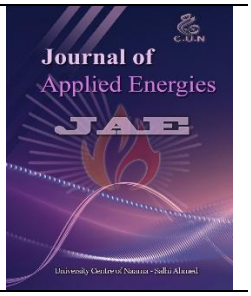
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Natural convection from H-shaped cross-section in square cavity: Effect of Rayleigh and Prandtl numbers

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Abstract: the present work is a numerical simulation of free convection heat transfer from H-shaped cross-section placed in square container. The work is accomplished by using the commercial code ANSYS-CFX. The studied parameters were the Prandtl and Rayleigh number. The simulations were in steady and laminar regime. The ranges of the studied parameters were as: *Ra* = 103, 104 and 105; *Pr* = 0.61, 7.01, 50 and 100. The results showed the mean value of Nusselt number of H-shaped cross-section increases with increasing Rayleigh number. While it remains constant with increasing Prandtl number.

Keywords: Heat transfer; Natural convection; Thermal science; CFD; Nusselt number.

1. INTRODUCTION

The natural convection is one of the natural and efficient thermal exchange processes due to the buoyancy impact. The natural mixing and convection are highly advantageous in modern

technology, for example in cooling of nuclear reactors, electrical systems, and computer equipment [1-4].

The natural convection in cavities of different shapes represents a great part of thermal exchange research, because the convection process is affected by various physical parameters influencing its hydrothermal development. Among the different works available in the literature, we will focus here on the recent progress. The main contributions to the convection process are the influence of solid particles [5], the uniformly and non-uniformly heated walls [6], the partially active side walls [7], the partial heating and cooling at vertical walls [8], the non-uniform wall heating with CuO nanofluid [9], the concave/convex side walls [10], the effect of an obstacle [11], the magnetic field impact [12], the c-shaped enclosure saturated by a nanofluid [13], the hybrid nanofluid [14], the presence of a rotating cylinder [15].

In this paper, we focus on the natural convective thermal exchange from H-shaped cross-section placed in square container. The work is done by numerical simulations of the process.

2. STUDIED DOMAIN AND GOVERNING EQUATION

Figure 1 shows the studied domain with appropriate grid. The domain consists of H-shaped cross-section in square chamber. The obstacle has a hot temperature (*Th*) while the container has the cold temperature (*Tc*). The obstacle locates in the middle of the chamber. The space between the obstacle and the chamber is filled with fluid which is defined by the Prandtl number. The geometric dimensions of the domain are presented in Table 1.

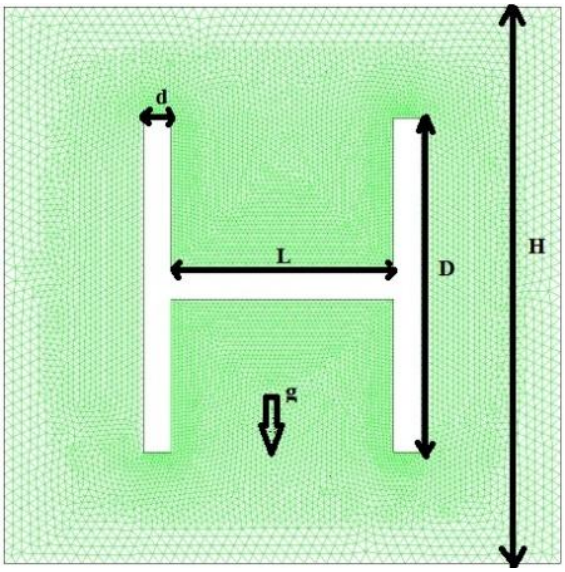


Figure 1: Studied domain

Table 1: Dimensions of the studied domain

D/H	*L/H*	*d/H*
0.5	0.3	0.01

The present investigations have the following characteristics: laminar regime, steady state, incompressible and Newtonian fluid. Finally, all thermo-physical characteristics are not linked with temperature except the density which treated by Boussinesq approximation. The governing equations for the present simulations are:

$$\left(\frac{\partial U}{\partial X}\right)+\left(\frac{\partial V}{\partial Y}\right)=0 \tag{1}$$

$$U\left(\frac{\partial U}{\partial X}\right)+V\left(\frac{\partial U}{\partial Y}\right)=-\left(\frac{\partial P}{\partial X}\right)+Pr\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{2}$$

$$U\left(\frac{\partial V}{\partial X}\right)+V\left(\frac{\partial V}{\partial Y}\right)=-\left(\frac{\partial P}{\partial X}\right)+Pr\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ra.Pr.\phi \tag{3}$$

$$U\left(\frac{\partial \phi}{\partial X}\right)+V\left(\frac{\partial \phi}{\partial Y}\right)=\left(\frac{\partial^2 \phi}{\partial X^2}+\frac{\partial^2 \phi}{\partial Y^2}\right) \tag{4}$$

The dimensionless quantities in above equations are given as:

$$X=\frac{x}{D}, Y=\frac{y}{D},\ U=\frac{uD}{\alpha},\ V=\frac{vD}{\alpha},\ P=\frac{pD^2}{\rho\alpha^2},\ \phi=\frac{(T-T_c)}{(T_h-T_c)},\quad Ra=\frac{g\beta(T_h-T_c)D^3}{\upsilon\alpha}\ \text{and}\ Pr=\frac{\upsilon}{\alpha} \tag{5}$$

The Nusselt number of the obstacle is calcuted based on the following expressions:

$$Nu_L=-\frac{\partial\phi}{\partial n_s},\quad Nu=\frac{1}{s}\int_0^s Nu_l ds \tag{6}$$

The adopted boundary conditions

- For the inner obstacle walls:

$$U=0, V=0,\ \phi=1 \tag{7}$$

- For the cavity walls:

$$U = 0, V = 0, \phi = 0 \quad (8)$$

3. NUMERICAL APPROACH

The present work was simulated by ANSYS-CFX. The governing equations have differential form. Therefore, the numerical method of finite volume was used for solving these equations. The relative errors considered for the equations are: 10^{-8}, 10^{-8} and 10^{-6} for momentum, continuity and energy, respectively.

In order to proof the present methodology in solving the partial differential equations, a validation test was incorporated. The results of the validation test against the works referred as [16, 17] are shown in Figure 2. The test is about a natural convection between two circular cylinders. From Figure 2, we notice a good agreement.

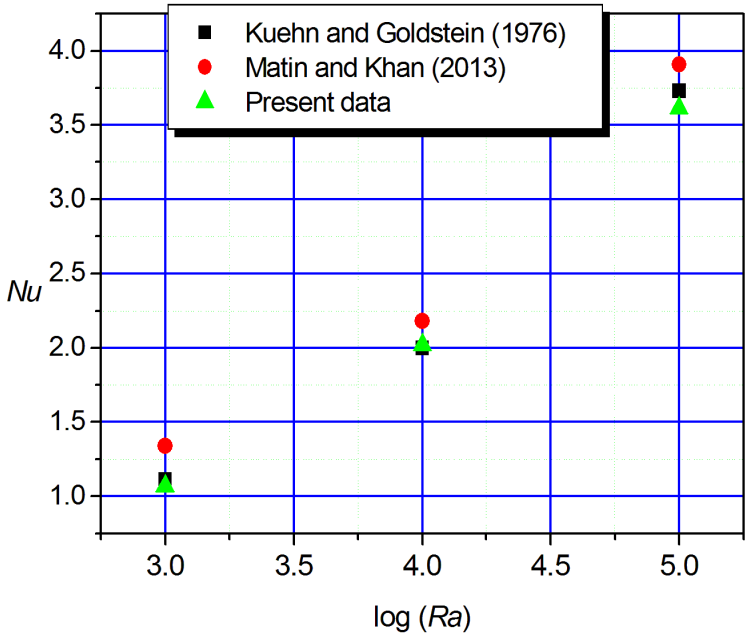


Figure 2: Validation test

4. RESULTS AND DISCUSSION

The present research studies the nature convection from H-shaped body in cold chamber. The main goal of this study is to present the influence of Rayleigh and Prandtl numbers on the thermal activity. Increasing Ra number means that the thermal buoyancy force increases. On other hand, increasing the Prandtl number means that changing the thermo-physical characteristic of the fluid.

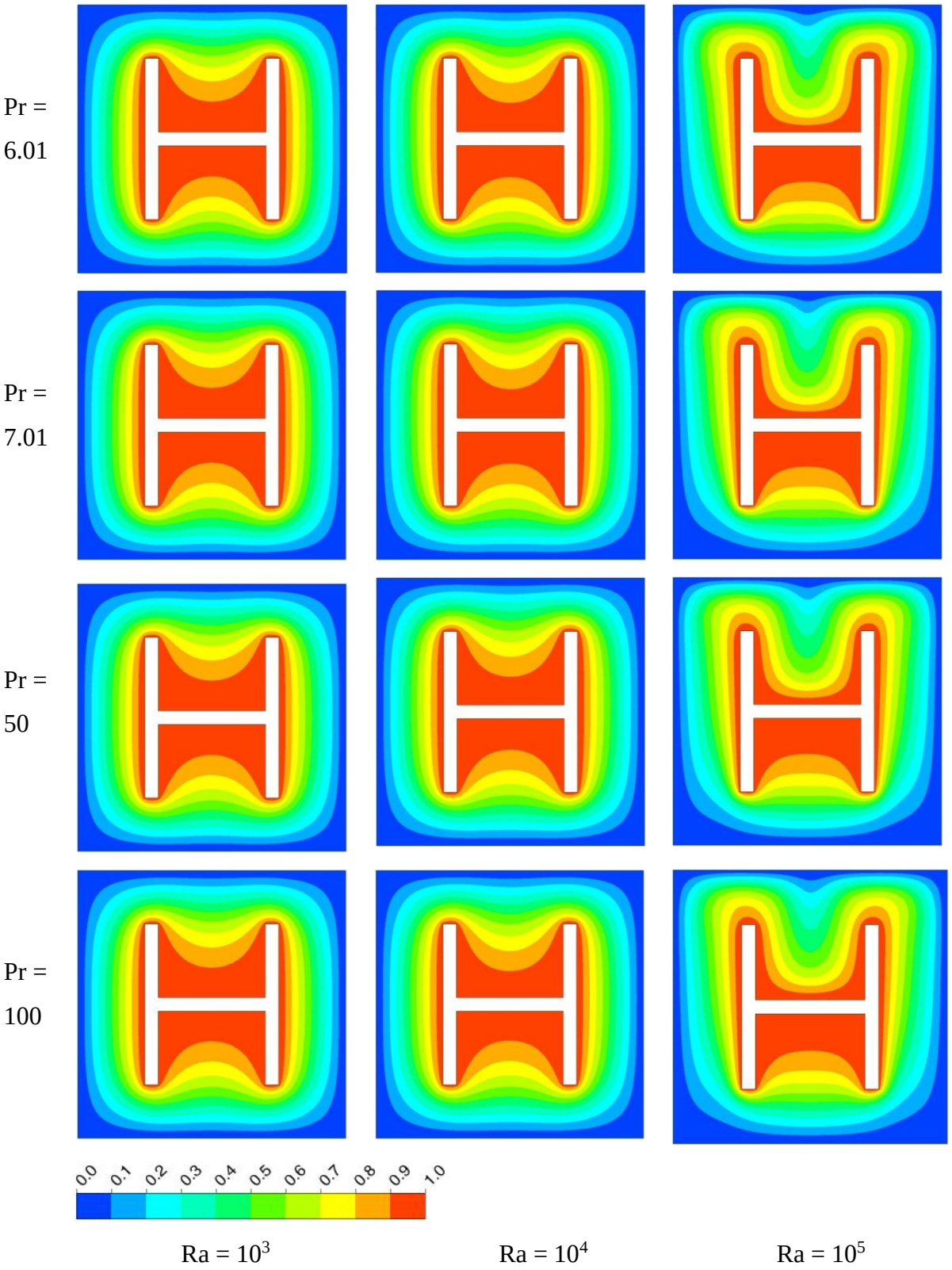


Figure 3: Isotherms contours for different values of Pr and Ra numbers.

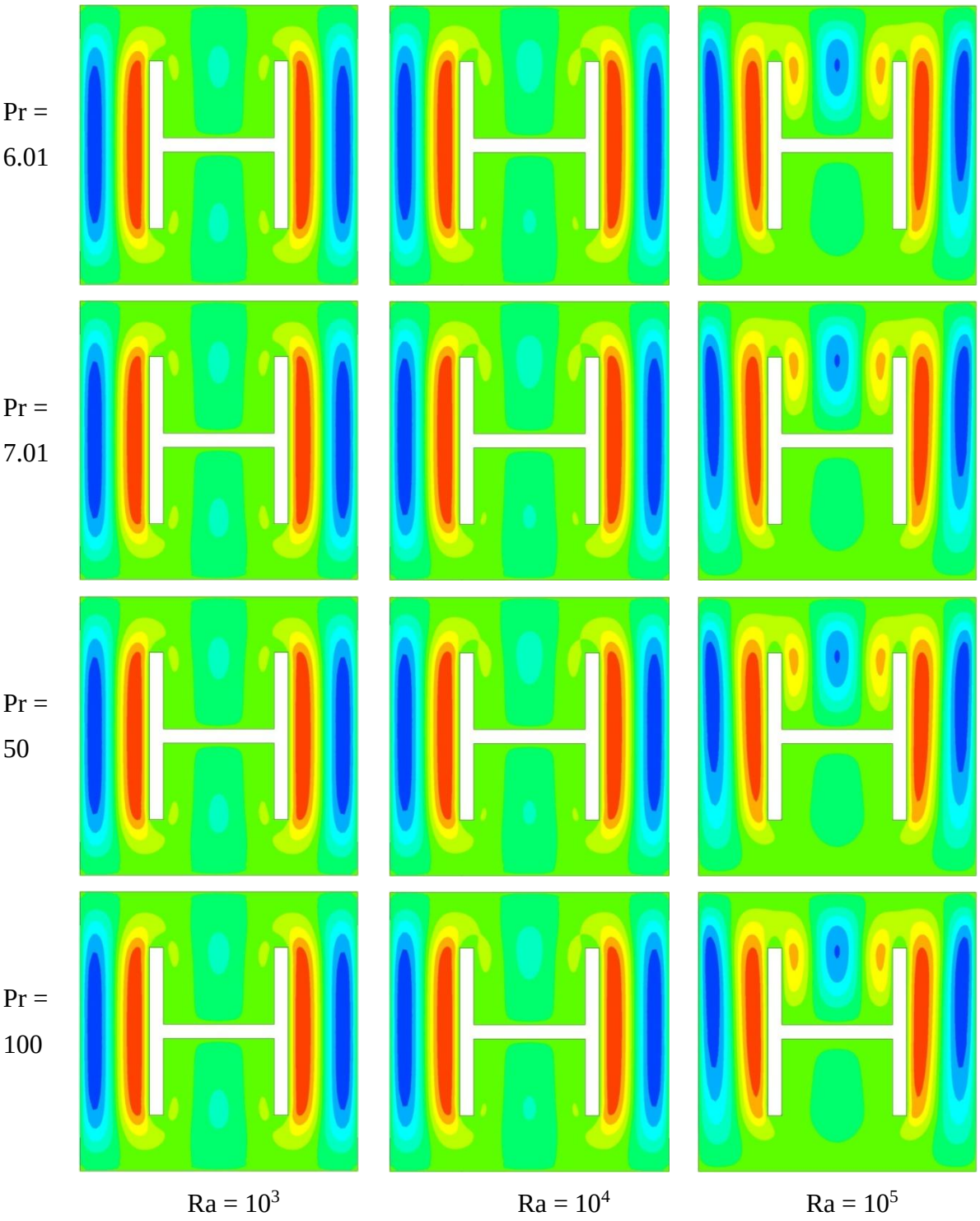


Figure 4: Velocity contours for different values of Pr and Ra numbers.

Figure 3 shows the isotherms in the studied domain. It is clear that the heated layers of fluid are around the obstacles. While the cold layers of the fluid are near the wall of the cavity. It is clear that when we increase Ra number the hot isotherms shift upwards due to the force of thermal buoyancy. On the other hand, the cold fluid is in the bottom the cavity due to the fact that when the fluid layers become cold, their density increases therefore they move in the same direction as the gravitational force. However, increasing the value Pr number does not on the isotherms. From here, we can predict that there is an influence of Ra number on in heat transfer, while it can be neglected with respect to Pr number.

Figure 4 shows the contours of velocity in chamber in terms of Pr and Ra numbers. It is clear that there is change in the distribution of velocity in terms of Ra number. Meanwhile, the behavior of Pr number on velocity contours remains constant. Increasing Ra number favorites extra movement of the flow in the cavity.

Figure 5 shows the variation of Nu numbers in terms of Ra and Pr number. These values are of the heated obstacle. It is clear that increasing Ra number augments the value of Nu. Because when we increase Ra, the velocity of the flow increases in the cavity which increases the evacuation of thermal energy from the heated walls. On other hand, we notice that the variation of Nu in terms of Pr is almost constant. The thermo-physical characteristics of the fluids have a limited effect on heat transfer for the case of natural convection.

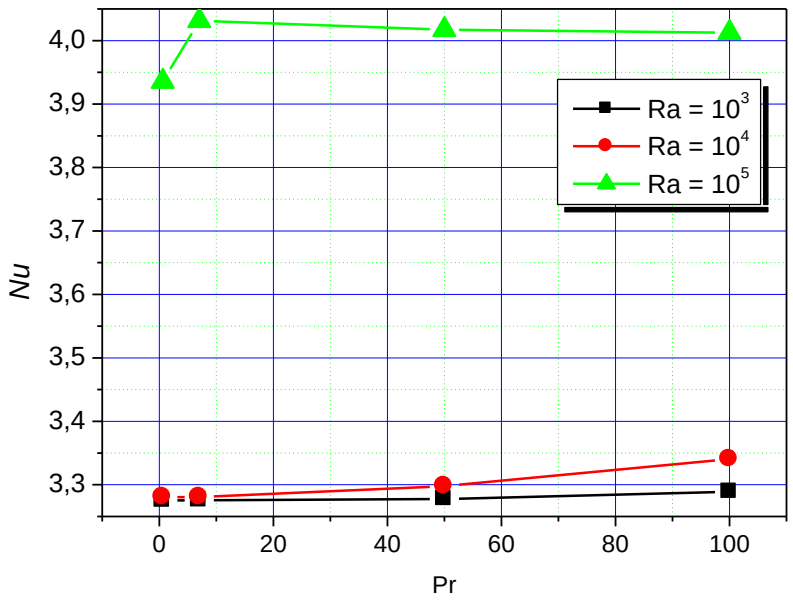


Figure 5: Variation of Nusselt number versus Pr and Ra numbers.

5. CONCLUSION

This work presented a numerical simulation of natural convection from H-shaped body located in square cavity. The walls of the body are heated and the walls of the cavity are cold. The studied parameters were Rayleigh and Prandtl numbers. This work allowed us to draw the following points:

- Increasing Ra improves the heat transfer from the hot body to the fluid.
- Increasing Ra number makes the flow in the cavity fester.
- The effect of Pr in this work is almost neglected.
- The development of heat transfer with the respect of thermo-physical characteristics is limited.

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