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NUMERICAL ANALYSIS OF LAMINAR AND PERMANENT THERMAL NATURAL CONVECTION IN A CLOSED ENCLOSURE WITH DIFFERENT CONDITIONS.

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1. ABSTRACT

In this study, we present a numerical analysis of laminar and permanent thermal natural convection in a closed enclosure with different conditions using FORTRAN language. The purpose of this study is to validate the proposed code's validity numerically by comparing the obtained findings with those of other authors. The resulting system of algebraic equations was then solved using the iterative method with the Gauss-Seidel algorithm and relaxation. The results are presented in the form of isotherms, velocity and stream lines as a function of the Rayleigh number, as well as the Nusselt number. The findings indicate that an increase in the Rayleigh number leads to a higher convective heat transfer within the enclosure.

2. INTRODUCTION

The study of natural convection in closed enclosures has been the subject of many theoretical and experimental studies. Many published works have been developed concerning natural convection in different shapes of enclosures (either experimental or numerical) with different calculation methods and with different data and boundary conditions. Kuznetsov et al. [1] examined the natural double diffusive convection inside a cubic cavity where lower wall is isothermal and maintained at a uniform concentration and the other walls are adiabatic and impermeable. They examined the influence of the Rayleigh number on the flow and rate of heat and mass transfer, the influence of the conductivity ratio on the heat and mass transfer and the effect of the of sources size of heat and mass on mass transfer regimes. Nikbakhti et al. [2] numerically analyzed the heat and mass transfer for air contained in a rectangular enclosure with partially thermally active walls. Teamah et al. [3] numerically studied a double diffusion flow of natural convection in an inclined rectangular enclosure in the presence of a magnetic field and a heat source. The authors concluded that: the inclination angle affects the buoyancy force, and the magnetic field reduces heat transfer and fluid circulation due to the delay effect of the electromagnetic body force.

3. MATHEMATICAL MODEL

The physical problem considered is schematized in figure 1. It is a closed two-dimensional enclosure of height H. The flow in the enclosure is due to the temperature difference and therefore to the density difference which leads to convective flow.

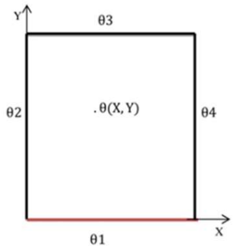

Fig. 1 Enclosure model with boundary conditions

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3.1 Governing equations

Dimensionless vorticity equation: To eliminate the pressure terms in the motion eqaution, we use the dimensionless vorticity equation W defined by:

$$U\frac{\partial W}{\partial X}+V\frac{\partial W}{\partial Y}=\frac{Ra}{Pr}\frac{\partial \theta}{\partial X}+(\frac{\partial^2 W}{\partial X^2}+\frac{\partial^2 W}{\partial Y^2}) \tag{1}$$

Dimensionless continuity equation: $\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0$ (2)

Dimensionless energy equation: $U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{Pr}(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2})$ (3)

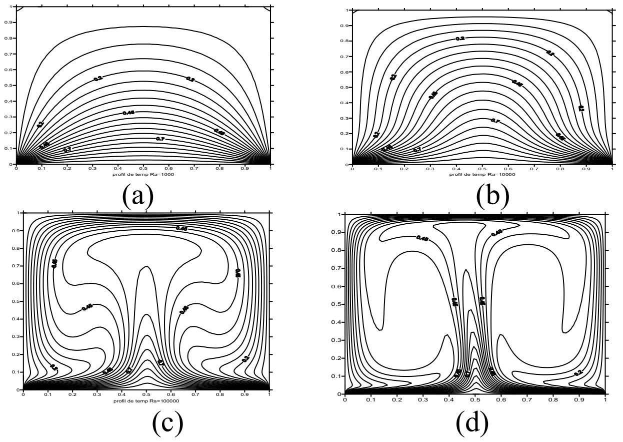
4. NUMERICAL FORMULATION

To resolve numerically the above equations, various numerical methods are used. Among these methods, we can cite the method of finite differences, finite elements and finite volumes. To carry out our numerical simulations, we opted for a calculation program written in FORTRAN language based on the finite difference method.

5. RESULTS AND DISCUSSION

5.1 Temperature profile (isotherms)

Figure (2) reflects the phenomenon of natural convection. The isotherms show that the heat recovered from the hot base of the enclosure is transformed by natural convection upwards to the middle of the enclosure by the pair of cells in the center. This explains the relatively high temperatures in the central part of the enclosure. Heat is dissipated equally through both side walls due to symmetry. For Ra $=10^3$, the isotherms become almost concentric ellipses and have a symmetrical structure with respect to the passing vertical plane thus these isotherms show that heat transfer by conduction is predominant (absence of transfer by convection). When Ra$=10^4$, the deformation of the isotherms increases. When Ra $=10^6$, the thermal boundary layers become thinner and the isotherms become stratified. The increase in the Rayleigh number causes the isotherms to move closer to each other in the zone located near the heated lower wall, i.e. the temperature gradients become higher near the heated lower wall. This implies an increase in heat transfer through the bottom wall of the enclosure for a higher Rayleigh number. Therefore, the highest temperatures are those of the fluid flowing parallel to the heated wall, while the lowest temperatures are those of the fluid flowing parallel to the cold walls [4].



(a) (b)

(c) (d)

Fig. 2 Structure of isotherms for different values named Rayleigh.
(a) Ra$=10^3$, (b) Ra$=10^4$, (c) Ra$=10^5$, (d) Ra$=10^6$

5.2 Velocity profile

Figure (3) illustrates the vertical velocity structure of fluid flow for different Rayleigh numbers. We notice a descent of the fluid at the level of the cold side walls and an increase at the level of the heated wall. This elevation increases with the increase in the Rayleigh number and reaches its maximum at the center of the heated wall, where the temperature is higher. This is due to the increase in the intensity of thermal thrust forces and therefore to the predominance of heat transfer by convection.

5.3. Local Nusselt number

Figure (4) illustrates the variation of the local Nusselt number on the active (hot) wall whatever the value of the Rayleigh number. We notice in this figure, zero values of the Nusselt number in the middle of the hot part that this is where the temperature gradient is the lowest and the heat transfer between the hot wall and the fluid takes place only by conduction, on the other hand, its maximum value at the terminals of the heated source given that this corresponds to the contact of the cold fluid coming from the side walls with the ends of the heated source, which will give rise to the strongest temperature gradients.

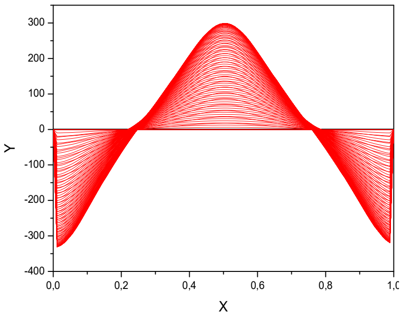


Fig. 3 Vertical speed profiles for Ra=10^5

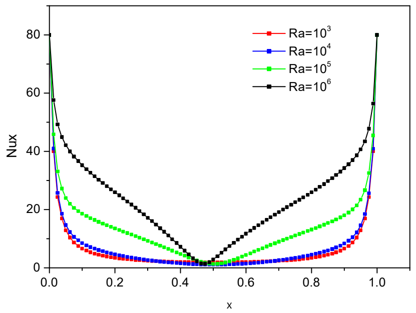


Fig. 4 Variation of the Nusselt number as a function of X

6. CONCLUSIONS

In this work, we presented a numerical study of heat transfer by natural convection in closed enclosure filled by air. Numerical simulation using FORTRAN are carried out for different Rayleigh numbers. The resolution of the equations governing flow and heat transfer was approached by the finite difference method with the relaxation method.

The results obtained show that:

- Increasing the Rayleigh number favors heat transfer in the cavity given the increase in convection currents and therefore the speed.
- The flow regime always remains laminar for the range of the Rayleigh number considered.
- The Nusselt number increases with increasing Rayleigh number.

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