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Research Article

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Influence of the Magnetic Field on the Natural Convection of Air between Two Square Cavities for Ra = 10^5

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Abstract In this numerical study, we have studied the influence of the magnetic field deflected by an angle θ = 30° with respect to the horizontal with a value of the Hartmann number Ha = 0.1 on the natural convection of the air confined between two square cavities for a Rayleigh number Ra = 10^5. The internal cavity is subjected to a heat flow of constant density and the external cavity is at a constant temperature. We have applied the vorticity current function formalism to free ourselves from the pressure gradient in the equation of motion because we do not have the motor of motion. In the absence of the magnetic field, we have noted for isotherms the formation of fungi on the upper internal cavity and for current lines, we have noted the formation of two recirculation zones circulating in opposite directions. In the presence of the magnetic field, we have realized a thermal and dynamic modification resulting in the formation of four recirculation zones for the current lines and for the isotherms a standardization of the temperature. To characterize the interaction between the cavity and the fluid, we have studied the behavior of the Nusselt number.

Keywords Ansys Fluent, Magnetic field, Natural convection, Finite volume

Introduction

Nowadays, natural convection is at the heart of many applications, especially in the field of meteorology, geophysics. Many scientific studies have been conducted in order to identify this phenomenon. Some have studied the natural convection of air without a magnetic field for a square cavity [1] others in rectangular [2] or cylindrical cavities [3], [4]. However, some researchers have examined the behavior of the magnetic field on natural convection for a nanofluid [5]. Despite the rarity of subjects identical to ours, we found a close case studying the convection of air between two square cavities in the absence of a magnetic field [6]. To better understand this phenomenon, it is proposed to study the influence of the magnetic field for a value of the Hartmann number Ha = 0.1 on the natural convection of air between two square cavities for Ra = 10^5.

Materials and Methods

In this work, we have studied the influence of the magnetic field on the natural convection of air between two square cavities for a value of Rayleigh number Ra = 10^5. The outer wall is at constant temperature while the inner wall is at heat flow of constant density. The air is subjected to a magnetic field oriented at an angle θ = 30° with respect to the x-axis.

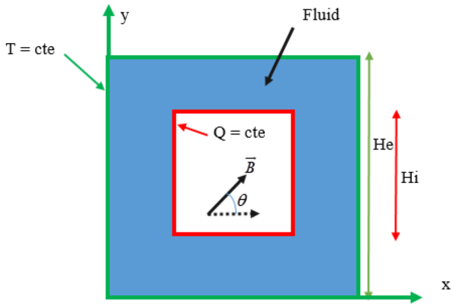


Figure 1: Schematization of the physical problem

To simplify and reduce the transfer equations, we have introduced reference quantities by dimensionalizing showing control parameters such as the Rayleigh number Ra but also we applied the rotational operator to the members of the equation of motion leading to the vorticity – current function formalism [7] to get rid of the pressure gradient which is a primitive variable and is not the central element in natural convection. The equations obtained are:

$$\frac{\partial\omega}{\partial t}+u\frac{\partial\omega}{\partial x}+v\frac{\partial\omega}{\partial y}=\Pr(\frac{\partial^2\omega}{\partial x^2}+\frac{\partial^2\omega}{\partial y^2})+R_a\Pr\frac{\partial T}{\partial x}+Ha^2\Pr(\frac{\partial v}{\partial y}\sin 2\theta+\frac{\partial v}{\partial x}\cos^2\theta-\frac{\partial u}{\partial y}\sin^2\theta) \quad (1)$$

Pr : Prandlt number, $\Pr=\frac{\upsilon}{\alpha}$ (2)

Ra : Rayleigh number, $Ra=\frac{g\beta\Delta TD^3}{\upsilon\alpha}$ (3)

Ha : Hartmann number, Ha = $Ha=B_OD\sqrt{\frac{\sigma}{\mu}}$ (4)

$$\frac{\partial T}{\partial t}+\frac{\partial}{\partial x}(uT-\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(vT-\frac{\partial T}{\partial y})=0 \quad (5)$$

$$(\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2})=-\omega \quad (6)$$

Initial conditions and boundary conditions have been set

Dimensionless initial condition

$$\vec{U}=\vec{0} \;;\; \psi=\omega=0 \;;\; T_o=0 \;;\; B=0 \quad (7)$$

Dimensionless boundary condition

- On the walls of the outer cavity
  - ✓ On the outer vertical wall:

$$\vec{U}=\vec{0} \;;\; \psi=cte \;;\; \frac{\partial\psi}{\partial y}=0 \;;\; \omega=-\frac{\partial^2\psi}{\partial x^2} \;;\; T=0 \quad (8)$$

  - ✓ On the outer horizontal wall:

$$\vec{U}=\vec{0} \;;\; \psi=cte \;;\; \frac{\partial\psi}{\partial x}=0 \;;\; \omega=-\frac{\partial^2\psi}{\partial y^2} \;;\; T=0 \quad (9)$$

- On the walls of the inner cavity
  - ✓ On the inner horizontal wall :

$$\vec{U}=\vec{0} \;;\; \psi=cte \;;\; \frac{\partial\psi}{\partial x}=0 \;;\; \omega=-\frac{\partial^2\psi}{\partial y^2} \;;\; T=\pm T_P \quad (10)$$

  - ✓ On the inner vertical wall :

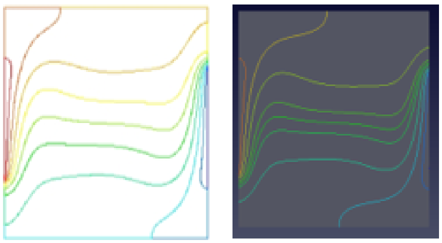
$$\vec{U} = \vec{0} \;;\; \psi = cte \;;\; \frac{\partial \psi}{\partial y} = 0 \;;\; \omega = -\frac{\partial^2 \psi}{\partial x^2} \;;\; T = \pm T_P \tag{11}$$

To characterize the heat transfer between the wall and the air fluid, a parietal quantity is introduced which the Nusselt number. The mean Nusselt number equal to the value of the Nusselt number on the surface S is given by this relation:

$$Nu_{moyenne} = \frac{1}{s}\int_s Nuds \tag{12}$$

In this work, we have used the finite volume method for discretizing equations. The equations obtained are implemented in Ansys Fluent software [8], [9], [10]. The resolution procedure is the SILMPLE algorithm with the power law as an approximate diagram.

Any scientific study deserves to be validated in order to verify the performance of the algorithm used, the discretization method chosen, which is that of finite volumes and the commercial Ansys Fluent calculation code used. Thus we compared the temperature contours for Ra = 10^5 of our work on the left (a) with the work of M.K.Kane on the right (b) using the Fortran software.



(a) (b)

Figure 2: Comparison contours temperature for Ra = 10^5

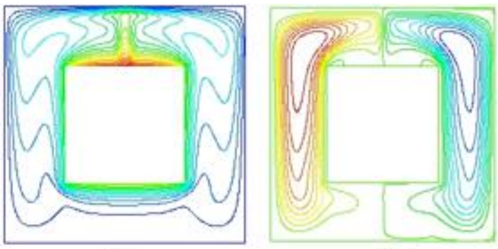
Results & Discussion

We found that the validation results are similar which allowed us to make an analysis that will focus on isothermal lines and current lines for a value of the Rayleigh number Ra = 10^5.

Evolution of isothermal lines and current lines without magnetic field Ha = 0

With regard to the isothermal lines ©, we have noted in the absence of magnetic field, a loosening of its isotherms and the formation of fungi on the upper internal cavity due to the buoyancy force which is important at this level but also a low intensity at the level of the lower horizontal cavity.

For current lines (d), we note the formation of two recirculation zones rotating in opposite directions and a gain in cell intensity



(c) (d)

Figure 3: evolution of isothermal lines © and current lines (d) for Ha = 0

Evolution of isothermal lines and current lines with magnetic field for Ha = 0.1

The application of the magnetic field has led to thermal and dynamic changes.

For isothermal lines, we noticed that the hot fluid accelerated on both sides according to the direction of the magnetic field and decelerated in the same direction as the field, tends to quickly reach the cold cavities causing a standardization of the temperature.

For current lines, we have noted the formation of four recirculation zones but also the formation of small cells following the direction perpendicular to the Lorentz force

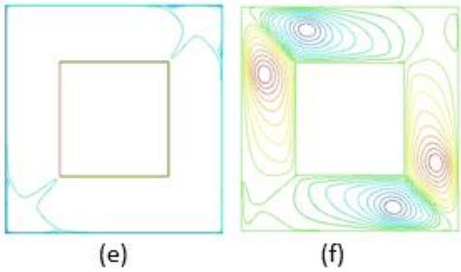


Figure 4: evolution of isothermal lines (e) and current lines (f) for Ha = 0.1

Variation of the Nusselt number at the level of the upper internal cavity

Without a magnetic field (g) for a value of Hartmann number Ha = 0, for a value of the number of Ra = 10^5, we have found that the temperature of the fluid tends to approach the temperature of the hot wall which leads to a decrease in the Nusselt number. When we go beyond the middle of the cavity, which corresponds to the critical value of the Rayleigh Rac number, we notice that the temperature of the fluid gradually moves away from the temperature of the hot wall and tends towards the temperature of the cold cavity resulting in an increase in the Nusselt number. The bowl shape noted in the immediate vicinity of the middle of the cavity tend to tighten.

With magnetic field (h) for Ha = 0.1, we have noted a deceleration of the fluid following the direction of the magnetic field which is manifested by a disturbance. This change is due to the Lorentz force whose direction is perpendicular to that where the magnetic field is applied.

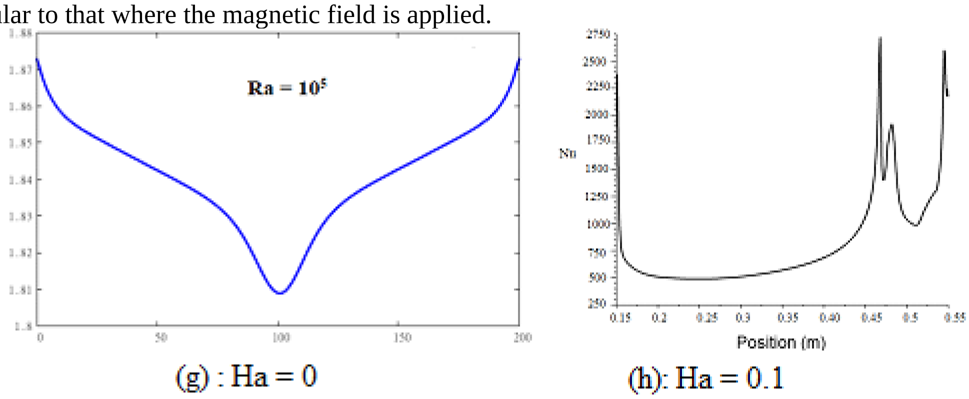


Figure 5: evolution of the Nusselt number on the upper internal cavity Ra = 10^5 for different positions

Conclusion

In this work, we have studied the influence of the magnetic field with a Hartmann number Ha = 0.1 on natural air convection for a value of the Rayleigh number Ra = 10^5. We have analysed and interpreted the isothermal and current lines in the absence and presence of a magnetic field. To this end, we have noted when the magnetic field is not applied, for isotherms the formation of fungi on the upper internal cavity and for current lines the formation of two recirculation zones in opposite directions of circulation. As soon as the magnetic field is applied, we have achieved temperature standardization and the formation of four recirculation zones for the current lines. With the Nusselt number, we have noted a narrowing around the middle of the cavity for Ha = 0 and a disturbance following the direction of the field when Ha = 0.1

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