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Full Length Article

Effect of radial magnetic field on natural convection flow in alternate conducting vertical concentric annuli with ramped temperature

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ABSTRACT

In this article, a numerical analysis has been performed to study the effect of radial magnetic field on natural convection of a viscous incompressible and electrically conducting fluid within the concentric vertical annuli containing a ramped type temperature profile at the surface of inner cylinder taking into account the induced magnetic field. Two cases are considered which are case 1, when inner cylinder is perfectly conducting and outer cylinder is non-conducting and case 2, has opposite configuration. The governing partial differential equations have been solved by using Matlab software. The influence of Hartmann number and magnetic Prandtl number on different profiles has been presented graphically. It is found that the effect of Hartmann number and magnetic Prandtl number is to decrease the velocity profile in both the cases. This study suggest that the heat transfer can be controlled by using ramped temperature and conductivity of the cylinder.

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1. Introduction

Free convective flow along vertical cylinders is one of the recent advances in the field of MHD. In recent years, researchers have shown their interest in this emerging field due to its wide range of applications in astrophysics, geophysics and engineering. These types of studies are important in nuclear power plants, drilling operations, geothermal power generation and space vehicles technology etc. Shercliff [1] investigated the flow of conducting fluids in circular pipes under the transverse magnetic field and found that when the induced field is sufficiently strong the velocity profile is found to degenerate into a core of uniform flow surrounded by boundary layers on each wall. The flow of an electrically conducting fluid between two infinite long vertical cylinders under the influence of magnetic field was analyzed by Globe [2]. Globe [2] show for the limiting case where the radii of annulus become infinite, but their difference remains finite then the solution behaves as a flow between infinite planes. Ramamoorthy [3] scrutinized the flow between two concentric rotating cylinders with a radial magnetic field. He compared the classical hydrodynamic velocity with the magneto hydrodynamic velocity between two rotating co-axial cylinders in presence of a radial magnetic field and by neglecting the induced magnetic field. Hughes and Young [4] introduced the Electromagnetodynamics of Fluids which proved to be useful for better understanding of electromagnetism.

Sparrow and Lloyd [5] have considered combined forced and free convective flow of a viscous incompressible fluid on vertical surface. Powe et al. [6] studied free convective flow patterns in cylindrical annuli. They presented graphs which helps in prediction of type of flow that occur for a wide range of cylindrical combinations and annulus operating conditions. Dube [7] analyzed the steady laminar flow of a viscous incompressible electrically conducting fluid between infinite long concentric porous cylinders under the influence of a radial magnetic field and found that the shearing stress at the inner cylinder decreases as cross flow Reynolds number increases. Kuehn and Goldstein [8] had carried out an experimental and theoretical study of natural convection in annulus between horizontal concentric cylinders and showed that the comparison between the present experimental and numerical results under similar conditions are in good agreement. Ghosh [9] presented a note on steady and unsteady hydrodynamic flow in a rotating channel in the presence of inclined magnetic field. Lee and Kuo [10] investigated the laminar flow in annular ducts with constant wall temperature at the boundaries. Harris et al. [11] have made the analysis of unsteady mixed convection from a vertical flat plate embedded in a porous medium and obtained the occurrence of transients when the buoyancy parameter is positive and negative. Chandran et al. [12] made a unified approach to analytic solution of a hydromagnetic free convection flow. Pal and

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Nomenclature

a	radius of inner cylinder
b	radius of outer cylinder
C_p	specific heat at constant pressure
g	acceleration due to gravity
H_0	constant magnetic field
Ha	Hartmann number
h'	induced magnetic field component along axis of cylinder
h	dimensionless induced magnetic field component along axis of cylinder
J	induced current density
J_θ	induced current flux
Nu_1	Nusselt number at inner cylinder
Nu_λ	Nusselt number at outer cylinder
Pm	magnetic Prandtl number
Pr	Prandtl number
r	dimensionless radial distance
r'	radial distance
t'	time
t	dimensionless time
t_0	characteristics time
T	dimensionless temperature
T'_a	temperature of inner cylinder
T'_f	temperature of the fluid
u	dimensionless velocity component along axis of cylinder
u'	velocity component along axis of cylinder
U	characteristics velocity

Greek symbols

β	coefficient of thermal expansion
κ	fluid thermal conductivity
λ	ratio of radii
μ_e	magnetic permeability
ν_h	magnetic diffusivity
ν	kinematic viscosity of fluid
ρ	density of fluid
σ	electrical conductivity
τ_1	skin friction at inner cylinder
τ_λ	skin friction at outer cylinder

Biswas [13] applied perturbation analysis to MHD oscillatory fluid over an infinite moving permeable plate saturated in porous medium in presence of chemical reaction. They deduced that with increase in the chemical reaction the skin-friction coefficient decreases at the wall while opposite behavior is observed by increasing the permeability parameter of the porous medium.

There raised some problems which were difficult to solve analytically. For solving those type of problems the Computational Techniques for Fluid Dynamics introduced by Fletcher [14] proved to be very useful. The mixed convection in vertical annulus under a radial magnetic field was considered by Mozayyeni and Rahimi [15] and it was found that velocity and temperature of fluid can be suppressed more effectively by using external magnetic field. Prasad and Kulacki [16] studied the free convective heat transfer in a liquid filled vertical annulus. They analyzed that in the laminar flow regime, the Nusselt number is weakly dependent on the aspect ratio when *Nu* and *Ra* are considered in terms of the annulus height and the starting of laminar flow regime is delayed with an increase in radius ratio. Joshi [17] has investigated the fully developed free convection flow in vertical annuli with isolated boundaries in which inner boundary is maintained at higher temperature and examined that the resulting flow and Nusselt number are function of annulus gap and non-dimensional temperature ratio. Ali et al. [18] presented the flow profiles for heat and mass transfer in presence of magnetic field oevr a inclined plate in the porous medium. Javaherdeh et al. [19] performed numerical investigation to study the heat and mass transfer in MHD fluid flow past a moving vertical plate in a porous medium and presented that the Grashof number enhances the flow velocity while the porosity parameter reduces the velocity profile. Also, the rate of heat and mass transfer decreases with increase in transverse magnetic field. Sandeep and Sulochana [20] examined the effect of non-uniform heat source/sink on an unsteady mixed convection boundary layer flow of a magneto micropolar fluid past a stretching/shrinking sheet. They gave conclusion that the mass transfer rate get enhanced with positive values of non-uniform heat source/sink parameters and the velocity and temperature boundary layers increase with increase in micropolar parameter.

Singh et al. [21] considered the study of steady fully developed laminar natural convection flow in open ended vertical concentric annuli in presence of radial magnetic field by considering the case of isothermal and constant heat flux on inner cylinder of concentric annuli. Sankar et al. [22] have presented the effect of magnetic field on natural convection in a vertical cylindrical annulus. Their computational results reveal that in shallow cavities the flow and heat transfer are suppressed more effectively by an axial magnetic field while in tall cavities a radial magnetic field is more effective. Sheikholeslami et al. [23] have done the numerical investigation of the effect of magnetic field on natural convection in a curved shape enclosure and concluded that Hartmann number can be a control parameter for heat and fluid flow. Deka et al. [24] have studied transient free convection flow past an accelerated vertical cylinder in a rotating fluid. They concluded that axial velocity component decreases with increase in Prandtl number but increases with increase in Grashoff number while transverse velocity component increases with increase in Grashoff number but decreases with increase in Prandtl number. Afrand et al. [25] presented the numerical simulation by using multi-objective particle swarm optimization algorithm on natural convection in a cylindrical annulus mold under magnetic field. Seth et al. [26] shown the effect of hall current, radiation and rotation on free convective flow past moving vertical plate. Hussanan et al. [27] have studied the free convective flow in presence of magnetic field with Newtonian heating and constant mass diffusion of heat and mass transfer. Afrand et al. [28] have done the numerical simulation of natural convection in presence of a magnetic field in an inclined cylindrical annulus and found that the effect of Hartmann number on the average Nusselt number is not noticeable in the case of horizontal annulus as compared to the case of vertical annulus.

These all studies were restricted to the case in which induced magnetic field has been neglected. Induced magnetic field strongly influences the flow formation and heat transfer. To control the flow formation rate more accurately, it is necessary to take induced magnetic field into consideration, Since, the induced magnetic field has many important applications in the experimental and theoretical studies of MHD flow due to its use in many industrial

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