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# Viscous dissipation and radiation effects on MHD natural convection in a square enclosure filled with a porous medium

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## HIGHLIGHTS

- *Ha* decelerates the flow field.
- *Ha* enhances conduction.
- Magnetic field orientation is important.
- Radiation parameter important.
- Nu decreases as *Ha* increases.

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## ABSTRACT

Numerical two-dimensional analysis using finite difference approach with "line method" is performed on the laminar magneto-hydrodynamic natural convection in a square enclosure filled with a porous medium to investigate the effects of viscous dissipation and radiation. The enclosure heated from left vertical sidewall and cooled from an opposing right vertical sidewall. The top and bottom walls of the enclosure are considered adiabatic. The flow in the square enclosure is subjected to a uniform magnetic field at various orientation angles ($\varphi = 0^{\circ}$, $30^{\circ}$, $45^{\circ}$, $60^{\circ}$ and $90^{\circ}$). Numerical computations occur at wide ranges of Rayleigh number, viscous dissipation parameter, magnetic field orientation angles, Hartmann number and radiation parameter. Numerical results are presented with the aid of tables and graphical illustrations. The results of the present work explain that the local and average Nusselt numbers at the hot and cold sidewalls increase with increasing the radiation parameter. From the other side, the role of viscous dissipation parameter is to reduce the local and average Nusselt numbers at the hot left wall, while it improves them at the cold right wall. The results are compared with another published results and it found to be in a good agreement.


## 1. Introduction

Magneto-hydrodynamic (MHD) was originally applied to astrophysical and geophysical problems. In recent years, this subject take more attention because of its various applications in agricultural engineering and petroleum industries. Astrophysical problems include solar structure, the solar wind bathing the earth and other planets, and interstellar magnetic fields. The primary geophysical problem is planetary magnetism, produced by currents deep in the planet. Recently, considerable attention has also been focused on new applications of magneto-hydrodynamics (MHD) and heat transfer such as metallurgical processing. Also, considerable efforts have been directed towards the study of magneto-hydrodynamic (MHD) flow and heat transfer in porous and non-porous media due to the effect of magnetic fields on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. In addition, this type

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**Nomenclature**

| Symbol | description Unit |
|---|---|
| $B$ | magnetic field (T) |
| $g$ | gravitational acceleration (m/s$^2$) |
| $Ha$ | Hartmann number |
| $C_p$ | Specific heat at constant pressure (J/kg K) |
| $K$ | permeability of porous media (m$^2$) |
| $k$ | Thermal conductivity (W/m K) |
| $L$ | width and height of the square enclosure $m$ |
| $Nu$ | local Nusselt number |
| $\overline{Nu}$ | average Nusselt number |
| $R$ | radiation parameter |
| $Ra$ | Rayleigh number |
| $T$ | temperature (K) |
| $U$ | non-dimensional velocity component in $X$-direction |
| $u$ | dimensional velocity component in $x$-direction (m/s) |
| $V$ | non-dimensional velocity component in $Y$-direction |
| $v$ | dimensional velocity component in $y$-direction (m/s) |
| $X$ | non-dimensional coordinate in horizontal direction |
| $x$ | Cartesian coordinate in horizontal direction (m) |
| $Y$ | non-dimensional coordinate in vertical direction |
| y | Cartesian coordinate in vertical direction (m). |

*Greek Symbols*

| | |
|---|---|
| $\alpha$ | thermal diffusivity (m$^2$/s) |
| $\beta$ | coefficient of thermal expansion (K$^{-1}$) |
| $\beta_R$ | extinction coefficient (m$^{-1}$) |
| $\theta$ | dimensionless temperature |
| $\varepsilon$ | viscous dissipation parameter |
| $\varphi$ | magnetic field orientation angle degree |
| $\Psi^*$ | stream function (m$^2$/s) |
| $\Psi$ | dimensionless stream function |
| $\sigma$ | Stephan–Boltzmann constant (W/m$^2$ K$^4$) |
| $\mu$ | dynamic viscosity (kg/m s) |
| $\nu$ | kinamatic viscosity (m$^2$/s) |
| $\rho$ | density (kg/m$^3$) |

*Subscripts*

| | |
|---|---|
| c | cold |
| h | hot |
| l | left |
| r | right |

*Abbreviations*

| | |
|---|---|
| MHD | magneto-hydrodynamics |

of flow finds applications in many engineering problems such as MHD generators, plasma propulsion in astronautics, nuclear reactors, and geothermal energy extractions. From the other hand, the viscous dissipation heat in the natural convective flow is important, when the flow field is of extreme size or at low temperature or in high gravitational field. Such effects are also significant in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number. Furthermore, the role of thermal radiation is of major importance in the design of many advanced energy convection systems operating at high temperature. Thermal radiation within the systems is usually the result of emission by hot walls and the working fluid. All of these important subjects have received much attention by many researchers. The problem of natural convection in a porous and non-porous mediums with viscous dissipation, radiation and MHD effects had been studied by Gebhart and Mollendorf (1969), Alam et al. (2006, 2007) and Ashish Gad and Balaji (2010). Also, Gebhart (1962) explained that the viscous dissipation effect played an important role in natural convection in various devices which were subjected to large deceleration or which operated at high rotative speeds. Mahajan and Gebhart (1989) reported the influence of viscous heating dissipation in natural convective flows, showing that the heat transfer rates were reduced by an increase in the dissipation parameter. Hossain (1992) studied the effect of viscous and Joule heating on the free convection flow of an electrically conducting and viscous incompressible fluid past a semi-infinite plate of which temperature varied linearly with the distance from the leading edge and in the presence of uniform transverse magnetic field. Chowdhury and Islam (2000) investigated MHD free convection flow of visco-elastic fluid past an infinite porous plate. Israel-Cookey et al. (2003) investigated the influence of viscous dissipation and radiation on unsteady magneto-hydrodynamic free-convection flow past an infinite vertical heated plate in a porous medium with time-dependent suction. Saeid and Pop (2004) studied numerically the viscous dissipation effect on natural convection in a porous cavity and found that the heat transfer rate at hot surface decreased with the increase of viscous dissipation parameter. Duwairi and Duwairi (2004) studied the thermal radiation heat transfer effects on the MHD-Rayleigh flow of gray viscous fluids under the effect of a transverse magnetic field. They found that increasing the magnetic field strength decreased the velocity inside the boundary layer. Hossain et al. (2005) investigated the effect of viscous dissipation on natural convection from a vertical plate placed in a thermally stratified environment. Effects of viscous dissipation and temperature stratification were also shown on the velocity and temperature distributions in the boundary layer region. Al-Mamun et al. (2005) investigated the effects of conduction and convection on magneto-hydrodynamic (MHD) boundary layer flow with viscous dissipation from a vertical flat plate. The dimensionless skin friction coefficient, the surface temperature distribution, the velocity distribution and the temperature profile over the whole boundary layer were shown graphically for different values of the magnetic parameter, the viscous dissipation parameter and the Prandtl number. Badruddin et al. (2006a) analyzed numerically using finite element method the heat transfer under the influence of radiation and viscous dissipation in a square cavity filled with saturated porous medium. The flow was assumed to follow Darcy law. Left vertical surface of the square cavity was maintained at isothermal hot temperature while the right vertical surface was maintained at isothermal cold temperature. Results were presented in terms of Nusselt number at hot and cold cavity walls for various values of viscous dissipation and radiation parameters. It was seen that the average Nusselt number at hot as well as cold walls increased with the increase in radiation parameter. Ridouane et al. (2006) studied numerically using the finite difference method coupled laminar natural convection with radiation in air-filled square enclosure heated from below and cooled from above for a wide variety of radiative boundary conditions at the sidewalls. Simulations were performed for two values of the emissivities of the active and insulated walls ($\varepsilon_1 = 0.05$ or 0.85, $\varepsilon_2 = 0.05$ or 0.85) and Rayleigh numbers ranging from $10^3$ to $2.3 \times 10^6$. It was found that, for a fixed Rayleigh number, the global heat transfer across the enclosure depended only on the magnitude of the emissivity of the active walls. Badruddin et al. (2007) investigated numerically using finite element method the effect of viscous dissipation and thermal radiation on natural convection in a porous medium embedded within a vertical annular cylinder. The inner surface of the cylinder was maintained at an isothermal temperature ($T_w$) while the outer surface was maintained at ambient temperature ($T_\infty$). Their study was focused to investigate the combined effect of viscous dissipation and radiation. It was observed that