EFFECTS OF RADIATION AND HALL CURRENT ON UNSTEADY MHD FREECONVECTIVE FLOW OVER INCLINED POROUS SURFACE

CH. BABY RANI¹, N. VEDAVATHI², G. DHARMAIAH³
& K. S. BALAMURUGAN⁴

¹Department of Mathematics, V. R. Siddhartha Engineering College, Kanuru, Andhra Pradesh, India

²Department of Mathematics, KoneruLakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

³Department of Mathematics, Narasaraopeta Engineering College, Yellamanda, Narsaraopet, Andhra Pradesh, India

⁴Department of Mathematics, RVR & JC College of Engineering, Chowdavaram, Guntur, Andhra Pradesh, India

ABSTRACT

This paper analyzes the Magnetohydrodynamic, Radiation and chemical reaction effects on unsteady MHD flow, heat, and mass transfer characteristics in a viscous, incompressible and electrically conductivity fluid flow over a semi-infinite inclined porous plate with hall effects. The porous plate is subjected to a transverse variable suction velocity. The governing equations for the flow are transformed into a system of non-linear ordinary differential equations are solved by a perturbation technique. The effects of the various parameters on the velocity, temperature, concentration profiles are presented graphically.

KEYWORDS: Hall Current, Chemical Reaction, Radiation, Free Convective & Inclined Plate

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INTRODUCTION

MHD (magnetohydrodynamic) flows with and without heat transfer in electrically conducting fluids have attracted substantial interest in the context of metallurgical fluid dynamics, re-entry aerothermodynamics, astronautics, geophysics, nuclear engineering, and applied mathematics. An early study was presented by Carrier and Greenspan[1] who considered unsteady hydromagn[etc flows past a semi-infinite flat plate moving impulsively in its own plane. Further excellent studies of unsteady free convection magnetohydrodynamic flows were reported by (Antimirov and Kolyshkin[2] for a vertical pipe and Rajaram, Ramprasad et al. [19], Charankumar et al. [20], vedavathi et al. [21] and Yu for a parallel-plate channel [3]. Chamkha[4]has analyzed the unsteady MHD free three-dimensional convection over an inclined permeable surface with heat generation/absorption. More recent communications on unsteady hydromagnetic heat transfer flows include the articles by Seddeek[5]incorporating variable viscosity effects, Zakaria[6] who considered a polar fluid, and Ghosh and Pop[7]who included Hall currents[8]. Zueco presented network simulation solutions for the transient natural convection MHD flow with viscous heating effects. In many industrial applications, hydromagnetic flows also occur at very high temperatures in which thermal radiation effects become significant. The vast majority of radiation-convection flows have utilized algebraic flux approximations to simplify the general equations of radiative transfer[9]. The most popular of these simplifications remains the Rosseland diffusion approximation

which has been employed by, for example, Ali et al. [10] and later by Hossain et al. [12]. Radiation magnetohydrodynamic convection flows are also important in astrophysical and geophysical regimes. Raptis and Massalas [11] considered induced magnetic field effects in their study of unsteady hydromagnetic-radiative free convection. Abd El-Naby et al. [13] numerically studied magnetohydrodynamic (MHD) transient natural convection-radiation boundary layer flow with variable surface temperature, showing that velocity, temperature, and skin friction are enhanced with a rise in radiation parameter increases, whereas Nusselt number is reduced. Abd-El Aziz [14] studied the thermal radiation flux effects on unsteady MHD micropolar fluid convection. Chamkha [15] studied the transient-free convection magnetohydrodynamic boundary layer flow in a fluid-saturated porous medium channel, and later [16] extended this study to consider the influence of temperature-dependent properties and inertial effects on the convection regime. Bég et al. [17] presented perturbation solutions for the transient oscillatory hydromagnetic convection in a Darcian porous media with a heat source present. Chaudhary and Jain [18] studied the influence of oscillating temperature on magnetohydrodynamic convection heat transfer past a vertical plane in a Darcian porous medium. Vedavathi et al. [22] presented a radiation effect on semi infinite flat plate.

The objective of the present study is to investigate the effect of various parameters like chemical reaction parameter, thermal Grashof number, mass Grashof number, rarefaction parameter, magnetic field parameter, radiation parameter, suction parameter, and Hall parameter on convective heat transfer along an inclined plate in the porous medium. The governing non-linear partial differential equations are first transformed into a dimensionless form and thus resulting non-similar set of equations has been solved using the perturbation technique. Results are presented graphically and discussed quantitatively for parameter values of practical interest from the physical point of view.

MATHEMATICAL ANALYSIS

Consider the unsteady two dimensional MHD free convective flow of a viscous incompressible, electrically conducting and radiating fluid in an optically thin environment past an infinite heated vertical porous plate embedded in a porous medium in presence of thermal and concentration buoyancy effects. Let the x -axis be taken in vertically upward direction along the plate and y -axis is normal to the plate. It is assumed that there exists a homogeneous chemical reaction of first order with a constant rate Kr between the diffusing species and the fluid. A uniform magnetic field is applied in the direction perpendicular to the plate. The viscous dissipation and the Joule heating effects are assumed to be negligible in the energy equation. The transverse applied the magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field is negligible. Also, it is assumed that there is no applied voltage so that the electric field is absent. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species, which are present, and hence the Soret and Dufour effects are negligible and the temperature in the fluid flowing is governed by the energy concentration equation involving radiative heat temperature. Under the above assumptions as well as Boussinesq's approximation, the equations of conservation of mass, momentum, energy, and concentration governing the free convection boundary layer flow over a vertical porous plate in the porous medium can be expressed as:

$$\frac{\partial v'}{\partial y'} = 0 \quad (1)$$

$$\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} = \nu \frac{\partial^2 u'}{\partial y'^2} + g \cos \alpha \beta (T' - T_\infty') + g \cos \alpha \beta^* (C' - C_\infty') - \frac{m}{1+m^2} \frac{\sigma B_0^2}{\rho} u' - \frac{\nu}{k'} u' \quad (2)$$

$$\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'} = \frac{k}{\rho c_p} \frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho c_p} \frac{\partial q'_r}{\partial y'} \quad (3)$$

$$\frac{\partial C'}{\partial t'} + v' \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} - K'_r (C' - C_\infty') \quad (4)$$

where u', v' are the velocity components in x', y' directions respectively, t' – the time, p' – the pressure, ρ – the fluid density, g – the acceleration due to gravity, β and β^* – the thermal and concentration expansion coefficients respectively, K' – the permeability of the porous medium, T' – the temperature of the fluid in the boundary layer, ν – the kinematic viscosity, σ – the electrical conductivity of the fluid, T_∞' – the temperature of the fluid far away from the plate, C' – the species concentration in the boundary layer, C_∞' – the species concentration in the fluid far away from the plate, B_0 – the magnetic induction, α – the fluid thermal diffusivity, q'_r – the radiative heat flux, c_p – specific heat at constant, D – the coefficient of chemical molecular diffusivity, K'_r – the chemical reaction, m – the hall parameter, α inclined angle.

The boundary conditions for the velocity, temperature, and concentration fields are given as follows:

$$\begin{aligned} u' = L' \left(\frac{\partial u'}{\partial y'} \right), T' = T_\infty' + \varepsilon (T'_w - T_\infty') e^{n' y'}, C' = C_\infty' + \varepsilon (C'_w - C_\infty') e^{n' y'} & \quad \text{at } y' = 0 \\ u' \rightarrow 0, \quad T' \rightarrow T_\infty', \quad C' \rightarrow C_\infty' & \quad \text{as } y' \rightarrow \infty \end{aligned} \quad (5)$$

Where T'_w and T_∞' are the temperature at the wall and infinity. C'_w and C_∞' are the species concentration at the wall and at infinity respectively.

By using the Rossel and approximation, the radiative flux vector q_r can be written as:

$$q'_r = - \frac{4\sigma^*}{3k'_1} \frac{\partial T'^4_w}{\partial y'} \quad (6)$$

Where, σ^* and k'_1 are respectively the Stefan-Boltzmann constant and the mean absorption coefficient. We assume that the temperature difference within the flow is sufficiently small such that T'^4 may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about the free stream temperature T_∞' and neglecting higher order terms, thus

$$T'^4_w \cong 4T_\infty'^3 T'_w - 3T_\infty'^4 \quad (7)$$

From Equation (1), it is clear that suction velocity at the plate is either a constant or function of time only. Hence the suction velocity normal to the plate is assumed to be in the form

$$v' = -V_0 \left(1 + \varepsilon A \exp^{i\omega t'} \right) \quad (8)$$

Where, A is a real positive constant, and ε is small such that $\varepsilon \ll 1$, $\varepsilon A \ll 1$, and V_0 is a non-zero positive constant, the negative sign indicates that the suction is towards the plate.

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional quantities are introduced.

$$\begin{aligned} u &= \frac{u'}{V_0}, v = \frac{v'}{V_0}, y = \frac{V_0 y'}{\nu}, u = \frac{u'}{V_0}, t = \frac{t' V_0^2}{4\nu}, \omega = \frac{4\omega' \nu}{V_0^2}, Q = \frac{k'_1 k}{4\sigma^* T_\infty'^3 \nu^2}, \\ \theta &= \frac{T' - T'_\infty}{T'_w - T'_\infty}, \phi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, K = \frac{K' V_0^2}{\nu^2}, \text{Pr} = \frac{\nu \rho c_p}{k}, h = \frac{V_0 L'}{\nu}, Kr = \frac{K'_r \nu}{V_0^2}, \\ Sc &= \frac{\nu}{D}, M = \frac{\sigma B_0^2 \nu}{\rho V_0^2}, Gr = \frac{\nu \beta g (T'_w - T'_\infty)}{V_0^3}, Gc = \frac{\nu \beta^* g (C'_w - C'_\infty)}{V_0^3}, \end{aligned} \quad (9)$$

In view of Equations (6), (7) (8) and (9), Equations (2), (3) and (4) can be reduced to the following dimensionless form.

$$\frac{1}{4} \frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t} \right) \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr_1 \theta + Gc_1 \phi - \left(M_1 + \frac{1}{K} \right) u \quad (10)$$

$$\frac{1}{4} \frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{i\omega t} \right) \frac{\partial \theta}{\partial y} = \frac{1}{\text{Pr}} \left(1 + \frac{4}{3Q} \right) \frac{\partial^2 \theta}{\partial y^2} \quad (11)$$

$$\frac{1}{4} \frac{\partial \phi}{\partial t} - \left(1 + \varepsilon A e^{i\omega t} \right) \frac{\partial \phi}{\partial y} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} - Kr \phi \quad (12)$$

$$Gr_1 = Gr \cos \alpha, Gc_1 = Gc \cos \alpha, M_1 = \frac{m}{1+m^2} M$$

Where

The corresponding dimensionless boundary conditions are

$$\begin{aligned} u &= h \frac{\partial u}{\partial y}, \quad \theta = 1 + \varepsilon e^{i\omega t}, \quad \phi = 1 + \varepsilon e^{i\omega t} \quad \text{at} \quad y = 0 \\ u &\rightarrow 0, \quad \theta \rightarrow 0, \quad \phi \rightarrow 0 \quad \text{as} \quad y \rightarrow \infty \end{aligned} \quad (13)$$

SOLUTION OF PROBLEM

The equations (10) to (12) are coupled, non-linear partial differential equations and these cannot be solved in closed form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. So this can be done, when the amplitude of oscillations ($\varepsilon \ll 1$) is very small, we can assume the solutions of flow velocity u , temperature field θ and concentration C in the neighborhood of the plate as:

$$u(y, t) = u_0(y) + \varepsilon e^{i\omega t} u_1(y) + O(\varepsilon^2) + \dots \quad (14)$$

$$\theta(y, t) = \theta_0(y) + \varepsilon e^{i\omega t} \theta_1(y) + O(\varepsilon^2) + \dots \quad (15)$$

$$\phi(y, t) = \phi_0(y) + \varepsilon e^{i\omega t} \phi_1(y) + O(\varepsilon^2) + \dots \quad (16)$$

Substituting (16), (17) and (18) in Equations (12) - (14) and equating harmonic and non-harmonic terms, and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain

$$u_0'' + u_0' - \left(M_1 + \frac{1}{K} \right) u_0 = -[Gr_1 \theta_0 + Gc_1 \phi_0] \quad (17)$$

$$u_1'' + u_1' - \left(M_1 + \frac{i\omega}{4} + \frac{1}{K} \right) u_1 = -[Gr_1 \theta_1 + Gc_1 \phi_1 + Au_0'] \quad (18)$$

$$\theta_0'' + \text{Pr} \left(1 + \frac{4}{3Q} \right) \theta_0' = 0 \quad (19)$$

$$\theta_1'' + \text{Pr} \left(1 + \frac{4}{3Q} \right) \theta_1' - \text{Pr} \frac{i\omega}{4} \left(1 + \frac{4}{3Q} \right) \theta_1 = -2A \text{Pr} \left(1 + \frac{4}{3Q} \right) \theta_0' \quad (20)$$

$$\phi_0'' + Sc \phi_0' - ScKr \phi_0 = 0 \quad (21)$$

$$\phi_1'' + Sc \phi_1' - \left(\frac{i\omega}{4} + Kr \right) Sc \phi_1 = -ASc \phi_0' \quad (22)$$

Where, the primes denote the differentiation with respect to y .

The corresponding boundary conditions can be written as

$$\begin{aligned} u_0 &= h \left(\frac{\partial u_0}{\partial y} \right), \quad u_1 = h \left(\frac{\partial u_1}{\partial y} \right), \quad \theta_0 = 1, \quad \theta_1 = 1, \quad \phi_0 = 1, \quad \phi_1 = 1 & \text{at} & \quad y = 0 \\ u_0 &\rightarrow 0, \quad u_1 \rightarrow 0, \quad \theta_0 \rightarrow 0, \quad \theta_1 \rightarrow 0, \quad \phi_0 \rightarrow 0, \quad \phi_1 \rightarrow 0 & \text{as} & \quad y \rightarrow \infty \end{aligned} \quad (23)$$

The analytical solutions of equations (17) – (22) with satisfying the boundary conditions (23) are given by

$$u_0 = N_8 e^{-m_4 y} + N_6 e^{-m_1 y} + N_7 e^{-m_2 y} \quad (24)$$

$$u_1 = N_{13} e^{-m_5 y} + N_9 e^{-m_1 y} + N_{10} e^{-N_1 y} + N_{11} e^{-m_3 y} + N_{12} e^{-m_2 y} \quad (25)$$

$$\theta_0 = e^{-N_1 y} \quad (26)$$

$$\theta_1 = N_2 e^{-N_1 y} + N_3 e^{-m_1 y} \quad (27)$$

$$\phi_0 = e^{-m_2 y} \quad (28)$$

$$\phi_1 = N_5 e^{-m_3 y} + N_4 e^{-m_2 y} \quad (29)$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$u(y, t) = N_8 e^{-m_4 y} + N_6 e^{-m_1 y} + N_7 e^{-m_2 y} + \mathcal{E} \left[\begin{array}{l} N_{13} e^{-m_5 y} + N_9 e^{-m_1 y} + N_{10} e^{-N_1 y} \\ + N_{11} e^{-m_3 y} + N_{12} e^{-m_2 y} \end{array} \right] e^{i\omega t} \quad (30)$$

$$\theta(y, t) = e^{-N_1 y} + \mathcal{E} \left[N_2 e^{-N_1 y} + N_3 e^{-m_1 y} \right] e^{i\omega t} \quad (31)$$

$$\phi(y, t) = e^{-m_2 y} + \mathcal{E} \left[N_5 e^{-m_3 y} + N_4 e^{-m_2 y} \right] e^{i\omega t} \quad (32)$$

RESULT AND DISCUSSIONS

The formulation of the problem that accounts for the effect of Hall current, radiation and chemical reaction on transient MHD free convective flow over an inclined plate through porous media was accomplished in the preceding sections. The governing equations of the flow field were solved analytically, using a perturbation method, and the expressions for the velocity, temperature, concentration, skin-friction, Nusselt number and Sherwood number were obtained. In order to get a physical insight of the problem, the above physical quantities are computed numerically for different values of the governing parameters viz., thermal Grashof number Gr , the Solutal Grashof number Gc , Prandtl number Pr , Schmidt number Sc , the radiation parameter R , inclined angle α , Hall parameter m and the chemical reaction parameter kr . For various values of inclined angle α is plotted in Figure 1. It is found that as α increases, fluid flow decreases. The effect of Hall parameter m is shown in Figure 2. It is observed that fluid flow reduces with increase of the hall current parameter. The effect of the magnetic parameter M is shown in Figure 3. It is observed that the tangential velocity of the fluid decreases with the increase of the magnetic field number values. The decrease in the tangential velocity as the magnetic parameter M increases is because the presence of a magnetic field in an electrically conducting fluid introduces a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present study. This resistive force slows down the fluid velocity component as shown in Figure 3. For different values of thermal radiation Q , the temperature profiles are shown in Figure 4 shows the behavior temperature for different values Prandtl number. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing temperature. It is observed that an increase in the Prandtl number results in a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore, heat is able to diffuse away from the heated surface more rapidly for higher values of Pr . Hence in the case of smaller Prandtl number as the thermal boundary layer is thicker and the rate of heat transfer is reduced. Figure 5. It is noticed that an increase in the thermal radiation results in an increase in the temperature within the boundary layer. Figure 6 illustrates the behavior concentration for different values of chemical reaction parameter K_r . It is observed that an increase in leads to a decrease in both the values of concentration. The effect of the Schmidt number Sc on the concentration is shown in Figure 7. As the Schmidt

number increases, the concentration decreases. This causes the concentration of buoyancy effects to decrease yielding a reduction in the fluid velocity. Reductions in the concentration distributions are accompanied by a reduction in the concentration boundary layers.

Figure 1: Velocity Profiles for Different Values of Inclined Angle

Figure 2: Velocity Profiles for Different Values of Hall Parameter

Figure 3: Velocity Profiles for Different Values of Magnetic Parameter

Figure 4: Temperature Profiles for Different Values of Prandtl Number

Figure 5: Temperature Profiles for Different Values of Radiation Parameter

Figure 6: Concentration Profiles for Different Values of Chemical Reaction Parameter

Figure 7: Concentration Profiles for Different Values of Schmidt Number

CONCLUSIONS

- As inclined angled enhances, velocity is decreases.
- Velocity is diminishes, with an increase of the hall current parameter.
- The thermal boundary layer thickness and in general lower average temperature within the boundary layer is decreases as an increase in the Prandtl number.
- An increase in the temperature within the boundary layer with the increasing of thermal radiation.
- As the Schmidt number increases, the concentration decreases.

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