Influence of Thermal and Solute Transport on Magnetohydrodynamic Flow over an Inclined Porous Plate in the Presence of a Chemical Reaction.

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Abstract

This investigation delves into the effects of heat and mass transfer on the magnetohydrodynamic (MHD) flow over an inclined porous plate in the presence of a chemical reaction. The study elucidates the interplay between the Soret effect, the inclination angle, and various factors including heat source, chemical reaction, and thermal radiation. The governing equations for momentum, energy, and concentration are derived, resulting in a set of coupled second-order partial differential equations. To facilitate analysis, the model is non-dimensional zed and governed by a range of dimensionless parameters. These dimensionless equations can be solved analytically through closed-form methods. The study showcases numerical findings for key parameters such as the Soret number (Sr), Grashof number (Gr) representing heat and mass transfer effects, Schmidt number (Sc), Prandtl number (Pr), chemical reaction parameter (Kr), permeability parameter (K), magnetic parameter (M), as well as skin friction (τ), Nusselt number (Nu), and Sherwood number (Sh).

Introduction

The study of magnetohydrodynamic (MHD) free convection heat and mass transfer in porous media has consistently attracted attention due to its prevalence in nature and diverse applications across various scientific disciplines and technologies [1]. These applications span a wide range, including scenarios like fiber and granular insulation in geothermal systems for heating and cooling, energy generation through fossil fuel combustion processes, and astrophysical phenomena [2]. The influence of MHD-driven free convection within porous media holds significant importance, particularly in domains such as the petroleum industry, where it affects the flow of oil through porous rock formations [3]. Furthermore, its relevance extends to chemical engineering applications, encompassing purification and filtration processes, among others. An example of previous research in this domain [4-6], who conducted an experimental investigation on natural convection heat transfer from an arbitrarily inclined plate [7].

The study encompasses mass transfer phenomena that arise in a wide array of physical scenarios involving the diffusion and convection of chemical substances within physical systems [8]. These mass transfer considerations hold relevance in diverse realms, including chemical engineering for separation processes, elimination of pollutants during various chemical reactions, and more. The governing equations for these mass transfer phenomena are linear in nature, and a precise solution has been attained through the application of a closed analytical approach [9-11]. The investigation specifically focuses on selected physical scenarios, particularly those involving seepage flow, where the orientation of the flow domain need not be strictly vertical or horizontal. This model possesses potential applications in industrial and engineering contexts, given that the inclination angle of the plate contributes to a reduction in fluid velocity [12]. Importantly, it is noted that the existing literature does not contain any prior studies concerning the flow past an inclined plate exhibiting parabolic velocity variations over time [13].

Mathematical formulation

Let's examine an unsteady magnetohydrodynamic (MHD) flow characterized by free convection in a viscous, incompressible, and electrically conductive fluid. This flow takes place over an infinite inclined porous plate, where the plate's velocity varies with time [14]. Simultaneously, heat and mass transfer occur within a saturated porous medium.

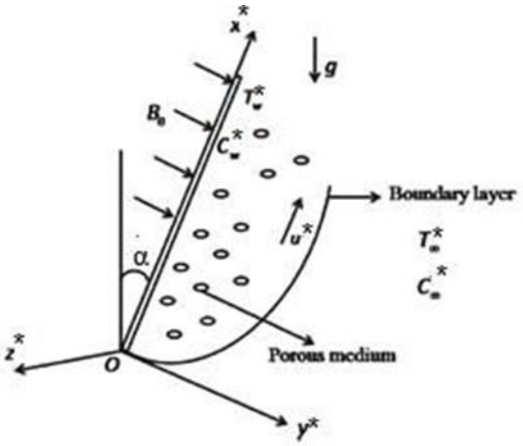


Figure 1: Physical configuration of the problem

In view of the above assumptions, the usual Boussinesq approximation, the governing equations considered are as follows:

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} = g[\beta(T^* - T_\infty^*)\cos\alpha + \beta^*(C^* - C_\infty^*)\cos\alpha] + \nu\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma B_0^2}{\rho}u^* - \frac{\nu u^*}{k_p^*}\,. \tag{2.1}$$

Energy equation

$$\rho C_p \frac{\partial T^*}{\partial t^*} = K_T \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q_r}{\partial y^*} + Q^*(T^* - T_\infty^*)\,. \tag{2.2}$$

Species equation

$$\frac{\partial C^*}{\partial t^*} = D_M \frac{\partial^2 C^*}{\partial y^{*2}} - K_C{}^*(C^* - C_\infty^*) + D_T \frac{\partial^2 T^*}{\partial y^{*2}} \tag{2.3}$$

The initial and boundary conditions of the physical model are presented by

$$t^* \le 0 : u^* = 0, \quad T^* = T_\infty^*, \quad C^* = C_\infty^* \forall y^*,$$

$$t^* > 0 : u^* = u_0\left(\frac{t^*}{t_0}\right)^2, \quad T^* = T_\infty^* + \frac{T_\omega^* - T_\infty^*}{\nu} u_0^2 \left(\frac{t^*}{t_0}\right),$$

$$C^* = C_\infty^* + \frac{C_\omega^* - C_\infty^*}{\nu} u_0^2 \left(\frac{t^*}{t_0}\right) \quad \text{at} \quad y^* = 0, \tag{2.4}$$

$$u^* \to 0, \quad T^* \to T_\infty^*, \quad C^* \to C_\infty^* \quad \text{as} \quad y^* \to \infty.$$

Using the Rosseland approximation the rate of radioactive heat flux is obtained by

$$\frac{\partial q_r}{\partial y^*} = -4a^* \sigma^* (T_\infty^{*4} - T^{*4}). \tag{2.5}$$

Methodology

This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the plate as

$$u(y,t) = u_0(y) e^{i\omega t},$$

$$\theta(y,t) = \theta_0(y) e^{i\omega t}, \tag{3.1}$$

$$\phi(y,t) = \phi_0(y) e^{i\omega t}.$$

Substituting (3.1) in Eqs (2.9) -(2.11) and (2.12) we get the differential equations

$$u_0'' - k_3^2 u_0 = -[\mathrm{Gr}\theta_0 \cos\alpha + \mathrm{Gm}\phi_0 \cos\alpha], \tag{3.2}$$

$$\theta_0'' - k_1^2 \theta_0 = 0. \tag{3.3}$$

$$\phi_0'' - k_1^2 \phi_0 = -\mathrm{SrSc}\theta_0''. \tag{3.4}$$

The corresponding boundary conditions are

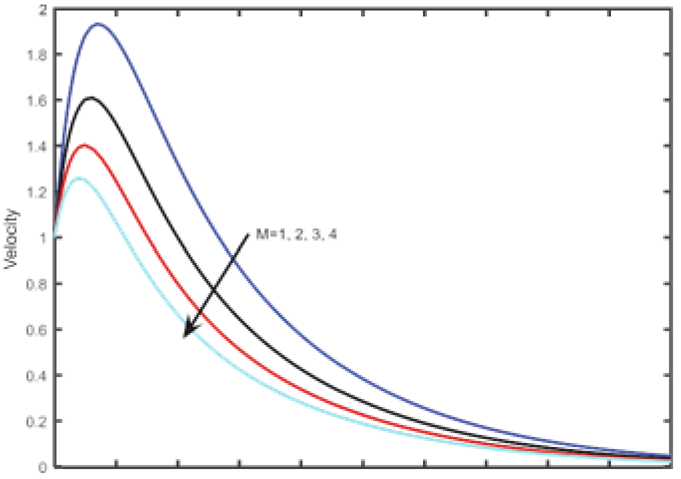
$$t \le 0 : \quad u_0 = 0, \quad \theta_0 = 0, \quad \phi_0 = 0 \forall y,$$

$$t > 0 : \quad u_0 = t^2 e^{-i\omega t}, \quad \theta_0 = t e^{-i\omega t}, \quad \phi_0 = t e^{-i\omega t} \quad \text{at} \quad y = 0, \tag{3.5}$$

$$\mathrm{u}_0 \to 0, \quad \theta_0 \to 0, \quad \phi_0 \to 0 \quad \text{as} \quad y \to \infty$$

Results

In Figure 2, the impact of the magnetic field on velocity profiles is illustrated. Notably, as the magnetic parameter (M) rises, the velocity exhibits a noticeable decrease [15]. This behavior stems from the influence of the Lorentz force on the fluid flow—a retarding force that contributes to the deceleration of fluid velocity, as depicted in the figure. Turning to Figure 3, the role of the permeability parameter in velocity profiles is depicted. This representation reveals that an augmented permeability parameter corresponds to an increased velocity. As the parameter grows, the fluid's velocity exhibits an observable rise, as illustrated in the figure.



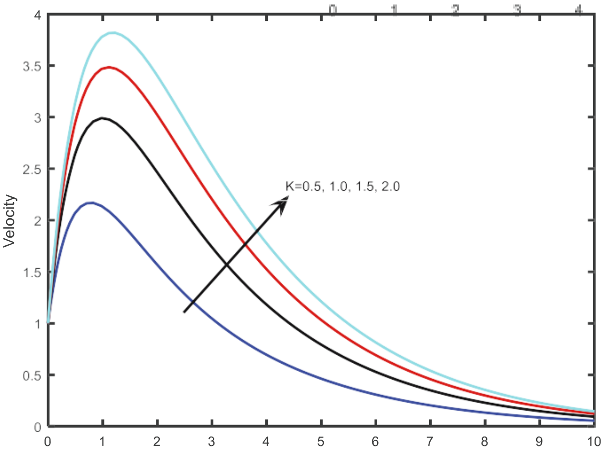


Fig.3. Velocity profiles for different values of the permeability parameter (K).

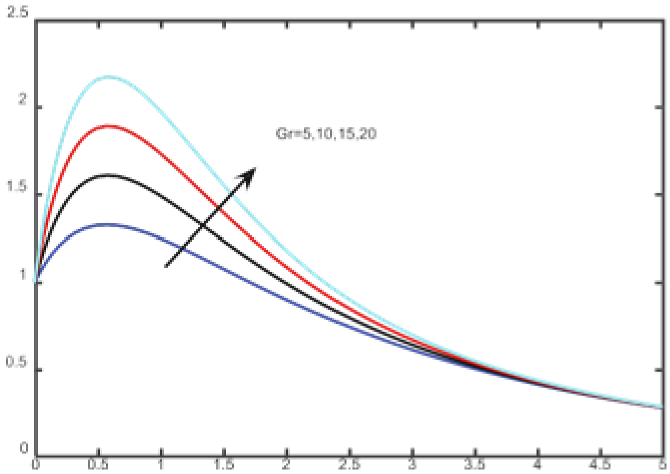


Fig.4. Velocity profiles for different values of the Grashof number (Gr).

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