MHD Free Convection Flow Past an Exponentially Accelerated Inclined Plate Embedded in Porous Medium

R. Swetha, J. Prakash, G. Viswanatha Reddy and S. Vijaya Kumar Varma

Abstract The consequences of radiation absorption and chemical reaction in the presence of heat generation on a MHD unsteady laminar flow with mass and heat transfer of an electrically conducting, incompressible, and viscous fluid over an accelerated exponentially inclined vertical moving porous plate in a porous medium are analyzed in closed form. A perfect solution for this flow problem was obtained by resolving the resulting governing equations by the technique of Laplace transforms. The exact solutions for profiles of concentration, temperature, velocity, and the gradient of velocity are presented, and the effects of these profiles for several values of various arguments are discussed through graphs.

1 Introduction

In recent years, flows through porous media have the considerable research activities such as the filtration of solids from liquids, the extraction of geothermal energy, flow of liquids through ion exchange beds, chemical reactor for purification of mixtures or economical separation and so on. These flows are also having many applications in engineering. Many engineering applications are susceptible to MHD analysis. In technological point of view, magnetohydrodynamic flow finds application in the fields of aeronautics, planetary and stellar magnetospheres, solar physics, cosmic fluid dynamics, electronics, chemical engineering, MHD generators, MHD accelerators, construction of turbines, and other centrifugal machines.

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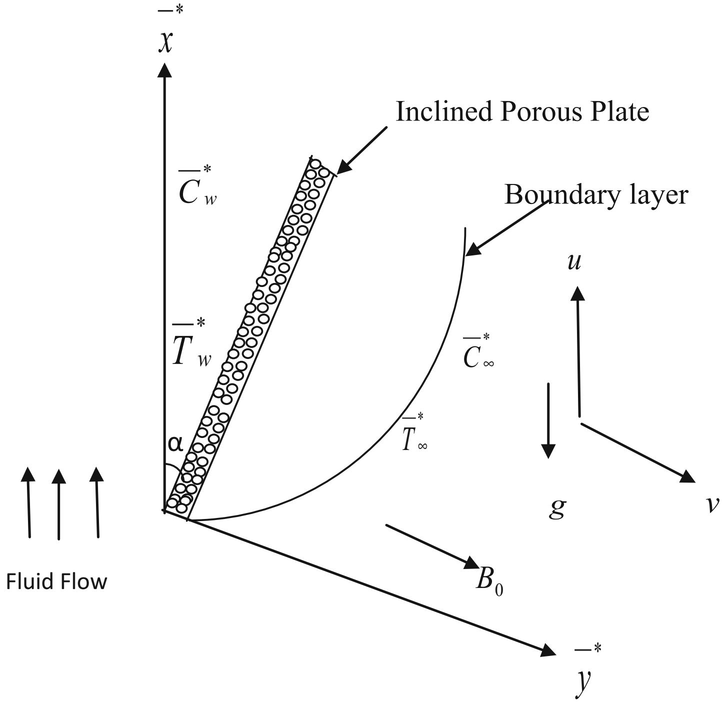
The consequence of chemical reaction on MHD convective transient free flow past a vertical moving plate was studied by Al-Odat and Al-Azab (2007).

Chamkha (2004) investigated the MHD unsteady convective mass and heat transfer with heat absorption over a permeable semi-transfinite vertical moving plate. Kafousias and Raptis (1981) continued this problem containing the leads of mass transfer corresponding to the varying suction or injection. Magnetohydrodynamic convective mixed flow, mass, and heat transfer with constant wall suction in porous medium past a vertical plate was presented by Makinde and Sibanda (2008). Muthucumaraswamy and Subramanian (2010) discussed the heat transfer consequences with mass flux and varying temperature on vertical accelerated plate. Raptis and Massalas (1998) identified the consequences of radiation in the presence of induced magnetic field on the oscillatory flow. Raptis and Perdikis (1985) numerically analyzed the convective free flow through porous medium bounded by a semi-transfinite vertical porous plate. Convective heat transfer with uniform free stream in a fluid which is electrically conducting at an extending surface was discussed by Vajravelu and Hadjinicolaou (1997).

The main intension of this flow problem is to discuss the consequences of heat source parameter, mass diffusion, chemical reaction, and radiation absorption with the constant temperature in the presence of applied uniform magnetic field on a magnetohydrodynamic unsteady convective free flow with mass and heat transfer past an inclined vertical porous plate which is accelerated exponentially in a porous medium.

2 Mathematical Analysis

For this flow problem, consider a transient mass and heat transfer flow of incompressible, natural, electrically conducting, radiation absorption, and viscous fluid with constant heat source past an inclined vertically moving porous plate which is accelerated exponentially in a porous medium in the presence of magnetic field and a chemical reaction. Presuming at all the points, initially in the stationary state, fluid and the plate are maintained the equal temperature T'_∞ with level of concentration C'_∞. The y' axis is chosen normal to the vertical plate, and x' axis is considered along the vertical plate. At time $t' > 0$, in its own plane, the vertical plate is accelerated exponentially with a velocity $u_0 e^{a't'}$. And at the same time, the vertical plate temperature raises to T'_w, and the level of concentration is also raises to C'_w near the plate. Also assuming that, a transverse magnetic field B_0 is applied normal to the vertical plate. Hence, the physical arguments are functions of coordinates t' and y' only because of the fluid flow is assumed to be in the direction of x' axis.



FLOW CONFIGURATION

By the usual approximation of Boussenique's, the governing equations in Cartesian frame of reference for this unsteady flow are

$$\frac{\partial \overline{u}^*}{\partial \overline{t}^*} = g\beta \cos\alpha\left(\overline{T}^* - \overline{T}^*_\infty\right) + g\overline{\beta}\cos\alpha\left(\overline{C}^* - \overline{C}^*_\infty\right) + \nu\frac{\partial^2 \overline{u}^*}{\partial \overline{y}^{*2}} - \frac{\sigma B_0^2 \overline{u}^*}{\rho} - \frac{\nu}{\kappa}\overline{u}^* \quad (1)$$

$$\frac{\partial \overline{T}^*}{\partial \overline{t}^*} = \frac{\kappa}{\rho C_p}\frac{\partial^2 \overline{T}^*}{\partial \overline{y}^{*2}} - \frac{Q_0}{\rho C_p}\left(\overline{T}^* - \overline{T}^*_\infty\right) + \overline{Q}^*_1\left(\overline{C}^* - \overline{C}^*_\infty\right) \quad (2)$$

$$\frac{\partial \overline{C}^*}{\partial \overline{t}^*} = D\frac{\partial^2 \overline{C}^*}{\partial \overline{y}^{*2}} - K_r\left(\overline{C}^* - \overline{C}^*_\infty\right) \quad (3)$$

with the conditions

$$\left.\begin{array}{llll} \overline{t}^* > 0: \overline{u}^* = u_0 e^{\overline{a}^*\overline{t}^*}, & \overline{T}^* = \overline{T}^*_w, & \overline{C}^* = \overline{C}^*_w & \text{at } \overline{y}^* = 0 \\ \overline{u}^* = 0, & \overline{T}^* \to \overline{T}^*_\infty, & \overline{C}^* \to \overline{C}^*_\infty & \text{as } \overline{y}^* \to \infty \\ \overline{t}^* \le 0: \overline{u}^* = 0, & \overline{T}^* = \overline{T}^*_\infty, & \overline{C}^* = \overline{C}^*_\infty & \forall\, \overline{y}^* \end{array}\right\} \quad (4)$$

And the introduced dimensionless quantities are

$$\left.\begin{array}{l} U=\dfrac{\bar{u}^{*}}{u_0},\quad t=\dfrac{\bar{t}^{*}u_0^2}{v},\quad y=\dfrac{\bar{y}^{*}u_0}{v},\quad Pr=\dfrac{\mu C_p}{\kappa},\quad a=\dfrac{\bar{a}^{*}v}{u_0^2} \\ Gr=\dfrac{g\beta v\left(\overline{T}_w^{*}-\overline{T}_\infty^{*}\right)}{u_0^3},\quad \theta=\dfrac{\overline{T}^{*}-\overline{T}_\infty^{*}}{\overline{T}_w^{*}-\overline{T}_\infty^{*}},\quad Gm=\dfrac{g\overline{\beta}v\left(\overline{C}_w^{*}-\overline{C}_\infty^{*}\right)}{u_0^3} \\ C=\dfrac{\overline{C}^{*}-\overline{C}_\infty^{*}}{\overline{C}_w^{*}-\overline{C}_\infty^{*}},\quad K=\dfrac{K_r v}{u_0^2},\quad Sc=\dfrac{v}{D},\quad Q_1=\dfrac{v\overline{Q}_1^{*}\left(\overline{C}_w^{*}-\overline{C}_\infty^{*}\right)}{u_0^2\left(\overline{T}_w^{*}-\overline{T}_\infty^{*}\right)} \\ M=\dfrac{\sigma B_0^2 v}{\rho u_0^2},\quad k_p=\dfrac{\kappa u_0^2}{v^2},\quad \phi=\dfrac{Q_0 v}{\rho C_p u_0^2} \end{array}\right\} \tag{5}$$

Using (5), the ruled equations (1)–(3) are reduced into the following dimensionless form:

$$\frac{\partial U}{\partial t}=Gr\theta\cos\alpha+GmC\cos\alpha+\frac{\partial^2 U}{\partial y^2}-\left(M+\frac{1}{k_p}\right)U \tag{6}$$

$$\frac{\partial\theta}{\partial t}=\left(\frac{1}{Pr}\right)\frac{\partial^2\theta}{\partial y^2}-\phi\theta+Q_1C \tag{7}$$

$$\frac{\partial C}{\partial t}=\left(\frac{1}{Sc}\right)\frac{\partial^2 C}{\partial y^2}-KC \tag{8}$$

And the corresponding conditions are

$$\left.\begin{array}{llll} \text{at } t>0\text{: } U=e^{at}, & \theta=1, & C=1 & \text{at } y=0 \\ \quad U\to 0, & \theta\to 0, & C\to 0 & \text{as } y\to\infty \\ \text{at } t\le 0\text{: } U=0, & \theta=0, & C=0 & \forall\, y \end{array}\right\} \tag{9}$$

3 Solution of the Problem

With the conditions (9), these non-dimensional ruled equations (6)–(8) are solved by the technique of Laplace transforms in closed form, and hence, the exact solutions for profiles of concentration, temperature, velocity, and the gradient of velocity are given by

$$C(y,t)=A_4 \tag{10}$$

$$\theta(y,t)=A_1+\frac{b}{c}(A_2-A_1)-\frac{b}{c}(A_3-A_4) \tag{11}$$

$$\begin{aligned}U(y,t) = D_1 &+ \frac{N_1}{p}(D_2 - D_3 - D_6 + D_7) + \frac{bN_1}{pc}(D_3 - D_7) + \frac{bN_1}{c(c-p)}(D_4 - D_8) \\ &+ \frac{bN_1}{p(p-c)}(D_2 - D_6) + \frac{bN_2}{cw}(D_9 - D_3) + \frac{bN_2}{c(c-w)}(D_{10} - D_4) \\ &+ \frac{bN_2}{w(w-c)}(D_{11} - D_5) + \frac{N_3}{w}(D_5 - D_3 - D_{11} + D_9)\end{aligned} \tag{12}$$

4 Velocity Gradient

From the field of velocity, the gradient of velocity in terms of Skin friction in dimensionless form is

$$\tau = -\left(\frac{\partial U}{\partial y}\right)_{y=0} \tag{13}$$

From (12) and (13), we get

$$\begin{aligned}\tau = B_1 &+ \frac{N_1}{p}(B_3 - B_2 + B_6 - B_7) + \frac{bN_1}{pc}(B_7 - B_3) + \frac{bN_1}{c(c-p)}(B_8 - B_4) \\ &+ \frac{bN_1}{p(p-c)}(B_6 - B_2) + \frac{bN_2}{cw}(B_3 - B_9) + \frac{bN_2}{c(c-w)}(B_4 - B_{10}) \\ &+ \frac{bN_2}{w(w-c)}(B_5 - B_{11}) + \frac{N_3}{w}(B_3 - B_5 + B_{11} - B_9)\end{aligned} \tag{14}$$

where

$$A_1 = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} - \sqrt{\phi t}\right)\mathrm{e}^{-y\sqrt{Pr}\sqrt{\phi}} + \operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} + \sqrt{\phi t}\right)\mathrm{e}^{y\sqrt{Pr}\sqrt{\phi}}\right]$$

$$A_2 = \frac{\mathrm{e}^{ct}}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} - \sqrt{(\phi+c)t}\right)\mathrm{e}^{-y\sqrt{Pr}\sqrt{\phi+c}} + \operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} + \sqrt{(\phi+c)t}\right)\mathrm{e}^{y\sqrt{Pr}\sqrt{\phi+c}}\right]$$

$$A_3 = \frac{\mathrm{e}^{ct}}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{(K+c)t}\right)\mathrm{e}^{-y\sqrt{Sc}\sqrt{K+c}} + \operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{(K+c)t}\right)\mathrm{e}^{y\sqrt{Sc}\sqrt{K+c}}\right]$$

$$A_4 = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{Kt}\right)\mathrm{e}^{-y\sqrt{Sc}\sqrt{K}} + \operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{Kt}\right)\mathrm{e}^{y\sqrt{Sc}\sqrt{K}}\right]$$

$$D_1 = \frac{e^{at}}{2}\left[e^{-y\sqrt{a+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} - \sqrt{\left(a+M+\frac{1}{k_p}\right)t}\right) + e^{y\sqrt{a+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} + \sqrt{\left(a+M+\frac{1}{k_p}\right)t}\right)\right]$$

$$D_2 = \frac{e^{pt}}{2}\left[e^{-y\sqrt{p+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} - \sqrt{\left(p+M+\frac{1}{k_p}\right)t}\right) + e^{y\sqrt{p+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} + \sqrt{\left(p+M+\frac{1}{k_p}\right)t}\right)\right]$$

$$D_3 = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} - \sqrt{\left(M+\frac{1}{k_p}\right)t}\right)e^{-y\sqrt{M+\frac{1}{k_p}}} + \operatorname{erfc}\left(\frac{y}{2\sqrt{t}} + \sqrt{\left(M+\frac{1}{k_p}\right)t}\right)e^{y\sqrt{M+\frac{1}{k_p}}}\right]$$

$$D_4 = \frac{e^{ct}}{2}\left[\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} - \sqrt{\left(c+M+\frac{1}{k_p}\right)t}\right)e^{-y\sqrt{c+M+\frac{1}{k_p}}} + \operatorname{erfc}\left(\frac{y}{2\sqrt{t}} + \sqrt{\left(c+M+\frac{1}{k_p}\right)t}\right)e^{y\sqrt{c+M+\frac{1}{k_p}}}\right]$$

$$D_5 = \frac{e^{wt}}{2}\left[e^{-y\sqrt{w+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} - \sqrt{\left(w+M+\frac{1}{k_p}\right)t}\right) + e^{y\sqrt{w+M+\frac{1}{k_p}}}\operatorname{erfc}\left(\frac{y}{2\sqrt{t}} + \sqrt{\left(w+M+\frac{1}{k_p}\right)t}\right)\right]$$

$$D_6 = \frac{e^{pt}}{2}\left[e^{-y\sqrt{Pr}\sqrt{p+\phi}}\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} - \sqrt{(p+\phi)t}\right) + e^{y\sqrt{Pr}\sqrt{p+\phi}}\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} + \sqrt{(p+\phi)t}\right)\right]$$

$$D_7 = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} - \sqrt{\phi t}\right)e^{-y\sqrt{Pr}\sqrt{\phi}} + \operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} + \sqrt{\phi t}\right)e^{y\sqrt{Pr}\sqrt{\phi}}\right]$$

$$D_8 = \frac{e^{ct}}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} - \sqrt{(c+\phi)t}\right)e^{-y\sqrt{Pr}\sqrt{c+\phi}} + \operatorname{erfc}\left(\frac{y\sqrt{Pr}}{2\sqrt{t}} + \sqrt{(c+\phi)t}\right)e^{y\sqrt{Pr}\sqrt{c+\phi}}\right]$$

$$D_9 = \frac{1}{2}\left[e^{-y\sqrt{Sc}\sqrt{K}}\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{Kt}\right) + e^{y\sqrt{Sc}\sqrt{K}}\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{Kt}\right)\right]$$

$$D_{10} = \frac{e^{ct}}{2}\left[e^{-y\sqrt{Sc}\sqrt{c+K}}\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{(c+K)t}\right) + e^{y\sqrt{Sc}\sqrt{c+K}}\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{(c+K)t}\right)\right]$$

$$D_{11} = \frac{e^{wt}}{2}\left[\operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} - \sqrt{(w+K)t}\right)e^{-y\sqrt{Sc}\sqrt{w+K}} + \operatorname{erfc}\left(\frac{y\sqrt{Sc}}{2\sqrt{t}} + \sqrt{(w+K)t}\right)e^{y\sqrt{Sc}\sqrt{w+K}}\right]$$

$$B_1 = e^{at}\left[\operatorname{erf}\left(\sqrt{\left(a+M+\frac{1}{k_p}\right)t}\right)\sqrt{\left(a+M+\frac{1}{k_p}\right)} + \frac{1}{\sqrt{\pi t}}e^{-\left(a+M+\frac{1}{k_p}\right)t}\right]$$

$$B_2 = e^{pt}\left[-\sqrt{\left(p+M+\frac{1}{k_p}\right)}\operatorname{erf}\left(\sqrt{\left(p+M+\frac{1}{k_p}\right)t}\right) - \frac{1}{\sqrt{\pi t}}e^{-\left(p+M+\frac{1}{k_p}\right)t}\right]$$

$$B_3 = \left[\operatorname{erf}\left(\sqrt{\left(M+\frac{1}{k_p}\right)t}\right)\sqrt{\left(M+\frac{1}{k_p}\right)} - \frac{1}{\sqrt{\pi t}}\mathrm{e}^{-\left(M+\frac{1}{k_p}\right)t}\right]$$

$$B_4 = \mathrm{e}^{ct}\left[-\sqrt{\left(c+M+\frac{1}{k_p}\right)}\operatorname{erf}\left(\sqrt{\left(c+M+\frac{1}{k_p}\right)t}\right) - \frac{1}{\sqrt{\pi t}}\mathrm{e}^{-\left(c+M+\frac{1}{k_p}\right)t}\right]$$

$$B_5 = \mathrm{e}^{wt}\left[-\operatorname{erf}\left(\sqrt{\left(w+M+\frac{1}{k_p}\right)t}\right)\sqrt{\left(w+M+\frac{1}{k_p}\right)} - \frac{1}{\sqrt{\pi t}}\mathrm{e}^{-\left(w+M+\frac{1}{k_p}\right)t}\right]$$

$$B_6 = \mathrm{e}^{pt}\left[-\operatorname{erf}\left(\sqrt{(p+\phi)t}\right)\sqrt{Pr(p+\phi)} - \frac{\sqrt{Pr}}{\sqrt{\pi t}}\mathrm{e}^{-(p+\phi)t}\right]$$

$$B_7 = \left[-\operatorname{erf}\left(\sqrt{\phi t}\right)\sqrt{\phi Pr} - \frac{\sqrt{Pr}}{\sqrt{\pi t}}\mathrm{e}^{-\phi t}\right]$$

$$B_8 = \mathrm{e}^{ct}\left[-\operatorname{erf}\left(\sqrt{(c+\phi)t}\right)\sqrt{Pr(c+\phi)} - \frac{\sqrt{Pr}}{\sqrt{\pi t}}\mathrm{e}^{-(c+\phi)t}\right]$$

$$B_9 = \left[-\operatorname{erf}\left(\sqrt{Kt}\right)\sqrt{KSc} - \frac{\sqrt{Sc}}{\sqrt{\pi t}}\mathrm{e}^{-Kt}\right]$$

$$p = \frac{M-\phi Pr+\frac{1}{k_p}}{Pr-1}, \quad w = \frac{M-KSc+\frac{1}{k_p}}{Sc-1}$$

$$B_{10} = \mathrm{e}^{ct}\left[-\sqrt{Sc(c+K)}\operatorname{erf}\left(\sqrt{(c+K)t}\right) - \frac{\sqrt{Sc}}{\sqrt{\pi t}}\mathrm{e}^{-(c+K)t}\right], \quad N_1 = \frac{Gr_1}{Pr-1}$$

$$B_{11} = \mathrm{e}^{wt}\left[-\operatorname{erf}\left(\sqrt{(w+K)t}\right)\sqrt{Sc(w+K)} - \frac{\sqrt{Sc}}{\sqrt{\pi t}}\mathrm{e}^{-(w+K)t}\right],$$
$$N_2 = \frac{Gr_1}{Sc-1}, N_3 = \frac{Gm_1}{Sc-1}$$

$$b = \frac{Q_1 Pr}{Sc-Pr}, \quad c = \frac{\phi Pr-KSc}{Sc-Pr}, \quad Gr_1 = Gr\cos\alpha, \quad Gm_1 = Gm\cos\alpha$$

5 Results and Discussion

In this flow problem, the consequences of the different profiles are discussed through graphs in Figs. 1, 2, 3, 4, 5, 5, 6, 7, 8, 9, 10, 11, and 12 for both heating and cooling of the plates. These leads are identified to illustrate the results of several

Fig. 1 Velocity results for several values of Sc and $Pr = 0.71$, $K_p = 0.1$, $Q_1 = 5$, $k = 0.5$, $M = 1$, $t = 0.4$, $a = 0.5$, $\phi = 5, \alpha = \pi/3$

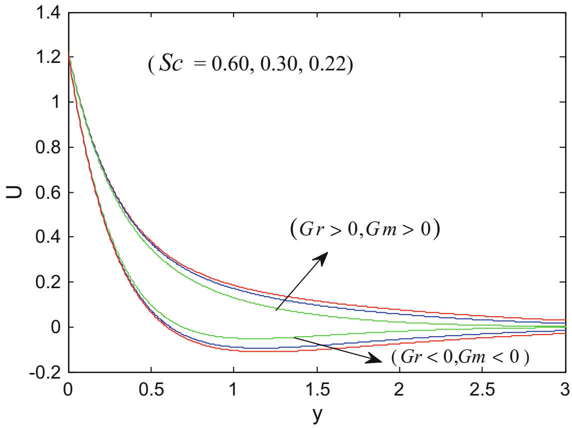


Fig. 2 Effect of k on velocity for different values of k and $Sc = 0.22$, $K_p = 0.1$, $Q_1 = 5$, $M = 1$, $Pr = 0.71$, $t = 0.4$, $a = 0.5$, $\phi = 5, \alpha = \pi/3$

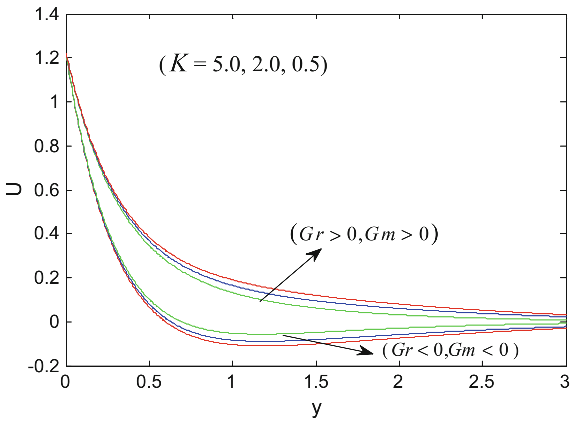


Fig. 3 Results of Q_1 on velocity for various values of Q_1 and $Sc = 0.22$, $k = 0.5$, $K_p = 0.1$, $Pr = 0.71$, $M = 1$, $t = 0.4$, $a = 0.5$, $\phi = 5, \alpha = \pi/3$

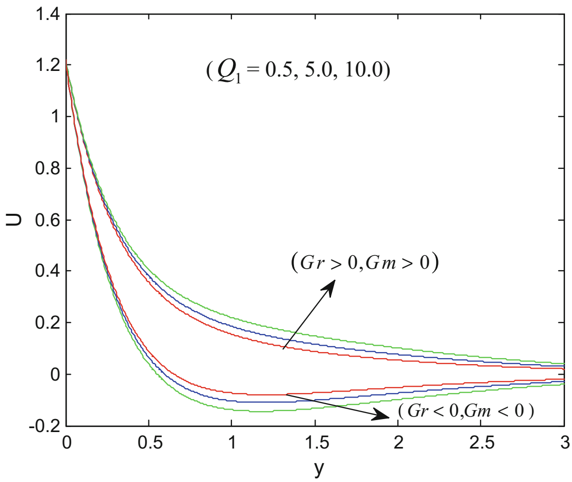


Fig. 4 Velocity effects for several values of α and $Sc = 0.22$, $K_p = 0.1$, $k = 0.5$, $Q_1 = 5$, $Pr = 0.71$, $t = 0.4$, $M = 1$, $a = 0.5$, $\phi = 5$

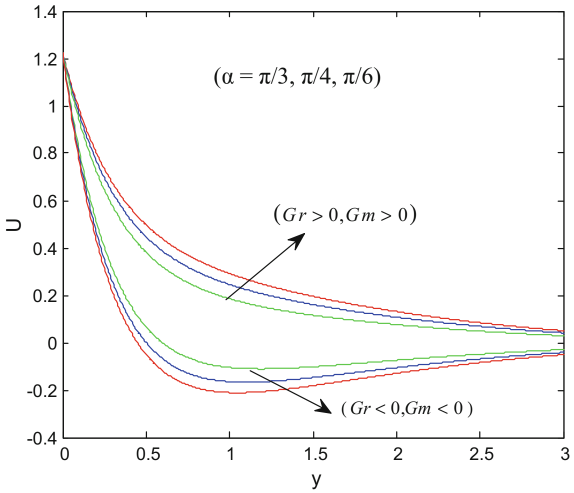
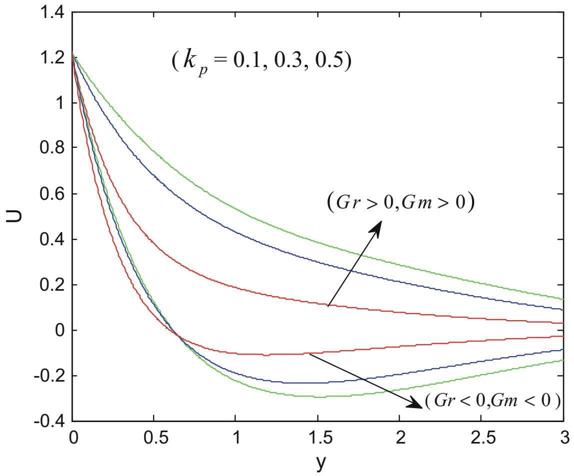


Fig. 5 Effects of K_p on velocity for various values of K_p and $k = 0.5$, Sc =0.22, $Q_1 = 5, M = 1, Pr = 0.71$, $t = 0.4$, $a = 0.5$, $\phi = 5, \alpha = \pi/3$



physical arguments involved in this flow problem such as angle of inclination (α), magnetic parameter (M), parameter of heat absorption (ϕ), parameter of radiation absorption (), Schmidt number (Sc), parameter of chemical reaction (k), Prandtl number (Pr), mass Grashof number (Gm), thermal Grashof number (Gr), time (t) on profiles of velocity, temperature, concentration, and the velocity gradient.

The consequences of velocity for several values of various arguments are studied and presented in Figs. 1, 2, 3, 4, 5, and 6 for the both heating ($Gr = -2$, $Gm = -4$) and cooling ($Gr = 2$, $Gm = 4$) plates. Figures 1, 2, 3, and 4 depict the results of velocity due to variation in Sc, k, Q_1, and α. It is identified that the velocity raise for the cooling plate, and it falls decreases for the heating plate with the fall of Sc, k, α and with the raise of Q_1. The profile of velocity for various values of K_p and M is

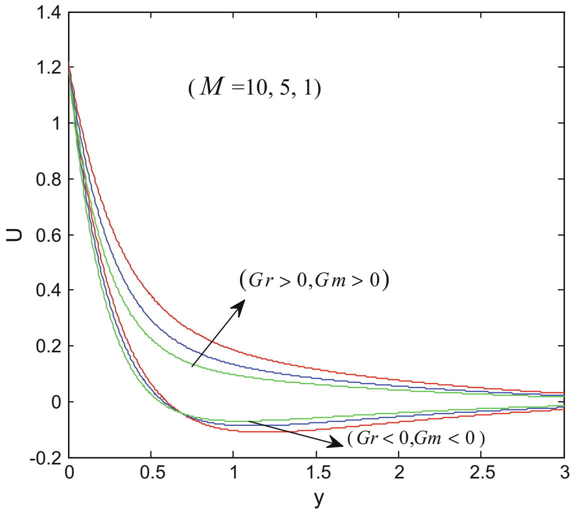


Fig. 6 Velocity results for various values of M and $Sc = 0.22$, $k = 0.5$, $K_p = 0.1$, $Q_1 = 0.5, Pr = 0.71$, $\phi = 5$, $t = 0.4$, $a = 0.5$, $\alpha = \pi/3$

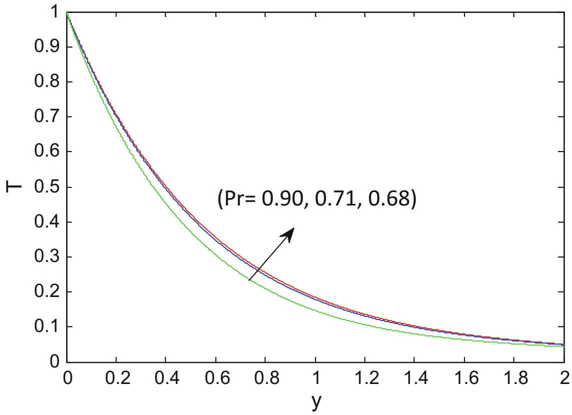


Fig. 7 Temperature results for several values of Pr and $k = 0.5$, $t = 0.4$, $Q_1 = 0.5$, $\phi = 5$, $Sc = 0.22$

discussed in Figs. 5 and 6 at $t = 0.4$. From Fig. 5, it is found that the velocity raises for cooling plate, whereas it raises near the plate and falls with a point of separation moving away from the plate for heating plate with the increase of K_p. Figure 6 describes the effect of M at t = 0.4; it is noticed that the velocity raises for cooling plate, whereas it falls near the plate and raises with a point of separation moving away from the plate for heating plate with the fall of M.

The leads of profiles of temperature for several values of various parameters are studied and discussed in Figs. 7, 8, 9, and 10. From these figures, it is identified that there is a raise in temperature with the fall of Pr, ϕ and with the raise of $Q1$, t.

The consequences of concentration profile for several values of various arguments are studied and presented in Figs. 11 and 12. Figures 11 and 12 reveal that there is a raise in concentration with the fall of Sc, k.

Fig. 8 Effects of temperature for different values of ϕ and $Sc = 0.22$, $t = 0.4$, $k = 0.5$, $Q_1 = 0.5, Pr = 0.71$

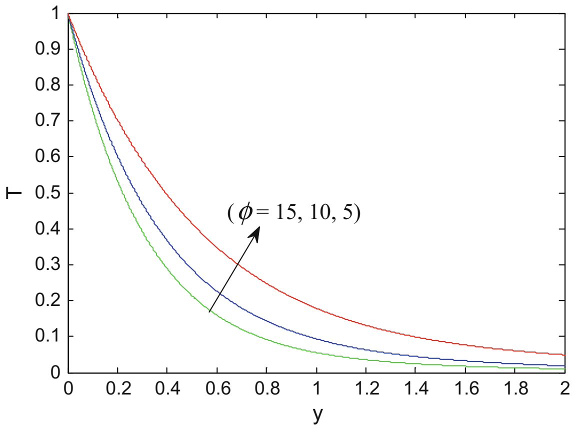


Fig. 9 Temperature effects for different values of Q_1 and $Sc = 0.22$, $t = 0.4$, $k = 0.5$, $\phi = 5$, $Pr = 0.71$

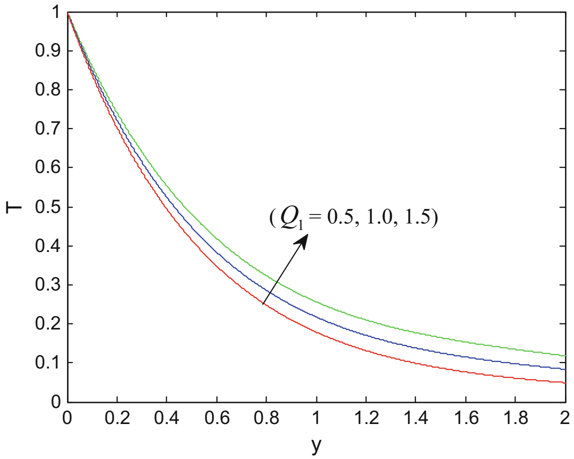
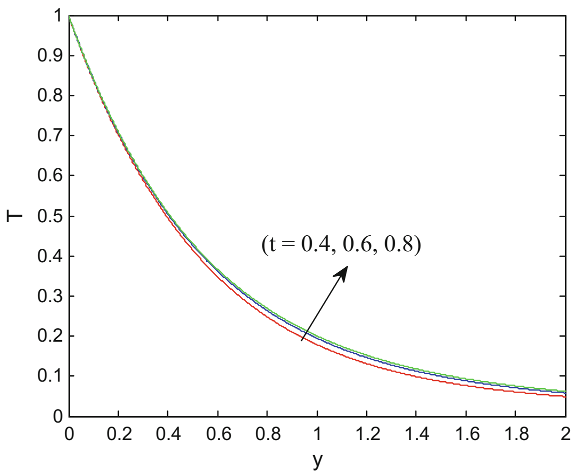


Fig. 10 Temperature leads for several values t and $Sc = 0.22$, $k = 0.5$, $\phi = 5$, $Q_1 = 0.5$, $Pr = 0.71$



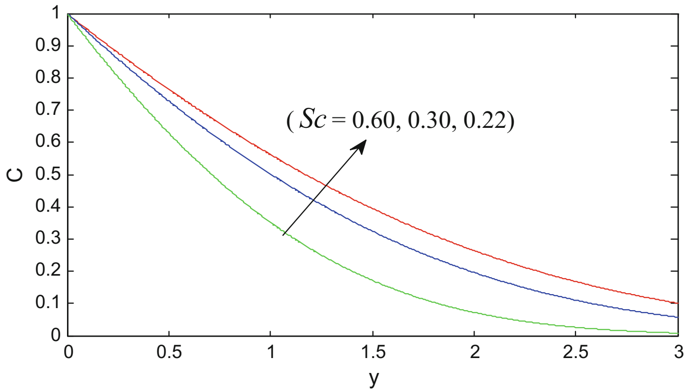


Fig. 11 Concentration effects for several values of Sc and t = 0.4, k = 0.5

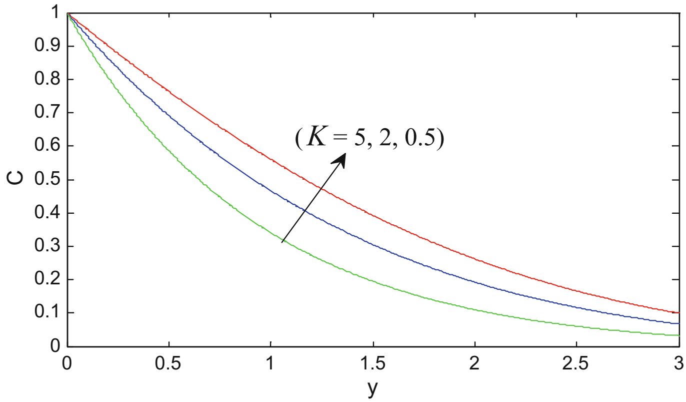


Fig. 12 Results of k on concentration for different values of k and Sc = 0.22

The gradient of velocity in terms of skin friction for several values of various arguments is discussed and is presented in Tables 1 and 2 for both heating ($Gr = -2$, $Gm = -4$) and cooling ($Gr = 2$, $Gm = 4$) plates. From Table 1, it is identified that there is a raise in skin friction with the raise of Pr, Sc, Q_1; also it decreases with raise of ϕ, K, M for cooling plate, and an opposite phenomenon was observed for heating plate and is shown in Table 2.

The same above results are noticed for both the cases in the absence of angle of inclination and parameter of the permeability of the porous medium. Hence, the results are in good agreement with the results of Vijaykumar et al. (2013).

Table 1 Cooling plates

Pr	Sc	ϕ	K	Q_1	M	A	Skin friction (for cooling plate) $\alpha = \pi/3$, $k_p = 0.1$	Skin friction (for cooling plate) $\alpha = 0$, $k_p \approx 0$
0.68	0.22	10	0.1	0.1	3	0.5	6.918657993	6.349229616
0.71	0.22	10	0.1	0.1	3	0.5	7.140507574	7.792928778
0.9	0.22	10	0.1	0.1	3	0.5	7.845391345	8.115749037
0.68	0.3	10	0.1	0.1	3	0.5	13.18412857	12.88017077
0.68	0.6	10	0.1	0.1	3	0.5	21.68903451	20.63490472
0.68	0.22	11	0.1	0.1	3	0.5	6.774587688	6.061089007
0.68	0.22	12	0.1	0.1	3	0.5	6.749025004	6.009963639
0.68	0.22	10	0.2	0.1	3	0.5	6.878243197	6.268400025
0.68	0.22	10	0.3	0.1	3	0.5	6.838386267	6.188686165
0.68	0.22	10	0.1	0.2	3	0.5	7.347101708	7.206117046
0.68	0.22	10	0.1	0.3	3	0.5	7.775545423	8.063004476
0.68	0.22	10	0.1	0.1	4	0.5	6.530715543	6.010236618
0.68	0.22	10	0.1	0.1	5	0.5	6.486863883	5.864913622

Table 2 Heating plates

Pr	Sc	ϕ	K	Q_1	M	A	Skin friction (for heating plate) $\alpha = \pi/3$, $k_p = 0.1$	Skin friction (for heating plate) $\alpha = 0$, $k_p \approx 0$
0.68	0.22	10	0.1	0.1	3	0.5	2.057514746	2.373056877
0.71	0.22	10	0.1	0.1	3	0.5	1.835665165	1.816756039
0.9	0.22	10	0.1	0.1	3	0.5	1.358104638	1.205914537
0.68	0.3	10	0.1	0.1	3	0.5	−4.20795583	−4.90399803
0.68	0.6	10	0.1	0.1	3	0.5	−5.015729484	−5.93614952
0.68	0.22	11	0.1	0.1	3	0.5	2.201585051	2.684916268
0.68	0.22	12	0.1	0.1	3	0.5	2.227147735	2.7137909
0.68	0.22	10	0.2	0.1	3	0.5	2.097929542	2.412227286
0.68	0.22	10	0.3	0.1	3	0.5	2.137786471	2.512513427
0.68	0.22	10	0.1	0.2	3	0.5	1.629071031	1.229944307
0.68	0.22	10	0.1	0.3	3	0.5	1.200627316	1.086831737
0.68	0.22	10	0.1	0.1	4	0.5	2.771673392	2.892152317
0.68	0.22	10	0.1	0.1	5	0.5	3.130764406	3.452714668

6 Conclusion

For this flow problem, the consequences of heat source parameter, mass diffusion, chemical reaction, and radiation absorption with the constant temperature are discussed in the presence of applied uniform magnetic field on a magnetohydrodynamic unsteady convective free flow with mass and heat transfer past an inclined vertical porous plate which is accelerated exponentially in a porous medium. The dimensionless governing equations for velocity, temperature, and concentration are solved by the Laplace transform technique. The effects of velocity, temperature, concentration, and skin friction are discussed for both ammonia and water vapor, and the conclusions are as follows:

- Velocity raises for the cooling plate, and it falls for the heating plate with the fall of chemical reaction parameter (K) and with the raise of radiation absorption parameter (Q_1).
- Temperature raises with the fall in heat absorption parameter (ϕ), and the concentration raises with the raise in time (t).
- Skin friction increases for cooling plate and decreases for heating plate with the increase in Sc and Q_1.

The same results are observed in the absence of inclined plate and permeability of the porous medium. Hence, these results are in good agreement with results of Vijaykumar (2013).

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