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CHEMICAL REACTION AND RADIATION ABSORBTION EFFECTS ON MHD CONVECTIVE HEAT AND MASS TRANSFER FLOW OF A VISCOELASTIC FLUID PAST AN OSCILLATING POROUS PLATE WITH HEAT GENERATION/ABSORPTION

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ABSTRACT

In this paper, the combined influence of chemical reaction and radiation absorption effects on hydromagnetic free convective heat and mass transfer flow of viscous, in-compressible, electrically conducting visco-elastic fluid through porous medium bounded by an oscillating porous plate in the presence of heat sources is studied. The expressions for velocity, temperature and concentration distribution, skin-friction, rate of heat and mass transfer coefficients at the plate are obtained using perturbation technique. The effect of various physical parameters occurring into the problem on velocity field is discussed with the help of graphs.

Key words: MHD, Chemical reaction, Radiation absorption, Visco-elastic, Skin-friction.

INTRODUCTION

The study of non Newtonian fluid flow has gained the attention of engineers and scientist in recent times due to its important application in various branches of science, engineering and technology: Particularly in chemical and nuclear industries, material processing, geophysics, and bio-engineering. In view of these applications an extensive range of mathematical models have been developed to simulate the diverse hydrodynamic behavior of these non-Newtonian fluids. In particular, different visco-elastic fluid model like the Rivlin-Ericksen second order model. Oldroyd model and Johnson-Seagalman model.

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The fluid, which exhibits the elasticity property of solids and viscous property of liquids are called visco-elastic fluid. These fluid flows are encountered in numerous areas of petrochemical, biomedical and environmental engineering including polypropylene coalescence sintering. Beard and Walter[1] had introduced the boundary layer treatment for an idealized visco-elastic fluid. The heat transfer in the forced convection flow of a visco-elastic fluid of Walter model was investigated by Rajagopal[2]. Some theoretical studies had analyzed the flow and heat transfer characteristics of Walter's Liquid-B fluid[3-7]. Devika et al.[8] investigated MHD oscillatory flow of a visco-elastic fluid in a porous channel with chemical reaction. Kumar and Sivaraj[9] studied MHD Visco-elastic fluid non-darcy flow along a moving vertical cone. Vidyasagar and Raman[10] reported a study on the radiation effect on MHD convection flow of Kuvshinshiki fluid with mass transfer past a vertical porous plate through porous medium. Sivaraj and Kumar[11] studied an unsteady MHD dusty visco-elastic fluid Couette flow in an irregular channel with varying mass diffusion.

In many chemical engineering processes, the chemical reaction do occur between mass and fluid in which plate is moving. These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing. In the light of the fact that, the combination of heat and mass transfer problems with chemical reaction are of importance in many processes, and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electricity is one in which electrical energy is extracted directly from the moving conducting fluid. Chamkha[12] studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction. Muthucumaraswamy and Ganesan[13] investigated the effects of a chemical reaction on the unsteady flow past an impulsively started semi-infinite vertical plate, which subjected to uniform heat flux. Ibrahim et al.[14] analyzed the effects of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Mohamed[15] has discussed double-diffusive convection radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and soret effects.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Chamkha[16] investigated unsteady convective heat and mass transfer past a semi-infinite porous moving plate with heat absorption. Shanker et al.[17] presented a numerical solution for radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation/absorption using Galerkin finite element method. Hady et al.[18] studied the problem of free convection flow along a vertical wavy surface embedded in electrically conducting fluid saturated porous media in the presence of internal heat generation or absorption effect. Hossian et al.[19] studies the problem of natural convection flow along a vertical wavy surface with uniform surface temperature in the presence of heat generation/absorption. Balamurugan et al.[20] investigated the effects of chemical reaction, thermal radiation and radiation absorption on unsteady double diffusive free convection flow of Kuvshinski fluid past a moving porous plate with heat generation under the influence of a uniform transverse magnetic field.

The aim of the present investigation is to study the influence of chemical reaction and radiation absorption on hydromagnetic free convective heat and mass transfer flow of viscous, in-compressible, electrically conducting visco-elastic fluid through porous medium bounded by an oscillating porous plate in the presence of heat source. The dimensionless governing equations are solved using the perturbation technique.

EXPERIMENTAL

Mathematical analysis

In this problem, we consider two dimensional unsteady free convection flow of an incompressible, electrically conducting, Visco-elastic fluid (Kuvshinski fluid) past a semi infinite vertical oscillating porous plate under the influence of a uniform magnetic field in the presence of chemical reaction, heat generation and radiation absorption. Let x^*-axis is taken along the porous plate in the upward direction and y^*-axis is normal to it. The fluid is assumed to be gray, absorbing-emitting but non-scattering medium. The radiative heat flux in the x^*-direction is considered negligible in comparison with that in the y^*-direction. It is assumed that there is no applied voltage of which implies the absence of an electric field. The transversely applied magnetic field and magnetic Reynolds number are very small and hence the induced magnetic field is negligible. The MHD term is derived from an order of magnitude analysis of the full Navier-stokes equation. It is assumed that the whole size of the porous plate is significantly larger than characteristics microscopic length scale of the porous medium. We regard the porous medium as an assemblage of small identical spherical particles fixed in space. The chemical reactions are taking place in the flow and all thermo physical properties are assumed to be constant of the linear momentum equation, which is approximation. The fluid properties are assumed to be constant except that the influence of density variation with temperature and concentration has been considered in the body force term. The magnetic and viscous dissipations are neglected. Due to the assumption that the plate in x^*-direction is of infinite length, all the flow variables except pressure are functions of y^* and t^* only.

Under the above assumptions, the governing boundary layer equation of the flow field are given by

$$\frac{\partial v}{\partial y}=0 \qquad \ldots(1)$$

$$\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-k_1^1\frac{\partial^3 u}{\partial y^2\partial t}+g\beta(T-T\infty)+g\beta^*(C-C_\infty)-\frac{\sigma_e B_0{}^2}{\rho}u-\frac{\nu}{K_0}u \qquad \ldots(2)$$

$$\rho C_p\left(\frac{\partial T}{\partial t}+v\frac{\partial T}{\partial y}\right)=\kappa\frac{\partial^2 T}{\partial y^2}-s^1\left(T-T_\infty\right)-R^1\left(C-C_\infty\right) \qquad \ldots(3)$$

$$\frac{\partial c}{\partial t}+v\frac{\partial c}{\partial y}=D\frac{\partial^2 c}{\partial y^2}-K^1\left(C-C_\infty\right) \qquad \ldots(4)$$

Where u,v are the velocity components in x, y directions, respectively. t- the time, ρ-the fluid density, ν - the kinematic viscosity, C_p- the specific heat at constant pressure, g- the acceleration due to gravity, β and β*- the thermal and concentration expansion coefficient, respectively, B_0- the magnetic induction, D- Coefficient of chemical molecular diffusivity, K^1- Reaction rate constant, R^1- Radiation absorption coefficient, s^1- Heat source/sink constant, K- Thermal conductivity, K_0-Permeability of the porous medium, $k_1{}^1$- the dimensional visco-elastic parameter, T- the dimensional temperature, C- the dimensional concentration.

The boundary conditions are –

$$u=U_0\left(1+\in\ e^{i\omega t}\right),\ T=T_w+\in\left(T_w-T_\infty\right)e^{i\omega t}\ C=\ C_w+\in\left(C_w-C_\infty\right)e^{i\omega t} \qquad at\quad y=0$$

$$u\to 0,\quad T\to T_\infty,\quad C\to C_\infty \qquad as\ y\to\infty \qquad \ldots(5)$$

Where U_0 is the plate velocity, T_w and C_w are the wall dimensional temperature and concentration, respectively, T_∞ and C_∞ are the free stream dimensional temperature and concentration, respectively, ω -the constant.

The equation (1) gives

$$v = -V_0 \qquad \text{…(6)}$$

Where V_0 is the constant suction velocity normal to the plate

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

$$y^* = \frac{U_0}{\nu}y,\quad u^* = \frac{u}{U_0},\quad \theta = \frac{T-T_\infty}{Tw-T_\infty},\quad \phi = \frac{C-C_\infty}{C_w-C_\infty},\quad t^* = \frac{U_0{}^2 t}{\nu},\quad V_0{}^* = \frac{V_0}{U_0},\quad W^* = \frac{\nu w}{U_0^2}$$

$$S_c = \frac{\nu}{D},\quad K_r = \frac{K^1\nu}{U_0{}^2},\quad M^2 = \frac{\sigma e B_0{}^2 \nu}{\rho U_0{}^2},\quad P_r = \frac{\mu C_p}{\kappa},\quad S = \frac{\nu^2 S^1}{U_0{}^2\kappa},\quad R_1 = \frac{R^1\nu^2}{U_0{}^2\kappa}\frac{(C_w-C_\infty)}{(T_w-T_\infty)}$$

$$G_r = \frac{\nu g\beta(T_w-T_\infty)}{U_0^3},\quad G_m = \frac{\nu g\beta^*(C_w-C_\infty)}{U_0^3},\quad K_p = \frac{U_0^2 K_0}{\nu^2},\quad \lambda_1 = \frac{U_0^2 K_1^1}{\nu^2\rho} \qquad \text{…(7)}$$

In view of the above non-dimensional quantities and the equation (6) the equations (2) to (4) after dropping the asterisks reduce to the following dimensionless form.

$$\frac{\partial u}{\partial t} - V_0\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m\phi - M_1 u - \lambda_1\frac{\partial^3 u}{\partial y^2\partial t} \qquad \text{…(8)}$$

$$P_r\frac{\partial\theta}{\partial t} - P_r V_0\frac{\partial\theta}{\partial y} = \frac{\partial^2\theta}{\partial y^2} - S\theta - R_1\phi \qquad \text{…(9)}$$

$$S_c\frac{\partial\varphi}{\partial t} - S_c V_0\frac{\partial\varphi}{\partial y} = \frac{\partial^2\varphi}{\partial y^2} - S_c K_r\varphi \qquad \text{…(10)}$$

Where $M_1 = M^2 + \frac{1}{K_P}$

The corresponding boundary conditions are –

$$u = 1 + \in e^{i\omega t},\quad \theta = 1 + \in e^{i\omega t},\quad \phi = 1 + \in e^{i\omega t} \quad at \quad y = 0 \qquad \text{…(11)}$$

$$u \to 0,\qquad \theta \to 0,\qquad \phi \to 0 \qquad \text{as} \quad y \to \infty$$

Solution of the problem

To solve the equations (8) to (10) subject to the boundary conditions (11), we apply the perturbation technique. Let the velocity, temperature and concentration fields as

$$u(y,t) = u_0(y) + \in u_1(y) \; e^{i\omega t}$$

$$\theta(y,t) = \theta_0(y) + \in \theta_1(y) \; e^{i\omega t}$$

$$\phi(y,t) = \phi_0(y) + \in \phi_1(y) \; e^{i\omega t} \qquad \ldots(12)$$

Where $\in$ is a small quantity ($\in << 1$), *Gr*, *Gm*, *M*, λ_1, P_r, *S*, R_1, *Sc* and *Kr* are the thermal Grash of number, Solutal Grashof number, Magnetic parameter, visco elastic parameter, Prandtl number, heat absorption parameter, radiation absorption parameter, Schmidt number and chemical reaction parameter, respectively.

Substituting equation (12) into the equations (8), (9) and (10) and equating the harmonic and non-harmonic terms, neglecting the terms of $\in^2$, we get

$$u_0^{11} + V_0 u_0^1 - M_1 u_0 = -G_r \theta_0 - G_m \phi_0 \qquad \ldots(13)$$

$$N_1 u_1^{11} + V_0 u_1^1 - N_2 u_1 = -G_r \theta_1 - G_m \phi_1 \qquad \ldots(14)$$

$$\theta_0^{11} + P_r V_0 \theta_0^1 \; - S\theta_0 \; = \; R_1 \phi_0 \qquad \ldots(15)$$

$$\theta_1^{11} + P_r V_0 \theta_1^1 \; - (S + iP_r \omega)\theta_1 \; = \; R_1 \phi_1 \qquad \ldots(16)$$

$$\phi_0^{11} + S_c V_0 \phi_0^1 - S_c K_r \phi_0 = 0 \qquad \ldots(17)$$

$$\phi_1^{11} + S_c V_0 \phi_1^1 - S_c \left(K_r + i\omega\right)\phi_1 = 0 \qquad \ldots(18)$$

Where $N_1 = 1 - i\lambda_1 \omega$, $N_2 = M_1 + i\omega$

Here the primes denote the differentiation with respect to y

The corresponding boundary conditions are

$$u_0 = 1,\; u_1 = 1,\; \theta_0 = 1,\; \theta_1 = 1,\; \phi_0 = 1,\; \phi_1 = 1 \text{ at } y = 0$$

$$u_0 \to 0,\; u_1 \to 0,\; \theta_0 \to 0, \theta_1 \to 0,\; \phi_0 \to 0,\; \phi_1 \to 0 \text{ as } y \to \infty \qquad \ldots(19)$$

In view of (19), solving the equation (13) – (18) we obtain – o

$$u_0(y) = A_5 e^{-a_4 y} + A_3 e^{-a_1 y} + A_4 e^{-a_2 y} \quad \ldots(20)$$

$$u_1(y) = A_6 e^{-b_1 y} + A_7 e^{-a_3 y} + A_8 e^{-a_5 y} \quad \ldots(21)$$

$$\theta_0(y) = A_1 e^{-a_1 y} + A_2 e^{-a_2 y} \quad \ldots(22)$$

$$\theta_1(y) = B_1 e^{-b_1 y} + B_2 e^{-a_3 y} \quad \ldots(23)$$

$$\phi_0(y) = e^{-a_1 y} \quad \ldots(24)$$

$$\phi_1(y) = e^{-b_1 y} \quad \ldots(25)$$

On substituting the expressions of u_0, u_1, θ_0, θ_1, ϕ_0, and ϕ_1 in the equations (12) the expressions for velocity, temperature and concentration are –

$$u(y,t) = \left(A_3 e^{-a_1 y} + A_4 e^{-a_2 y} + A_5 e^{-a_4 y}\right) + \in \left(A_6 e^{-b_1 y} + A_7 e^{-a_3 y} + A_8 e^{-a_5 y}\right) e^{i\omega t} \quad \ldots(26)$$

$$\theta(y,t) = \left(A_1 e^{-a_1 y} + A_2 e^{-a_2 y}\right) + \in \left(B_1 e^{-b_1 y} + B_2 e^{-a_3 y}\right) e^{i\omega t} \quad \ldots(27)$$

$$\phi(y,t) = e^{-a_1 y} + \in \; e^{-b_1 y} e^{i\omega t} \quad \ldots(28)$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin-friction at the plate in the non-dimensional form is given by –

$$\tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(a_1 A_3 + a_2 A_4 + a_4 A_5\right) + \in \left(b_1 A_6 + a_3 A_7 + a_5 A_8\right) e^{i\omega t} \quad \ldots(29)$$

The rate of heat transfer on the well in terms of nusselt number is given by –

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(a_1 A_1 + a_2 A_2\right) + \in \left(b_1 B_1 + a_2 B_2\right) e^{i\omega t} \quad \ldots(30)$$

The rate of mass transfer on the wall in terms of Sherwood number Sh is given by –

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = a_1 + \in\ b_1 e^{i\omega t} \qquad \ldots(31)$$

Where

$$a_1 = \frac{S_c V_0 + \sqrt{S_c^{\,2} V_0^{\,2} + 4 S_c K_r}}{2},\ b_1 = \frac{S_c V_0 + \sqrt{S_c^{\,2} V_0^{\,2} + 4 S_c \left(K_r + i\omega\right)}}{2}$$

$$a_2 = \frac{P_r V_0 + \sqrt{P_r^{\,2} V_0^{\,2} + 4S}}{2},\ \mathrm{a}_3 = \frac{\mathrm{P_r} + \sqrt{\mathrm{P_r}^2 + 4\mathrm{S}_1}}{2},\quad a_4 = \frac{V_0 + \sqrt{V_0^{\,2} + 4M_1}}{2},$$

$$a_5 = \frac{V_0 + \sqrt{V_o^{\,2} + 4N_1 N_2}}{2},\ A_1 = \frac{R_1^{\,2}}{a_1^{\,2} - P_r V_0 a_1 - S},\ S_1 = S + iP_r\omega^2,\ M_1 = M^2 + \frac{1}{K_P}$$

$$A_2 = 1 - A_1,\ B_1 = \frac{R_1}{b_1^{\,2} - b_1 P_r - S_1},\ B_2 = 1 - B_1,\ \mathrm{A}_3 = \frac{-\left(\mathrm{G_r A_1 + G_m}\right)}{\mathrm{a}_1^2 - \mathrm{V_0 a_1} - \mathrm{M}_1}$$

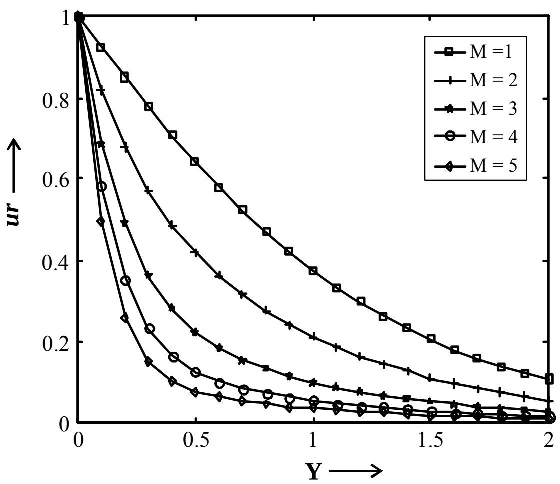
$$A_4 = \frac{-G_r A_2}{a_2^2 - a_2 V_0 - M_1},\ A_5 = 1 - A_3 - A_4,\ A_6 = \frac{\left(G_m + B_1 G_r\right)}{N_1 b_1^2 - V_0 b_1 - N_2},$$

$$A_7 = \frac{-B_2 G_r}{N_1 a_3^2 - V_0 a_3 - N_2},\ A_8 = 1 - A_6 - A_7,\ N_1 = 1 - i\lambda_1\omega\ ,\ N_2 = M_1 + i\omega$$

RESULTS AND DISCUSSION

In order to get the physical insight into the problem, we have plotted velocity profiles and the following discussion is set out. Throughout the computations we employ $Pr = 0.71$ (air), Sc = 0.22 (hydrogen), $\omega = 1$, $V_0 = 1$, $Gr = 1$, $Gm = 1$, $M = 1$, $S = 2$, $t = \frac{\pi}{2}$, $Kr = 1$, $Ra = 1$, $\varepsilon = 1$, $Kp = 1$, $\lambda_1 = 1$.

Figs. 1 and 2 indicate the behavior of primary and secondary velocities with the variations in magnetic parameter M. It is observed that an increase in the magnetic parameter leads to decrease both the primary velocity and secondary velocity profiles. This is due to the application of a magnetic field to an electrically conducting fluid produces a drag line force, which causes reduction in the fluid velocity.



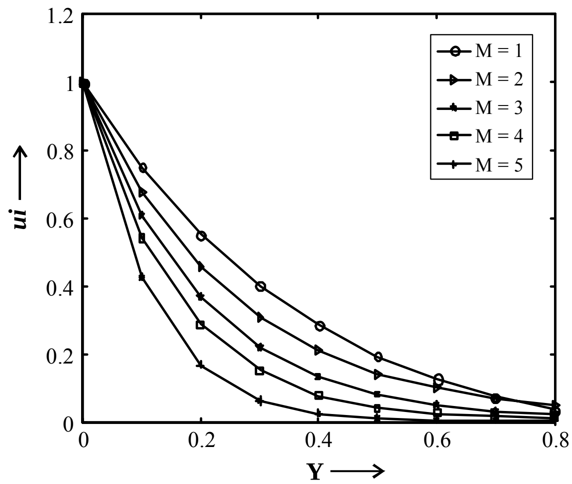
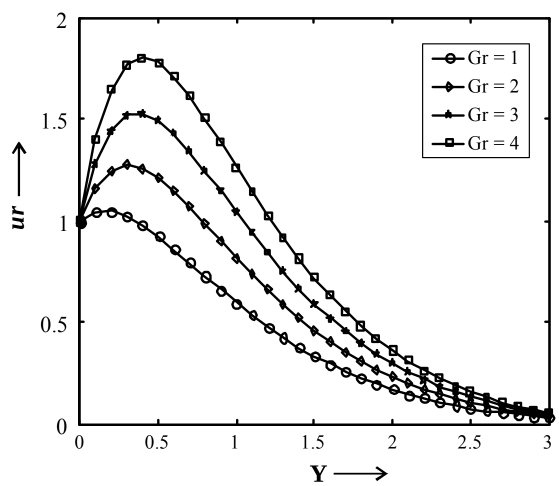


Fig. 1: Effect of *M* on primary velocity *ur* **Fig. 2: Effect of *M* on secondary velocity *ui***

Figs. 3 and 4 discuss the effect of Grash of number for heat transfer *Gr* on the primary and secondary velocity of the flow field. It is found that an increase in *Gm* leads to acceleration in the primary and secondary velocity profiles.



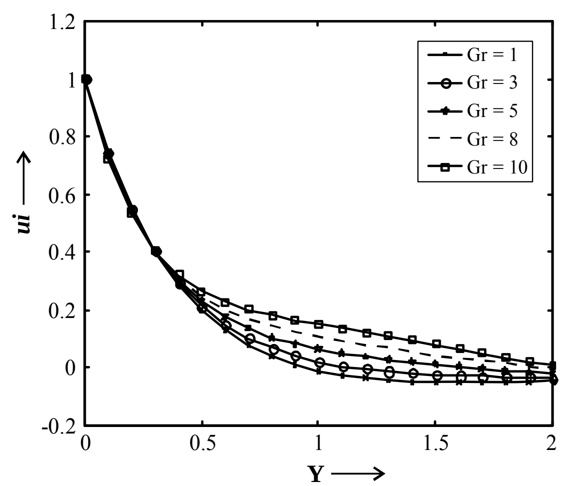


Fig. 3: Effect of *Gr* on primary velocity *ur* **Fig. 4: Effect of *Gr* on secondary velocity *ui***

Figs. 5 and 6 depict the primary and secondary velocity profiles for fluid flow, respectively for different values of the Schmidt number *Sc*. The Schmidt number *Sc* embodies the ratio of the momentum diffusivity to the mass (species) diffusivity. It is observed that for primary and secondary velocities, for heavier diffusing foreign species i.e., increasing Schmidt number Sc leads to an increase in the primary and secondary velocity profiles. The primary and secondary velocity for different values of Chemical reaction parameter *Kr* is shown in Figs. 7 and 8. From the Figs., in the case of primary velocity, it is found that the velocity increases with an increase in Kr. But the reverse effect is found in the case of secondary velocity.

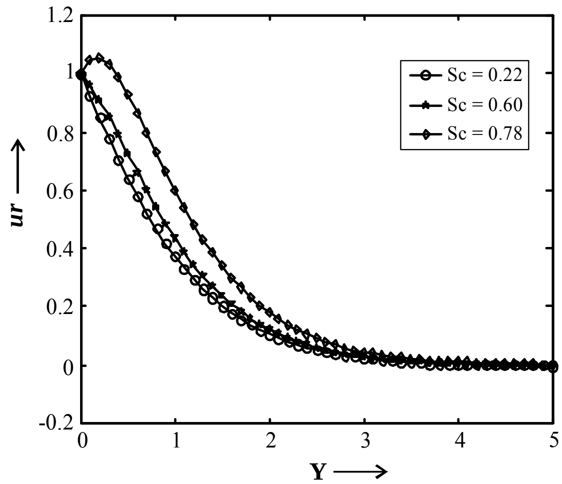


Fig. 5: Effect of *Sc* on primary velocity *ur*

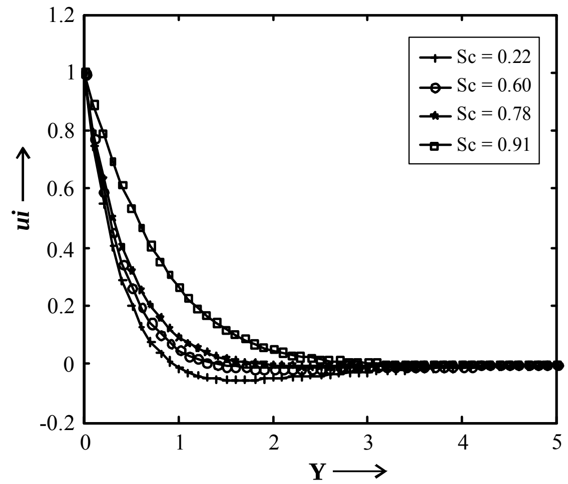


Fig. 6: Effect of *Sc* on secondary velocity *ui*

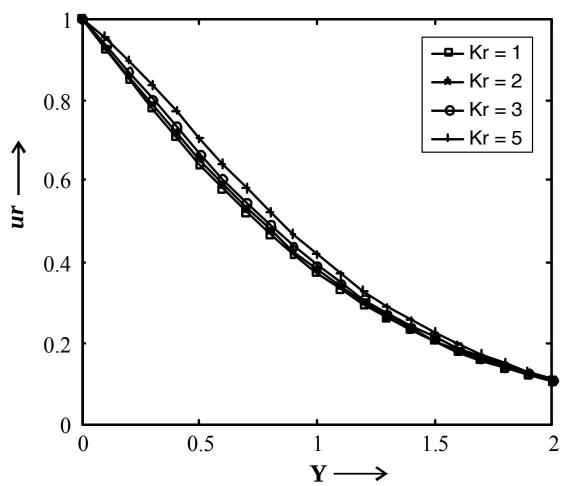


Fig. 7: Effect of *Kr* on primary velocity *ur*

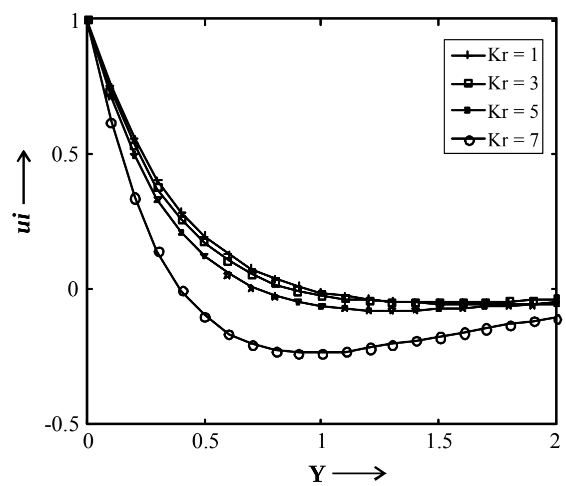


Fig. 8: Effect of *Kr* on secondary velocity *ui*

Figs. 9 and 10 represent the variation of Prandtl number *Pr* in the primary and secondary velocity profiles. It is observed that an increase in the *Pr* leads to decrease both the primary velocity and secondary velocity profiles. The primary and secondary velocity profiles are plotted in Figs. 11 and 12 for different values of heat source parameter *S*. It is observed that with the increase in heat source parameter decreases the primary velocity, while the secondary velocity increases.

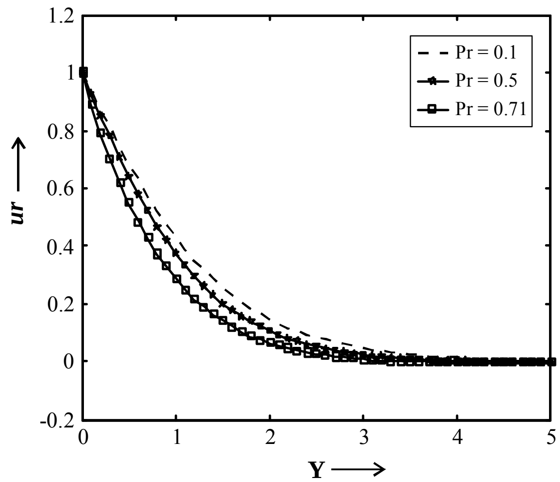


Fig. 9: Effect of *Pr* on primary velocity *ur*

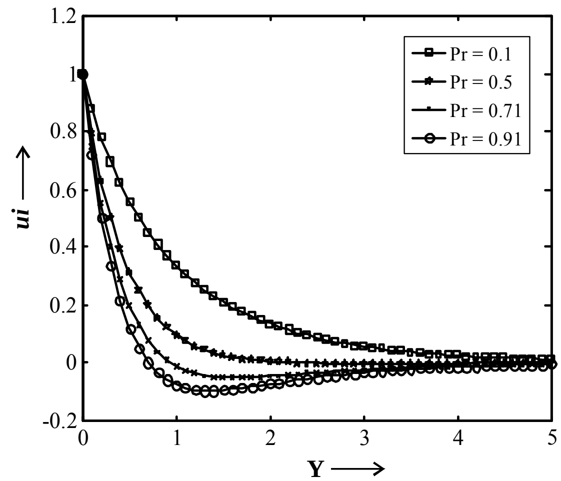


Fig. 10: Effect of *Pr* on secondary velocity *ui*

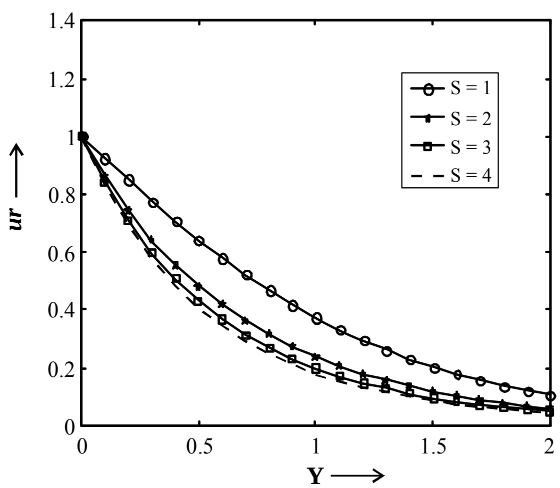


Fig. 11: Effect of *S* on primary velocity *ur*

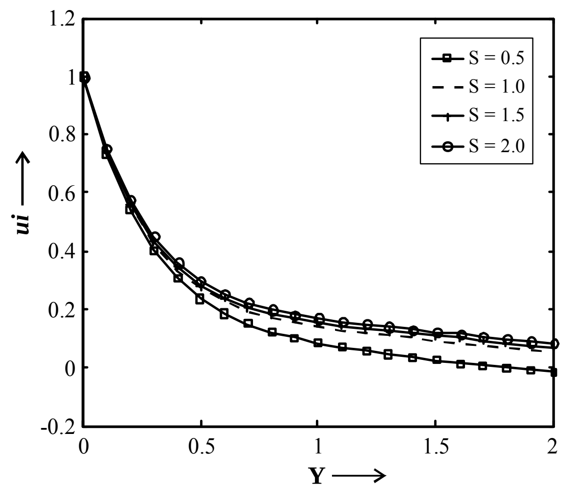


Fig. 12: Effect of S on secondary velocity *ui*

Effects of radiation absorption *Ra* are plotted in Figs. 13 and 14. As Ra increases a considerable reduction in the primary velocity occurs. As the radiation absorption parameter increases the thickness of the momentum boundary layer increases for secondary velocity.

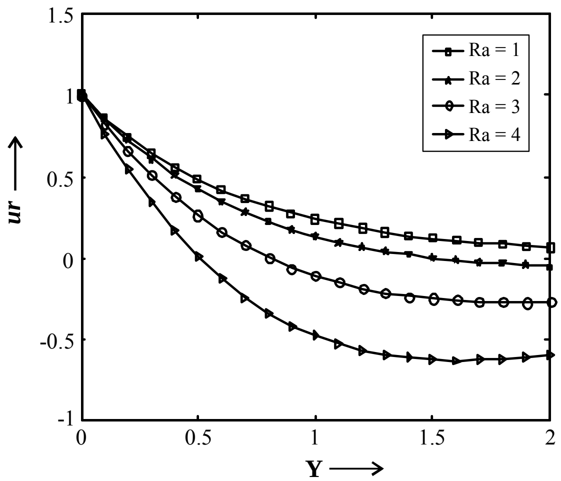


Fig. 13: Effect of *Ra* on primary velocity *ur*

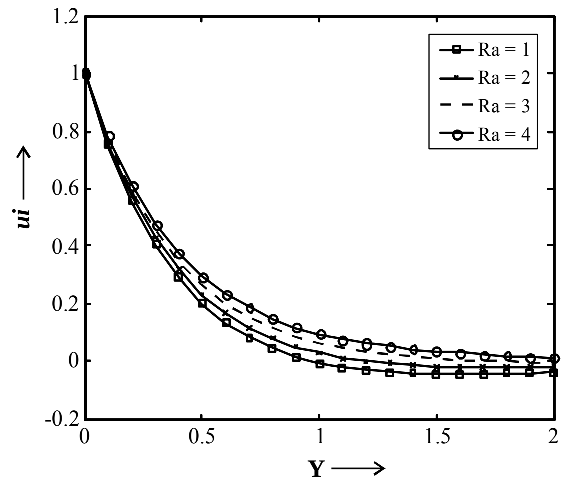


Fig. 14: Effect of *Ra* on secondary velocity *ui*

Figs. 15 and 16 display the effect of visco-elastic parameter λ_1 on primary and secondary velocity profiles. It is observed that an increasing in λ_1 leads to decreasing the thermal boundary layer thickness.

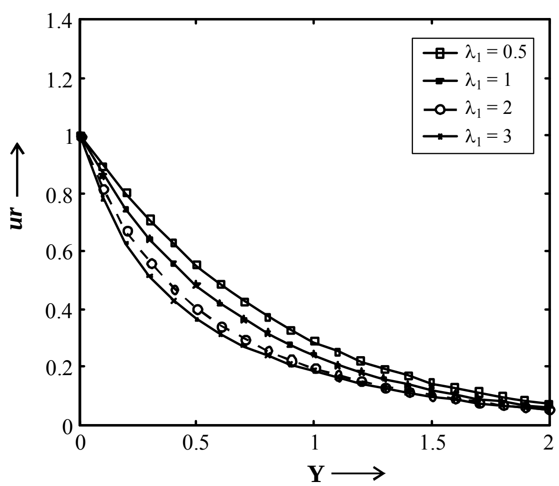


Fig. 15: Effect of λ_1 on primary velocity *ur*

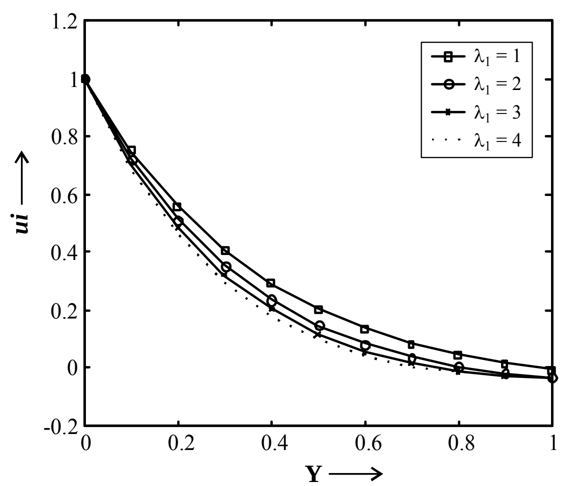


Fig. 16: Effect of λ_1 on secondary velocity *ui*

CONCLUSION

In this study, an analytical solution of unsteady hydromagnetic free convective heat and mass transfer flow of viscous, in-compressible, electrically conducting visco-elastic fluid through porous medium bounded by an oscillating porous plate in the presence of chemical reaction, radiation absorption and heat source has been investigated. The conclusions of the study are follows:

(i) The Hartmann number has the effect of decreasing the flow field both primary and secondary velocity at all the points due to the magnetic pull of the Lorentz force acting on the flow field. So magnetic field can effectively be used to control the flow.

(ii) The primary and secondary velocity along main flow increase with increasing thermal Grash of number.

(iii) There is an accelerating effect of Sc on the primary and the secondary velocity in presence of heavier diffusing species.

(iv) The chemical reaction parameter has the effect of decreasing the both primary and secondary velocity profiles.

(v) The Prandtl number has a retarding effect on the primary and secondary velocity of the flow field.

(vi) The primary velocity decreases with an increase in heat source parameter and radiation absorption parameter, where as secondary velocity increases with an increase in heat source parameter and radiation absorption parameter.

(vii) The visco elastic parameter has the influence of decreasing the primary and secondary velocity.

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