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MHD Mixed Convection in a Lid-Driven Octagonal Cavity with Circular Rotating Heater

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Abstract:- *A numerical analysis of MHD mixed convection in a lid-driven octagonal cavity with a circular rotating heater has been carried out in the present study. In this cavity, there has a circular heater in the middle of the cavity which is rotating with a dimensional velocity 5 m/s and its temperature is T_h. There has no adiabatic wall and the four walls which are parallel to the x-axis and y-axis respectively are taken high temperature T_h and remaining walls are kept as cold temperature T_c. Moreover, the left side three walls and right side three walls are sliding with velocity 5 m/s and -5 m/s respectively. Two-dimensional Navier-Stokes equation and energy equation have been solved by using the Galerkin weighted residual scheme of finite element method. The focus of the work is investigated the effects of Hartmann number, Grashof number and Reynolds number on the fluid flow and heat transfer characteristics inside the enclosure. A set of graphical results is presented in terms of streamlines, isotherms, velocity profiles, temperature profiles, average Nusselt number, and local Nusselt number. The results reveal that the heat transfer rate increases with increasing Reynolds number and Hartmann number. The method used is validated against previous works. It is also observed that the Hartmann number is a good control parameter for heat transfer in fluid flow in the octagonal cavity.*

Keywords: Lid-driven, MHD, Mixed convection, Octagonal cavity, Rotating circle, Finite element method.

1. INTRODUCTION

Rotating magnetic-hydrodynamics systems attract a great interest because of their wide distribution in nature. So, several researchers feel interest to use rotating cavity with mixed convection in many type of geometrical model for flow and heat transfer. Moreover, mixed convection which combined forced and free convection flow as well as heat transfer in cavities has been investigated widely due to its potential applications in engineering fields, such as, ventilation of rooms, heat exchanger, cooling of electronic devices, lubrication technologies, nuclear reactor technologies, drying technologies, food processing, float glass production, solar collectors and solar ponds etc. In every field of our commercial life, there has many practical use of MHD mixed convection some of them have been reported in the present literature.

Ali et al. [1] studied numerically the magneto-hydrodynamics mixed convection flow in a hexagonal enclosure. . Later on, they [2, 3] analyzed the flow and heat transfer for magneto-hydrodynamic free convection flow in a differentially heated enclosure having a square block. Imran et al. [4] studied numerically magneto-hydrodynamic mixed convection in a partially heated rectangular enclosure with elliptic block. Rahman et al. [5] performed a numerical study on the conjugate effect of joule heating and magneto-hydrodynamics mixed convention in an obstructed lid-driven square cavity. Muneer et al. [6] conducted a numerical investigation on mixed convection flow in a square cavity with moving walls having partial slip to analyze the flow and heat transfer performances. Sivasankaran et al. [7] reported a numerical study on mixed convection flow in a lid driven square enclosure. Moreover, Victor and Stanislav [8] investigate about vibrational suspension of light sphere in a tilted rotating cylinder with liquid. In addition, Hakan et al. [9] performed a numerical study in MHD mixed convection in a lid-driven cavity with corner heater. Sarkar et al. [10] investigated the problem of MHD mixed convection in a lid-driven cavity with complicated boundary surfaces and found that higher Rayleigh numbers a relatively stronger magnetic field was needed to decrease the heat transfer through mixed convection.

The main objective of this work is to present the effects of the magnetic field on mixed convection problem for a lid-driven octagonal cavity on the flow and heat characteristics. It should be mentioned that the previous studies of mixed convection flows in the presence of a magnetic field in lid-driver enclosures have different types of heaters, whereas the present study considers including rotating hot circle with magnetic field.

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2. PHYSICAL CONFIGURATION

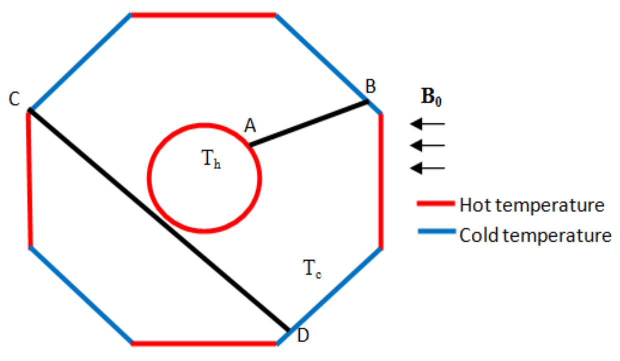


Figure-1. Schematic configuration of the physical model

Considered two dimensional models are illustrated in Fig. 1 with boundary conditions. It is an octagonal enclosure with circular rotating heater in the middle of the figure. As seen from the schematically view, four walls parallel to x and y axis respectively are kept in hot temperature $T_h$which symbolized by red color lines and the other walls are in cold temperature $T_c$which indicated by blue color lines. The circular block which is reserved heated T_h, maintaining $T_h>T_c$. Moreover, left vertical and inclined walls and circular heater are sliding with dimensional velocity 5m/s and right walls with right vertical and inclined walls are sliding with dimensional velocity -5m/s. The uniform magnetic field B_0 is also applied to the fluid in the direction parallel to x-axis. Here, also have two lines which indicated by AB and CD are kept for further uses on line graphs.

3. GOVERNING EQUATIONS ALONG WITH BOUNDARY CONDITIONS

The governing equations for the present model can be written non-dimensional form as follows:

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0 \quad (1)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\Pr\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \quad (2)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\Pr\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{Gr}{\mathrm{Re}^2}\Pr\theta-Ha^2\Pr V \quad (3)$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \quad (4)$$

The following dimensionless variables have been introduced to obtain the above governing equations in non-dimensional form:

$$X=\frac{x}{L},\ Y=\frac{y}{L},\ U=\frac{u}{U_{lid}},\ V=\frac{v}{U_{lid}},\ P=\frac{p}{\rho U_{lid}^2},\ \theta=\frac{T-T_c}{T_h-T_c}\ U_{lid}=\frac{\alpha}{L} \quad (5)$$

Here *Pr* is Prandtl number, *Gr* is the Grashof number, *Re* is the Reynolds number and *Ha* is the Hartmann number, which are defined as

$$\Pr=\frac{\nu}{\alpha},\ Gr=\frac{g\beta(T_h-T_c)L^3}{\nu^2},\ \mathrm{Re}=\frac{U_{lid}L}{\nu},\ Ha=B_0\sqrt{\frac{\sigma L}{\mu}}$$

The corresponding boundary conditions are as follows:

On the angular walls: $U=1, V=0, \theta=0$

On the circular rotating heater: $U=V=1, \theta=1.$

On the top, bottom, left and right walls: $U=0, V=0, \theta=1$

From technical point of view, it is important to calculate local Nusselt number and average Nusselt number to estimate the heat transfer rate. These are defined as follows:

$$Nu_{local}=-\left.\frac{\partial\theta}{\partial Y}\right|_{Y=0}\quad Nu_{av}=\int_0^1\left(-\left.\frac{\partial\theta}{\partial Y}\right|_{Y=0}\right)dX$$

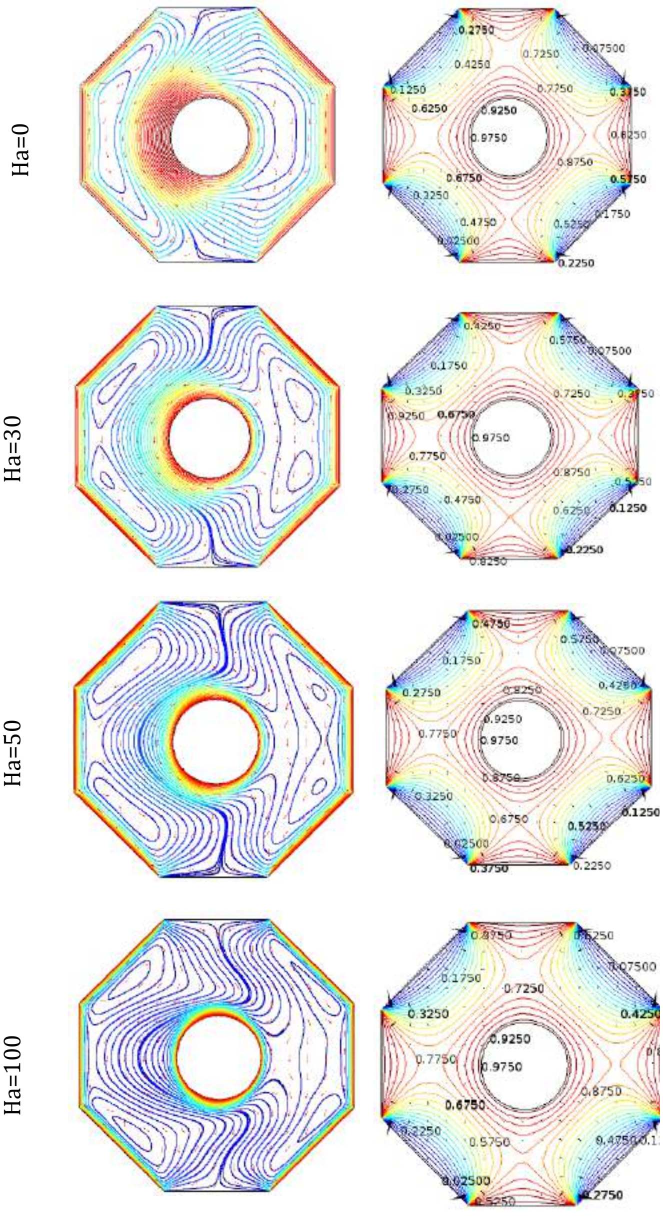
4. RESULTS AND DISCUSSION

In this section, some demonstrative results are presented to illustrate the effects of various controlling parameters on the fluid flow. These controlling parameters include Reynolds number which ranging from 50 to 500 and the Hartmann number varying from 0 to 100 with fixed Grashof number Gr = 10^5 and Prandtl number Pr = 0.71. The results are presented in terms of streamlines, isotherms, local Nusselt number, average Nusselt number, velocity profiles and dimensionless temperature profile along the cavity.

Effects of Hartmann Number

In this section, results have been obtained for the Hartmann number which ranging from 0 to 100 with fixed Grashof number *Gr* = 10^5, Reynolds number *Re* = 10^3 and Prandtl number *Pr* = 0.71. The results are presented in terms of streamlines and temperatures are shown in Fig. 2(a) and 2(b). Now (on the left column) when *Ha*=0that's mean absence of the magnetic field, it is observed that the sliding lids are very strong and the circulation of streamlines are covered the rotating circle which moves with velocity. Moreover, among the right side wall and circle there has a cavity which turns into two oval shapes when Ha becomes 30. There have two oval cavities in the left side wall also. When *Ha,* increase 50 the right side ovals are become bigger and the left side ovals are become smaller. Moreover, as *Ha*=100, the circulation is totally different than before where it gather in the middle of the excavation and also in the middle of the right wall and circle.

It is pragmatic from the temperature in Fig. 2(b). Heat circulation lines are becoming more compact from high temperature to low temperature as well. The changes for increasing *Ha* number is not much more noticeable. However, the lines comes nearer in the lower wall for high temperature and they gather gradually with the increasing *Ha* number until *Ha*=50 than settled again. The presence of magnetic field, here temperature affects quite low without showing the changing places of point.

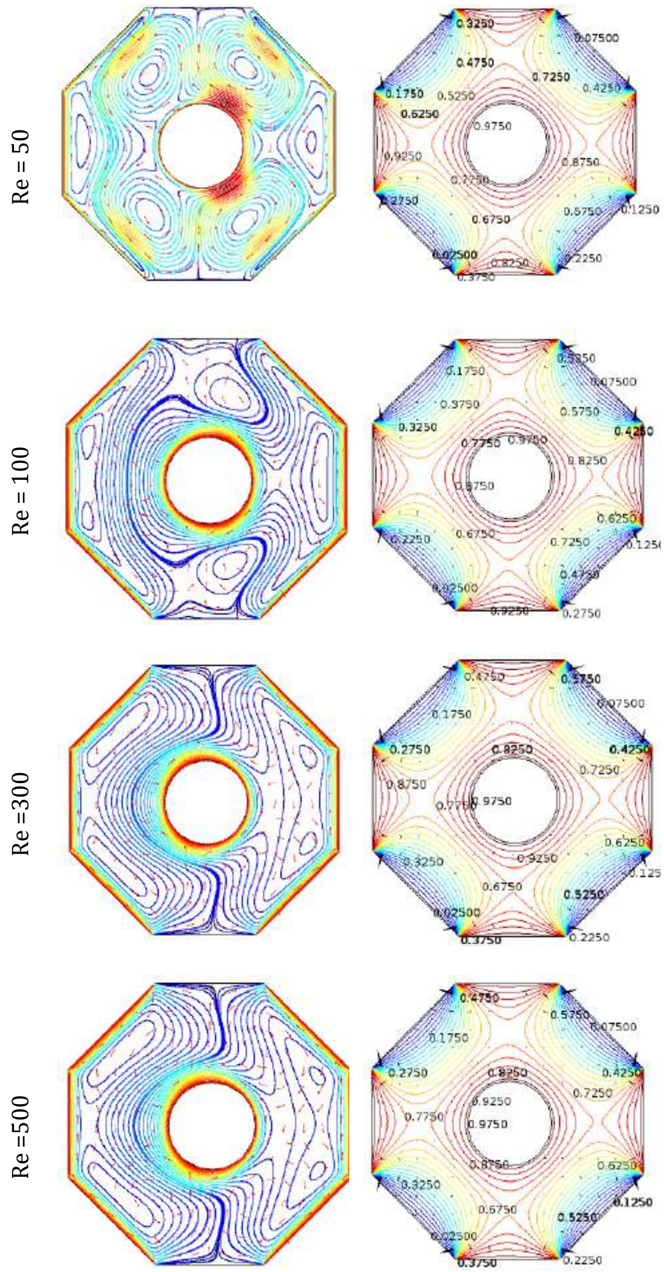


(a) Streamlines (b) Temperature

Figure-2. Streamlines and temperatures are for different values of Hartmann numbers *Ha* = 0, 30, 50, 100, 150 when *Re* = 1000, *Gr* = 10^5, and *Pr* = 0.71.

Effects of Reynolds Number

The results are presented in terms of streamlines and temperatures obtained numerical results are discussed in this section. Streamlines for different values of Reynolds number *Re*= 50-500 while *Ha* = 50, *Gr* =$10^5$and *Pr*= 0.71 are presented in Fig. 3(a). To understand the effect of Reynolds number on flow field and temperature distribution at *Re* = 50 and in the exchange of magnetic field (*Ha* = 50) four circulation cells are formed around the circular heater in octagonal cavity shown in Fig. 3(a). As *Re* increases to 100 the effect of mixed convection increase and the four circular cavities are vanished and the one circulation is observed around the heater. Again *Re*=300, its circulation is totally different. However, for *Re*=500 the circulation are similar at previous one. In Fig 3(b) since we use magnetic field, the temperature effect are not so noticeable.



(a) Streamlines (b)Temperature

Figure-3. Streamlines and temperature for different values of Reynolds numbers *Re* = 50- 1500 when *Ha = 50*, *Gr* = 10^5 and *Pr* = 0.71.

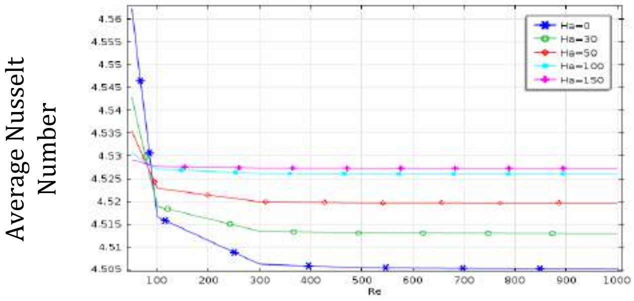


Figure-4. Variation of average Nusselt number versus Reynold's number for different Hartmann number Ha = 0, 30, 50, 100 When Gr =10^5 and Pr = 0.71.

The influence of Reynold's number on average Nusselt number versus different Hartmann numbers for vertical wall is displayed in Figure 4 at Gr = 10^5 and Pr = 0.71. It is clearly observed that adding Reynold's number inside the octagonal enclosure cause are suction in the average Nusselt number. Also rate of increment on heat transfer clearly depends on the value of Reynold's number.

5.CONCLUSION

Numerical study on mixed convection in a lid-driven octagonal cavity with a circular rotating heater has been performed. Results have been presented in terms of streamlines, isotherms, local Nusselt number, average Nusselt number, velocity profile and dimensionless temperature. The results are obtained for a wide range of pertinent dimensionless parameters such as Reynold's number and Hartmann numbers. In view of the obtained results, the following findings are précised:

1) The flow characteristics and heat transfer mechanism inside the octagonal cavity are strongly dependent on the Hartmann number.

2) The significant suppression of the convective current in the enclosure is due to increase of Hartmann numbers.

3) The large values of Reynold's number lead to increase in the lid-driven effect whereas the small values of Reynold's number lead to increase the effect of the presence of the heat source on the flow and heat characteristics.

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