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CFD Modeling of Natural Air Convection for a Rayleigh Number Ra = 10^4 in the Presence of a Magnetic Field

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Abstract:- In this numerical simulation, we have studied the natural convection of air under the influence of a magnetic field of Hartmann number Ha = 0.1 for a value of the Rayleigh number Ra = 104. The air fluid is confined between two rectangular parallelepipeds of square straight sections whose internal cavity is subjected to a heat flow of constant density and the external cavity is at constant temperature. We have applied the vorticity current function formalism to get rid of the pressure gradient in the equation of motion because the fundamental element of natural convection is the Rayleigh number. Without a magnetic field, we notice, for isothermal lines, a loosening of cells and formation of a peak in the middle of the upper internal cavity while for current lines, we have two cellular areas of opposite direction that tend to approach towards the middle of the cavity. As soon as the magnetic field is applied for a Hartmann number Ha = 0.1, we will see thermal and dynamic changes causing the formation of four recirculation zones for the current lines and a standardization of the temperature for the isotherms. To see the interaction between the wall and the fluid, we have studied the behavior of parietal quantities such as the Nusselt number and the coefficient of friction.

Keywords:- *Ansys Fluent; Convection; Finite Volume; Magnetic Field.*

I. INTRODUCTION

In recent years, natural convection has been at the center of several areas with the scope of application of thermal comfort and ventilation systems. Many studies are done for a good understanding of convection. Some researchers have worked on the natural convection of air without a magnetic field for a square cavity [1] others on the other hand have done their studies in rectangular cavities [2] or even cylindrical [3], [4]. Nevertheless, some researchers have investigated the influence of the magnetic field on natural convection for a nanofluid [5]. However it is difficult to see a study similar to ours but a nearby case studying the convection of air between two square cavities in the absence of magnetic field [6] has been treated. To understand this phenomenon, we propose to study the influence of the magnetic field for a value of the Hartmann number Ha = 0.1 on the natural convection of air two rectangular parallelepipeds of square straight sections for Ra = 10^4.

II. METHOD AND MATERIAL NUMERICAL

In this paper, we have studied the influence of the magnetic field on the natural convection of air between two rectangular parallelepipeds of square straight sections for a value of Rayleigh number Ra = 10^4. The outer cavity is kept at a constant temperature while the inner cavity is subjected to a heat flux of constant density. The air is subjugated to a magnetic field deflected by an angle = 30° with respect to the x-axis.

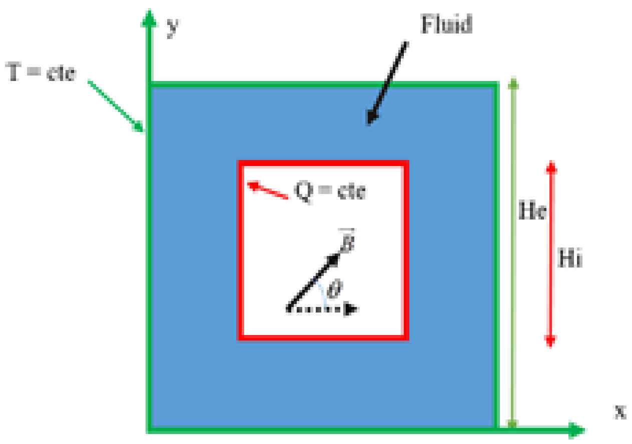

Fig 1 Diagram of the problem

To destroy the transfer equations, we will incorporate reference quantities which allows us to obtain control parameters such as the Rayleigh number Ra, the Prandlt number Pr as well as the Hartmann number. In the equation of motion, there is a pressure gradient and since we do not have information on boundary conditions, it is desirable to free ourselves from this term using the vorticity-current function formalism [7]. The equations give us:

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

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

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

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

To close the system, initial conditions and boundary conditions were set: Initial conditions and boundary conditions have been set Dimensionless initial condition t= 0

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

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 :*

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

To determine the heat transfer between the cavity and the air, we have attached a parietal quantity the Nusselt number. The mean Nusselt number equal to the value of the Nusselt number on the surface S is given by this relation:

$$Nu_{moyenne}=\frac{1}{s}\int_s Nu\,ds \quad (12)$$

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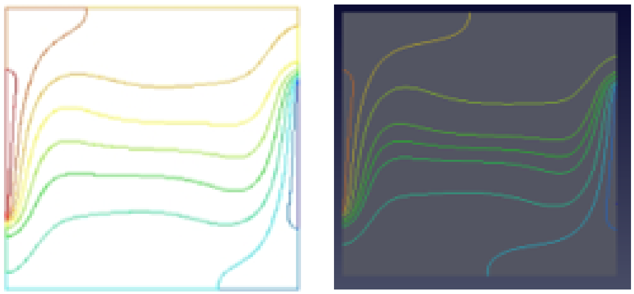
In this work, we have adopted as a discretization method that of finite volumes The acquired equations are anchored in the Ansys Fluent software [8], [9], [10]. We have used the SILMPLE algorithm to solve these equations with the power law as a developed scheme. To reassure ourselves of the efficiency of the algorithm adopted, we have 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) applying the Fortran software.



(a) (b)

Fig 2 Comparison contours temperature for Ra = 10^5

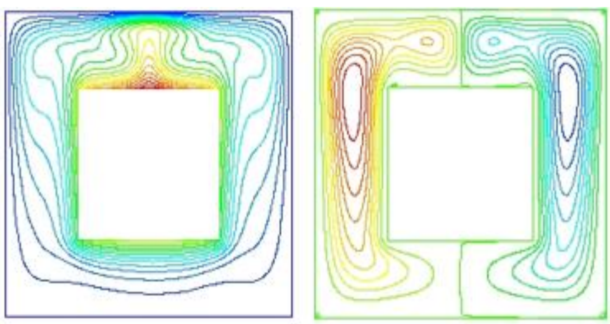
III. RESULTS AND DISCUSSIONS

We have noted that the comparison results are indistinguishable which allowed us to see the behavior of isothermal lines and current lines for a Rayleigh number Ra = 10^4.

- *Evolution of isothermal lines and current lines Ha = 0*

For isotherms (c), we have found a low movement at the level of the lower horizontal cavity and a relaxation of its isotherms.

For current lines (d), we have noted the formation of two recirculation zones that rotate in opposite directions and tend to approach the middle of the cavity. This leads to an emolument in intensity of cells.



(c) (d)

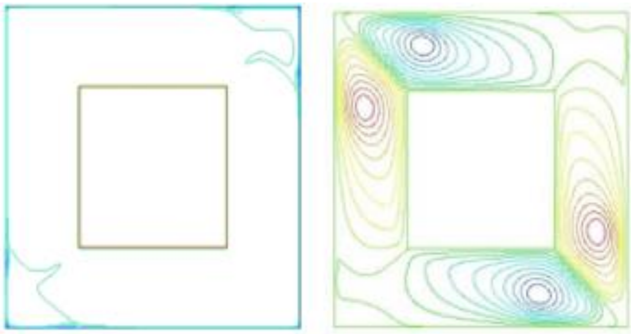
Fig 3 Evolution of Isothermal Lines (C) and Current Lines (D) for Ha = 0

- *Evolution of isothermal lines and current lines for Ha = 0.1*

When the magnetic field is applied, we have noted the presence of the Lorentz force which causes thermal and dynamic changes.

For isothermal lines(e), in addition to the constant density heat flux applied at the level of the inner cavity, the application of the magnetic field allows the fluid to be accelerated on both sides following the direction of the magnetic field and to be decelerated in the direction perpendicular to the Lorentz force.

For current lines (f), we have observed four recirculation zones with some throttles following the direction of the magnetic field that can lead to the birth of new cells in the long run.



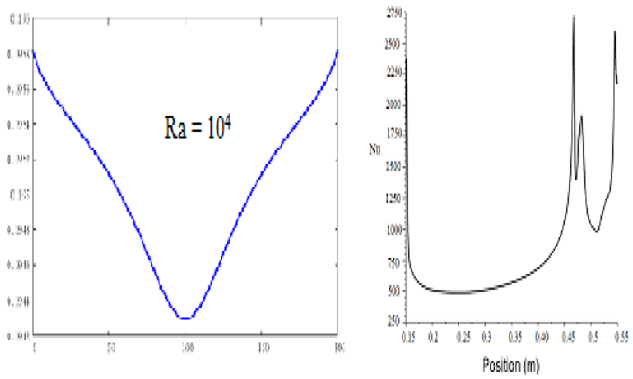
(e) (f)

Fig 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 :*

For a Hartmann number Ha = 0 (g), for a value of the number Ra = 10^4, we find that the temperature of the fluid moves away from the temperature of the upper cavity resulting in a decrease in the Nusselt number. Around the middle of the cavity, we notice a slight shrinkage and as soon as we have exceed this medium, the Nusselt number rises due to the fact that the air temperature has the feeling of dissipating from the temperature of the hot cavity.

With magnetic field (h) for Ha = 0.1, we have noted a disturbance following the direction perpendicular to the Lorentz force.

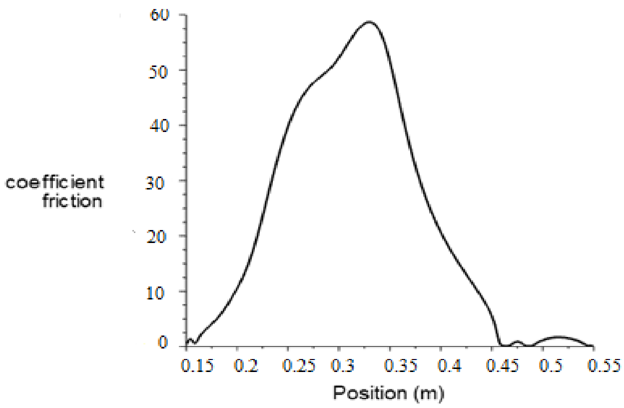


(g) : Ha = 0 (h): Ha = 0.1

Fig 5 Evolution of the Nusselt Number on the Upper Internal Cavity Ra = 10^5 for Different Positions

- *Behaviour of the coefficient of friction on the upper internal cavity*

This coefficient of friction also reflects the interaction between the fluid and the wall. When we look at the hot cavity, we see an increase in the coefficient of friction (k) as opposed to the number of nusselt. As soon as we exceed the middle of the cavity, the coefficient of friction increases due to an approach of the fluid towards the cold wall thanks to the buoyancy force.



(k): Ha = 0.1

Fig 6 Evolution of the Coefficient of Friction on the Upper Internal Cavity Ra = 10^4 for Different Positions.

IV. CONCLUSION

In this study, we made a CFD modeling of the natural convection of air between two rectangular parallelepipeds of square straight sections for a value of Rayleigh number Ra = 104 under the influence of a magnetic field of Hartmann number Ha = 0.1. We have made a dissection and exegesis of isothermal lines and current lines without and with magnetic field.

At this end, we have noted without the magnetic field (Ha = 0) a decrease and loosening of the isotherms and low movement at the level of the lower horizontal wall.

With regard to current lines, the formation of two recirculation zones in the opposite direction of traffic is observed. With the magnetic field (Ha = 0.1), we have obtained a standardization of the temperature and the formation of four recirculation zones for the current lines. Parietal quantities such as the Nusselt number and the coefficient of friction have been developed.

REFERENCES

[1]. De Vahl Davis.G, Natural convection of air in a square cavity: a bench mark numerical solution, Int. J. for Numerical Methods in Fluids, Vol. 3, pp. 249-264, (1983).

[2]. Zarrit. R, Teggar.M ,Kherrour.S « Étude numérique du transfert de chaleur par convection naturelle dans des enceintes rectangulaires ». Open Journal of Physics and Energetics vol.2 14-19. Juillet (2018).

[3]. Kuehn.T.H and Goldstein.R.J, Correlating equations for natural convection heat transfer between horizontal circular cylinders, Int. J. Heat Mass Transfer, 19, 1127-1134, (1976).

[4]. Kabdi .Z, Shin. C, Daguenet. M, « Laminar steady and two-dimensional thermal natural convection In cylindrical lunulas » Revue Générale de thermique ELSEVIER vol 36, issue 5 Mai 1997.

[5]. Mahmoudi. A, Mejri.I, Abbassi.M.A and Omri.A, "Analysis of MHD natural convection in a nanofluid-filled open cavity with non uniform boundary condition in the presence of uniform heat generation/absorption", Powder Technology, vol. 269, pp.275–289, (2015).

[6]. Diouf, A. Drame, O. Koita, M, N. « Numerical simulation of the natural convection of air between two square cavities for different Rayleigh values with a constant magnetic field » Open Journal of Chemical, Biological and Physical Science Vol. 12. No.1 ; 034- 039. Décembre 2021

[7]. Kane, M, K; Mbow, C; Sow, M, L. and Sarr, (2018). J. Numerique simulation of Two-dimensional Natural Convection in a Confined Environment with the vorticity-stream function formulation. Open Journal of Fluid Dynamics, 8, 44-58.

[8]. Versteeg H. K. and Malalasekera W. (1995): An introduction to Computational Fluid Dynamics The Finite Volume Method, Longman Scientific and Technical, Essex,

[9]. N. Reidar and B. Olsen, (2000) "CFD Computational Fluid Dynamics Algorithms for hydraulic engineering", Department of hydraulic environmental Engineering, the Norwegian University of Sciences and Technology.

[10]. Fluent 19.0, (2017), User's Guide