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# Simulation Heat Transfer Enhancement in a Laminar Channel Flow with Built-in Triangular Prism

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**ABSTRACT : In this research work heat transfer and fluid flow characteristics in a channel in the presence of a triangular prism has been numerically investigated in the laminar flow regime. The computations are performed for a Reynolds number of 50 and blockage ratio (b) of 0.25, where blockage ratio is the ratio of prism base to the channel height. The Navier Stokes equations along with the energy equation have been solved by using SIMPLE Technique. The unstructured triangular mesh is used for the computational domain. The results show that in the presence of triangular prism the average Nusselt number is 7.37 % more as compared to plane channel. The enhancement is due to the formation of vortices which travels long way in the downstream direction. 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.**

**Keyword :** Heat exchanger, Fluent, Reynold Number, Navier Stock Eqn., Triangular Prism.

## I. INTRODUCTION

Heat transfer enhancement is the process of improving the performance of a heat transfer system. To date large numbers of attempts have been made to reduce the size and costs of the heat exchangers. Compact heat exchangers are widely used in many industries, so improvement in their performance with respect to reducing manufacturing costs by using less material or lowering operating cost by reducing energy loss is of great technical, economical, and, not least ecological importance. Heat augmentation techniques play a vital role for laminar flow, since the heat transfer coefficient is generally low in plain tubes. During recent years, serious attempts have been made to apply different active and passive mechanisms for heat transfer enhancement in compact heat exchangers for the automotive industry, air-conditioning and refrigerant applications, internal cooling for gas turbine blades, electrical circuits in electronic chipsets, etc. Achieving higher heat transfer rates through various augmentation techniques can result in substantial energy savings, more compact and less expensive apparatus with higher thermal efficiency.

## II. LITERATURE REVIEW

Abbassi *et al.* [1] studied the structure of laminar flow and heat transfer in a two dimensional horizontal plane channel with a built-in triangular prism. 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 for 50 ? Re ? 200 and Gr = 0 the space and time averaged Nusselt number can be described by a linear function of Reynolds number. Further Chattopadhyay *et al.* [2] numerically investigated the heat transfer in a channel in presence of a triangular prism. The simulation was assumed two dimensional in nature. The Reynolds Number was varied from 10000 to 20000. The order of heat transfer was 15 %. But the enhancement also resulted in increased skin friction. Manay *et al.* [3] 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.* [4] investigated the effect of the blockage ratio on 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.* [5] 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. Sohankar *et al.* [6] studied the heat transfer augmentation in a rectangular channel with a vee-shaped vortex generator. The vortex generators are attached on the bottom wall of the channel and their angles in respect to the main flow are between 10? and 30?. The Prandtl number is 0.71 and the Reynolds numbers based on the inflow velocity and the height of channel are varied from 200 to 2000. It is observed that flow and heat transfer become steady at lower Reynolds numbers while they are unsteady at the higher Reynolds numbers. The results show that Nusselt number, pressure coefficient, bulk temperature, friction factor and Colburn factor change significantly when the Reynolds numbers and the incidence angles increase. These changes are caused by the generation of the longitudinal and horseshoe vortices with different strengths and circulation. It is found that the vortex strength increases with Reynolds number and it decays in the stream wise direction. Eiamsa-ard *et al.* [7] experimentally investigated the heat transfer and friction factor characteristics in a double pipe heat exchanger fitted with regularly spaced twisted tape elements. The results, obtained from the tube with twisted tape insert, were compared with those without twisted tape. The results show that the heat transfer coefficient increased with twist ratio (y). Whereas the increase in the free space ratio (S) would improve both the heat transfer coefficient and friction factor. The results from each case were correlated for Nusselt number and friction factor. Subsequently, the predicted Nusselt number and friction factor from the correlations were plotted to compare with the experimental data. It was found that Nusselt number was within ±15% and ±10% for friction factor. Sachdeva *et al.* [8] 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. Chen and Shu [9] described the Effects of an external delta-wing vortex generator on the flow and heat transfer characteristics in fan flows and uniform flows. Results show that the external delta-wing vortex generator in fan flows has little overall effect on the near-wall averaged axial mean velocity and axial vorticity, but increases the turbulent kinetic energy. The increase in the turbulent kinetic energy by the delta-wing has little effect on heat transfer in the inherently vortical fan flows. Consequently, the delta-wing vortex generator in fan flows has little effect on the heat transfer augmentation. Sommers and Jacobi [10] studied, an array of delta-wing vortex generators is applied to a plain-fin-and-tube heat exchanger with a fin spacing of 8.5 mm. Heat transfer and pressure drop performance are measured to determine the effectiveness of the vortex generator under frosting conditions. For air-side Reynolds numbers between 500 and 1300, the air-side thermal resistance is reduced by 35-42% when vortex generation is used. Correspondingly, the heat transfer coefficient is observed to range from 33 to 53 W / m2K 1 for the enhanced heat exchanger and from 18 to 26 W / m2K 1 for the baseline heat exchanger.

## 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.* $H$ = 1.0. The prism base is placed at a distance of “3.69 H”. The prism base is perpendicular to the direction of flow. The blockage ratio ($b$ = 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.

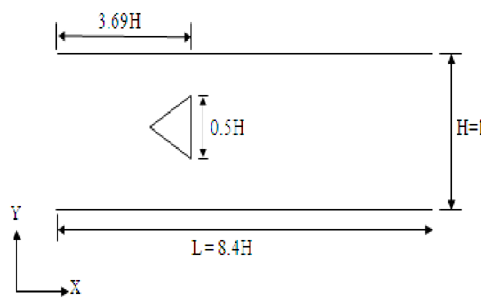


Fig. 1. A parallel plate channel having triangular prisms with blockage ratio 0.5.

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

By following parameters:

* Reynolds Number (Re)
* Blockage Ratio ($b$)
* Effect of dual triangular prisms

The Reynolds number is varied from 50 to 100 and blockage ratio is varied from 0.25 to 0.5. In case of more than one prism the following arrangement are used

(1) Inline arrangement

(2) Side by side arrangement

A two dimensional domain having a dual prism with inline arrangement and blockage ratio 0.5 is shown in figure 2. The two triangular prism are placed in series one following the other. The first triangular prism is placed at a distance of 3.0165 H from the start of channel and the second triangular prism is placed at a distance of 3.0165 H from the rear end of the channel

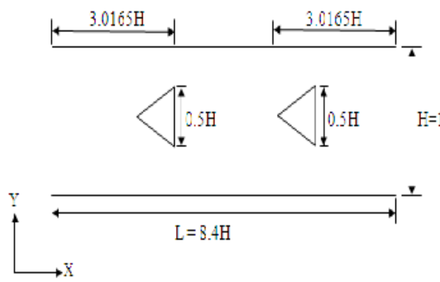


Fig. 2. A parallel plate channel having dual inline triangular prisms with blockage ratio 0.5.

A two dimensional domain having a dual prism with side by side arrangement is shown in the figure 3. The base of the prism is taken as 0.25 H.

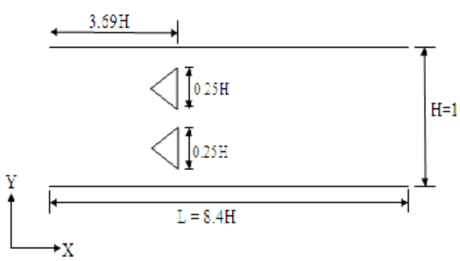


Fig. 3. A parallel plate channel having dual side-by-side triangular prisms with blockage ratio 0.25.

## 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 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

Flow Characteristics and Heat Transfer Characteristics for Re = 50 and Blockage Ratio ($b$ = 0.25).

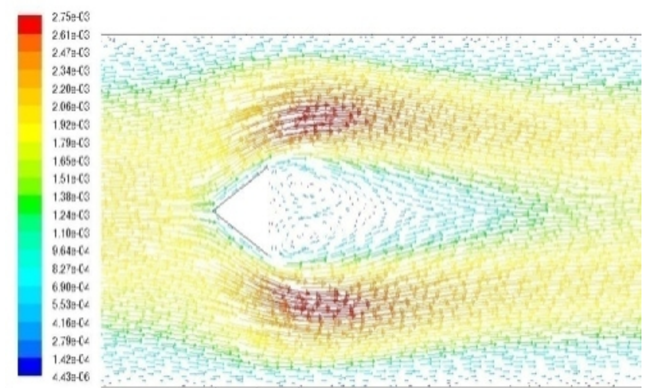

Fig. 4. Velocity vector plot for Re = 50 and blockage ratio = 0.25.

Temperature Contours and Heat Transfer Characteristics.

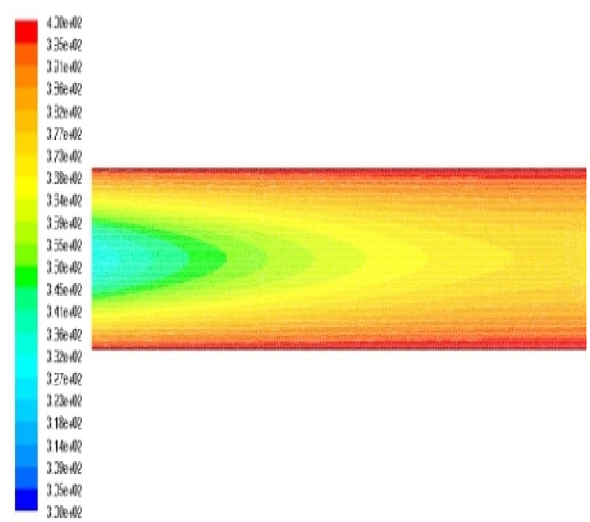

Fig. 5. Temperature contours of the computation domain at Re = 50 and without prism.

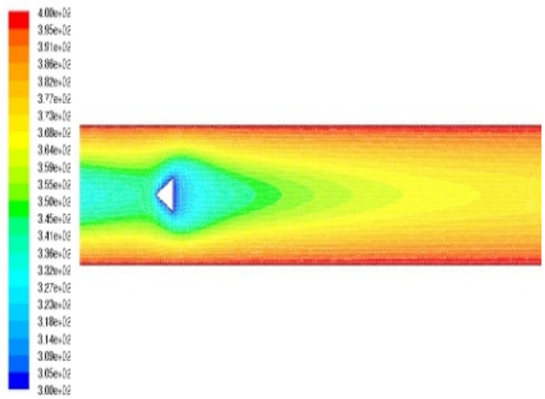

Fig. 6. Temperature contours of the computation domain at Re = 50 and with triangular prism having blockage ratio = 0.25.

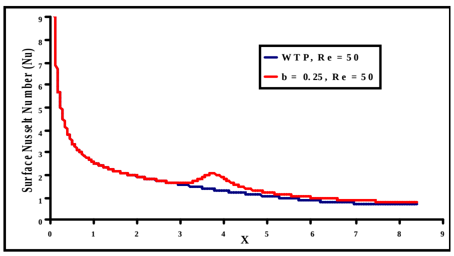


Fig. 7. Variation of Nusselt number along the channel length with prism of blockage ratio 0.25 and without prism at Re = 50.

### Pressure Characteristics

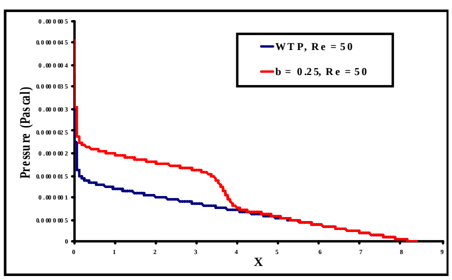


Fig. 8. Pressure variation along the channel length with a blockage ratio of 0.25 and without prism at Re = 50.

### Inline Arrangement

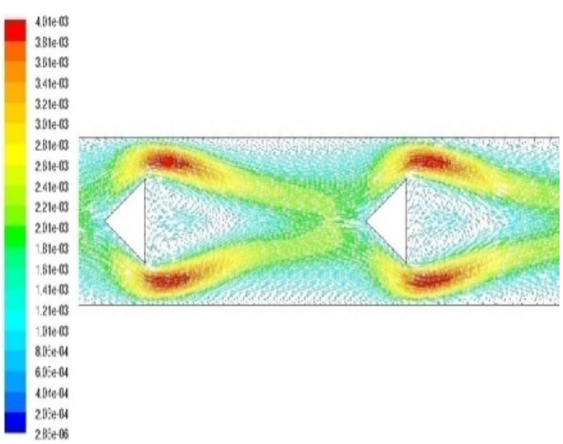

Fig. 9. Velocity vector plot for Re = 100 and *b* = 0.5 with dual prism in inline arrangement.

Fig. 9 shows the velocity vector plot for Re = 100 and *b* = 0.5 with dual prism having inline arrangement. By inserting dual prisms two vortex regions are produced. 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.

### Side-By-Side (SBS) Arrangement

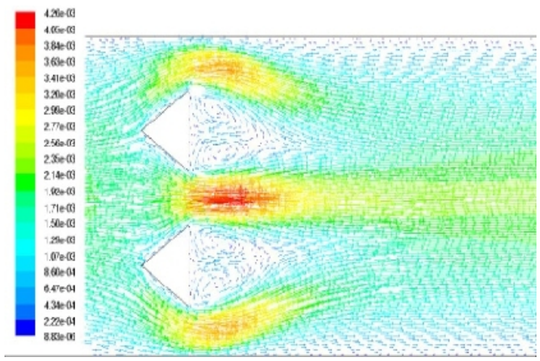

Fig. 10. Velocity vector plot for dual prism in side-by-side arrangement at Re = 100 and blockage ratio = 0.25.

## IV. CONCLUSION

In the present problem the numerical simulation of laminar flow in a parallel plate channel with a built-in triangular prism 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:

1. The presence of triangular prism significantly improves the heat transfer performance. The percentage increase in average Nusselt number with the use of triangular prism having blockage ratio 0.25 is 7.37 % more as compared to plane channel at Reynolds number 50.
2. The heat transfer increases as the blockage ratio is increased. The percentage increase in average Nusselt number with blockage ratio 0.5 is 5.5 % more as compared to blockage ratio 0.25 at the same Reynolds number of 50.
3. Heat transfer increases as the Reynolds number is increased. The percentage increase in average Nusselt number at Reynolds number of 100 is 3.7 % more as compared to average Nusselt number at Reynolds number of 50 at the same blockage ratio 0.5.
4. Heat transfer enhancement for dual triangular prisms is more as compared to the single triangular prism for same blockage ratio.

5. The percentage increase in average Nusselt number with dual prisms having inline arrangement at Reynolds number of 100 and blockage ratio of 0.5 is 7 % more as compared to average Nusselt number with single triangular prism at the same Reynolds number and blockage ratio.
6. The percentage increase in average Nusselt number with dual prisms having side-by-side arrangement at Reynolds number of 100 and blockage ratio of 0.25 is 4.5 % more as compared to average Nusselt number with single triangular prism at the same Reynolds number and blockage ratio
7. 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 triangular prism.

The pressure loss increases with an increase in blockage ratio and Reynolds number.

## V. SCOPE FOR FUTURE WORK

The results of this work reveal that the triangular prism as a vortex generator is a useful device for improving heat transfer in a parallel plate 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 two prisms. The simulation can be performed for various positions of triangular prisms.
3. The study can be performed for other different geometries and can be compared for the best geometry.

## REFERENCES

[1] H. Abbassi, H., S. Turki and S. Ben Nasrallah, "Numerical investigation of forced convection in a horizontal channel with a built-in triangular prism". *ASME Journal of Heat Transfer* **124**: (2002) 571-573.

[2] Himadri Chattopadhyay, "Augmentation of heat transfer in a channel using a triangular prism". *International Journal of Thermal Science* **45**: (2007) 501-505.

[3] E. Manay, S. Gunes, E. Akcadirci and V. Ozceyhan, "Numerical analysis of heat transfer and pressure drop in a channel equipped with triangular bodies in side-by-side arrangement". *The Online Journal on Power and Energy Engineering* (*OJPEE*) **1**: (2009) 85-89.

[4] S. Turki, H. Abbassi and S. Ben Nasrallah, "Effect of the blockage ratio on the flow in a channel with a built-in square cylinder". *Computational Mechanics* **33**: (2003) 22-29.

[5] Nasiruddin, M.H. Kamran Siddiqui, "Heat transfer augmentation in a heat exchanger tube using a baffle". *International Journal of Heat and Fluid Flow* **28**: (2007) 318-328.

[6] A. Sohankar, "Heat transfer augmentation in a rectangular channel with a vee-shaped vortex generator". *International Journal of Heat and Fluid Flow* **28**: (2007) 306-317.

[7] Smith Eiamsa-ard, Chinaruk Thianpong, and Pongjet Promvonge "Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements".

[8] Gulshan Sachdeva, K.S. Kasana and R. Vasudevan, "analysis on heat transfer enhancement by using triangular shaped inserts as secondary fins in cross flow plate fin heat exchanger". *International Journal of Dynamics of Fluids* **6**: (2010) 41-47.

[9] T.Y. Chen and H.T. Shu, "Flow structures and heat transfer characteristics in fan flows with and without delta-wing vortex generators". *Experimental Thermal and Fluid Science* **28**: (2004) 273-282.

[10] A.D. Sommers and A.M. Jacobi, "Air-side heat transfer enhancement of a refrigerator evaporator using vortex generation". *International Journal of Refrigeration* **28**: (2005) 1006-1017.