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# Effects of Magnetic Field on Natural Convection of Non-Newtonian Fluid in a Square Enclosure with a Central Heat Source

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**ABSTRACT:** In this study, the incompressible laminar flow of non-Newtonian fluid is studied in a cavity with a central heat source under a uniform inclined magnetic field. The governing equations are converted into nonlinear ordinary differential equations using similarity transformations and solved using finite difference based numerical methods. In the current study, the effect of non-Newtonian power-law fluid is investigated for power-law indices of 0.75, 1 and 1.4. The results are compared with the ones in which the magnetic field is not applied. It is found that the implementation of a magnetic field for different fluid indices in different Rayleigh numbers does not show similar behaviors and the results show that the magnetic field affects the convection flow, leading to a reduction in it. Also can be said that with the implementation of a magnetic field in the range of indices $n \geq 1$ for power-law model fluid, increased Rayleigh number leads to reduced average Nusselt number and for $n < 1$, the average Nusselt increases. For $n < 1$, with increased Rayleigh number in the presence of a fixed magnetic field, free convection can be weakened while this trend for $n < 1$ occurs with reduced Rayleigh number.

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## 1. INTRODUCTION

One of the natural convection heat transfer control methods is the use of a magnetic field effect on the flow. Analysis of fluid flow exposed to the magnetic field is known as magnetohydrodynamics. Natural convection heat transfer and magnetohydrodynamics that focus on the interaction effects of the fluid and magnetic field, have different uses in industry and attracted the attention of many researchers. These uses include cooling the electronic components, nuclear reactors, solar collectors, health industries, food industries, etc. Sheikholeslami et al. [1] in their study used a new numerical method to simulate the effects of magnetic force and radiation on nanofluid heat transfer through a permeable middle environment. In this study, they considered different amounts of radiation, magnetic force, and buoyancy force and showed their effects on water-alumina nanofluid heat transfer. Their results showed that the Brownian movement influences thermal conductivity and fluid viscosity. Also, by strengthening magnetic forces, heat transfer reduces and through radiation, Nusselt number can be increased. Atashafrooz et al. [2] investigated the interaction effect of nanofluid and magnetic field under a specific angle on forced convection heat transfer in a channel with sudden contraction in the flow path. Their results showed that the Hartmann number and magnetic field angle significantly increase the irreversibility in the flow while they have an inverse effect on the heat transfer rate. Also, total entropy and average Nusselt number increase with the volume fraction of nanoparticles. Sajadi et al. [3] simulated the three-dimensional natural convection heat transfer of magnetohydrodynamics within a square enclosure with sinusoidal heat distribution on one side of the wall using Multiple-Relaxation-Time Lattice Boltzmann Method (MRT-LBM). One of the results of this study was that the MRT-LBM method is a suitable method to simulate three-dimensional flows with complex boundary conditions. Also, their results showed that an increase in the Hartmann number leads to a reduction in heat transfer while an increase in the Rayleigh number and volume percentage of nanoparticles results in an increase in heat transfer. In another study, Sajadi et al. [4] simulated the natural convection of magnetohydrodynamics within a square cavity using the double MRT-LBM method. They pointed out that the effect of Hartmann number variations on heat transfer increases with the Grashof number so that by increasing the Hartmann number from 0 to 100, the average Nusselt number increases by 12% and 71% for Grashof numbers of $2\times10^3$ and $2\times10^5$ respectively.

## 2. METHODOLOGY

In this study, natural convection of laminar steady non-Newtonian power-law fluid in an enclosure with middle heat source has been simulated numerically using ANSYS FLUENT software. The magnetic field with the intensity of $B_0$ under the angle of 45 relative to the horizon is applied to the enclosure. The upper wall of the enclosure is insulated

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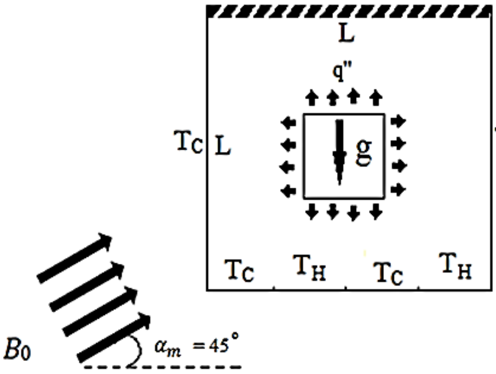


**Fig. 1. Schematic of the enclosure studied**

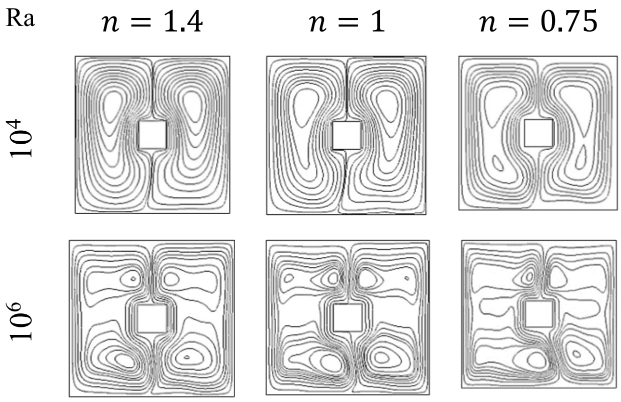


**Fig. 2. Flow lines in Rayleigh numbers and various indexes (n)**

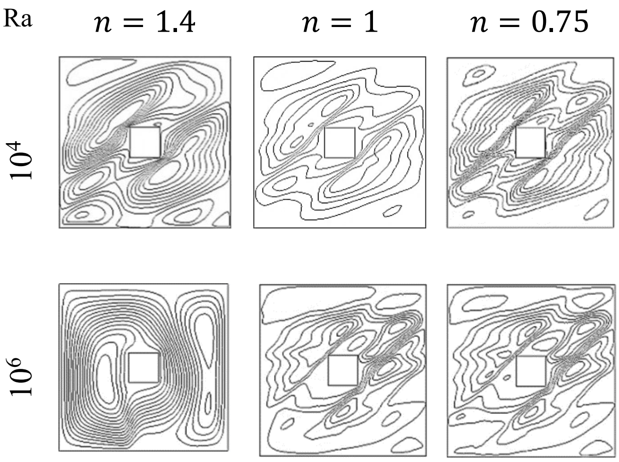


**Fig. 3. Flow lines in Rayleigh numbers and various indexes (n) with magnetic field**

and vertical walls are under a constant temperature of $T_C$. The lower wall of the enclosure is divided into four equal sections with $T_H$ and $T_C$ temperatures as illustrated in Fig. 1.

The convergence criterion for the continuity and momentum equations is less than $10^{-5}$ and the energy equation is less than $10^{-6}$. The power-low index ($n$) for pseudo-plastic fluid is 0.7 and for dilatant one is 1.4.

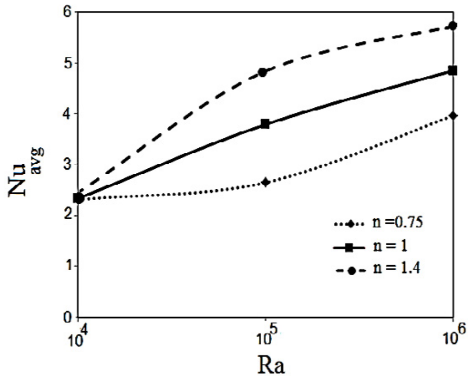


**Fig. 4. Variations of average Nusselt in the Rayleigh numbers for different power indexes**

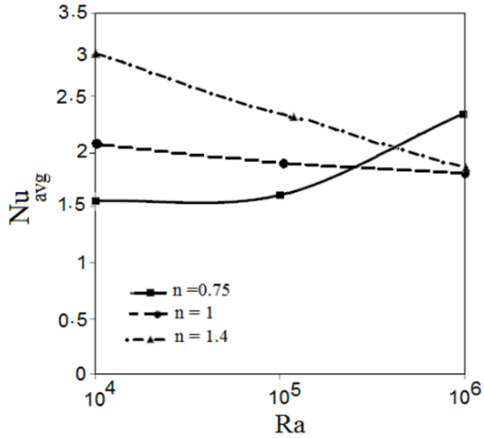


**Fig. 5. Variations of average Nusselt in the Rayleigh numbers for different power indexes in the presence of magnetic field**

## 3. RESULTS AND DISCUSSION

The purpose of the study is to investigate the effect of magnetic field application on the flow behavior of the power-law model with various indices in the natural convection heat transfer process. Further, the effect of the Rayleigh number and also the power-law index is investigated on the behavior of the fluid inside the square enclosure.

Due to the streamlines in Fig. 2, it appears that in all states two separate regions of vortices are created on the right and left sides of the enclosure

With respect to Fig. 3, it can be seen that the application of the magnetic field due to the Lorentz force has a significant effect on the flow and temperature fields. So, with the application of the field, the axis of the central vortices is tilted, and with increasing Rayleigh number, and also increasing the index $n$, the fluid rotation and vortex orientation are affected.

It can be seen from Figs. 4 and 5 that without a magnetic field for Rayleigh number of $10^4$, the natural convection is weak and the conduction heat transfer is dominant. In this case, for all indices, the average Nusselt number has approximately the same value, which increases with the Rayleigh number.

## 4. CONCLUSIONS

According to the numerical results, it can be stated that for all power-law indices, at low Rayleigh numbers, the rotation of streamlines relative to the *Y* axis at the center of the enclosure shows higher symmetry and by increasing the Rayleigh number, this symmetry reduces. Also, by applying the magnetic field, convection in the enclosure reduces. This issue is observed in streamlines by the removal of symmetrical vortices around the middle heat source and the creation of weak vortices in the middle part of the square enclosure.

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