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*RESEARCH ARTICLE*

# NUMERICAL STUDY OF THE INFLUENCE OF THE RAYLEIGH NUMBER ON THE NATURAL CONVECTION OF THE CONFINED AIR BETWEEN TWO SQUARE CAVITIES

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## *Abstract*

In this article, we study the influence of the Rayleigh number on the natural convection of air between two square cavities. The internal cavity is subjected to a constant flow of heat while the external cavity is kept at a constant temperature. This temperature difference leads to a decrease in the density that represents the motor of the movement. Especially since the information on pressure is not sufficient, we have used the formalism vorticity current function to eliminate the pressure term in the equation of movement. Adimensionnals equations transfers were solved using the finite volume. In order to examine the heat transfer between the cavity and the fluid, we have used Rayleigh values ranging from $10^3 \leq Ra \leq 10^6$ and Prandtl Pr = 0.7. The results obtained have shown from Rayleigh number Ra = $10^3$, the isotherms line are quasicircular and bicellular current lines of high intensity on both sides of the median axis. When we increase the Rayleigh number from Ra = $10^4$ through Ra =$10^5$ to Ra = $10^6$, we have noticed that the isotherms tend to decrease and split. This results in the formation of small oscillations in the middle of the internal cavity. For the current lines, we have noticed the formation of secondary cells in the upper cavity and low movement in the horizontal cavity.

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## Introduction:-

In recent years, natural convection has been the subject of investigation of many studies on the experimental and digital level in applications such as geophysics, astrophysics, technology. Many studies are done with a single cavity sometimes square, rectangular, cylindrical or even spherical. Research results regarding the natural convection of a fluid confined between two square cavities have not been overdeveloped in the literature. This lack of research information based in this area proves our interest in this configuration. Among the studies found in the literature, we have seen natural convection with a single square cavity [1] serving as a reference. We improved our search for pure natural convection of a fluid by exploiting comparable studies carried out theoretically [2], [3], [4],[5]. To have more similarities and tend towards reality with the use of two cavities, we have exploited similar studies [6]. Basing on all these considerations, we have opted to apply a constant heat flow to the lower cavity and maintained a constant temperature to the upper cavity. This temperature difference creates a decrease in density that represents the motor of the movement.

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## Materials And Method Numericals:-

The geometry of our problem consists of two square cavities between which air is confined. The external cavity of dimension He is maintained at a constant cold temperature (T = cte) and the internal cavity is heated with a heat flow of constant density (q = cte). (**Figure 1)**

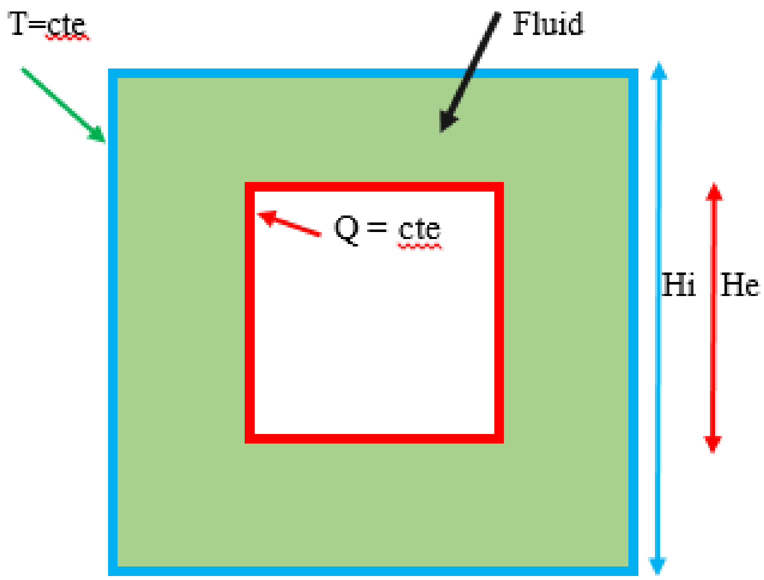


**Figure 1**:- Geometry of the problem.

Using the vorticity-current function formalism,the equations that govern our study are adimensionalized by introducing reference quantities.In our problem, the flow is incompressible laminar and satisfies the Boussinesq approximation [7].

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

$$\frac{\partial T}{\partial t}+\frac{\partial}{\partial x}(uT-\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(vT-\frac{\partial T}{\partial y})=0 \quad (2)$$

$$\omega=-(\frac{\partial^2 \psi}{\partial x^2}+\frac{\partial^2 \psi}{\partial y^2}) \quad (3)$$

$$u=\frac{\partial \psi}{\partial y} \quad \text{et} \quad v=-\frac{\partial \psi}{\partial x} \quad (4)$$

Prandtl number $\Pr=\frac{\nu}{\alpha}$

Rayleigh number $Ra=\frac{g\beta \Delta T D^3}{\upsilon \alpha}$

**Conditions to the limits** :

- $t=0$

$u=v=\psi=\omega=0$ ;T = 0 (5)

- $t \succ 0$
  - the walls of the exterior cavity

On the outer vertical wall:

$$U = 0 \;; V = 0 \;; \frac{\partial \psi}{\partial y} = 0 \;; \omega = -\frac{\partial^2 \psi}{\partial y^2} \;; T = 0 \text{ ou } 1 \qquad (6)$$

On the outer horizontal wall:

$$U = 0 \;; V = 0; \frac{\partial \psi}{\partial x} = 0 \;; \omega = -\frac{\partial^2 \psi}{\partial x^2} \;; \text{et } T = 0 \text{ ou } 1 \qquad (7)$$

- the walls of the interior cavity

On the inner horizontal wall:

$$U = 0 \;; V = 0 \;; \frac{\partial \psi}{\partial x} = 0 \;; \omega = -\frac{\partial^2 \psi}{\partial x^2} \;; \frac{\partial T}{\partial y} = \pm 1 \qquad (8)$$

On the inner vertical wall:

$$U = 0 \;; V = 0 \;; \frac{\partial \psi}{\partial y} = 0 \;; \omega = -\frac{\partial^2 \psi}{\partial y^2} \;; \frac{\partial T}{\partial x} = \pm 1 \qquad (9)$$

The Nusselt Number provides a comparison between the flux transmitted by thermal convection and that transmitted by conduction. It is given in its dimensionless form for the interior cavity by the following expression:

$$Nu_{interne} = \frac{1}{T_p} \qquad (10)$$

In our study, we have used the numerical method of finite volumes used by Ansys Fluent [8], [9], [10] because the analytical resolution of the equations of movement, heat and current function seem almost inaccessible. As a resolution scheme is highly recommended for resolution, we have chosen the one that is easy to implement and allow to obtain a good approximation which is the power law scheme. The algorithm have used in finite volume for solving the Navier-Stokes equations that offers us more guarantees on convergence is the SIMPLE Algorithm developed by Patankar [11]. It is on this basis that we have similar results (Figure 2)

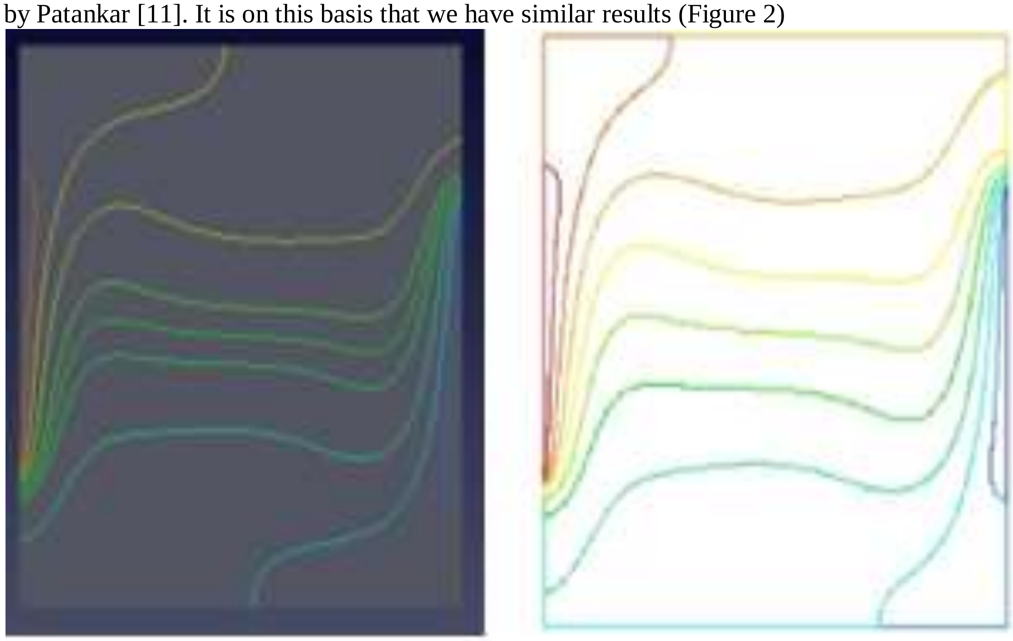

**Figure 2**:- Comparison of the isotherms of our work on the right with that of Kane M.K [1] on the left for Ra = $10^5$

In this study, we have made a simulation by making a comparison of the isothermal lines with other studies [1] for a single cavity of Rayleigh number Ra = $10^5$. Figure 2. We have found that the results were almost similar. This allowed us to validate this work.

## Results and Discussions:-

The heat transfer equations of natural convection confined between two square cavities are examined with different values of the Rayleigh number which take values between $10^3$ and $10^6$ and the Prandtl number Pr = 0.7 in air occurrence.

**Effect of Rayleigh numbers on isothermal lines**

For the distribution of the temperature field, we have seen for a Rayleigh number Ra = $10^3$, we have noted that the conductive effect dominates the convective effect. This is manifested by isothermal lines have almost circular profiles around the internal cavity. They are highly concentrated at the level of the lower cavity.

For Ra = $10^4$, when convection sets in, we have noted a fungus formation above the inner cavity and that increases with the increase in Ra. We can see the symmetry of these heat lines.

For numbers of Ra = $10^6$, there is a rather stable flow, a greater natural convection with a high temperature materialized by slight oscillations on the upper wall. This can be explained by the fact that the buoyancy force is greater at this level.

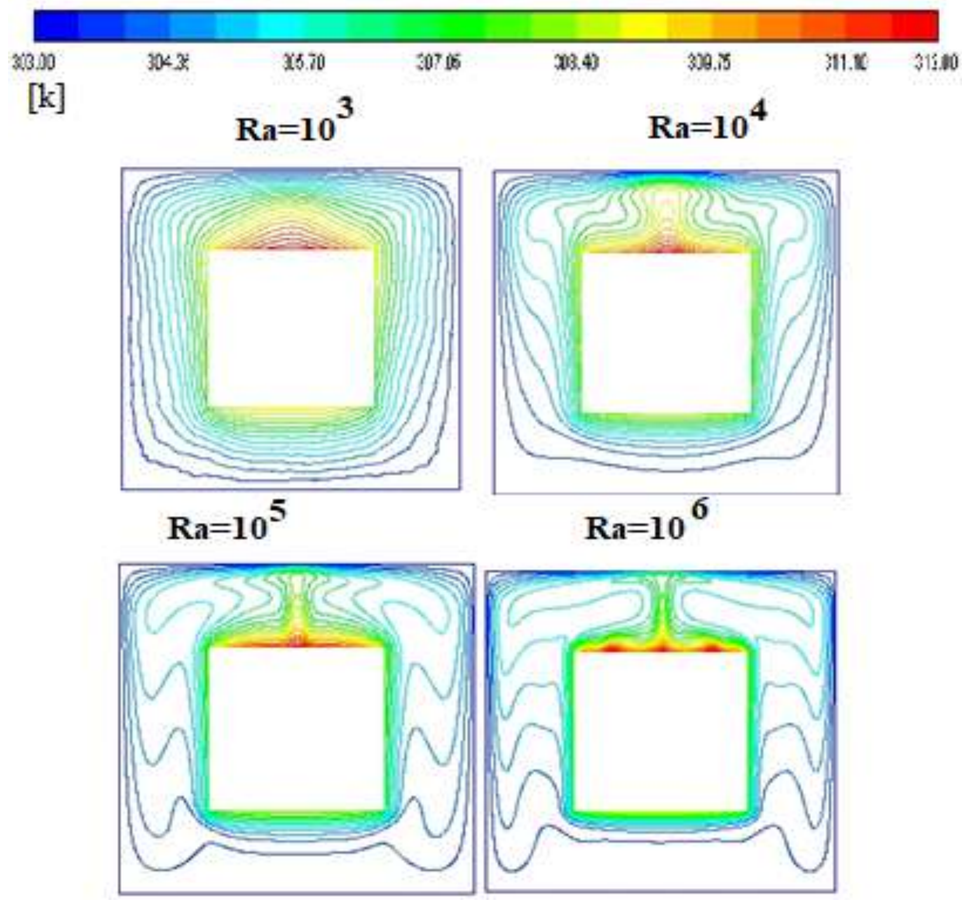


**Figure 3:-** Evolution of isotherms for different Raleigh numbers.

**Effect of Rayleigh number on streamlines**

Concerning the streamlines, we note for a value of number of Ra = $10^3$ where the conduction prevails over the convection, the formation of two cells that circulate in the opposite direction with an area of low intensity on the lower horizontal cavity.

When convection begins to settle for values of the number of Ra = $10^4$ and Ra = $10^5$, there is a rapprochement of the cells towards the middle of the vertical cavity and a gradual increase in volume of the cells.

As soon as the convection grows to a value of number of Ra = $10^6$, there is a change in the shape of the cells that gain in intensity with the formation of new small cells on the upper internal cavity and the birth of a small cell at the bottom. This is due to the fact of a decrease in the density of heated particles. The latter will rise again because of the buoyancy force.

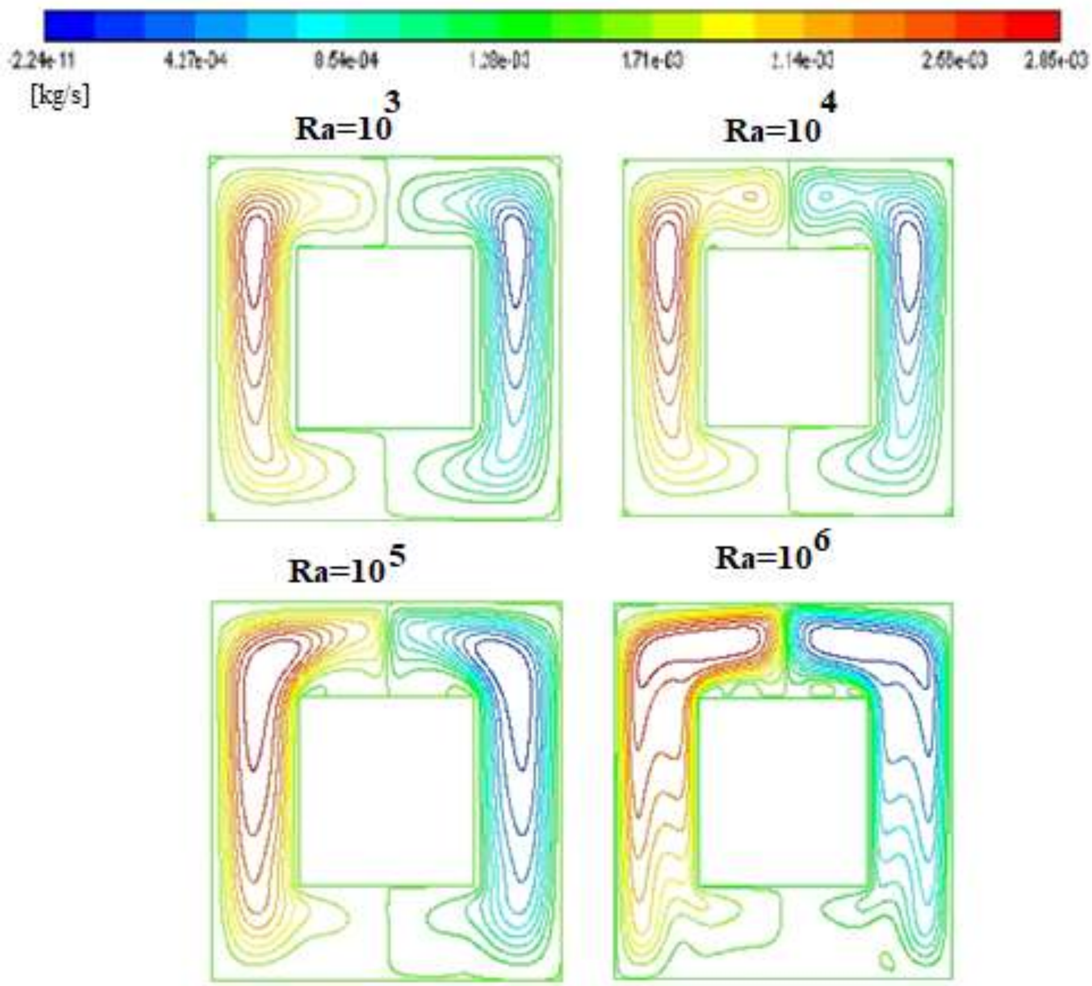


**Figure 4:-**Evolution of streamlines for different Rayleigh values.

**Effect of the Rayleigh number on the evolution of the Nusselt number at the level of the internal cavity**

The Nusselt number characterizes the heat exchanges between the wall and the fluid. For a Rayleigh value of number Ra = $10^3$, heat transfer is essentially by conduction. For values of $Ra \succ 10^3$, the heat exchange will be dominated by natural convection. The temperature of the fluid tends to approach the temperature of the hot wall. When the middle of the cavity is exceeded, the temperature of the fluid moves away as the temperature of the hot wall progresses and tends towards the temperature of the cold cavity. For Ra = $10^6$, the succession of high and low temperatures on the upper internal cavity caused by a high intensity that the cells gain, leads to oscillations of the Nusselt number at this level.

Note that at the level of the inner lower cavity for Ra = $10^6$, the temperature increases when we get closer to the medium, leading thus to a decrease in the Nusselt number.

Beyond the middle of the cavity, the temperature of the fluid decreases in relation to the temperature of the hot cavity which leads to an increase in the number of Nusselt.

In the vicinity of the middle of the cavity the Nusselt number varies more and more weakly for values of Ra = $10^5$, Ra = $10^4$, Ra = $10^3$. Beyond the middle of the cavity, the temperature of the fluid moves away from the temperature of the hot cavity.

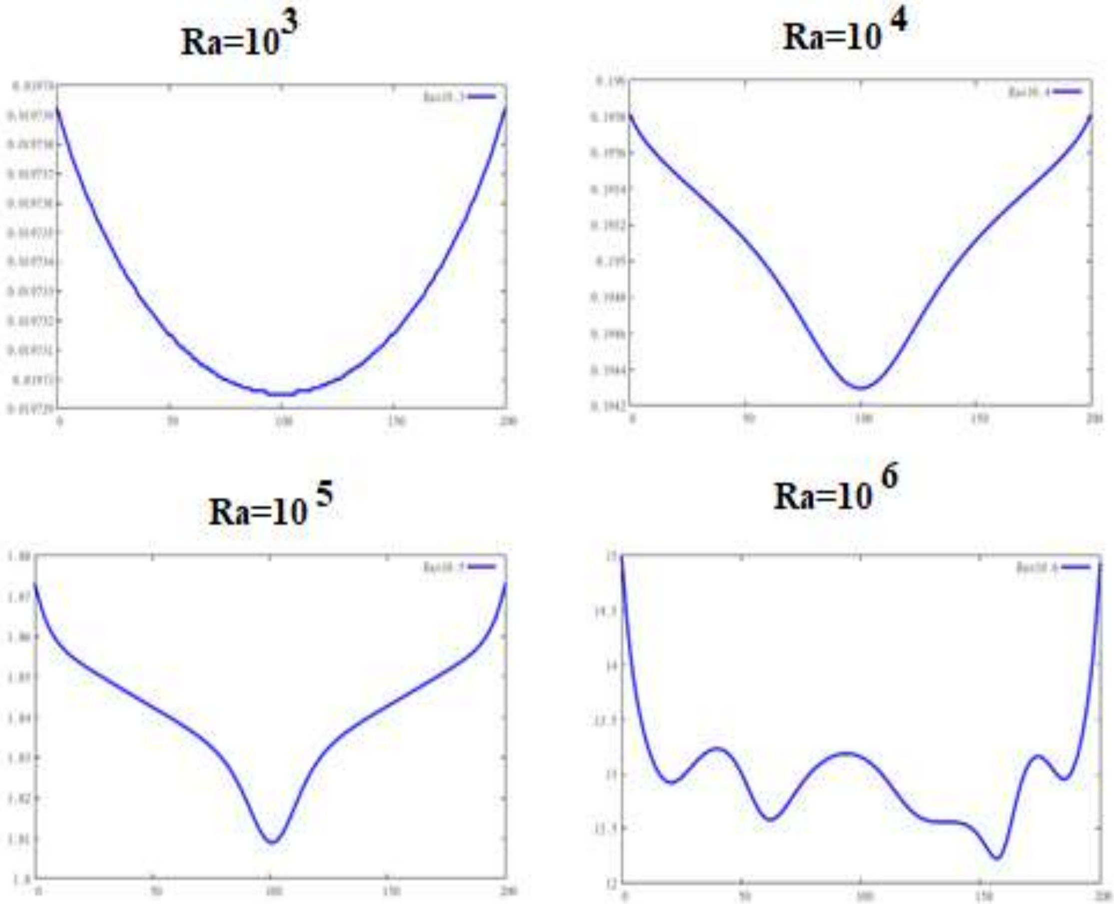


**Figure 5:-** Nusselt number variation for different Rayleigh numbers.

## Conclusion:-

In this study, we simulated an airflow for different Rayleigh numbers of the natural convection of air confined between two square cavities. After having written the dimensionless transfer equations, we used the finite volume method for the numerical resolution of nonlinear equations. This resolution was obtained thanks to the ANSYS FLUENT calculation code. The results obtained during these simulations showed that when the Rayleigh number increases up to Ra = $10^6$, a slight oscillation of the isotherms. During the streamlines, there is a deformation of the cells and the appearance of new small cells.


## Acknowledgements:-

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**Nomenclature**

**Latin letters**

D : Reference length D = He – Hi [m]
g : Acceleration of gravity [$m.s^{-2}$]
He : Side of the external cavity [m]
Hi : Side of the internal cavity [m]
q : Heat flow density [$W.m^{-2}$]
t : Dimensionless time
T : Dimensionless temperature
To : dimensionless initial temperature
$\vec{U}$ : Velocity
x, y : Dimensional Cartesian coordinates

**Dimensionless numbers**

Nu : Nusselt number
Pr : Prandlt number,
Ra : Rayleigh number

**Greek letters**

$\alpha$ : Thermal diffusivity [$m^2.s^{-1}$]
$\beta$ : Coefficient of thermal expansion [$K^{-1}$]
$\lambda$ : Thermal conductivity [$W.m^{-1}.K^{-1}$]
$\upsilon$ : Kinematic viscosity [$m^2.s^{-1}$]
$\rho'$ : Density [$kg.m^{-3}$]
$\sigma$ : Electrical conductivity [ $\Omega^{-1}.m^{-1}$]
$\psi$ : Dimensionless current function
$\omega$ : Dimensionless vorticity
$\mu$ : Dynamic viscosity [$kg.m^{-1}.s^{-1}$]