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Exploration of Magnetohydrodynamic (MHD) Mixed Convective Flow over a Vertical Porous Surface, Accounting for Viscous Dissipation.

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Abstract

This investigation delves into the combined influences of thermal radiation and chemical reaction on the steady mixed convective flow of heat and mass transfer in the presence of magnetohydrodynamics (MHD). The scenario involves a semi-infinite vertical porous plate subject to Joule heating and viscous dissipation. The governing set of partial differential equations (PDEs) is transformed into a non-dimensional form using dimensionless variables. These non-dimensional equations are subsequently solved numerically employing a two-term perturbation technique. The study examines the impact of various parameters within the problem on the distribution of dimensionless velocity, temperature, and concentration profiles across the boundary layer.

Introduction

The exploration of heat and mass transfer characteristics along an inclined plate has captivated considerable attention from various domains, including uranology, renewable energy systems, and hypersonic mechanics, spanning multiple decades. MHD flow phenomena have been extensively studied due to their significant applications in industrial processes, such as plasma studies, petroleum industries, magneto-electromagnetic hydrokinetics, cooling of power generators and nuclear reactors, as well as fluid dynamics control. Numerous researchers have delved into the influence of magnetic fields on heat and mass transfer, encompassing natural, mixed, and forced convective scenarios. The complexities of heat transfer arise from chemical reactions and inherent process characteristics. Instances of MHD-induced free convection fluid flows are prevalent in nature [7]. The passage of fluid through porous media has garnered considerable interest, with many researchers drawn to its applications in fields like agriculture engineering, where understanding spring water resources is crucial, and technology, where the dynamics of fuel, oil, and water flow over reservoirs are of significant concern. This study investigates the outcomes of mixed convection within an unsteady stagnation flow of a viscous fluid, considering variable rates of free stream.

Das et al. [1] observed the influence of mass transfer on an unstable flow over a mobile vertical porous plate. Sattar [2] investigated free convective mass transfer in an infinite vertical porous plate with time-dependent temperature and concentration. In a magnetic field, Chen et al. [3] studied heat and mass transfer along an inclined surface, considering natural convection with variable wall temperature and concentration. Employing the Homotopy Analysis Method (HAM), Ali et al. [4] formulated the MHD mixed convection Falkner-Skan flow with convective boundary conditions. Duwairi and Al-Kablawi [5] discussed limitations in MHD conjugative heat transfer from vertical surfaces immersed in saturated porous media. Nasir Uddin et al. [6] examined conjugative heat and mass transfer effects in magnetoelectric machine hydraulics mixed convective flow across an inclined plate through a porous medium. The significance of radiation effects on natural convective flows is evident in applications such as chamber design, glass production, power generation, thermo-nuclear fusion, casting, levitation, electronics, cosmic flights, propulsion systems, renewable energy technology, satellite re-entry, and

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aerothermodynamics[8-10]. It is noteworthy that, in contrast to conduction and convection, accounting for radiation in the governing equations introduces considerable complexity to the results.

Mathematical formulation

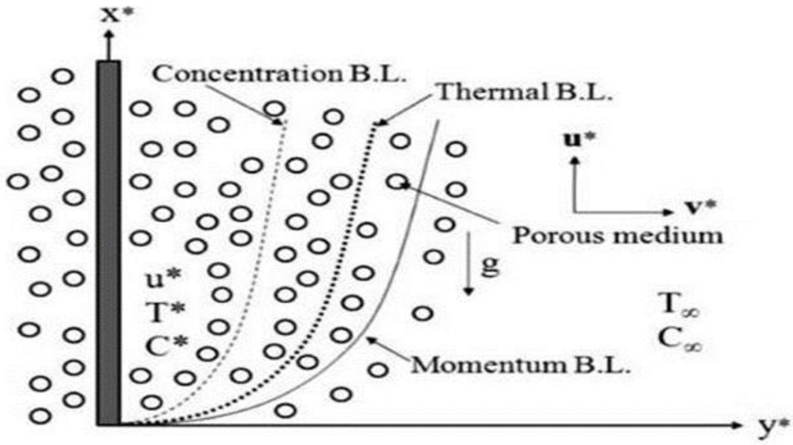

Figure 1: Physical model

The governing equations are given by

$$\frac{\partial v^*}{\partial y^*} = 0 \Rightarrow v^* = - v_0 \,(\text{constant}) \tag{1}$$

$$\frac{\partial p^*}{\partial y^*} = 0 \Rightarrow P^* \text{ is independent of } y^* \tag{2}$$

$$\rho v^* \frac{\partial u^*}{\partial y^*} = \mu \frac{\partial^2 u^*}{\partial y^{*2}} + \rho g \beta \left(T^* - T_\infty^*\right) + \rho g \beta^* \left(C^* - C_\infty^*\right) - \sigma B_0^2 u^* - \frac{\nu u^*}{K^*} \tag{3}$$

$$\rho C_p v^* \frac{\partial T^*}{\partial y^*} = k \frac{\partial^2 T^*}{\partial y^{*2}} + \mu \left(\frac{\partial u^*}{\partial y^*}\right)^2 - \frac{\partial q_r^*}{\partial y^*} + \sigma B_0^2 u^{2*} \tag{4}$$

$$v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - R^* \left(C^* - C_\infty^*\right) \tag{5}$$

The radiative heat flux is given by

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$$\frac{\partial q_r}{\partial y^*} = 4\left(T^* - T_\infty^*\right) I' \qquad 6)$$

where $\int_0^\infty K_{\lambda w}\left(\frac{de_{b\lambda}}{dT^*}\right)_w d\lambda,\ K\lambda w$ is the absorption coefficient at wall and $e_{b\lambda}$ is Planck's function.

The boundary conditions are

$$\begin{aligned} &u^* = 0, T^* = T_w, C^* = C_w \text{ at } y^* = 0 \\ &u^* \to 0, T^* \to T_\infty, C^* \to C_\infty \text{ as } y^* \to \infty \end{aligned} \qquad (7)$$

Introducing the following non-dimensional quantities

$$\begin{aligned} &u = \frac{u^*}{v_0}, y = \frac{v_0 y^*}{\nu}, \theta = \frac{T^* - T_\infty^*}{T_w - T_\infty}, C = \frac{C^* - C_\infty^*}{C_w - C_\infty}, \Pr = \frac{\mu c_p}{k}, Sc = \frac{\nu}{D}, \\ &Gr = \frac{g\beta\nu(T_w - T_\infty)}{v_0^3}, Gm = \frac{g\beta^*\nu(C_w - C_\infty)}{v_0^3}, M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, K = \frac{v_0^2 K^* \rho}{\nu^2}, \\ &E = \frac{v_0^2}{C_p\left(T_w - T_\infty\right)}, F = \frac{4I'\nu}{\rho c_p v_0^2}, Kr = \frac{\nu R^*}{v_0^2} \end{aligned} \qquad (8)$$

$$u'' + u' - \left(M + \frac{1}{K}\right)u = -\left[GrT + GmC\right] \qquad (9)$$

$$T'' + \Pr T' - F\Pr T + \Pr Ec(u')^2 + \Pr EcMu^2 = 0 \qquad (10)$$

$$C'' + ScC' - ScKrC = 0 \qquad (11)$$

where Gr is the Grashof number, Gm – the modified Grashof number, Pr - the Prandtl number, F- the radiation parameter, Sc- the Schmidt number, E-the Eckert number, M-the magnetic parameter, Kr-the chemical reaction.

The corresponding boundary conditions in non-dimensional form are reduced to

$$\begin{aligned} &u = 0, T = 1, C = 1 \quad \text{at } y = 0 \\ &u \to 0, T \to 0, C \to 0 \quad \text{as } y \to \infty \end{aligned} \qquad (12)$$

Solution of the problem

To reduce the above system of PDEs into the system of ODEs in a dimension less form, we may represent velocity, temperature, concentration

$$\begin{aligned} u(y) &= u_0(y) + \varepsilon u_1(y) + O(\varepsilon^2) \\ T(y) &= T_0(y) + \varepsilon T_1(y) + O(\varepsilon^2) \\ C(y) &= C_0(y) + \varepsilon C_1(y) + O(\varepsilon^2) \end{aligned} \qquad (13)$$

Results

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In the present study, we have examined the effects of combined convection flow on a continuous, viscous, electrically conducting fluid over an infinite vertical porous plate. This investigation incorporates considerations of flow dynamics, heat and mass transfer. Additionally, the influence of radiation and a magnetic field is accounted for, utilizing the classical model for radiative heat flux [11]. The obtained outcomes provide visual representations that elucidate the impact of various parameters on the velocity distribution, temperature profile, and concentration field. These parameters include the thermal Grashof number (Gr), solutal Grashof number (Gm), magnetic field parameter (M), permeability parameter (K), radiation parameter (F), Schmidt number (Sc), Prandtl number (Pr), and chemical reaction parameter (Kr). The Figures (2) to (5) display these effects while holding the remaining parameters constant [12].

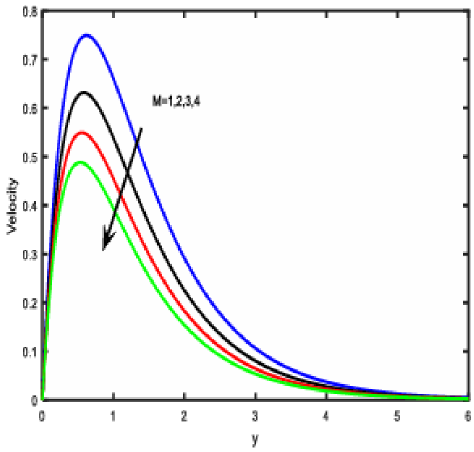

FIGURE 2. Velocity profiles for different values of magnetic parameter (M).

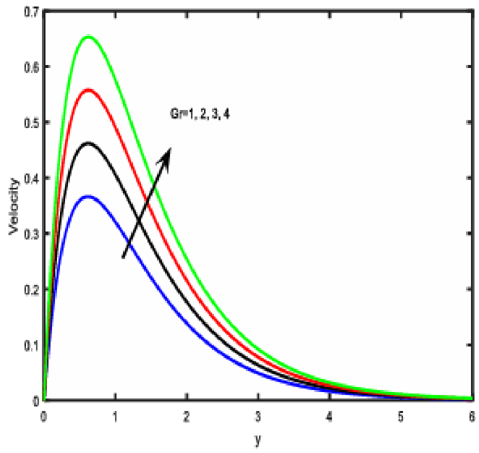

FIGURE 4. Velocity profiles for different values of Grashof Number (Gr).

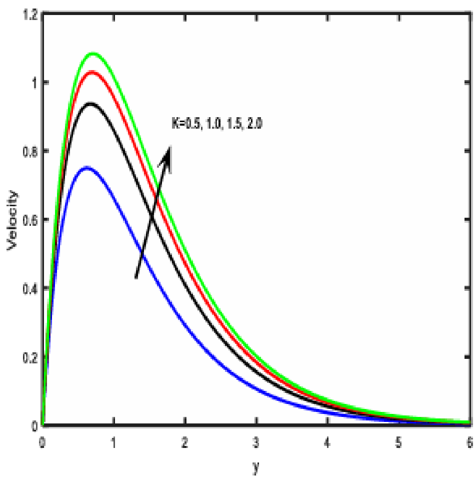

FIGURE 3. Velocity profiles for different values of permeability parameter (K).

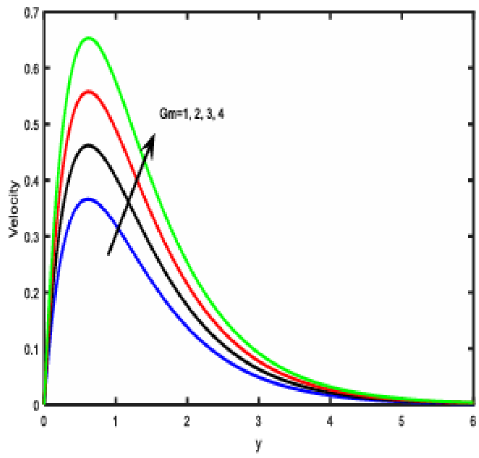

FIGURE 5. Velocity profiles for different values of solutal Grashof Number (Gm).

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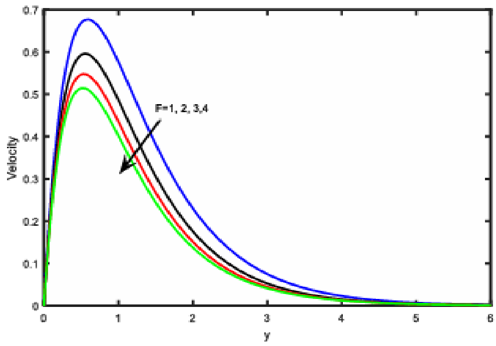

FIGURE 6. Velocity profiles for different values of radiation parameter (F).

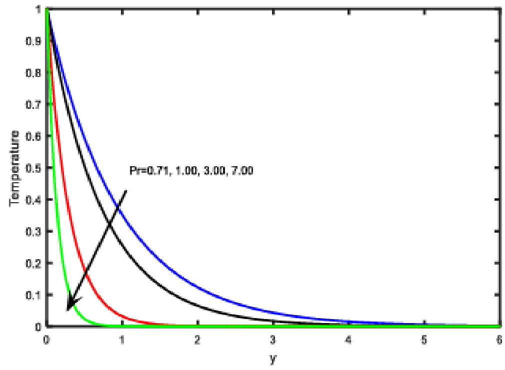

FIGURE 9. Temperature profiles for different values of Prandtl number (Pr).

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