# Heat Transfer Enhancement In A Channel Flow With Built-In Equilateral Triangular Prism In Zig-Zag Arrangement

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***Abstract-*** *In this research work, heat transfer and fluid flow characteristics in a channel in the presence of triangular prism have been numerically investigated in the laminar and turbulent flow regime. The computations are performed for Reynolds number varying from 50 to 500 for laminar, 5000 to 20000 for turbulent and blockage ratio (BR) of 0.25, where blockage ratio is the ratio of prism base to the channel height. The Navier Stokes equation and the energy equation are solved by using Fluent [14.0]. The unstructured triangular mesh is used for the computational domain. The objective of this study is to investigate the effect of the spacing between the channel wall and triangular prism on heat transfer and fluid characteristics. The results shows that in the presence of triangular prism in zig-zag arrangement, the average Nusselt number is 10.72 % more as compared to presence of a single triangular prism. It is further observed that the heat transfer increases with the increase in Reynolds number (Re).The enhancement is due to the formation of vortices which travels long way in the downstream direction. However the heat transfer enhancement is associated with greater pressure drop.*

***Keywords***- Heat transfer enhancement; zig-zag arrangement; Triangular Prism, Reynolds Number.

## I. INTRODUCTION

Heat transfer enhancement technology is extensively used in heat exchanger applications; such as automotives, refrigeration process and chemical industry, etc. There exist various methods for enhancing heat transfer. Thermal performance of heat transfer devices can be improved by heat transfer enhancement techniques. Many techniques based on both active and passive methods have been proposed to enhance heat transfer in these applications. Among these methods one can find systems involving vortex generators such as fins, turbulence promoters and other cylinders. The turbulent generator with different geometrical configurations have been used as one of the passive heat transfer enhancement techniques and are the most widely used in several heat transfer applications, such as cooling of electronic systems, internal cooling inside turbine blades, compact heat exchangers, biomedical devices, etc. The geometrical characteristics of vortex generators play a significant role in the rate of heat transfer. Disturbance promoters increase fluid mixing and interrupt the development of the thermal boundary layer, leading to enhancement of heat transfer. Placing sharp edged prism in a smooth channel is also an effective method for enhancing heat transfer . This yields flow turbulence, separation and leading to higher heat transfer rates. The prism placed in a smooth channel cause an increase in turbulent intensity and flow mixing, thus induce a recirculation zone or vortices flow behind the prism. So, the geometric dimensions of the prism, spacing between triangular prisms and channel wall play important role on heat transfer and fluid characteristics.

## II. LITERATURE REVIEW

H. Abbassi *et al*. [1] proved that the use of a triangular prism could enhance significantly the heat transfer in a two dimensional horizontal channel. The Reynolds Number and Grash of numbers are varied from 30 to 200 and from 0 to 1.5 × 104 respectively at Pr = 0.71.The results shows that the space and time averaged Nusselt number can be described by a linear function of Reynolds number. H. Chattopadhyay *et al*. [2] obtained numerically the rate of heat transfer enhancement in a channel in the presence of a triangular element. The results indicate that heat transfer in the channel is augmented by around 15%.But the enhancement also resulted in increased in skin friction. Turbulent flow and heat transfer in a heated channel with a triangular prism has been investigated, numerically by A. C. Benim [3]. The results showed larger heat transfer augmentation. The control of laminar steady forced convection heat transfer in a channel, with three blocks and a triangular adiabatic control element, has been studied numerically by H. F. Oztop, Y. Varol, and D. E. Alnak [4]. Manay *et al.* [5] studied the effect of Reynolds number with respect to both heat transfer and flow characteristics in a 2 D channel equipped with two triangular bluff bodies in side- by-side arrangement. The calculations were performed for a Reynolds number varying from 10000 to 40000 under steady state conditions. The heat transfer increased as the Reynolds number was increased. The increase in Nusselt number resulted in increase in pressure drop. Turki *et al.* [6] investigated the effect of the blockage ratio in the laminar flow in a channel with a built-in square cylinder. The results show that the critical value of Reynolds number relative to transition from steady to periodic flow increases by increasing blockage ratio. Also for a high blockage ratio and Reynolds number, the square cylinder has a stable transversal posture to the flow. Nasiruddin *et al.* [7] explained heat transfer enhancement in a heat exchanger tube by installing a baffle. The effect of baffle size and orientation on the heat transfer enhancement was studied in detail. Three different baffle arrangements were considered. The results show that for the vertical baffle, an increase in the baffle height causes a substantial increase in the Nusselt number but the pressure loss is also very significant. For the inclined baffles, the results show that the Nusselt number enhancement is almost independent of the baffle inclination angle, with the maximum and average Nusselt number 120% and 70% higher than that for the case of no baffle, respectively. For a given baffle geometry, the Nusselt number enhancement is increased by more than a factor of two as the Reynolds number decreased from 20,000 to 5000. Simulations were conducted by introducing another baffle to enhance heat transfer. The results show that the average Nusselt number for the two baffles case is 20% higher than the one baffle case and 82% higher than the no baffle case. The above results suggest that a significant heat transfer enhancement in a heat exchanger tube can be achieved by introducing a baffle inclined towards the downstream side, with the minimum pressure loss. Balvinder Budania *et al.* [8] obtained numerically the rate of heat transfer enhancement in a 2D channel in the presence of a triangular prism. The results show that in the presence of triangular prism the average Nusselt number is 7.37 % more as compared to plane channel. It is further observed that the heat transfer increases with the increase in blockage ratio (b) and also by increasing the Reynolds number (Re). The effect of inserting dual prisms in different arrangement is also investigated. Heat transfer enhancement for triangular dual prisms is more as compared to the single triangular prism for same blockage ratio. However the heat transfer enhancement is associated with greater pressure drop. Mahir, N. and Altac, Z *et al.* [9] numerically studied the laminar convective heat transfer from dual isothermal cylinders in tandem arrangement for unsteady flow regime. The mean and local Nusselt number for the upstream and downstream cylinders were obtained. They concluded that the mean Nusselt number of the upstream cylinder came close to that of a single isothermal cylinder for L/D > 4, and, the mean Nusselt number of the downstream cylinder was approximately 80% of the upstream cylinder. Rosales, J.L., Ortega *et al* .[10] investigated the flows over square cylinders in tandem arrangement both numerically and experimentally. The effect of spacing ratio between the bodies on heat transfer and flow characteristics were analyzed. Eyuphan Manay *et al.*[11] investigate the effect of the spacing between equilateral dual triangular bodies symmetrically placed into the channel axis under steady state conditions on heat transfer and fluid characteristics by using artificial neural networks (ANN). The Back Propagation (BP) training algorithm was applied to train the model. Sachdeva *et al.* [12] analyzed a single element of a cross flow plate fin heat exchanger in which the triangular shaped inserts were used as secondary fins. These secondary fins increased the ratio of heat transfer area to overall volume. The complete Navier-Stokes equations together with the governing equation of energy were solved for the laminar flow at Reynolds number 100 and 200 by using the MAC algorithm. Isothermal boundary conditions are applied on all the no slip surfaces. Air was considered as the working fluid. It was found that bulk temperature increased by 35.46% while using the inserts in plane rectangular channel at Reynolds number 100. It was analyzed that by the use of triangular secondary inserts in plane rectangular channels, heat transfer can be enhanced at the cost of more pumping power requirement.

## III. GEOMETRY AND MATHEMATICAL FORMULATION

Fig.1 represents a two dimensional computational domain. Two neighboring plates form a channel of height "H" and length “8.4 H”. The distance between the plates is taken as unity *i.e.* $H$ = 1 m. Four prisms are placed in zig-zag arrangement. The prism base is placed at a distance of “3.69 H” in single prism arrangement. The prism base is perpendicular to the direction of flow. The blockage ratio (BR = B/H) is taken as 0.25, where “*B*” is the base of the prism. The sides of the prism form an equilateral triangle. Air has been taken as working fluid.

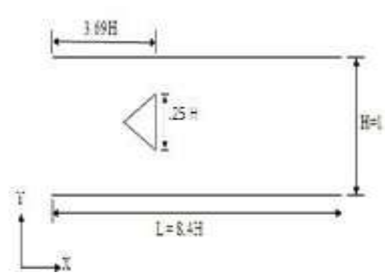


Fig. 1: A parallel plate channel having triangular prisms with blockage ratio 0.25 H

The flow field in the channel with built-in triangular prism is characterized by the
Following parameters:

- Reynolds Number (Re)
- Blockage Ratio (*b*)
- Effect of varying the distance between channel wall and triangular prism
- The Reynolds number is varied from 50 to 500 for laminar flow and 5000 to 20000 for turbulent flow. In case of more than one prism the following arrangement are used:
- Zigzag arrangement, distance between the channel walls and prism is .125 H
- Zigzag arrangement, distance between the channel walls and prism is .25 H

A two dimensional domain having four prism placed in zigzag arrangement and blockage ratio .25 is shown in figure 2.The four triangular prism are placed in zig-zag way having .125 H distance from the channel wall. The first triangular prism is placed at a distance of 1.7233 H from the start of channel and the last($4^{th}$) triangular prism is placed at a distance of 1.5068 H from the rear end of the channel.

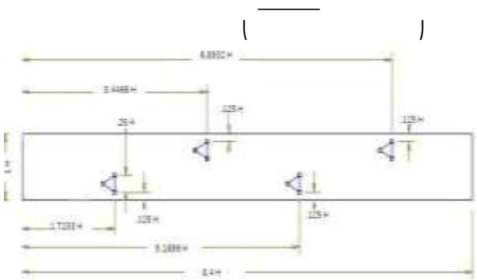

Fig. 2: A parallel plate channel having four triangular prism placed in zig-zag way having .125 H distance from the channel wall with blockage ratio 0.25.

A two dimensional domain having four prism placed in zig-zag arrangement and blockage ratio .25 is shown in figure 3.The four triangular prism are placed in zig-zag way having .25 H distance from the channel wall.

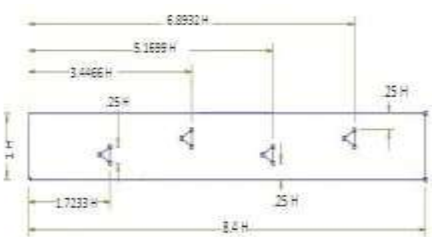


Fig. 3: A parallel plate channel having four triangular prism placed in zig-zag way having .25 H distance from the channel wall with blockage ratio 0.25.

## IV. GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

CFD calculations are performed to solve the problem depending on the numerical model, boundary conditions, assumptions, and numerical values in order to determine the temperature and velocity distributions in the flow field. CFD is fundamentally based on the governing equations of fluid dynamics. The fundamental governing equations for an incompressible two dimensional flow are continuity equations, momentum equations and energy equations.

The incompressible, steady state two dimensional continuity, momentum and energy equations are:

Continuity equation

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0$$

Momentum equation

$$\frac{\partial V}{\partial \tau}+\frac{\partial (UV)}{\partial X}+\frac{\partial (V^2)}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{1}{Re}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)$$

Energy equation

$$\frac{\partial \theta}{\partial \tau}+\frac{\partial U\theta}{\partial X}+\frac{\partial V\theta}{\partial Y}=\frac{1}{Re\,Pr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right)$$

k−ε turbulence model is used to predicting the heat transfer and fluid flow characteristics in turbulent flow when Reynolds no is varying from 5000 to 20000.

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 top and bottom 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 gauge. No-slip boundary conditions are taken for the prism. Aluminum is selected as the material for prism.

## V. RESULTS AND DISCUSSION

A. Zig-Zag arrangement, distance between the channel walls and prism is .125 H

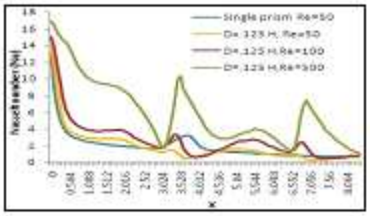


Fig. 4: Variation of Nusselt number along the channel length with Single prism and zig-zag arrangement having .125 H distance from the channel wall with blockage ratio 0.25 at Re = 50 to500

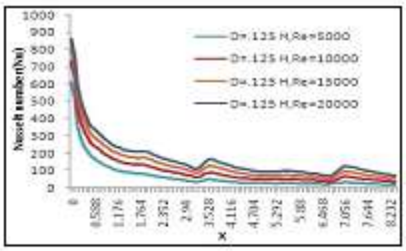


Fig. 5: Variation of Nusselt number along the channel length with prism in zig-zag arrangement having .125 H distance from the channel wall with blockage ratio 0.25 at Re no = 5000 to20000.

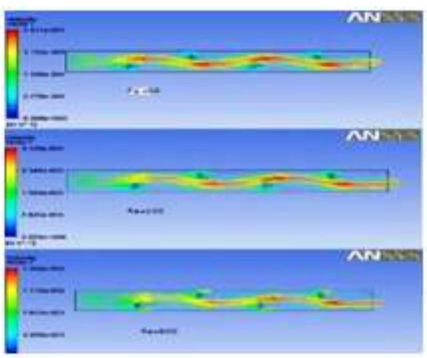

Fig. 6: Velocity vector plot for Re no = 50 to 500 and *b* = 0.25 with prism in zig-zag arrangement, D=.125 H.

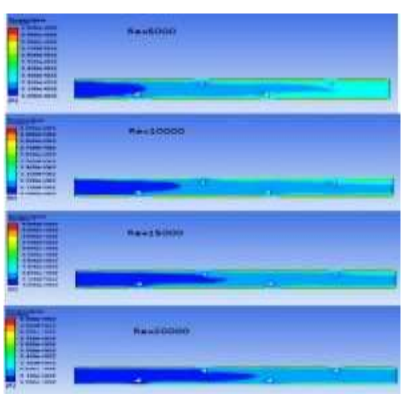

Fig. 7: Temperature contours of the computation domain at Re no = 5000 to 20000.,D=.0125 H

B. Zig-Zag arrangement, distance between the channel walls and prisms is .25 H

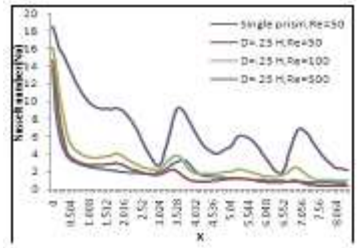


Fig. 8: Variation of Nusselt number along the channel length with Single prism and zig-zag arrangement having.25 H distance from the channel wall with blockage ratio 0.25 at Re no = 50 to500

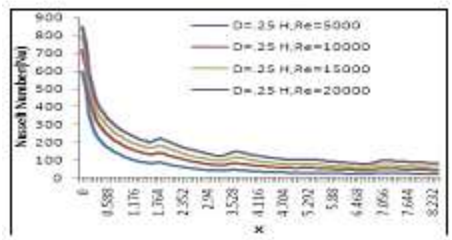


Fig. 9: Variation of Nusselt number along the channel length with prism in zig-zag arrangement having .25 H distance from the channel wall with blockage ratio 0.25 at Re no = 5000 to20000

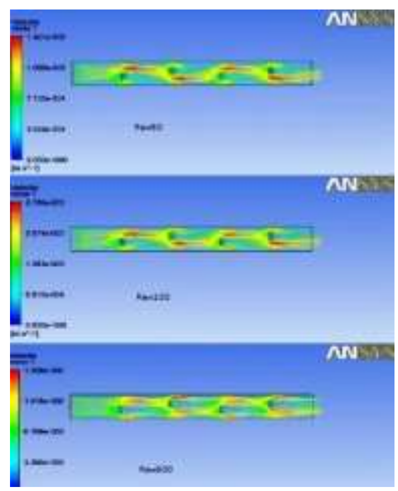

Fig. 10: Velocity vector plot for Re no = 50 to 500 and *b* = 0.25 with prism in zig-zag arrangement D=.25 H

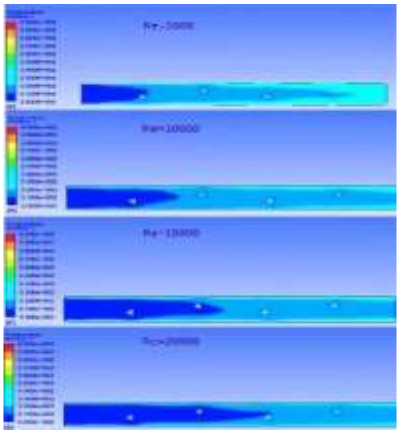

Fig. 11: Temperature contours of the computation domain at Re no = 5000 to 20000. D=.25 H

## VI. CONCLUSION

In the present problem the numerical simulation of laminar and turbulent flow in a parallel plate channel with built-in triangular prism in zig-zag arrangement is performed. The flow structure and heat transfer characteristics are studied in detail.

On the basis of the results obtained, the following conclusions are made:

In laminar flow, the average Nusselt number decreases with the increase in Reynolds number up to 100, but after this the average Nusselt number increases with the increases in Reynolds number.

Heat transfer increases as the Reynolds number increased. The percentage increase in average Nusselt number at Reynolds number of 500 when the distance b/w the channel wall and prism is .25 H , is 3.55% more as compared to average Nusselt number at Reynolds number of 500 with single prism.

Heat transfer enhancement for four triangular prism in zig-zag arrangement is more as compared to the single prism for same blockage ratio.

The average Nusselt number is also increased when the distance b/w the channel wall and prism is increased. The % increase in average Nusselt number at Reynolds number of 500 when distance is .25 H , is 22.69 % more as compared to average Nusselt number at Reynolds number of 500 when distance is .125 H.

Also in Turbulent flow, heat transfer increases with the increase of distance b/w the channel wall and prism. The % increase in average Nusselt number having zig-zag arrangement when distance b/w the channel wall and prism is .25 H at Reynolds number of 5000, is 4.12 % more as compared to average number when distance b/w the channel wall and prism is .125 H.

The enhancement of heat transfer achieved by using triangular prism in zig-zag arrangement is associated with an increase in the pressure loss due to the presence of the triangular prism. The pressure loss increases with an increase in Reynolds number.

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