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Heat Transfer Enhancement in a Laminar Channel Flow with Built-in Triango-Circular Inserts

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Abstract:

The Nusselt number and the flow characteristics in the 2-D rectangular channel with built-in triango-circular inserts have been studied numerically in the periodically fully developed regime using ANSYS 15.0. The flow of fluid is assumed to be incompressible, steady and laminar with constant thermo physical properties. The calculations are performed for a Reynolds number 50 and 100 angle of tip triango -circular inserts 60˚. The Navier Stokes equations along with the energy equation have been solved by using SIMPLE Technique. The unstructured quadrilateral mesh is used for the computational domain. The simulation results show that there is 6.025% increase in nusselt number at Reynolds number 50 and 12.18% increase in nusselt number at Reynolds number 100. There was a significant pressure drop in the duct.

Keywords: Heat exchanger, Fluent, Reynolds Number (Re), Nusselt number, Navier Stocks Eqn., Energy Equation, Triango-circular inserts.

I. INTRODUCTION

Heat transfer enhancement is the process of enhancing the performance of a heat transfer unit. There are several methods used to increase the heat transfer rate in compact heat exchangers [1]. The majority of these methods have a common objective, i.e., to disturb the boundary layer on the solid surface, and replace it with fluid from the wall, which creates a new boundary layer with an increased temperature gradient. This subject has received considerable attention to get high efficiency, small size, low cost, and light weight of heat transfer unit. Compact heat exchangers are widely used in numerous industries, so enhancement in their performance with respect to reducing manufacturing costs by using less material. To achieve higher heat transfer rate through a variety of augmentation methods can result in significant energy savings, more compact and less pricey apparatus with higher thermal efficiency.

II. LITERATURE REVIEW

The convective heat transfer and the flow characteristics in the 2-D channel with quasi-streamlined fins have been numerically studied in the fully developed system [2]. The value of the Reynolds number ranges from the laminar to the turbulent flow. The consequence of the fin angle, the plate thickness v/s the Reynolds number on the nusselt number and the friction factor has been acknowledged. The heat transfer enhances monotonically with the fins angle from 0˚to 30˚. Article [3] presents a numerical investigation of fully developed periodic laminar flow and heat transfer in a constant temperature-surfaced square duct fixed with V-baffle (or winglets) vortex generators. The computations are based on a finite volume method using SIMPLE algorithm. The laminar fluid flow and heat transfer rates are presented for Reynolds numbers depending on the hydraulic dia. of the channel varying from 100 to 2000. To generate a duo of stream wise counter-rotating vortex (P-vortex) flows through the tested channel, the V-baffle with the attack angle of 30° are mounted in tandem and inline arrangement on both walls (upper and lower) of the tested channel with the V-baffle tip pointing downstream (V-Downstream). Effects of different baffle heights at a constant pitch ratio of 1.5 and BR in range from 0.1-0.4 on heat transfer and pressure loss in the square channel are studied. It is evident that the P-vortex flow exists and helps to stimulate impinging flows on a side wall and the lower and upper wall leading to extreme heat transfer enhancement over the test channel. As the baffle height increases, there is a rise of heat transfer and friction factor. Nishimura and Matsune [4] replicated and visualized the dynamical performance of vortices flow in test channels. Fabbri and Rossi [5,6] numerically studied the laminar convective heat transfer characteristics in the corrugated and smooth channels. Cheng and Wang [7] calculated the forced convection of micro polar fluid flow above the wavy surfaces. The vortex generators VGs usually take configurations of tiny protrusions which may be incorporated into the main surface of the channel by punching, stamping, attaching, mounting and embossing [8]. Nasiruddin et al. [9] explained heat transfer augmentation in a heat exchanger tube by installing a baffle. The effect of baffle size and arrangement on the heat transfer increase was studied in detail. Three different baffle orientations were considered. The outcome shows that for the vertical baffles increase in the baffle height results in a considerable increase in the nusselt number and the pressure drop is also significant. For the inclined baffles, it is observed from the results that the nusselt number improvement is roughly independent of the baffle inclination angle, with maximum 120% and average nusselt number 70% higher than that for the case with no baffle, respectively. For specified baffle geometry, the nusselt number augmentation is amplified by more than a factor of two as the Reynolds number reduced from 20,000 to 5000. Simulations were conducted by adding another baffle to enhance heat transfer. The outcomes show that the average nusselt number for the 2 baffles case is 20% more than the 1 baffle case and 82% higher than the no baffle case. These results advice that a significant heat transfer increase in a heat exchanger tube can be achieved by adding a baffle inclined downstream side, with the minimum pressure drop. Sommers and Jacobi [10] studied; a collection of delta-wing vortex generators applied to a plain fin and tube heat exchanger with a fin spacing of 8.5 mm. Heat transfer using nusselt number and pressure loss is measured to find out the effectiveness of the vortex generator with frosting environment. For air side Reynolds number was taken between 500 and 1300, the air side thermal resistance was decreased by 35-42% when vortex generation was used. Similarly, the value of heat transfer coefficient is observed between 33 and 53 W/m^{2}K for the enhanced heat exchanger and between 18 and 26 W/m^{2}K for the baseline heat exchanger. The article provided a research for the heat transfer improvement and flow field through a two dimensional wavy duct [11]. The average heat transfer coefficient in 2nd region is nearly 1.5 times of 1st region which means better heat transfer characteristics.

III. GEOMETRY AND MATHEMATICAL FORMULATION

Fig. 1 represents a two dimensional computational domain. Two adjoining plates form a channel of height "H" and length "8.4 H". The distance between the plates is taken as unity i.e. H = 1m. The insert base is placed at a distance of "3.0165 H" from inlet. The insert base is perpendicular to the direction of flow. The insert in 1st column are the combination of triangle and circle. The sides of the insert form an equilateral triangle. The inserts in 2nd column are made using arcs and insert base is placed at a distance of "3.0165 H" from outlet. Air has been taken as working fluid.

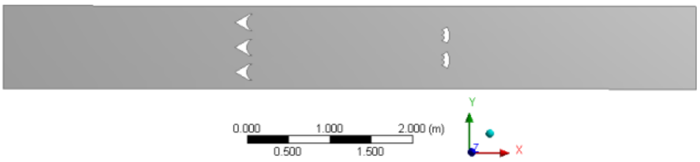

Fig. 1 Shape of inserts

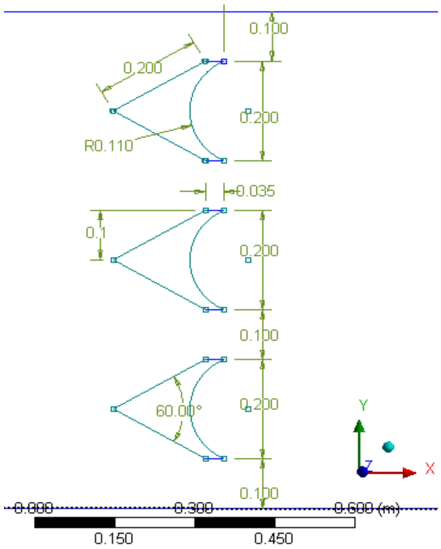

Fig. 2(a) Zoomed projection of inserts in 1st column

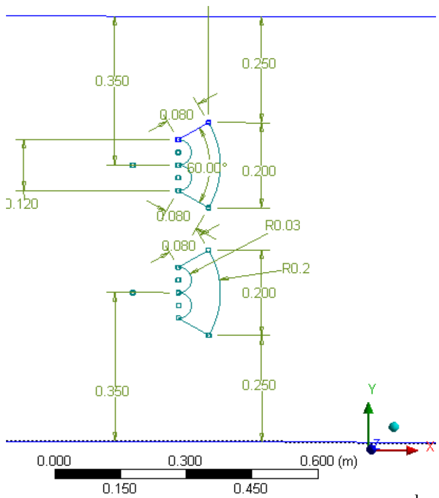

Fig. 2(b) Zoomed projection of inserts in 2nd column

IV. GOVERNING EQUATIONS AND BOUNDARY EQUATIONS

CFD is fundamentally based on the governing equations of fluid dynamics. The fundamental governing equations for an incompressible two dimensional laminar flow are continuity equations, momentum equations and energy equations. The incompressible steady two dimensional continuity, momentum and energy equations are:

A. Continuity equation

B. Boundary Conditions

The solution domain of the considered two dimensional flows is geometrically simple, which is a rectangle on the x – y plane, enclosed by the inlet, outlet and wall boundaries. The working fluid is air. The inlet temperature of air is considered to be uniform at 300 K. On walls, no-slip boundary conditions are used for the momentum equations. A constant surface temperature of 400 K is applied to the upper and lower wall of the channel. A uniform one dimensional velocity is applied as the hydraulic boundary condition at the inlet of the computational domain. The pressure at the outlet of the computational domain is set equal to zero gauges. No-slip boundary conditions are taken for insert.

V. RESULTS AND DISCUSSION

Flow Characteristics and Heat Transfer Characteristics for Re = 50 and 100 are:

1.) Velocity Characteristics

When the air passes through the triango-circular inserts, there is increase in velocity of air due to diverging section ahead.

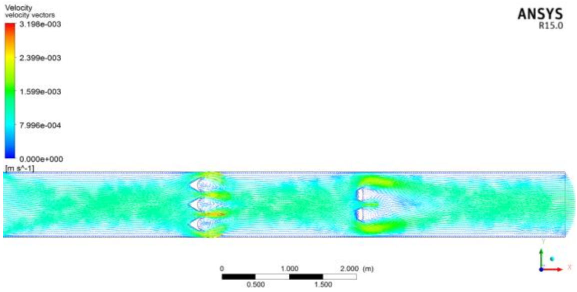

Fig. 3 Velocity streamlines for Re = 50

As there is increase in Reynolds number the velocity of air increases proportionally as length, density and viscosity of the air is constant for all cases.

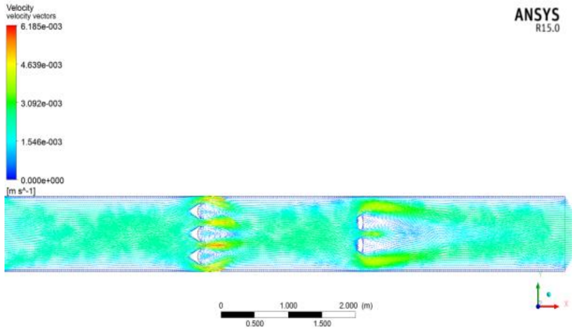

Fig. 4 Velocity streamlines for Re = 100

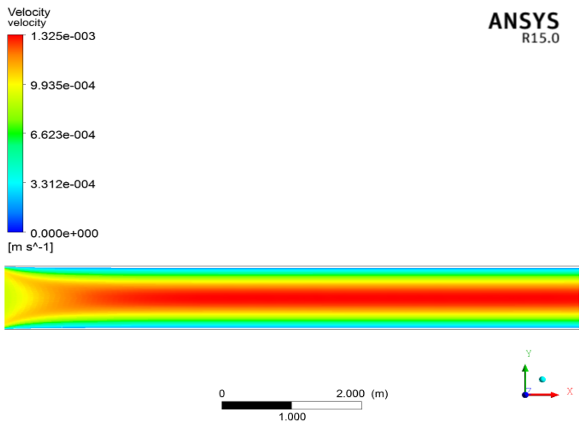

Fig. 5 - Velocity streamlines for Re = 50 without insert

2.) Temperature Contours and Heat Transfer Characteristics

Temperature of the upper and lower walls is constant at 400K. Air enters the duct with 300K. As it passes through the duct it takes heat from the walls. At Re=50 the average temperature of the air at outlet is 388.2K and at Re=100 the average temperature of the air at outlet is 374.51K. As reynold number inc., velocity of air inc. and air remains inside the duct for less time so it absorbs less heat from the walls. Therefore, average temperature of air at outlet reduces as reynold number increases.

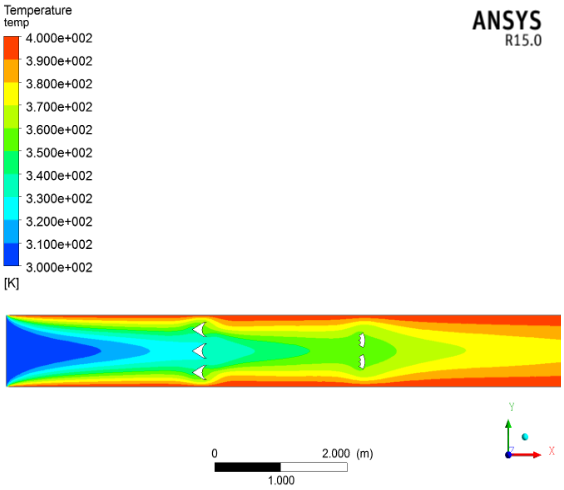

Fig. 6 - Temperature contours of the computation domain at Re =50

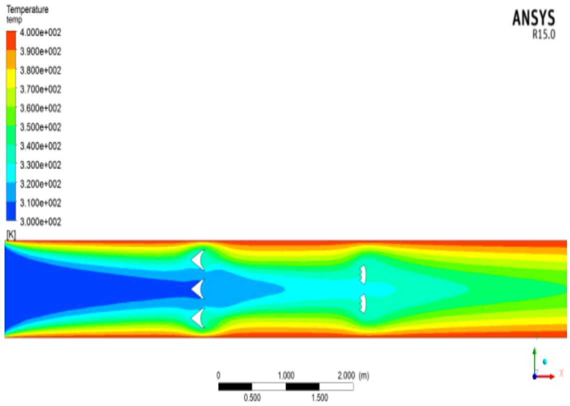

Fig. 7 - Temperature contours of the computation domain at Re = 100

3.) Nusselt Number Variation along length

When the air comes in contact with inserts velocity of the air increases. It breaks the thermal boundary layer at walls. Hence, at that point there is a increase in nusselt number. This also shows that by adding inserts heat transfer has been enhanced. Also, we can verify it by comparing it with a rectangular duct without inserts.

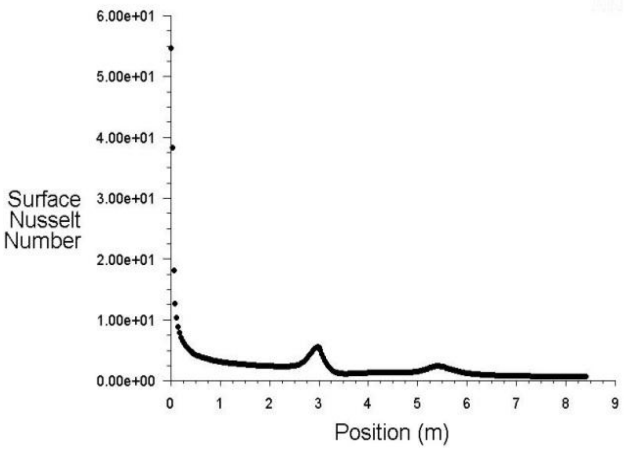

Fig. 8 - Variation of Nusselt number along the channel length at Re = 50

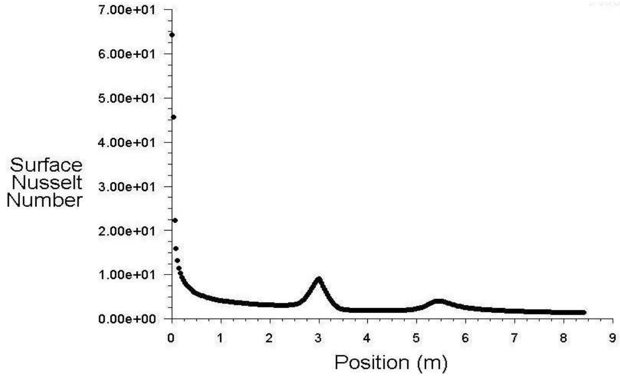

Fig. 9 - Variation of Nusselt number along the channel length at Re = 100

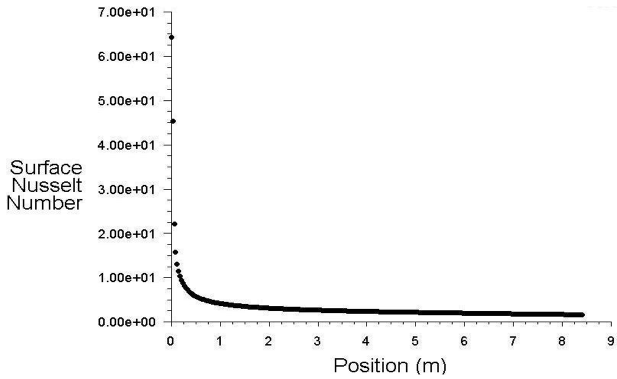

Fig. 10 - Variation of Nusselt number along the channel length at Re = 100 without insert

At the first prism the flow divides itself into two streams as it strikes the prism. As it tends to recombine, it strikes the next prism and is again divided into two streams. As the strength of the vortex decreases after the first prism, it is regained at the second prism. So in case of dual prism the overall strength of vortex increases and there is more mixing of the flowing fluid.

4.) Pressure Characteristics
When the velocity of air increases by coming in contact with inserts there is a significant drop in pressure.

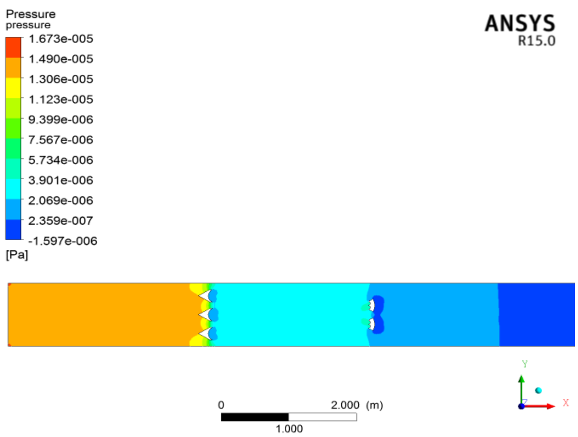

Fig. 11 - Pressure contours of the computation domain at Re = 50

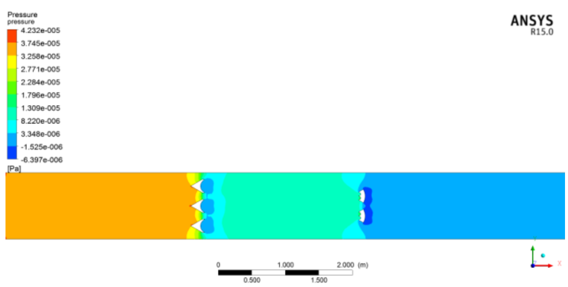

Fig. 12 - Pressure contours of the computation domain at Re = 100

VI. CONCLUSION

In this problem the numerical simulation of steady, laminar flow in a rectangular channel with a built-in triango-circular inserts is performed. The effect of Reynolds number and angle of tip of triango-circular insert on flow characteristics and heat transfer enhancement.

Following conclusions can be made:

1. Using triango-circular insert there is a significant increase in heat transfer rate. There was 6.025% increase in the average nusselt number using triango-circular insert with an angle of 60˚ and Re = 50 as compared to a rectangular duct without inserts with same conditions.
2. Heat transfer increases as the Reynolds number is increased. Average nusselt number at Re = 100 increases by 102.16% as compared to average nusselt number at Re = 50 with same tip angle of triango-circular insert i.e. 60˚.
3. There was 12.18% % increase in the average Nusselt number using triango -circular insert with an angle of 60˚ and Re = 100 as compared to a rectangular duct without inserts with same conditions.

The enhancement of heat transfer achieved by using a triangular prism is associated with an increase in the pressure loss due the presence of the triango-circular insert.

VII. SCOPE FOR FUTURE WORK

The results of this work reveal that the triango-circular inserts as a vortex generator is a useful device for improving heat transfer in a rectangular channel. Here the computations have been done assuming flow regime to be laminar. The present problem can be extended in future in the following ways:

1. The present study can be extended for the turbulent flow. Using an appropriate turbulent model, the performance of the purposed design can be computed for higher Reynolds number.
2. The present problem can be extended for more than five inserts. The simulation can be performed for various positions of triango-circular inserts.
3. The study can be performed for other different geometries and can be compared for the best geometry.

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