Effect of dual Rhombus prisms obstacle on Heat Transfer and Fluid Flow Characteristics of laminar flow through parallel plate channel

Ghanshyam Dass[1], Yajvinder Kumar[2], Vikarm[3], Ajay Kumar[4]
[1]Reseach Scholar, Department of Mechanical Engineering, Punjab Technical University, Jalandhar, Punjab (India)
[2]Research Scholar, Department of Mechanical Engineering, Guru Jambheshwar University of Science & Technology, Hisar, Haryana (India)
[3]Assistant professor, Department of Mechanical Engineering, Manav Institute of Technology & Management, Hisar, Haryana (India)
[4]Assistant professor, Department of Mechanical Engineering, K R Mangalam University, Gurugram, Haryana (India)

Abstract

The present work numerically investigated the impact of Rhombus prism obstacle on heat transfer and fluid flow characteristics in a parallel plate channel having laminar flow regime with constant thermo-physical properties. Reynolds Numbers 50, 100, and 150 and fixed blockage ratio (b) of 0.5, were used to performed computations. Two dimensional Navier Stokes and energy equations were numerically solved for fluid flow and temperature field simulation, using control volume method on FLUENT 6.3 while the required unstructured triangular mesh was generated using GAMBIT. It is clearly illustrated from results that heat transfer performance significantly improves with presence of Rhombus prism obstacle. In compared to plane channel, Rhombus prism having 0.5 blockage ratio increases the 2.78%, 7.90% and 11.73% more Nusselt Number at Reynolds Number of 50, 100, and 150 respectively.

Keywords: Fluid flow, Heat Transfer enhancement, Reynols Number

1. INTRODUCTION

Heat removal rate is highly concern factor in various industries like power plants, chemical process, production, transportation and electronics. Various techniques for heat transfer have been suggested to meet the increasing need for cooling of high heat flux surfaces. However, many industries use the heat transfer as input energy source while other remove the heat produced in the system, so intensifying of heat transfer techniques have become an important task in today's world.

For heat transfer enhancement investigation, various experimental studies have been performed. However, comprehensive review of the subject matter is out of scope of present study but some studies have been cited in the following text. A study by Abbassi et al. [1] investigated the thermal characteristics laminar flow in the parallel plate channel having triangular prism obstacle. They used Grashof Number in variation from 0 to 1.5×104 and kept Reynolds Number between 30 to 200 at constant Pr = 0.71. Later Chattopadhyay et al. [2] used similar structure for numerical investigation of heat transfer in a channel with built-in triangular prism. However, their investigation was based on Reynolds number variation from 10000 to 20000 and they resulted that the order of heat transfer was 15% more compared channel without obstacle. In a computational study of heat transfer, Kumar and Dalal [3] placed triangular cylinder as obstacle in laminar flow in parallel plate channel. They varied the Reynolds Number in range of 80-200 whereas blockage ratio was kept from 0.084 to .33. In a study of a cross flow plate heat exchanger, Sachdeva et al. [4] inserts triangular shaped obstacles as secondary fins. They analyzed a single element of heat transfer and founded that the bulk temperature by 35.46% when triangular shaped were inserted in a rectangular channel at Reynolds number 100. In a numerical investigation study carried out by Tiwar et al. [5], the heat transfer behavior was characterized. In this study a circular tube having longitudinal fin at rear end was structured in cross flow configuration. In another study, Sachdeva et al. [6] experimented on a plate-fin heat exchanger having delta wing vortex generator. In this arrangement, they performed on triangular shaped obstacle to analyze the heat transfer enhancement computationally. This investigation was performed at Reynolds number of 100 and 200 and angles used to attack by wings were 15°, 20°, 26° and 37°. In another study (Sachdeva et al. [7]) experiment was performed on a viscous and incompressible fluid with laminar flow and Reynolds Number used under 200. In structural arrangement, rectangular wing vortex generators were attached on triangular shaped fins on plate-fin heat exchanger to investigate the heat transfer enhancement. If combined span wise results illustrated, about 35% increase in average Nusselt Number noted for rectangular wing vortex generator in comparison to results noted for same exchanger without any vortex generator. Gupta et al. [8] studied to evaluate the heat transfer performance of plate-fin heat exchanger having in-built rectangular winglet. In this study attack angle for the winglet was set on various values i.e., 20, 26, and 37° whereas Reynolds number of 100, 150, and 200 were used. In another numerical investigation by Gupta et al. [9] the effects of rectangular winglet pair on heat transfer and flow structure performance were analyzed for plate-fin heat exchanger. In this computational study, Reynolds number was set on 200 and angle of attack of winglet was performed at 20°. Heat transfer was increased by 13%, event at exit, with the winglet pair as per result illustrations. Study also performed for varying Reynolds number from 200 to 500 at Pr=0.71 and also for varying heights of winglet pair. A study by Gupta et al. [10] numerically analyzed the characteristics of fluid flow with obstacles of dual triangular prisms in side-by-side arrangement in a parallel plate channel. In this computational study Reynolds number of 100 and 0.25 of blockage ratio were used. Results illustrated that in this arrangement average Nusselt number is 8.5% more compared to plane channel whereas 4.5% more compared to single prism obstacle arrangement at same Reynolds number and blockage ratio. Gupta et al. [11] investigated the performance of heat transfer and fluid flow characteristics of a channel having inclined block as a obstacle. The heat transfer augmentation with the inclined block is compared with a plane channel at same Reynolds number. The side of the block is taken as b= 0.25. The fluid flow is steady, laminar and incompressible. CFD technique is to be used for the solution of the particular problem.

2. PROBLEM STATEMENT AND FORMULATION

2.1 Numerical Modeling

Dual Rhombus prisms are inserted with inline arrangement in a two dimensional domain whereas 0.5 blockage ratio is used as shown in figure 1. The series arrangement one following other is used to place two Rhombus prisms. A distance of 3.0165 H is kept between the Centre of first Rhombus prism and starting point of channel and second Rhombus prism is placed such that its initial point apart with distance of 5.3835 H from initial point of the channel.

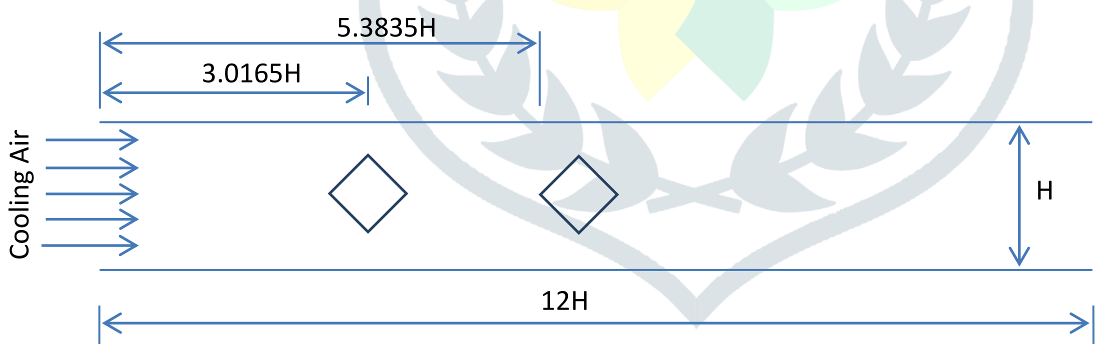

Figure 1: Arrangement of Rhombus prisms in parallel plate channel having 0.5 blockage ratio.

The fluid dynamics governing equations are fundamental base of the CFD. The following two dimensional continuity, momentum and energy equations are fundamental governing equations for incompressible, steady, and laminar flow.

Continuity equation

$$\frac{\partial U}{\partial X}+\frac{\partial U}{\partial Y}=0 \tag{1}$$

Momentum equations

$$\frac{\partial U}{\partial t}+\frac{\partial (U^2)}{\partial X}+\frac{\partial (UV)}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{2}$$

$$\frac{\partial V}{\partial t}+\frac{\partial (UV)}{\partial X}+\frac{\partial (V^2)}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right) \tag{3}$$

And the Energy equations is

$$\frac{\partial \theta}{\partial t}+\frac{\partial U\theta}{\partial X}+\frac{\partial V\theta}{\partial Y}=\frac{1}{\mathrm{Re}\,\mathrm{Pr}}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \tag{4}$$

2.2 Boundary Conditions

A very simple geometrical shape of rectangle generated for solution domain on x-y coordinate system which is enclosed with inlet, outlet and wall boundaries. Air is considered as working fluid and at inlet; air temperature is set on 300 K whereas pressure at outlet is kept equal to zero gauge. It is assumed that there are no-slip boundary conditions for momentum equations for wall. Top and bottom walls of channel are kept at uniform temperature of 400 K. For hydraulic boundary condition at inlet, a uniform one dimensional velocity is applied in computational domain. In material, Aluminum is selected and in boundary conditions, no-slip boundary conditions are selected for prism.

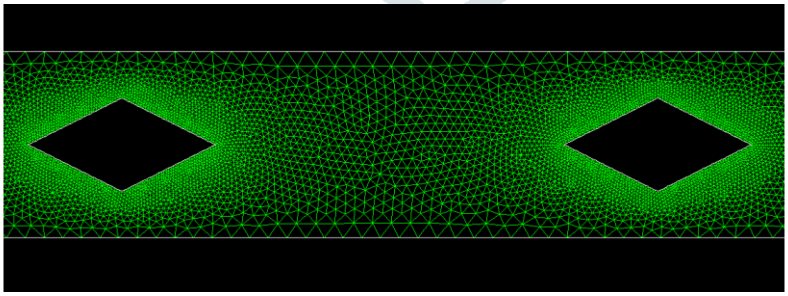

Figure 2: Triangular mesh used for the computational domain in Rhombus prisms.

3. RESULT AND DISCUSSION

3.1 Temperature Contours and Heat Transfer Characteristics

Figures 3, 4 and 5 shows the temperature contours of the computation domain with Rhombus prism having blockage ratio 0.5 at Reynolds Number 50,100,150. These plots illustrate that in vortex region, the fluid temperature is high as compare to plane channel. The Contour rotating vortices formation is resulted due presence of obstacle which causes the fluid mixing and hence increase the temperature of the fluid as compared to the plane channel.

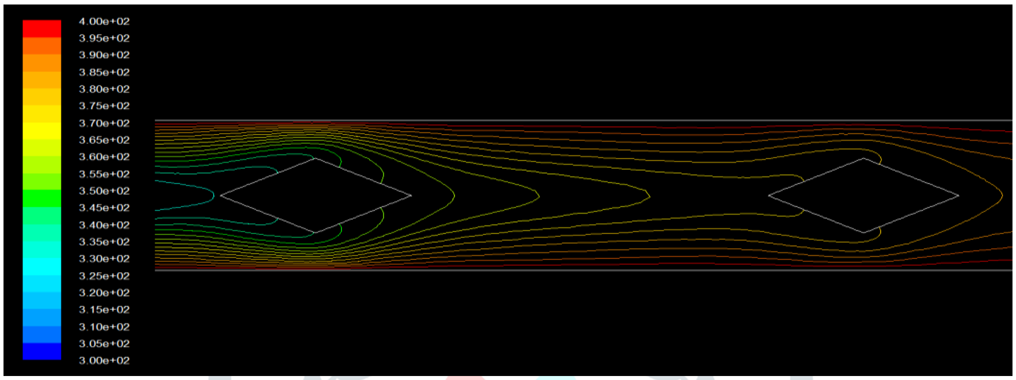

Figure 3: Temperature contours of the computation domain at Re=50

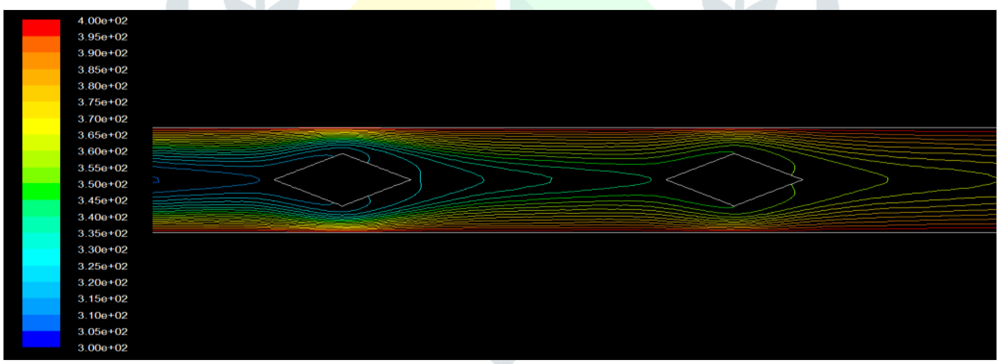

Figure 4: Temperature contours of the computation domain at Re=100

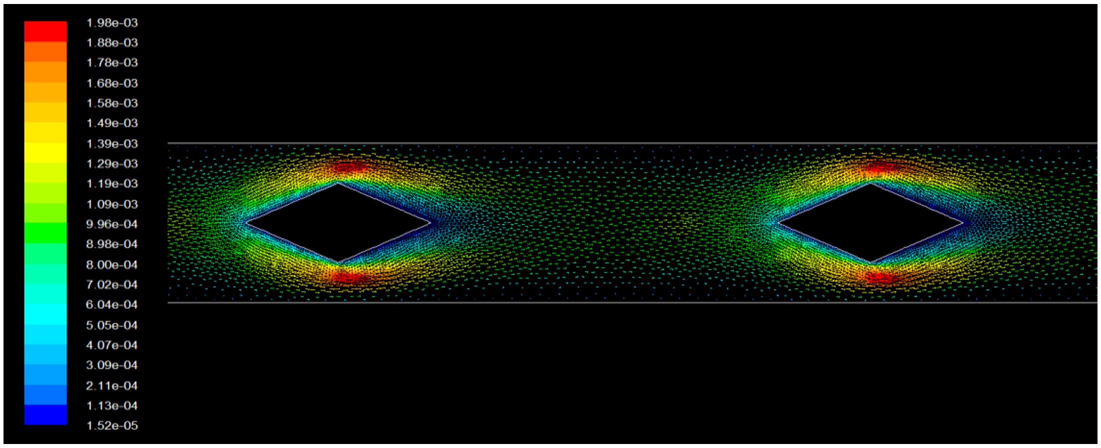

Figure 5: Temperature contours of the computation domain at Re=150

The distinguishing of time averaged flow structure in this case can discerned from velocity vector plot. Figures 6, 7, and 8 are showing velocity vector plot for laminar flow through parallel plate channel having Rhombus prism blockage ratio of 0.5 at Reynolds number 50, 100, and 150 respectively. From these figures, it can be observed that when flow hit the Rhombus prism it divided in two parts and combines again after passing Rhombus prism. Hence, formation of pair of counter rotating of vortices takes place just after these two Rhombus prisms in computational domain.

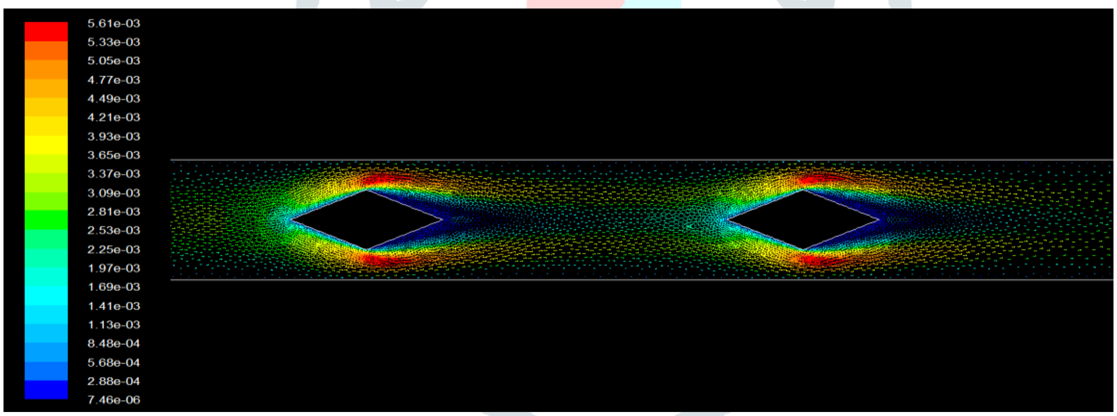

Figure 6: Velocity vector plot for Re=50

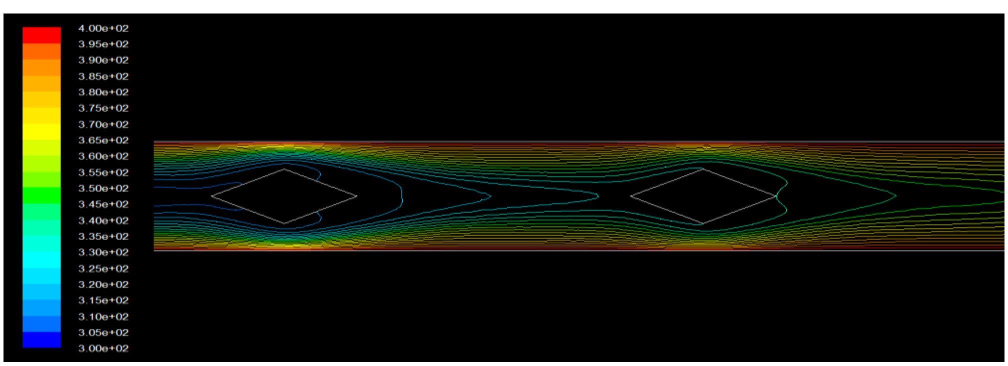

Figure 7: Velocity vector plot for Re=100

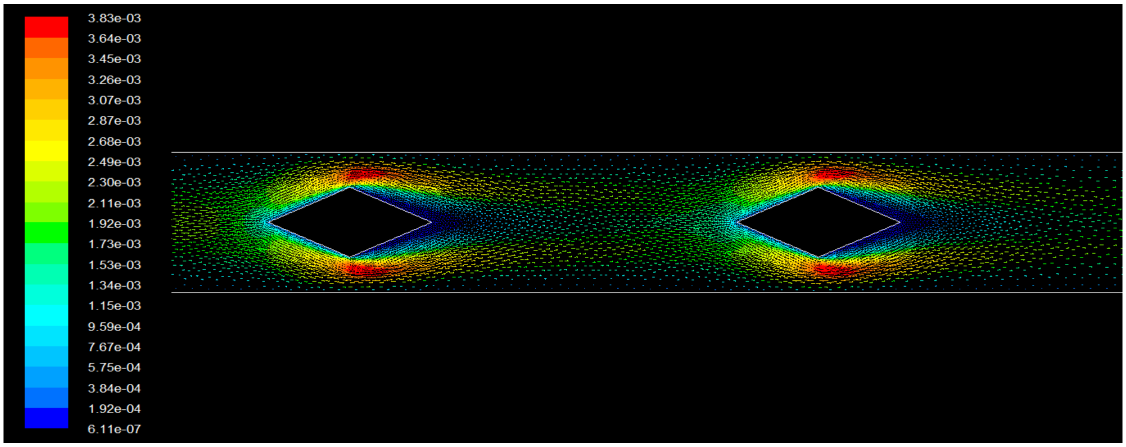

Figure 8: Velocity vector plot for Re=150

For same blockage ratio when Reynolds number is increased, the heat enhancement also increases. Figure 9 represents the Nusselt Number distribution along the walls of channel having 0.5 blockage ratio at Reynolds Number 50, 100, and 150. It can be clearly seen from this figure that Nusselt Number is highest for Reynolds Number 150. However, Nusselt Number variation pattern are same for different Reynolds number but average Nusselt Number is more for a high Reynolds Number.

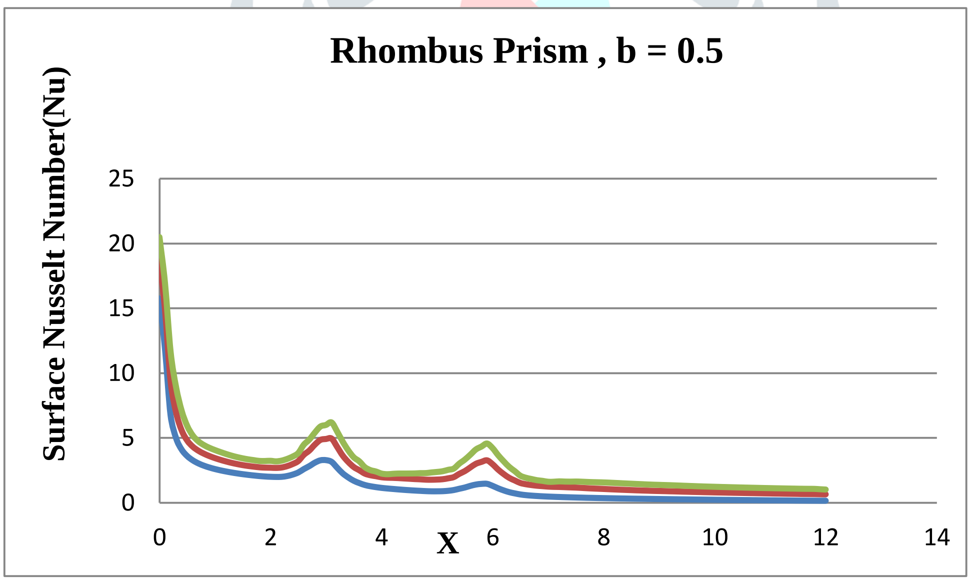

Figure 9: Nusselt Number variation along channel wall at different Reynolds number

In terms of percentage, the value of average Nusselt number at Reynolds number 150 is 27.37% and 63.94% more as compared to vale of average Nusselt Number at Reynolds number of 100 and 50 respectively for the same blockage ratio of 0.5.

3.2 Pressure Characteristics

Pressure loss due to effect of variation of Reynolds Number for the same blockage ratio is represented in figure 10. The pressure decrease in the streamwise direction and this trend is similar for different Reynolds Number. It can also be seen from the result that pressure loss increases on increasing the Reynolds Number for same blockage ratio and pressure loss is maximum for the Reynolds Number 150.

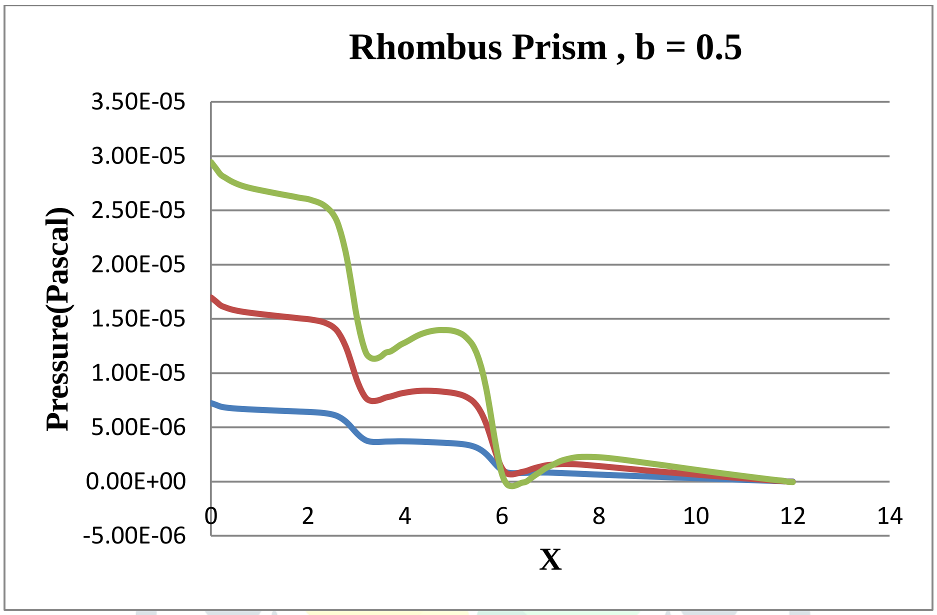

Figure 10: Pressure variation along channel walls at different Reynolds Number

4. CONCLUSION

In this study computational simulation performed for heat enhancement and fluid flow characteristics of laminar flow through parallel plate channel having in-built arrangement of dual Rhombus prism obstacle. Heat transfer performance significantly improved with presence of Rhombus prism. The average values of Nusselt Numbers for parallel plate channel with Rhombus prism are 2.78%, 7.90%, and 11.73% more as compared to simple parallel plate channel at Reynolds Number 50, 100, and 150 respectively at same blockage ratio of 0.5.

5. NOMENCULTURE

H	Distance between plates
P	Non-dimensional pressure
Re	Reynolds Number
Pr	Prandtl number
U,V,W	Axial, normal and spanwise component of velocity (non-dimensionalized by Uav)

x,y,z Axial, normal and spanwise coordinates

X,Y,Z Axial, normal and spanwise coordinates (non-dimensionalized by H)

6. SYMBOLS

θ Temperature (non-dimensional)

t Time (non-dimensional)

7. REFENCES

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