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ORIGINAL ARTICLE

Hall effects on an unsteady magneto-convection and radiative heat transfer past a porous plate

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Abstract Hall effects on an unsteady magnetohydrodynamic (MHD) free convective flow of a viscous incompressible electrically conducting optically thick radiating fluid past a vertical porous plate in the presence of a uniform transverse magnetic field are examined. The governing equations are solved numerically using the fourth-order Runge–Kutta–Fehlberg method with the shooting technique. Effects of the pertinent parameters on the flow field, temperature distribution, shear stresses and rate of heat transfer at the plate are presented in graphs and tables followed by a quantitative discussion. The results reveal that the flow field and the temperature distribution are greatly influenced by thermal radiation parameter. Hall currents moderate the flow field significantly. Suction (or injection) has a profound effect on the boundary layer thickness in which the suction reduces the thermal boundary layer thickness whereas injection thickens it.

1. Introduction

The study of magnetohydrodynamic flow and heat transfer has received considerable attention in recent years due to its essential applications in engineering and technology such as MHD generators, MHD flow meters, pumps, plasma studies, bearings, nuclear reactors and geothermal energy extractions. Interaction between the electrically conducting fluid and a magnetic field is used as a control mechanism in material manufacturing industry, as the convection currents are suppressed by Lorentz force which is produced by the magnetic field. Convection problems of electrically conducting fluid in the presence of transverse magnetic field have got much importance because of its wide applications in geophysics, astrophysics, plasma physics, missile technology, etc. MHD principles find its applications in medicine and biology also.

A considerable interest has been shown in the study of thermal radiation on boundary layer flow and heat transfer in fluids due to its significant effects in the surface heat transfer. Radiation is another process of heat transfer through electromagnetic waves. Radiative convection flows are encountered in countless industrial and environment processes such as heating and cooling chambers, evaporation from large open water reservoirs, astrophysical flows and solar power technology, fossil fuel combustion energy processes and space vehicle re-entry. Radiative heat transfer in such processes plays very

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important role [1]. Thermal radiation transfer is also essential in Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles. The gravity-driven convection heat transfer is a vital phenomenon in the cooling mechanism of many engineering systems such as electronic industries, solar collectors and cooling systems for nuclear reactors because of its minimum cost, low noise, smaller size and reliability. There has been increasing interest in studying the problem of MHD with convection boundary layer flow and heat transfer characteristics over a vertical plate [2].

The study of magneto hydrodynamic gravity-driven convection through an optically thick fluid past an infinite vertical plate is considered very essential in understanding the behavior of the performance of fluid motion in several applications. The problem of gravity-driven convection in a regular fluid past a vertical plate is a classical problem solved by Ostrach [3]. Siegel [4] was the first to study the transient free-convective flow past a semi-infinite vertical plate by integral method. Convective flows with radiation are also encountered in many industrial processes such as heating and cooling of chambers, energy processes, evaporation from large reservoirs, solar power technology and space vehicle re-entry. Thermal radiation effects of an optically thin gray gas bounded by a stationary vertical plate have been investigated by England and Emery [5]. Soundalgekar and Takhar [6] have presented the free convective flow of an optically thin radiating gray gas past a semi-infinite vertical plate. Hossain and Takhar [7] have examined the radiation effects on mixed convection along an isothermal vertical plate.

When the conducting fluid is an ionized gas, and the strength of the applied magnetic field is very strong, the conductivity normal to the magnetic field is reduced due to the free spiraling of electrons and ions about the magnetic lines of force before suffering collisions and a current is induced in a direction normal to both electric and magnetic fields. This current is known as Hall current. When the medium is rarefied or if a strong magnetic field is present, the conductivity of the fluid is anisotropic and the effect of Hall currents cannot be neglected. The study of magnetohydrodynamic flows with Hall currents has important applications in problems of Hall accelerators as well as flight magnetohydrodynamics. The devices with the Hall effect produce a very low signal level and thus require amplification. While suitable for laboratory instruments, the vacuum tube amplifiers available in the first half of the 20th century were too expensive, power consuming and unreliable for everyday applications. It was only with the development of the low cost integrated circuit that became suitable for mass applications.

The combined effects of Hall currents and thermal radiation on the magnetohydrodynamic flows continue to draw the attention of researchers owing to extensive applications of such flows in the context of ionized aerodynamics, nuclear energy systems control, improved designs in aerospace MHD energy systems, manufacture of advanced aerospace materials, etc. There is a vast amount of literature on the magnetohydrodynamic flows taking Hall currents. Pop and Watanabe [8] have examined the Hall effects on a magnetohydrodynamic free convection past a semi-infinite vertical flat plate. The magnetohydrodynamic free convective heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with Hall currents and radiation absorption have been studied by Kinyanjui [9]. Aboeldahab and Elbarbary [10] have analyzed the Hall effects on a magnetohydrodynamic free convective flow past a semi-infinite vertical plate with mass transfer. Takhar et al. [11] have studied an unsteady free convective flow past an infinite vertical porous plate taking Hall currents. Aboeldahab and El Aziz [12] have studied the effects of Hall and ion-slip currents on an MHD free convection from a vertical plate with power-law variation in surface temperature. Chaudhary and Jain [13] have addressed the Hall effects on an unsteady hydromagnetic flow of a viscous elastic fluid past a vertical porous plate. Abdul Hakeem and Sathiyanathan [14] have obtained an analytic solution of an oscillatory flow through a porous medium. Effects of Hall currents on an MHD mixed convective flow over a vertical surface in porous medium have been described by Shateyi [15]. Saha et al. [16] have presented the effects of Hall currents on an MHD natural convective flow past a vertical permeable flat plate with uniform surface heat flux. Ali et al. [17] have examined the effects of Hall currents on an MHD mixed convection boundary layer flow over a stretched vertical flat plate. Jain and Singh [18] have described the Hall and thermal radiative effects on an unsteady rotating free convective slip flow. Chaudhary et al. [19] have presented the effects of Hall currents and thermal radiation on an unsteady free convective slip flow along a vertical plate embedded in a porous medium with constant heat and mass flux. The effects of Hall currents and rotation on an MHD natural convection flow past an impulsively moving vertical plate with ramped plate temperature in the presence of thermal diffusion with heat absorption have been investigated by Seth et al. [20]. Das et al. [21] have examined the Hall effects on an MHD free convection boundary layer flow past a vertical flat plate. Sarkar et al. [22] have studied the Hall effects on an unsteady MHD free convective flow past an accelerated moving vertical plate with viscous and Joule dissipations. The effects of Hall currents and radiation on an unsteady MHD flow past a heated moving vertical plate have been discussed by Das et al. [23]. Seth et al. [24] have investigated the Hall effects on a natural convective flow past a moving vertical plate with heat and mass transfer. Recently, Gireesha [25] have reported the combined effects of the thermal radiation and Hall currents on boundary layer flow past a non-isothermal stretching surface embedded in porous medium with non-uniform heat source/sink and fluid-particle suspension. The conjugate natural convection flow over a vertical surface with radiation has been presented by Siddiqa [26]. Kataria and Mittal [27] have developed a mathematical model for velocity and temperature of gravity-driven convective optically thick nanofluid flow past an oscillating vertical plate in the presence of magnetic field and radiation.

The main objective of the present study was to examine the effects of Hall currents and thermal radiation on an MHD flow of a viscous incompressible electrically conducting fluid past a vertical porous plate in the presence of a uniform transverse magnetic field. It is assumed that the magnetic Reynolds number is small enough to neglect induced magnetic field. A strong magnetic field is assumed and thus the electromagnetic force becomes very large which results into the phenomenon of Hall currents. The Hall currents give rise to a velocity in the cross-flow direction. The governing equations are solved numerically using fourth-order Runge–Kutta scheme coupled with the shooting technique. The effects of the pertinent parameters on the velocity components, temperature distribution and rate of heat transfer and shear stresses are analyzed in detail.