ISSN PRINT 2319 1775 Online 2320 7876

Research paper UGC CARE Listed (Group -I) Journal Volume 10, Spl Iss 2, 2021

Analysing the Impact of Temperature and Concentration Variations on Radiative Chemically Reactive Magnetohydrodynamic Viscoelastic Fluid Flow Over a Moving Porous Plate.

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Abstract

The investigation considered a dynamic scenario involving a magnetohydrodynamic viscoelastic fluid flowing past a vertically moving plate within a porous medium, accounting for varying temperature and radiation impacts. The study also incorporated chemical reactions and concentration effects. Employing an analytical approach through perturbation techniques, the governing mathematical model was tackled. The primary objective of this research was to scrutinize the influence of various parameters and factors on the fluid flow, as well as on thermal and concentration profiles. The magnetic parameter played a pivotal role, notably diminishing the velocity profile due to the opposing Lorentz force against the flow direction. Meanwhile, heightened thermal radiation led to an augmented temperature profile, whereas intensified chemical reactions and a greater Schmidt number caused a reduction in the concentration distribution. The Schmidt number, a crucial factor in multiphase flows, indicated the relative ease of molecular momentum and mass transfer.

Introduction

Convection holds profound significance across diverse realms, spanning engineering, industry, and environmental contexts. Its applications range from electronic device cooling, air conditioning, and atmospheric dynamics to energy system security and thermal insulation design. The interplay of thermal and mass transfer within porous media finds pivotal roles in industrial spheres like filtration processes and power engineering, catering to electronic devices, microchips, circuit boards, and photovoltaic sheets. Furthermore, this phenomenon finds relevance in various engineering and geophysical conundrums. In numerous engineering and technological landscapes, the significance of non-Newtonian fluids remains undeniable. These materials encompass a wide spectrum, including shampoos, mayonnaise, blood, paints, alcoholic beverages, yogurt, cosmetics, and syrups, among others. The mathematical depiction of such fluids proves intricate, as conventional Navier-Stokes equations fall short in capturing the nuances of non-Newtonian fluid behaviour. These fluids can be classified into differential, rate, and integral types. Among them, viscoelastic fluids constitute a subclass that exhibits a memory effect, characterized by a measure of stored energy leading to partial elastic recovery upon stress removal. Pioneers like Beard and Walters [1] initiated boundary layer analysis of idealized viscoelastic fluids, while Singh et al. [2] proposed natural convection

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flow between parallel vertical plates. Sajid et al. [3] further extended this study to encompass fully mixed convection flow between permeable vertical walls within a viscoelastic context. The exploration of viscoelastic fluid flow, considering diverse parameters, has been undertaken by multiple researchers [4-6].

Governing equations

We investigate the unsteady two-dimensional magnetohydrodynamic (MHD) flow of an incompressible electrically conducting fluid over a semi-infinite vertical permeable moving plate, which also serves as a permeable stretching surface [7]. This study incorporates the influence of thermal radiation. The coordinate system is established such that the x-axis aligns with the sheet, while the y-axis stands orthogonal to it, as illustrated in Figure 1. The contribution of the induced magnetic field is considered negligible in comparison to the applied magnetic field [8-10]. We operate under the assumption that the governing equations adhere to the viscoelastic fluid flow model proposed by Babu et al. In the context where pressure gradients are absent, the fundamental equations expressing the principles of mass conservation, momentum, energy, and species conservation take the following form:

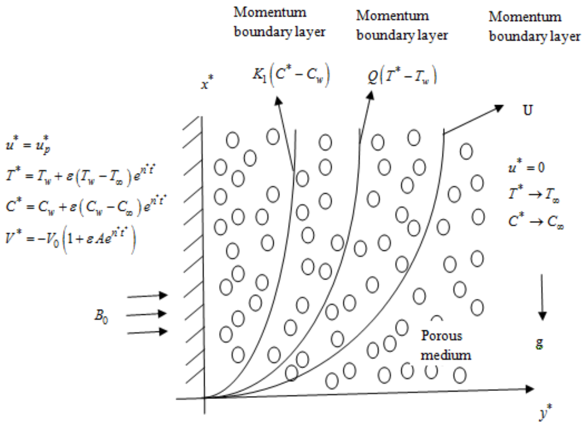

Fig 1. Physical model of problem

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$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\frac{\partial u^*}{\partial y^*} + v^* \frac{\partial u^*}{\partial y^*} = \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} - \left(\frac{\sigma B_0^2}{\rho} + \frac{\upsilon}{K^*} \right) u^* + g\beta_T (T^* - T_\infty)$$
$$+ g\beta_C (C^* - C_\infty) - k_0 \left(\frac{\partial^3 u^*}{\partial t^* \partial y^{*2}} + v^* \frac{\partial^3 u^*}{\partial y^{*3}} \right) \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p} \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p} \frac{\partial q_r^*}{\partial y^*} - \frac{Q_0}{\rho C_p} \left(T^* - T_\infty \right) \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - k_1 \left(C^* - C_\infty \right) \tag{4}$$

The boundary conditions for the above described model

$$u^* = u_{p^*} ,\ T^* = T_w + \varepsilon \left(T_w - T_\infty \right) e^{n^* t^*} , \tag{5}$$

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It is unambiguous that Eq. (1) that the velocity of suction at the surface plate is time function. Presuming it yields into the form:

$$v^* = -V_0\left(1+\varepsilon A e^{n^* t^*}\right) \tag{6}$$

ε and A are small such that $\varepsilon << 1, A << 1$.
Acknowledging a self-similar solution of the form

$$u=\frac{u^*}{V_0},\ u=\frac{v^*}{V_0},\ y=\frac{V_0 y^*}{\upsilon},\ t=\frac{V_0^2 y^*}{\upsilon},\ u_p=\frac{u_p^*}{V_0},$$
$$n=\frac{n^*\upsilon}{V_0^2},\ \theta=\frac{T^*-T_\infty}{T_w-T_\infty},\ C=\frac{C^*-C_\infty}{C_w-C_\infty} \tag{7}$$

the basic field Eqns. (2) to (4) can be expressed in non-dimensional form as

$$\frac{\partial u}{\partial t}-\left(1+\varepsilon A e^{nt}\right)\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\left(M+\frac{1}{K}\right)u+Gr\theta+GmC$$
$$-E\left[\frac{\partial^3 u}{\partial t\partial y^2}-\left(1+\varepsilon A e^{nt}\right)\frac{\partial^3 u}{\partial y^3}\right] \tag{8}$$

$$\frac{\partial \theta}{\partial t}-\left(1+\varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-(Q+R)\theta \tag{9}$$

$$\frac{\partial C}{\partial t}-\left(1+\varepsilon A e^{nt}\right)\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-KrC \tag{10}$$

$$u=u_p,\ \theta=1+\varepsilon e^{nt},\ C=1+\varepsilon e^{nt}\ \text{at}\ y=0$$
$$u\to 0,\ \theta\to 0,\ C\to 0\ \text{as}\ y\to\infty \tag{11}$$

$$Gr=\frac{(T_w-T_\infty)\beta_T g\upsilon}{V_0^3},\ Gm=\frac{(C_w-C_\infty)\beta_C g\upsilon}{V_0^3},$$
$$R=\frac{4\upsilon}{\rho C_p V_0^2},\ \Pr=\frac{\rho C_p \upsilon}{k},\ K=\frac{K^* V_0^2}{\upsilon^2},\ Kr=\frac{K_1\upsilon}{V_0^2}, \tag{12}$$
$$Sc=\frac{\upsilon}{D},\ Q=\frac{\upsilon Q_0}{\rho C_p V_0^2},\ E=\frac{k_0 V_0^2}{\upsilon^2}$$

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Results

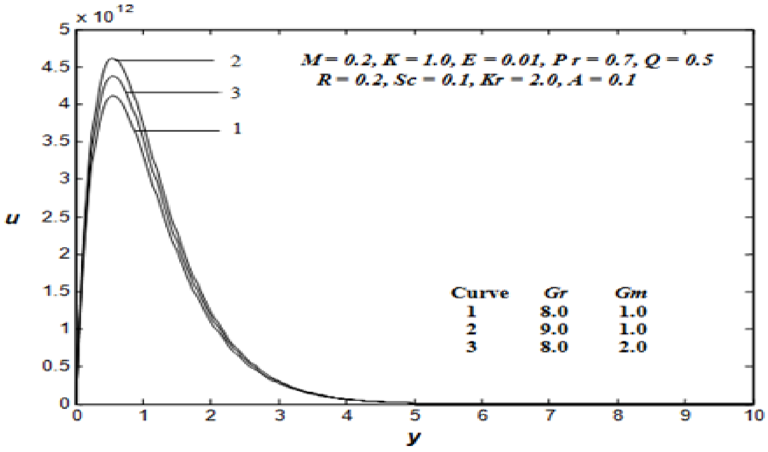

Figure 2. Distribution of u for Gr & Gm

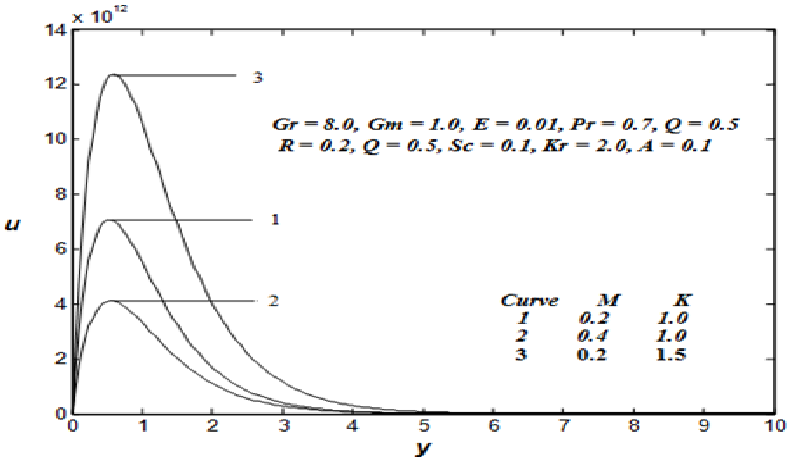

Figure 3. Distribution of u for M & K

Conclusion

In this investigation, we have constructed a mathematical framework to replicate the two-dimensional unsteady magnetohydrodynamic flow of an incompressible electrically conducting fluid over a permeable moving plate situated within a porous medium. This study takes into account the significant influences of thermal radiation and chemical reactions. The governing mathematical formulation is tackled through analytical methods employing perturbation techniques.

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