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Heat transfer effects on a viscous dissipative fluid flow past a vertical plate in the presence of induced magnetic field

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Abstract A theoretical analysis is performed to study induced magnetic field effects on free convection flow past a vertical plate. The $\bar{x}$-axis is taken vertically upwards along the plate, $\bar{y}$-axis normal to the plate into the fluid region. It is assumed that the plate is electrically non-conducting and the applied magnetic field is of uniform strength (H_0) and perpendicular to the plate. The magnetic Reynolds number of the flow is not taken to be small enough so that the induced magnetic field is taken into account. The coupled nonlinear partial differential equations are solved by Perturbation technique and the effects of various physical parameters on velocity, temperature, and induced magnetic fields are studied through graphs and tables. Variations in Skin friction and rate of heat transfer are also studied. It is observed that an increase in magnetic parameter decreases the velocity for both water and air. It is also seen that there is a fall in induced magnetic field as magnetic Prandtl number, and magnetic field parameter increase.

1. Introduction

Induced magnetic forces modify the free stream flow and this in turn, affects the external pressure gradient or the free stream velocity that is imposed on the boundary layer. From the technological point of view, MHD free-convection flows have great significance for the applications in the fields of Stellar and Planetary magnetospheres, Aeronautics, Chemical engineering, and Electronics. The effect of magnetic field on free convection flow of electrically conducting fluid past a plate studied by many investigators [1–12]. MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates was studied by Ravikumar et al. [13]. Effect of aligned Magnetic field on unsteady flow between a stretching sheet and oscillating porous plate with constant suction was studied by Reddy et al. [14]. Hydro magnetic Flow and Heat Transfer of a Heat-Generating Fluid over a Surface Embedded in a Porous Medium was considered by Chamkha

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Nomenclature

C_p	specific heat at constant pressure (J kg^{-1} K)
E_c	Eckert number (–)
g	acceleration due to gravity (m s^{-2})
G_m	mass Grashof number (–)
G_r	thermal Grashof number (–)
H	induced magnetic field (–)
H_0	uniform magnetic field (–)
H_x	induced magnetic field along x-axis (–)
J	current density (–)
M	Hartmann number (–)
P_r	Prandtl number (–)
P_{rm}	magnetic Prandtl number (–)
$\overline{T}$	temperature (K)
$\overline{T}_W$	fluid temperature at the surface (K)
$\overline{T}_\infty$	fluid temperature in the free stream (K)
u	velocity component in x-direction (m s^{-1})
U_0	dimensionless free stream velocity (m s^{-1})
v_0	suction velocity (m s^{-1})

Greek symbols

β	coefficient of volume expansion due to temperature (K^{-1})
μ_0	magnetic diffusivity (–)
v	kinematic viscosity (m^2 s^{-1})
κ	thermal conductivity (W m^{-1} K^{-1})
ρ	Density (kg m^{-3})
σ	electrical conductivity (S m^{-1})
θ	dimensionless fluid temperature (K)

Sub scripts

w	condition at the wall
∞	free stream conditions, primes denote dimensional quantities

[15]. In their study Takhar et al. [16] investigated an unsteady flow and heat transfer on a semi-infinite flat plate with an aligned magnetic field. Chamkha and Subaie [17] considered the effects of heat generation or absorption on hydrodynamic buoyancy induced flow of a particular suspension through a vertical pipe. The study of flow through porous medium finds application in geophysics, agricultural engineering and technology. Further the free convection flow in enclosures has become increasingly important in engineering applications in recent years due to fact growth of technology, effecting cooling of electronic equations ranges from individual transistors to mainframe computers and so on. Heat and mass transfer for Soret and Dufour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid was studied by Hayat et al. [18]. Makinde and Mhone [19], considered heat transfer to MHD oscillatory flow in a channel filled with porous medium. Magyari et al. [20] found analytical solution for unsteady free convection flow through porous media. Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction was studied by Kim [21]. MHD flow with slip effects and temperature-dependent heat source in a vertical wavy porous space was investigated by Srinivas and Muthuraj [22].

Analytical solutions to the problems of mixed convective flows, which arise in fluids due to the interaction of the force of gravity and the density difference caused by the simultaneous diffusion of thermal energy and chemical species, have been presented by many authors due to their applications in geophysics and engineering. The problems of steady and unsteady mixed convection flows were studied by many authors. Savic and Steinruck [23] studied mixed convection flow past a horizontal plate. Mixed convection over a horizontal plate: self-similar and connecting boundary layer flows were investigated by Steinruck [24]. Siddiqa1 and Hossain [25], considered mixed convection boundary layer flow over a vertical flat plate with radiative heat transfer. Analysis of fully developed opposing mixed convection between inclined parallel plates was studied by Lavine [26]. Bhattacharya et al. [27] investigated a similarity solution of mixed convective boundary layer slip flow over a vertical plate. Raju et al. [28], considered MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom wall in the presence of viscous dissipation and Joule heating. The problem of combined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction, was studied by Ravikumar et al. [29].

- The above studies on convective heat transfer phenomena in different flow geometries in the presence of a magnetic field have been limited to the case when the induced magnetic field is not taken into account. This is due to the fact that the mathematical description as well as solution of such problems involves some less effort.
- Thus, the main aim of this paper is to present the fully developed viscous dissipative, magneto hydrodynamic, steady free convective heat transfer flow over an infinite vertical porous plate in the presence of induced magnetic field.
- The magnetic Reynolds number of the flow is not taken to be small enough so that the induced magnetic field cannot be neglected.

2. Mathematical formulation

The two-dimensional steady magneto-hydrodynamic mixed convective heat transfer flow of a Newtonian, electrically-conducting, viscous incompressible fluid over a porous vertical infinite plate with viscous/magnetic dissipation of energy has been considered. The $\bar{x}$-axis is taken vertically upwards along the plate, $\bar{y}$-axis normal to the plate in the fluid region. It is assumed that the plate is electrically non-conducting and the applied magnetic field is of uniform strength (H_0) and perpendicular to the plate (see Fig. 1). The magnetic Reynolds number of the flow is taken into consideration, so that the presence