angles of 15°,45°and75°respectively. Measurements are carried out for a rectangular channel of an aspect ratio of AR = 2, for a winglet transverse pitch (S) to a longitudinal winglet height (e) ratio of S/e = 0.59, and a winglet height (e) to a channel height (H) ratio of e/H = 0.6. The heat transfer results of the vortex generators were compared with those of a smooth plate. The best heat transfer performance was obtained with the PTVGs.

As per the results, the increase in heat transfer due to introduction of vortex was found to be 23-55%. These vortex generators show a more significant increase in heat transfer coefficient for channel flows.

A.A. Gholami,et al [3],In the current work, heat transfer enhancement and pressure loss penalty for fin-and-tube compact of heat exchangers with the wavy rectangular winglet as special forms of winglet were numerically investigated in a relatively low Reynolds number flow. To increase the heat transfer performance of fin and tube compact heat exchanger, a rectangular winglet was installed which had a particular wavy form.They also inspected the effect of Reynolds Number in the range of 400-800 with angle of attack 30° of wavy rectangular winglets. The effects of using the wavy rectangular winglet, conventional rectangular winglet configuration and without winglet as baseline configuration, on the heat transfer characteristics and flow structure were studied and analysed for the inline tube arrangements. As per the observed data, it was concluded that the wavy rectangular shaped winglet 20is the most optimum and efficient for heat transfer in case of fin and tube compact heat exchanger with a pressure drop penalty of 21.

Ya-Ling He, et al [4],investigated, for a relatively lower Reynolds number range, the heat transfer improvement and pressure loss penalty for tube and fin compact heat exchangers. The aim of this study was to elaborate in detail the fundamental mechanism between the local flow structure and the heat transfer augmentation. The RWPs were placed with a special orientation for the purpose of enhancement of heat transfer. The effects of attack angle of RWPs, row-number of RWPs and placement of RWPs on the heat transfer characteristics and flow structure was scrutinized in detail. It observed that the longitudinal vortices caused by RWPs and the impingement of RWPs directed flow on the downstream tube was important reasons of heat transfer enhancement for fin-and-tube heat exchangers with RWPs. An interesting fact revealed during this research was that the pressure loss penalty can be decreased by changing the structure of placing the RWPs from inline array to staggered array without compensating for the heat transfer. The results shows that the rectangular winglet pairs (RWPs) can significantly improved the heat transfer performance of the fin and tube heat exchangers with a moderate pressure loss penalty.

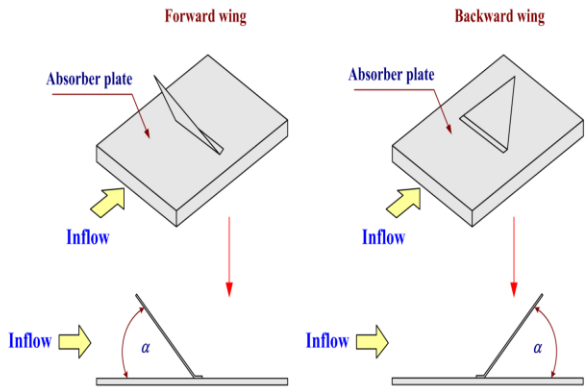
Henk Huisseune et al. [5], Louvered fin and round tube heat exchangers was widely used in air conditioning devices and heat pumps. They studied the the effect of punching delta winglet vortex generators into louvered fin surface in the near wake region of each tube. The delta winglets reduce the size of the tube wakes. Heat transfer enhancement is observed due to them through three different phenomena. First, due to the swirling motion of the generated vortices, hot air is removed from the tube wake to the mainstream regions and vice versa. Second, the boundary layer is made thin locally because of induced wall-normal. Third, because of delay in flow separation from the tube surface, the size of wake zones was reduced.

Lei Luo,et al.[6] In this study, delta-winglet vortex generators (DWVGs), and the combination of DWVGs and obstacles were numerically investigated to explore the effects on a solar receiver heat exchanger and the heat transfer, friction factor and mixing. The DWVGs were placed on the heated plate. Four different obstacles, i.e., perturbation triangular ribs, perturbation semi-cylinder ribs, triangular grooves and semi-cylinder grooves, were under the consideration in study. The Reynolds number is ranging from 4000 to 40,000. Results of the flow field, friction factor, temperature heated plate, Nu number, and turbulent kinetic energy (TKE) were included. From the results

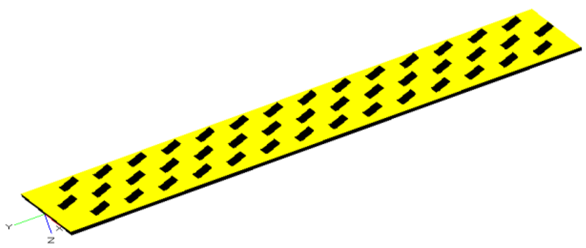
it was observed that the installation of DWVGs generates pressure gradients on more than one direction which causes vortex generation. The flow velocity was increased as the flow approaches the DWVGs. The highest heat transfer enhancement was observed with perturbation semi-cylinder ribs as the vortex is disturbed by the smooth cylinder surface. From the thermal performance, it was concluded that the semi cylinder grooves together with DWVGs result in the highest performance.
J.M. Wu, et al.[7],studied the average convective heat transfer on the top and bottom surfaces of a plain plate and four plates with a pair of delta winglet longitudinal vortex generator punched directly from the plates at attack angles of 15°, 30°, 45°and 60° respectively. Experimental results showed that the average Nusselt number on the surfaces of plate increases directly with the attack angle of delta winglet pair compared with that of plain plate without delta winglet pair in the test range. The average Nusselt number of the plate with attack angle of 60° is slightly higher than that of plate with attack angle of 45°.

3.Geometric model

The geometry of the proposed design is shown in figure.Longitudinal vortex generator i.e. triangular winglet is investigated for heat transfer enhancement potential over a flat plate. A combined geometry of punched rectangular and triangular geometries is implemented, while a separate analysis is to be done for triangular and rectangular winglets so as to get accurate results.



(a) Triangular geometry


(b) Rectangular geometry
Fig.1 Vortex generator

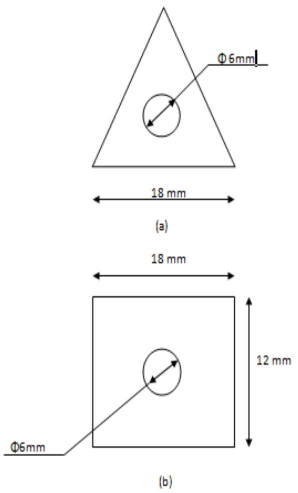


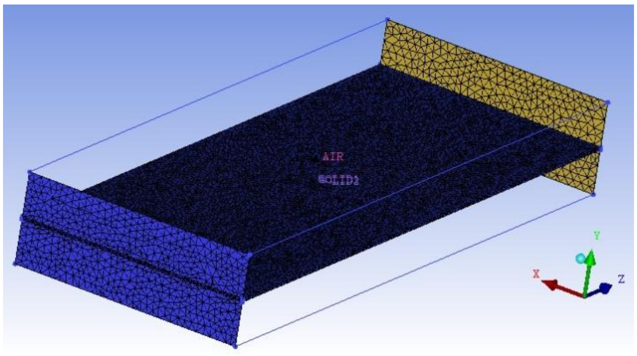
Fig.2 block diagram of winglet a) Triangular b) Rectangular

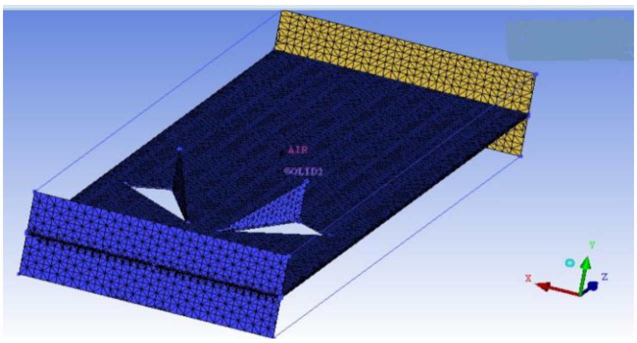
So first we had done CFD on plain triangular winglet and got the result. Here we had studied the sample geometry from the research paper of J.M. Wu.

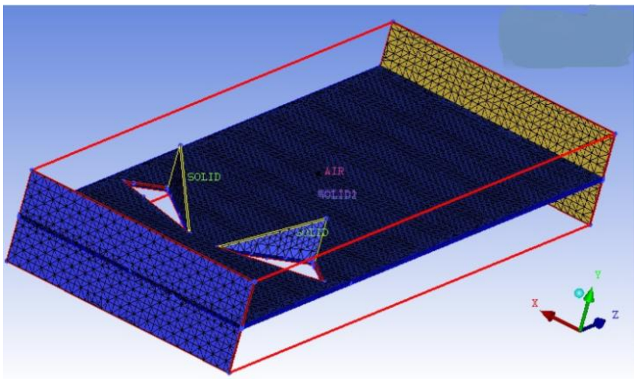
4. Numerical analysis

The boundary condition at inlet velocity 1.9 m/s at Re 800, Zero gauge Pressure Outlet and Constant Heat Flux 546.785 W/m^2

The computational model of test plate after meshing is shown in fig. 3. The mesh type used here is mixed tetra type. The mesh density is provided around curved rectangular vortex generators on test plate to get more reliable and accurate results.


(a)


(b)



(c)
Fig.3 CFD meshing of different geometries

5.Experimental setup and procedure

The block diagram for experimental setup is as shown in figure 4. The experimental setup consists of 150mm* 150mm* 10mm aluminum test plate with vortex generators placed in inline configuration and staggered configuration at a fixed angle of attack of 30°,45⁰,60°. The plate heater is placed exactly below test plate.Figure 4 shows the block diagram for experimental setup.

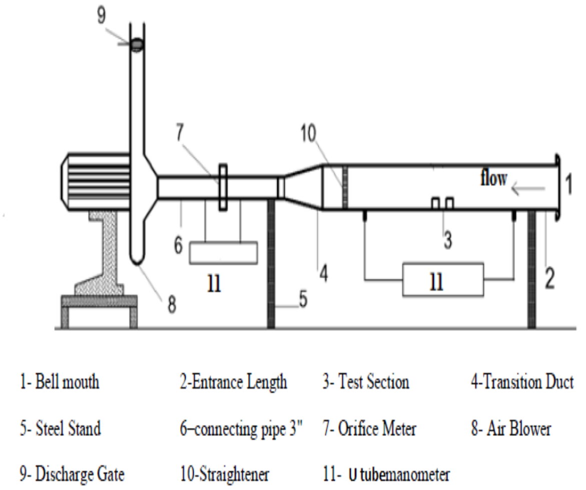


Fig.4.Praposed experimental set up

This test plate assembly with thermocouple as temperature measuring device is placed in acrylic duct of size 2500mm*150mm*100mm. Air blowers connected at inlet section of rectangular channel. Temperature indicator and wattmeter are connected to respective connectors. The proper insulation is provided with insulating tape. The instruments used for experimentation are heater plate of nichrome wire with dimensions same as that of test plate, variable speed type blower with rpm range of 1600, Pt-100 Simplex type thermocouples with three core cable, vane probe anemometer with velocity measuring range 0to30m/s and wattmeter with capacity to measure 0to750watts.
A constant power input is provided with respective velocity during the testing. Temperature of air at inlet and exit of test section and at test plate are recorded at steady state conditions. The data is collected for different specified velocities and power input combinations for smooth plate, inline configuration and staggered configuration.

6.Data reduction

Nusselt number and Reynolds number where based on average of channel wall temperature and outlet temperature. All fluid properties were found at overall mean bulk temperature. Values for air temperatures and plate temperatures are obtained from temperature plots at respective locations. Heat transfer coefficient (h) and Nusselt number (Nu) are calculated from data. Pressure drop (ΔP) is obtained from pressure plot. These values are used for investigation of various deciding parameters.
Following equations are used for evaluation of parameters,

Reynolds number (Re):

$$Re = \frac{\rho v Dh}{\mu}$$

Heat transfer coefficient (h):

$$Q = hA\Delta T$$

Nusselt number (Nu):

$$Nu = \frac{hDh}{K}$$

Hydraulic Diameter(Dh):

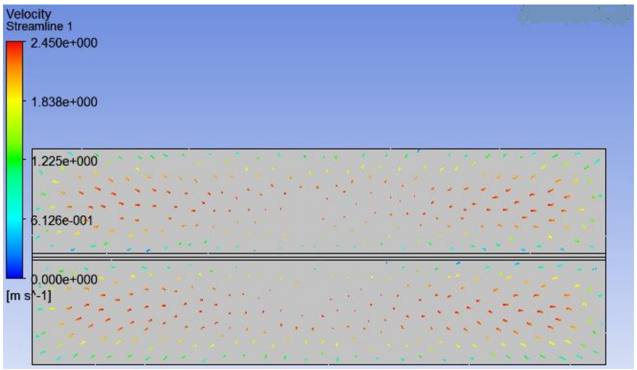
Dh=2(w*H)/ (w+H)

7.Grid Independence Study and Boundary conditions

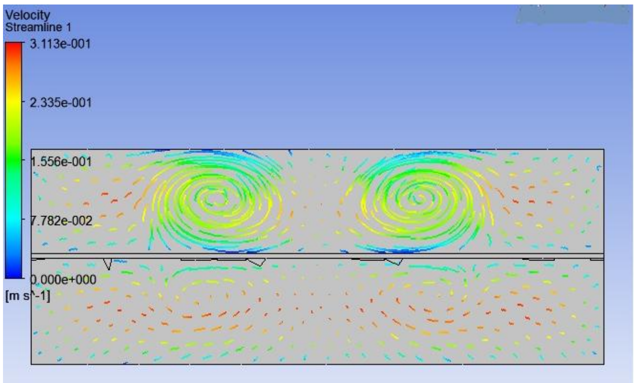
Grid independence study is carried out over the different numbers of cells. An effort is undertaken to obtain the grid independent results in a rectangular channel. The numbers of grid cells that were used for simulation are 458623, 529394 and 685478. A close agreement is found between the results Obtained for grid cells 529394 and 685478. It is observed that the maximum discrepancy in the value of Nusselt number (Nu) for 529394 and 685478. is found to be within 0.45%. Hence to save the computational time and cost, grid system of 529394 cells is adopted for this computational model.
The boundary condition at inlet velocity 1.9 m/s at Re 800, Zero gauge Pressure Outlet and Constant Heat Flux 546.785 W/m²

8.Result and discussion

From CFD analysis J.M.Wu is found that Nu number is 6.5,8.8.2.5 for plain,30°,45° respectively and from our CFD work got the Nu number 5.1,6.6 and 7.3 respectively. Here we conducted the CFD for all angle of attack by keeping Re=800.
The figures below shows the effect of Re on the average Nu of the different plates. In comparison with the plain plate, the average Nu for the plate with delta winglet pair at β=30°, 45°, increased by 15-20%, 21-29%, respectively at the experimental range. The average Nu increased with the increase of the Re in the channel. We can find that the average Nu for the case of β=45°. is just slightly higher than that of β=30°.



(a)Velocity profile of Smooth / Plain Test section at Re 800



(b)Velocity profile of Vortex Generator Test Section at Re 800 β=30^{0}

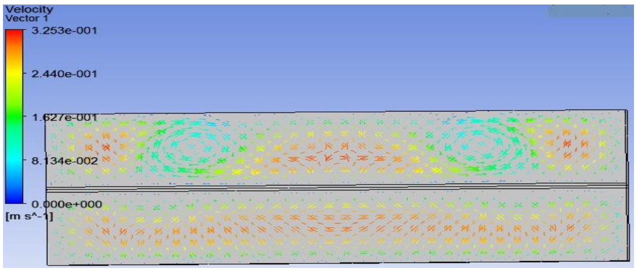


Fig.(c)Velocity vectors of Vortex Generator Test Section at Re 800 β=45^{0}

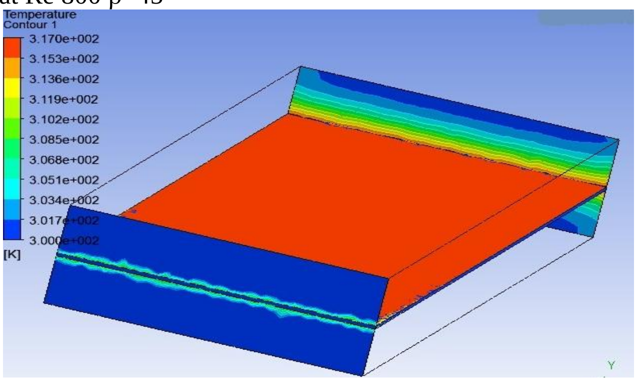


Fig.(d)Temperature profile of Smooth / Plain Test section at Re 800

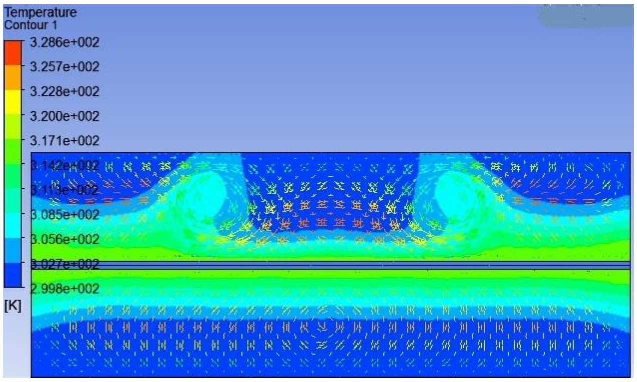


Fig.(e)Temperature profile of Vortex Generator Test Section at Re 800 β=30^{0}

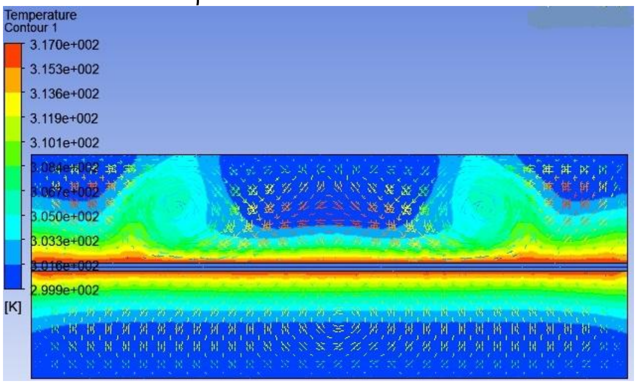


Fig.(f)Temperature profile of Vortex Generator Test Section at Re 800 β=45^{0}

Fig.5 Velocity and temperature profile

To analyze the effect of the generated LVs on the flow and heat transfer in the channels, the calculated temperature and velocity fields are given in fig 5c and 5f. In these figures, there is a cross section at the downstream of one chord-length away from the trailing edge of delta winglet pair with attack angle of 45°, Re of 800. As found in this research, we can see a pair of longitudinal vortices is generated in the upper channel. Because of the traverse flow through the punched holes, a pair of weaker vortices is as well generated. This can also be validated from numerical analysis that the generated LVs in the upper channel can go down to the outlet of channel.

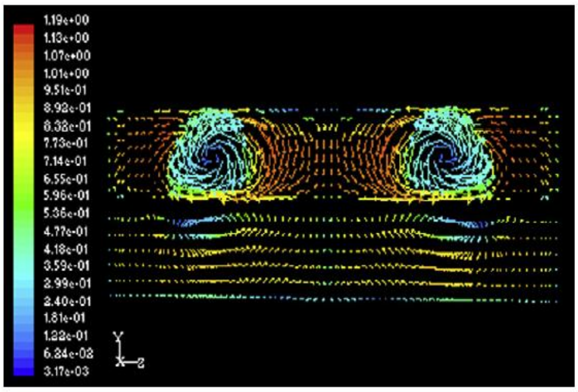


Fig. 10. Computed longitudinal vortices at the downstream cross section one chord away from the trailing edge ($\beta = 45°$, $Re = 800$).

(a)

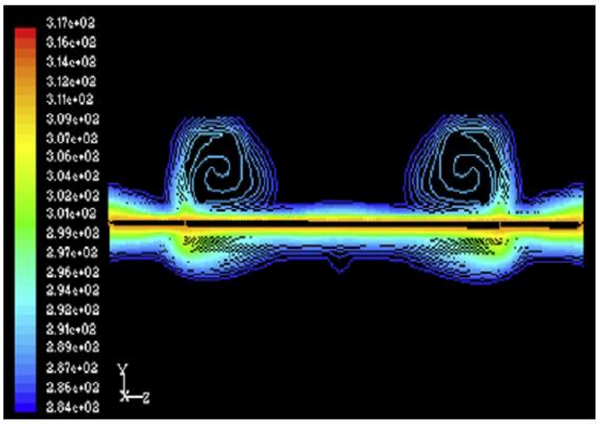


Fig. 11. Computed temperature field at the downstream cross section one chord away from the trailing edge ($\beta = 45°$, $Re = 800$).

(b)

Fig.6.Velocity and temperature profile of J.M.Wu

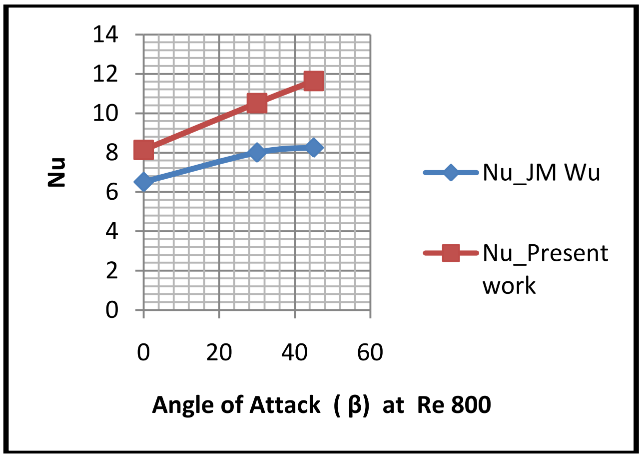


Fig.7.comparison of Nu number from JM Wu and present work

From above graph we can conclude that there is variation of 26 to 12 % in result reported by JM Wu and Present CFD simulation.

9. Conclusion

a)Here we have used a combined geometry of punched rectangular and triangular geometries inserted on a flat plate.

b)A separate analysis for rectangular and triangular configurations was done for better accuracy.

c)The average heat transfer of both surface of the plate with delta winglet pair increases in direct proportion with Reynolds number and angle of attack.

d)Strong and persistent LVs are visualized in the upper channels of the present study.

e) It is observed that the transverse flow through the punched holes under delta winglets disturbs the flow field of the lower channel.

f)More disturbances were detected in fluid flow and hence heat transfer coefficient at attack angle 45° than 30°.

g)From CFD analysis by J.M.Wu, it is found that Nu number is 6.5,8.8.2.5 for plain, 30°,45° respectively whereas, from our CFD work, we got the Nu number 5.1,6.6 and 7.3 respectively. Here we conducted the CFD for all angle of attack by keeping Re=800.

h)In comparison with the plain plate, the average Nu for the plate with delta winglet pair at β=30°, 45°, increased by 15-20%, 21-29%, respectively in the experimental range.

10. References

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