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Numerical Study of Natural Convection Heat Transfer inside a Triangular Cavity with Flexible Sidewalls Containing a Cylindrical Heat Source

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ABSTRACT: In this study, the natural convection heat transfer within a triangular cavity with elastic diagonal walls containing a cylindrical heat source is investigated. The assumed fluid inside the cavity is air. The flexible diagonal walls of the cavity are considered to be at a constant cold temperature of Tc and the cylindrical heat source is at the hot temperature of Th. In this study, the interaction of fluid and solid fields and the effect of cylindrical heat source position on flow and temperature fields are examined. For this purpose, the effect of Rayleigh number and changing the position of the heat source along the vertical centerline on the deformation of flexible walls, flow and temperature fields, and heat transfer rate are investigated. The results show that for a fixed position of the heat source, an increase in the Rayleigh number increases the maximum of the stream function, the average Nusselt number, and the deformation of the flexible walls. Also, the results show that the position of the heat source depending on the Rayleigh number has different effects on the temperature and flow fields. As the heat source moves to the bottom of the cavity, the average Nusselt number for Rayleigh numbers of 104 and 105 decreases, and Rayleigh number of 106 first increases and then decreases.

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1- Introduction

The fluid-structure interaction affects the performance of many scientific, engineering, and natural systems. Failure to consider this fundamental interaction between the solid and fluid domains can have devastating consequences. Ghalambaz et al. [1] numerically analyzed the convection heat transfer inside an L-shaped enclosure with a flexible blade at its middle. By examining the effects of Rayleigh number and modulus of elasticity, they found that with increasing Rayleigh number, heat transfer rate increases, and the modulus of elasticity affects the flow pattern as well as the isotherms inside the enclosure. Based on this, increasing the elastic modulus reduces the heat transfer. Raisi and Arvin [2] examined natural convection heat transfer inside a square enclosure with a flexible upper wall and containing a flexible blade. They found that increasing the Rayleigh number, in addition to increasing the natural convection heat transfer inside the enclosure, caused a significant deformation in the upper wall and the flexible blade. Also, they showed that the outward movement of the flexible wall reduces the strength of the vortex formed inside the enclosure, and the inwards movements increase it. In addition to the above, they found that increasing the blade length for both flexible and rigid systems in very large and small amounts of the Rayleigh number increases and decreases the average Nusselt number, respectively.

2- Problem Statement and Governing Equations

Fig. 1 shows a schematic diagram of the enclosure examined in this paper. The diagonal walls of the triangular enclosure are flexible and the horizontal wall is rigid, and a cylindrical heat source is installed inside the enclosure.

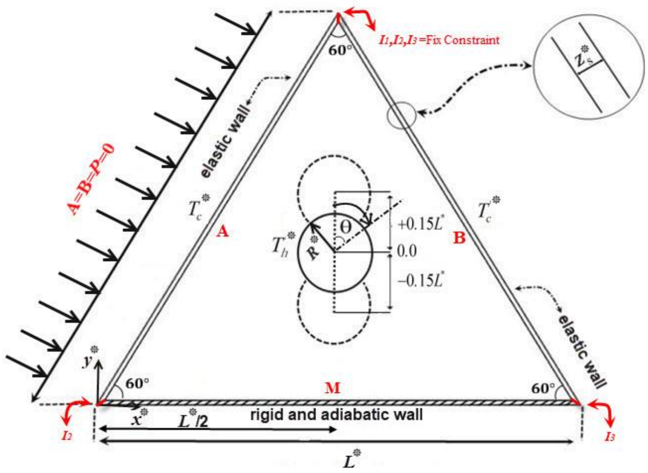

Fig. 1. The geometry of the present study

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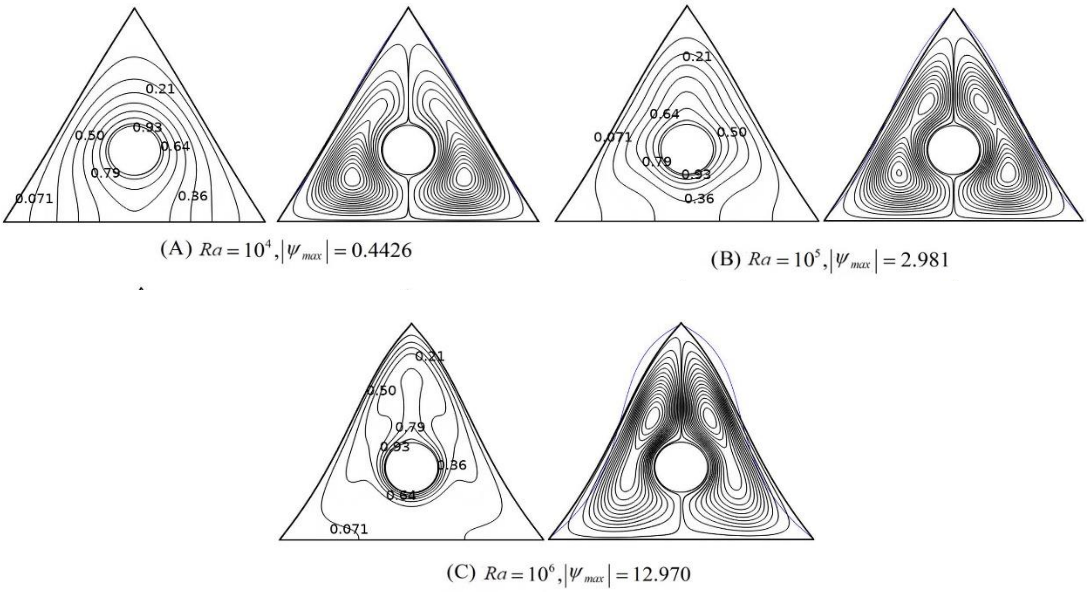

Fig. 2. Isotherms (left) and streamlines (right) for different values of Rayleigh number

The fluid-structure interaction equation includes equations of the fluid and structure, which include continuity, momentum, and energy for fluid domain and linear momentum equations for solid domain [3]:

$$\frac{\partial u_f^*}{\partial x^*} + \frac{\partial v_f^*}{\partial y^*} = 0 \quad 1)$$

$$\begin{aligned} &\frac{\partial u_f^*}{\partial t} + (u_f^* - u_g^*).\frac{\partial u_f^*}{\partial x^*} + (v_f^* - v_g^*).\frac{\partial u_f^*}{\partial y^*} = \\ &-\frac{1}{\rho_f}\frac{\partial P_f^*}{\partial x^*} + \upsilon_f\left(\frac{\partial^2 u_f^*}{\partial x^{2^*}} + \frac{\partial^2 u_f^*}{\partial y^{2^*}}\right) \\ &\frac{\partial v_f^*}{\partial t} + (u_f^* - u_g^*).\frac{\partial v_f^*}{\partial x^*} + (v_f^* - v_g^*).\frac{\partial v_f^*}{\partial y^*} = \\ &-\frac{1}{\rho_f}\frac{\partial P_f^*}{\partial y^*} + \upsilon_f\left(\frac{\partial^2 v_f^*}{\partial x^{2^*}} + \frac{\partial^2 v_f^*}{\partial y^{2^*}}\right) + \beta_f g(T^* - T^*_c) \end{aligned} \quad (2)$$

$$\frac{\partial T^*}{\partial t} + (u_f^* - u_g^*).\frac{\partial T^*}{\partial x^*} + (v_f^* - v_g^*).\frac{\partial T^*}{\partial y^*} = \alpha_f\left(\frac{\partial^2 T^*}{\partial x^{2^*}} + \frac{\partial^2 T^*}{\partial y^{2^*}}\right) \quad (3)$$

$$\rho_s \frac{d^2 d_s^*}{dt^2} - \nabla^* \sigma^* = F_v^* \quad (4)$$

3- Results and Discussion

Fig. 2 shows the Rayleigh number effect Ra=10^4,10^5,10^6 on isotherms, streamlines, and deformation of flexible walls for δ=0. As can be seen, for the density of streamlines at the top of the enclosure is less than at the bottom of the enclosure due to the weak strength of the vortices formed. As the Rayleigh number increases, the buoyant force increases, and the role of the convection mechanism in heat transfer increases. Therefore, the strength of the vortices increases, and the core of the vortices moves to the top of the enclosure. As a result, the density of streamlines at the top of the enclosure increases compared to the Ra=10^4.

In addition, as the buoyant force increases, the hydrodynamic force applied to the flexible diagonal walls of the chamber increases and causes a very noticeable deformation in the walls. The pattern of isotherms shows that in low Rayleigh numbers, conduction is the dominant heat transfer mechanism and in high Railey numbers, natural convection is the dominant heat transfer mechanism.

In Table 1 the steady-state average Nusselt number on the cylindrical heat source surface has been presented at different values of Riley number for both flexible and rigid systems.

As the Rayleigh number increases, the buoyant force increases, and the vortices are strengthened. As a result, the temperature gradient near the cold and hot surfaces increases, and the average Nusselt number enhancements. The results presented in Table 1 show that the average Nusselt number of the flexible system has increased slightly compared to the average Nusselt number of a rigid system. This slight increase in the average Nusselt number

Table 1. The steady-state average Nusselt number on the cylindrical heat source surface

	Nu_m		
Ra	10^4	10^5	10^6
Elastic walls	6.9643	8.8580	18.299
Rigid walls	6.9332	8.7698	18.013

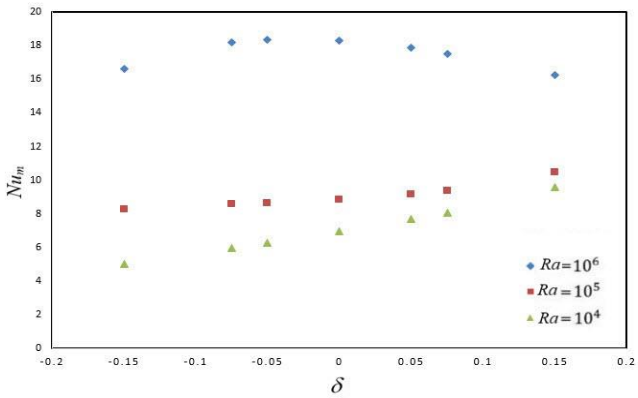

Fig. 3. Variations of the average Nusselt number of the heat source surface for the flexible system for different values of Ra and δ

is due to the fact that when the enclosure walls are deformed, the streamlines adjacent to these walls become in more coordination with the boundaries and the formed vortex penetrates better into the corners of the enclosure.

Fig. 3 shows the variations of the average Nusselt number on the cylindrical heat source surface in terms of the position of the heat source for different values of the Rayleigh number. At low Rayleigh numbers ($Ra=10^4, 10^5$) conduction is the main heat transfer mechanism. Therefore, by moving the heat source to the top of the enclosure, the distance between the hot surface of the heat source and the cold surfaces of the enclosure decreases, and the heat transfer rate increases.

At $Ra=10^6$, convection plays a major role in heat transfer, so the position of the heat source affects the strength of the vortices on the one hand and the space that the vortices have for rotation on the other.

4- Verification

The natural convection heat transfer was analyzed by considering flexible diagonal walls for a Triangular Cavity enclosure with an internal isotherm heat source.

Increasing the Rayleigh number increased the strength of the vortices formed inside the enclosure and thus increased the rate of heat transfer as well as the deformation of the flexible walls. Also, changing the position of the heat source inside the enclosure had an effect on the heat transfer rate and the average Nusselt number depending on the value of the Rayleigh number

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