

# Radiation and Chemical Reaction Effects on MHD Free Convective Heat and Mass Transfer Flow of a Viscoelastic Fluid Past a Porous Plate with Heat Generation/Absorption

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## Abstract

Radiation and chemical combined effects on MHD free convective heat and mass transfer flow of viscous, incompressible, conducting elastic fluid through porous medium finite by a porous plate within the presence of heat generation/absorption is studied. The momentum, energy and mass diffusion equations are coupled non-linear partial differential equations; these are solved by applying two term perturbation methodology and mistreatment software system MATLAB. The options of the fluid flow, heat and mass transfer characteristics are analyzed by plotting graphs and mentioned qualitatively.

**Keywords:** MHD; Chemical reaction; Radiation; Viscoelastic; Skin-friction; Porous medium

## Introduction

The heat and mass transfer in free convective through porous media has been broadly investigated in the current years due to its applications in engineering. The study of non-Newtonian fluid flow by engineers and experts has risen in recent times due to its useful application in various fields. Keeping its importance in mind an extensive range of mathematical models has been established to simulate the various hydrodynamic behaviors of these non-Newtonian fluids. Various viscoelastic fluids classical like the Rivlin-Ericksen 2<sup>nd</sup> order model, Oldroyd model and Johnson-Seagalman model. The fluid, which exhibits the elasticity property of solids and viscous property of liquids are called viscoelastic fluid. Fluid models of this type come across petrochemical, biomedical and environmental engineering including polypropylene combination sintering.

Beard and Walter [1] had presented the boundary layer treatment for unidealized viscoelastic fluid. The heat transfer in convection flow of viscoelastic fluid of Walter model was investigated by Rajagopal [2]. Ibrahim [3] discussed the effects of

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the radiation and chemical reaction on the unsteady MHD convection flow through semi-infinite vertical porous plate with heat source and suction.

Muthucumaraswamy and Ganesan [4] studied the unsteady flow through impulsively semi-infinite vertical plate, which subjected to uniform heat flux of a chemical reaction effect. Chamkha [5] was studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat and chemical reaction. Chamkha [6] discussed unsteady convective heat and mass transfer through semi-infinite porous plate with heat absorption. Hossain [7] were analyzed natural convection flow of a vertical surface with uniform temperature in the presence of heat generation/absorption. Hady [8] are 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. Mohamed [9] has discussed double-diffusive convection radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects.

Shanker et al. [10] were 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. Kumar and Sivaraj [11] studied MHD Visco-elastic fluid non-Darcy flow along a moving vertical cone. Vidyasagar and Raman [12] reported a study on the radiation effect on MHD convection flow of Kuvshinski fluid with mass transfer past a vertical porous plate through porous medium. Bhikshu [13] investigated peristaltic flow of a conducting Williamson fluid in a vertical asymmetric channel with heat transfer through porous medium. Devika [14] investigated MHD oscillatory flow of a visco-elastic fluid in a porous channel with chemical reaction. Bhikshu [15] studied the effects of magnetohydrodynamics on the peristaltic flow of fourth grade fluid in an inclined channel with permeable walls. Sivaraj and Kumar [16] were studied an unsteady MHD dusty visco-elastic fluid Couette flow in an irregular channel with varying mass diffusion. Authors are discussed in many chemical engineering processes; the chemical reaction does occur between mass and fluid in which plate is moving [17-20].

These processes occur in varied industrial applications like compound production, producing of ceramics or glasswork and food process. The aim of this work is to investigate the influence of radiation and chemical on MHD convective heat and mass transfer flow of viscous, in-compressible, electrically conducting elastic fluid through porous medium delimited by a porous plate within the presence of heat generation and absorption. Regular perturbation method is adopted to solve governing equations are solved by the perturbation technique [21,22].

### **Mathematical Formulation of the Problem**

We think about two-dimensional unsteady convective flow of Viscous-elastic fluid (Kuvshinski fluid), electrically conducting, an incompressible, past a semi-infinite vertical periodical porous plate in the presence of magnetic field, chemical reaction, heat generation and radiation absorption. Let  $x^*$ -axis is taken along the porous plate in the rising direction and  $y^*$ -axis is standard to it. It is assumed that there is no applied voltage of which implies the absence of an electric field. The squarely applied magnetic field and magnetic Reynolds number are very small and hence the made magnetic field is very small. The MHD term is defined from an order of magnitude analysis of the Navier-stokes equation. We take the porous medium as a collection of minor identical spherical particles fixed in space. The chemical reactions are occurring in the flow

and physical properties are taken constant. The magnetic and viscous dissipations are very small. Due to the assumption that the plate in  $x^*$ -direction is of unlimited length, all the flow variables except pressure are functions of  $y^*$  and  $t^*$  only.

The governing boundary layer equation of the flow field considering the above assumptions are given by:

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

$$\frac{\partial u}{\partial t} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} - K_1' \frac{\partial^3 u}{\partial y^2 \partial t} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\sigma_e B_0^2}{\rho} u - \frac{\nu}{K_0} u \tag{2}$$

$$\rho C_p \left( \frac{\partial T}{\partial t} + v \frac{\partial T}{\partial y} \right) = k \frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} - s'(T - T_\infty) - R'(C - C_\infty) \tag{3}$$

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

Where  $u, v$  are the velocity components in  $x, y$  directions respectively,  $t$ -the time,  $\rho$ -the fluid density,  $\nu$ -the kinematic viscosity,  $C_p$ -the specific heat at constant pressure,  $g$ -the acceleration due to gravity,  $\beta$  and  $\beta^*$ -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,  $K_1'$ -the dimensional visco-elastic parameter,  $T$ -the dimensional temperature,  $C$ -the dimensional concentration.

Here the boundary conditions are:

$$\begin{aligned} u = U_0(1 + \epsilon e^{i\omega t}), T = T_w + \epsilon(T_w - T_\infty)e^{i\omega t}, C = C_w + \epsilon(C_w - C_\infty)e^{i\omega t} \quad \text{at } y = 0 \\ u \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty \quad \text{as } y \rightarrow \infty \end{aligned} \tag{5}$$

Where  $U_0$  is the plate velocity,  $T_w$  and  $C_w$  are the wall dimensional temperature and concentration, respectively,  $T_\infty$  and  $C_\infty$  are the free stream dimensional temperature and concentration, respectively,  $\omega$ -the constant.

From equation (1) we get,

$$v = -V_0 \tag{6}$$

Where  $V_0$  is the suction velocity normal to the plate.

Introducing the following non-dimensional quantities:

$$\begin{aligned}
 y^* &= \frac{U_0}{v} y, u^* = \frac{u}{U_0}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty}, t^* = \frac{U_0^2 t}{v}, V_0^* = \frac{V_0}{U_0}, W^* = \frac{vW}{U_0^2}, \\
 S_c &= \frac{v}{D}, K_r = \frac{K^1 v}{U_0^2}, M^2 = \frac{\sigma_e B_0^2 v}{p U_0^2}, P_r = \frac{\mu C_p}{k}, S = \frac{v^2 S^1}{U_0^2 k}, R_1 = \frac{R^1 v^2 (C_w - C_\infty)}{U_0^2 k (T_w - T_\infty)}, \quad (7) \\
 G_r &= \frac{vg\beta(T_w - T_\infty)}{U_0^3}, G_m = \frac{vg\beta^*(C_w - C_\infty)}{U_0^3}, K_p = \frac{U_0^2 K_0}{v^2}, \lambda_1 = \frac{U_0^2 K_1}{v^2 \rho}
 \end{aligned}$$

Using the above non-dimensionless quantities and equation (6) the equations (2)-(4) will become,

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

$$P_r \frac{\partial \theta}{\partial t} - P_r V_0 \frac{\partial \theta}{\partial y} = \frac{\partial^2 \theta}{\partial y^2} - (S + F)\theta - R_1 \phi \quad (9)$$

$$S_c \frac{\partial \phi}{\partial t} - S_c V_0 \frac{\partial \phi}{\partial y} = \frac{\partial^2 \phi}{\partial y^2} - S_c K_r \phi \quad (10)$$

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

The corresponding boundary conditions are,

$$\begin{aligned}
 u = 1 + \epsilon e^{i\omega t}, \theta = 1 + \epsilon e^{i\omega t}, \phi = 1 + \epsilon e^{i\omega t} \quad \text{at } y = 0 \\
 u \rightarrow 0, \theta \rightarrow 0, \phi \rightarrow 0 \quad \text{as } y \rightarrow \infty
 \end{aligned} \quad (11)$$

### Solution of the Problem

The equations 8-10 with boundary conditions (11) are solved, by using the perturbation technique. Let the velocity, temperature and concentration fields as:

$$\begin{aligned}
 u(y, t) &= u_0(y) + \epsilon u_1(y) e^{i\omega t} \\
 \theta(y, t) &= \theta_0(y) + \epsilon \theta_1(y) e^{i\omega t} \\
 \phi(y, t) &= \phi_0(y) + \epsilon \phi_1(y) e^{i\omega t}
 \end{aligned} \quad (12)$$

Where  $\epsilon$  is a small quantity ( $\epsilon \ll 1$ ),  $G_r, G_m, M, \lambda_1, P_r, S, R_1, S_c$  and  $K_r$  are the thermal Grashof number, Solutal Grashof number, Magnetic parameter, viscoelastic parameter, Prandtl number, heat absorption parameter, radiation absorption parameter, Schmidt number and chemical reaction parameter, respectively.

Substituting equation (12) into the equations (8)-(10) and equating the like terms, neglecting the terms of  $\epsilon^2$ , then we get,

$$u_0'' + V_0 u_0' - M_1 u_0 = -G_r \theta_0 - G_m \phi_0 \quad (13)$$

$$N_1 u_1'' + V_0 u_1' - N_2 u_1 = -G_r \theta_1 - G_m \phi_1 \quad (14)$$

$$\theta_0'' + P_r V_0 \theta_0' - (S + F)\theta_0 = R_1 \phi_0 \tag{15}$$

$$\theta_1'' + P_r V_0 \theta_1' - (S + F + iP_r \omega)\theta_1 = R_1 \phi_1 \tag{16}$$

$$\phi_0'' + S_c V_0 \phi_0' - S_c K_r \phi_0 = 0 \tag{17}$$

$$\phi_1'' + S_c V_0 \phi_1' - S_c (K_r + i\omega)\phi_1 = 0 \tag{18}$$

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 boundary conditions are:

$$\begin{aligned} u_0 = 1, u_1 = 1, \theta_0 = 1, \theta_1 = 1, \phi_0 = 1, \phi_1 = 1 \text{ at } y = 0 \\ u_0 \rightarrow 0, u_1 \rightarrow 0, \theta_0 \rightarrow 0, \theta_1 \rightarrow 0, \phi_0 \rightarrow 0, \phi_1 \rightarrow 0 \text{ at } y \rightarrow \infty \end{aligned} \tag{19}$$

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

We obtain,

$$u_0(y) = b_{10}e^{-m_6 y} + b_7 e^{-m_4 y} + b_8 e^{-m_2 y} + b_9 e^{-m_2 y} \tag{20}$$

$$u_1(y) = b_6 e^{-m_5 y} + b_4 e^{-m_3 y} + b_5 e^{-m_1 y} \tag{21}$$

$$\theta_0(y) = b_3 e^{-m_4 y} + b_2 e^{-m_2 y} \tag{22}$$

$$\theta_1(y) = (1 - b_1) e^{-m_3 y} \tag{23}$$

$$\phi_0(y) = e^{-m_2 y} \tag{24}$$

$$\phi_1(y) = e^{-m_1 y} \tag{25}$$

On substituting the expressions of  $u_0, u_1, \theta_0, \theta_1, \phi_0$ , and  $\phi_1$  in the equations (12) the expressions for velocity, temperature and concentration are:

$$u(y, t) = b_{10}e^{-m_6 y} + b_7 e^{-m_4 y} + b_8 e^{-m_2 y} + b_9 e^{-m_2 y} + \epsilon e^{i\omega t} (b_6 e^{-m_5 y} + b_4 e^{-m_3 y} + b_5 e^{-m_1 y}) \tag{26}$$

$$\theta(y, t) = b_3 e^{-m_4 y} + b_2 e^{-m_2 y} + \epsilon (1 - b_1) e^{-m_3 y} e^{i\omega t} \tag{27}$$

$$\phi(y, t) = e^{-m_2 y} + \epsilon e^{-m_1 y} e^{i\omega t} \tag{28}$$

Skin-friction at the plate in dimensionless form is given by:

$$\begin{aligned} \tau = -\left(\frac{\partial u}{\partial y}\right)_{y=0} \\ = (b_{10}m_6 + b_7 m_4 + b_8 m_2 + b_9 m_2) + \epsilon e^{i\omega t} (b_6 m_5 + b_4 m_3 + b_5 m_1) \end{aligned} \tag{29}$$

**Nusselt number**

Knowing the rate of heat transfer on the well in terms of Nusselt number  $N_u$  is given by:

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = b_3 m_4 + b_2 m_2 + \epsilon (1 - b_1) m_3 e^{i\omega t} \tag{30}$$

**Sherwood number**

Knowing the rate of mass transfer on the wall is given by:

$$S_h = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = m_2 + \epsilon m_1 e^{i\omega t} \tag{31}$$

**Result and Discussion**

The physical characteristic of the problem is obtained for the above physical quantities by computing numerically for different values of the governing parameters viz. the Grashof number (Gr), Modified Grashof number (Gm), Prandtl number (Pr), Schmidt number (Sc), magnetic parameter, Permeability parameter (K), Eckert number (Ec) and Heat absorption parameter (Q), heat source parameter (S) radiation parameter (F) and chemical reaction parameter (Kr).

FIG.1 shows the impact of field on magnetic profiles within the boundary layer. Here we have an observed to determined that the velocity profiles are decreases with increasing the magnetic parameter (M). The transverse magnetic field opposes the motion of the fluid and the velocity of transport is significantly reduced. It's due to with the increase within the magnetic parameter (M), force will increase and it produces a lot of resistance to the flow. Because it will increase, the thermal boundary layer thickness will increase however the momentum boundary layers get belittled. The contribution of the porosity parameter of the fluid bed on the speed field is illustrated in FIG. 2. In general, it's noticed that, because the porousness will increase, the speed profiles is additionally will increase for different parameters area unit mounted constants.

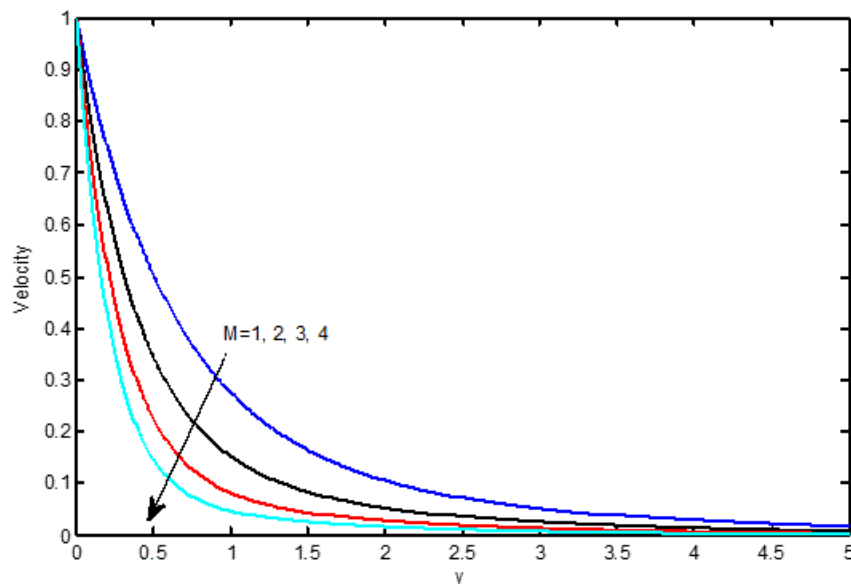


FIG. 1. Effects of velocity profiles for different values of magnetic parameter (M).

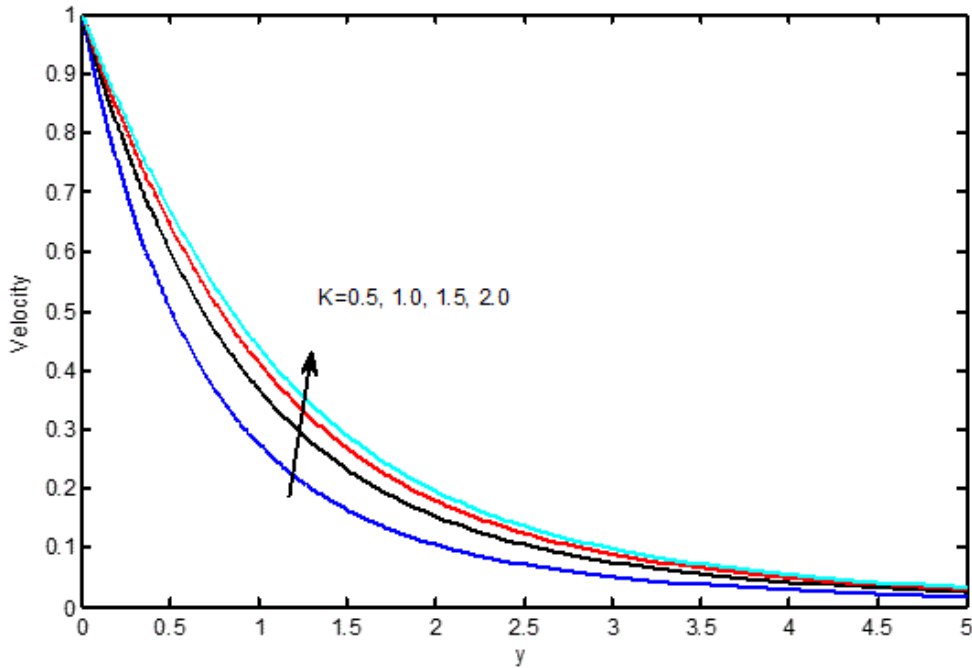


FIG. 2. Effects of velocity profiles for different values of permeability parameter (K).

FIG. 3 shows that the impact of solutal Grashof range ( $G_m$ ) on velocity profiles. It's detected that the dimensionless velocity will increase with associate degree increasing the Grashof range. FIG. 4 illustrates distinct velocity profiles within the boundary layer for numerous values of solutal Grashof range ( $G_m$ ). The solutal Grashof range ( $G_m$ ) defines the quantitative relation of the species buoyancy force to the viscous hydro dynamic force. It's detected that the velocity will increase with associate degree increasing values of the solutal Grashof range. Additionally, it's found that an increase in metric weight unit ends up in acceleration within the velocity profiles. FIG. 5 to 11 illustrate velocity and temperature profiles for various values of Prandtl range ( $Pr$ ). The numerical results show that the impact of increase values of Prandtl range leads to a decreasing velocity. From FIG. 11 to 14, it's detected that an increase within the Prandtl range results a decrease of the thermal physical boundary layer and normally lower average temperature among boundary layer. In the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer reduced.

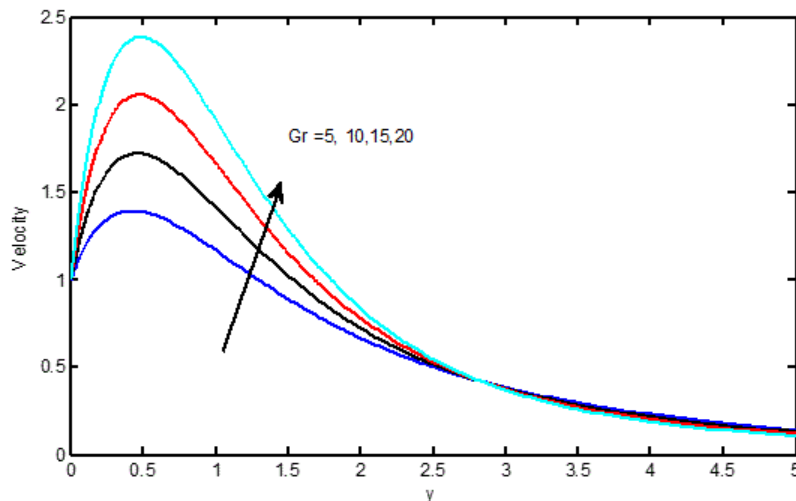


FIG. 3. Effects of velocity profiles for different values of Grashof number (Gr).

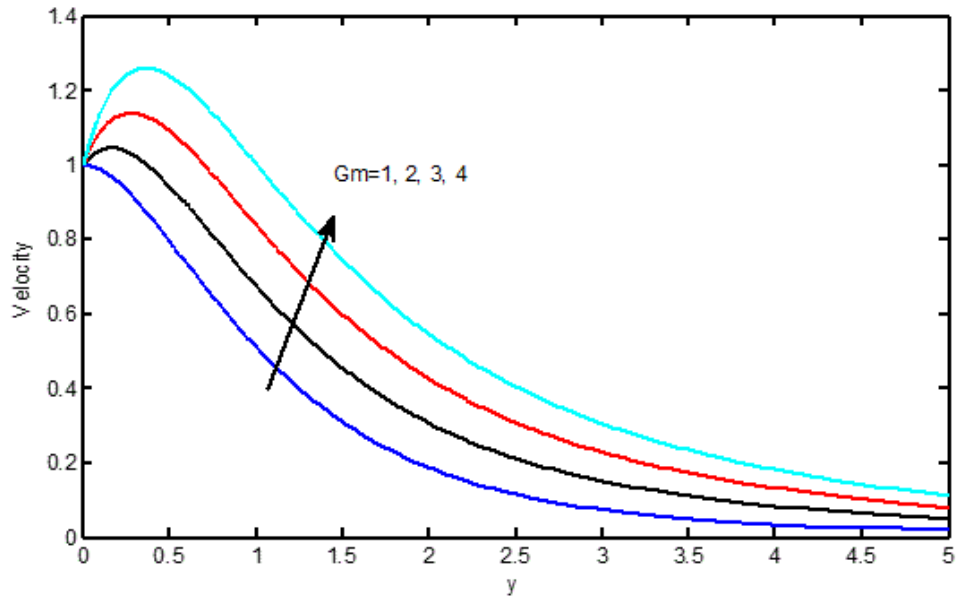


FIG. 4. Effects of velocity profiles for different values of modified Grashof number (Gm).

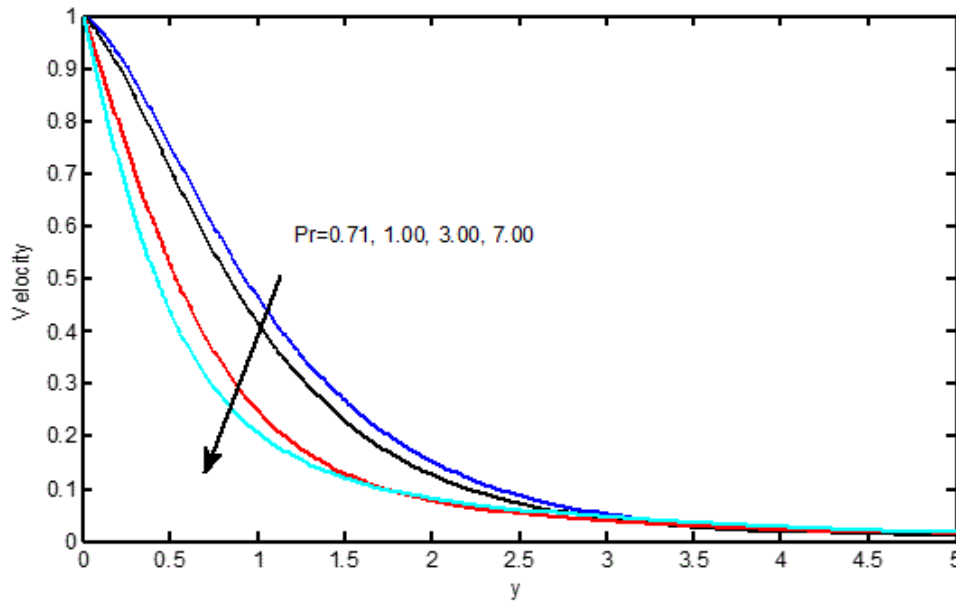


FIG. 5. Effects of velocity profiles for different values of Prandtl number (Pr).

From FIG. 6 and FIG. 15 we observe that for different values of the Schmidt number (Sc), the velocity and concentration profiles are plotted and that the reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers, which is evident.

FIG. 7 and FIG. 16 are shows that the effects of the chemical reaction (Kr) on the velocity and concentration profiles, respectively. It is noticed that as chemical reaction increases, the considerable reduction in the velocity profiles and the presence of the peak indicates that the maximum value of the velocity occurs in the body of the fluid close to the surface but



not at the surface. Also, with an increase in the chemical reaction parameter, the concentration decreases. It is evident that the increase in the chemical reaction ( $K_r$ ) significantly alters the concentration boundary layer thickness but does not alter the momentum boundary layers.

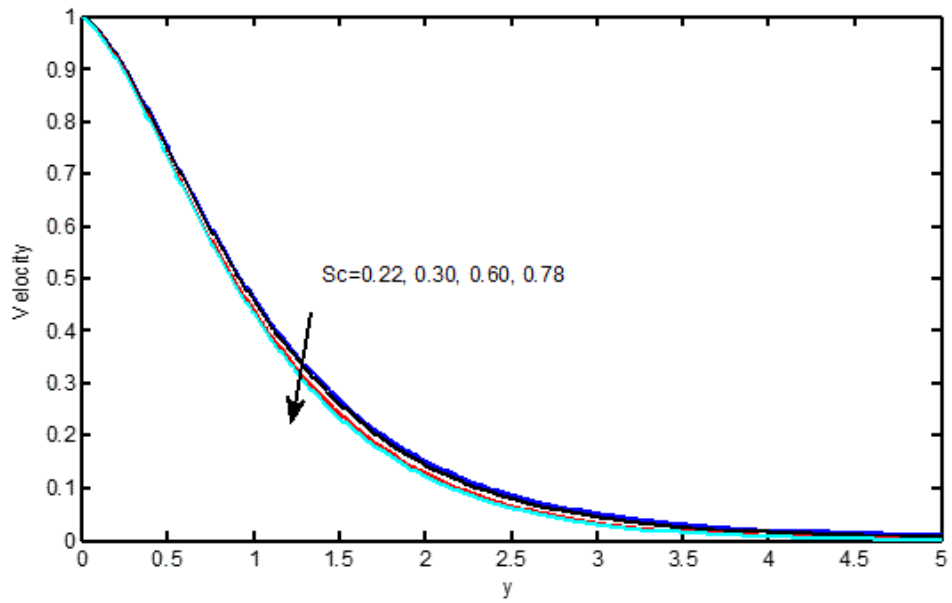


FIG. 6. Effects of velocity profiles for different values of Schmidt number (Sc).

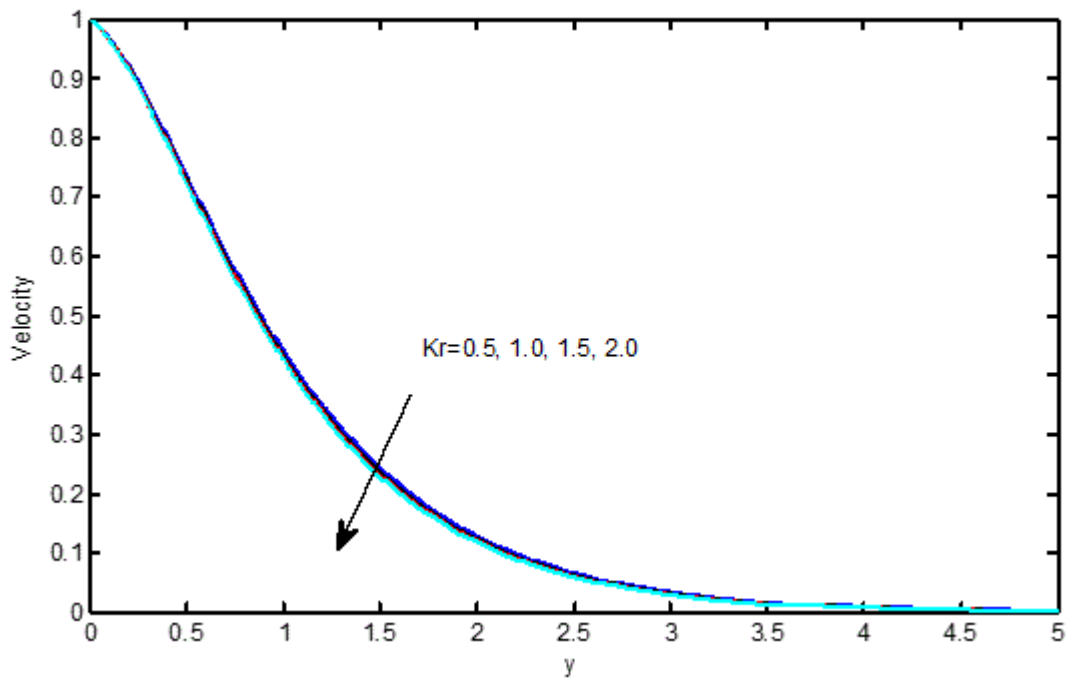


FIG. 7. Effects of velocity profiles for different values of chemical reaction parameter (SC).

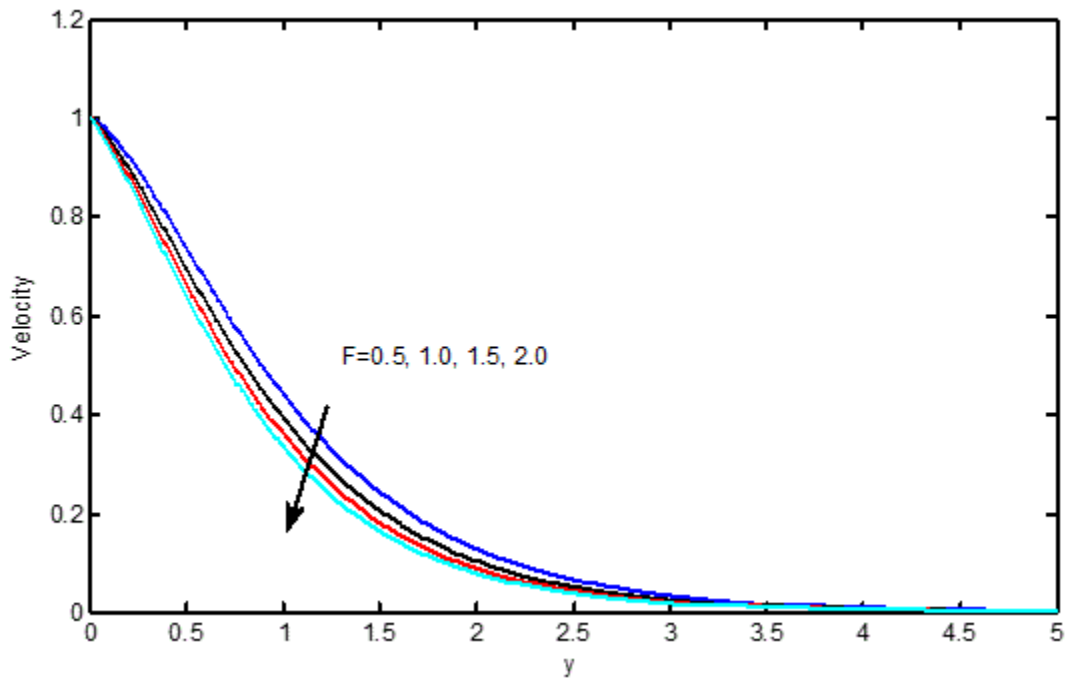


FIG. 8. Effects of velocity profiles for different values of radiation parameter (F).

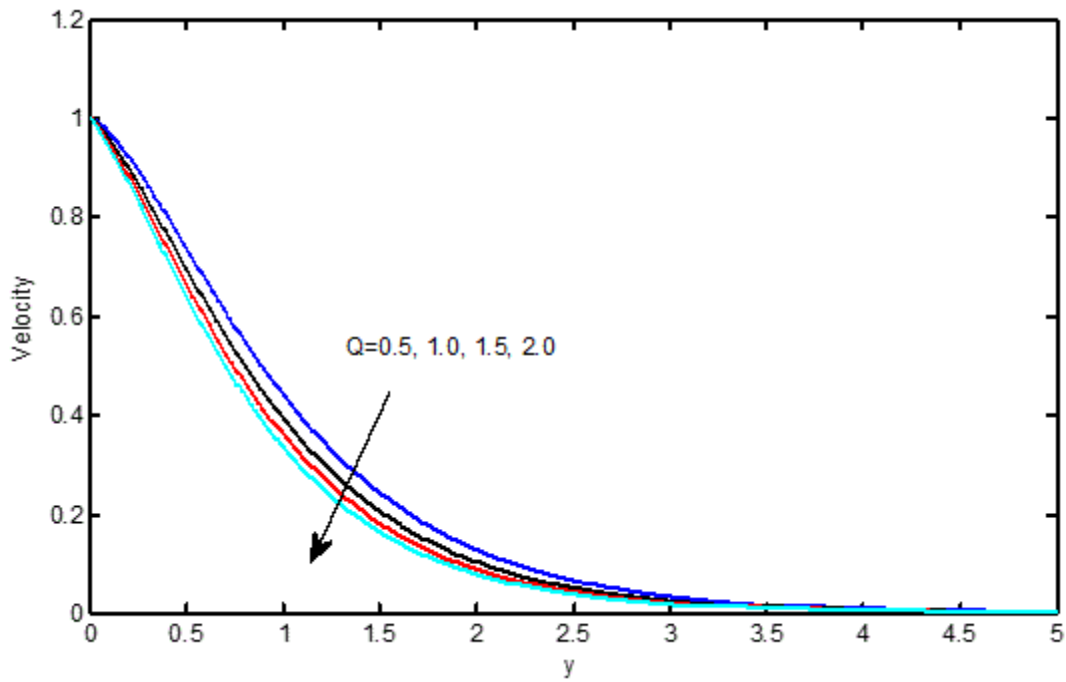


FIG. 9. Effects of velocity profiles for different values of heat absorption parameter (Q).

FIG. 8 and FIG. 13 are shows that the influence of the thermal radiation parameter (F) on the velocity and temperature (FIG. 10 and 11). It is observed that an increase in the radiation parameter results in decreasing velocity and temperature within the boundary layer. The effect of increasing the value of the Heat absorption parameter (Q) is to decrease the boundary layer as

shown in FIG. 9 and FIG. 14, which is as expected since when heat is, absorbed the buoyancy force decreases which retard the flow rate and thereby giving rise to decrease in the velocity profiles.

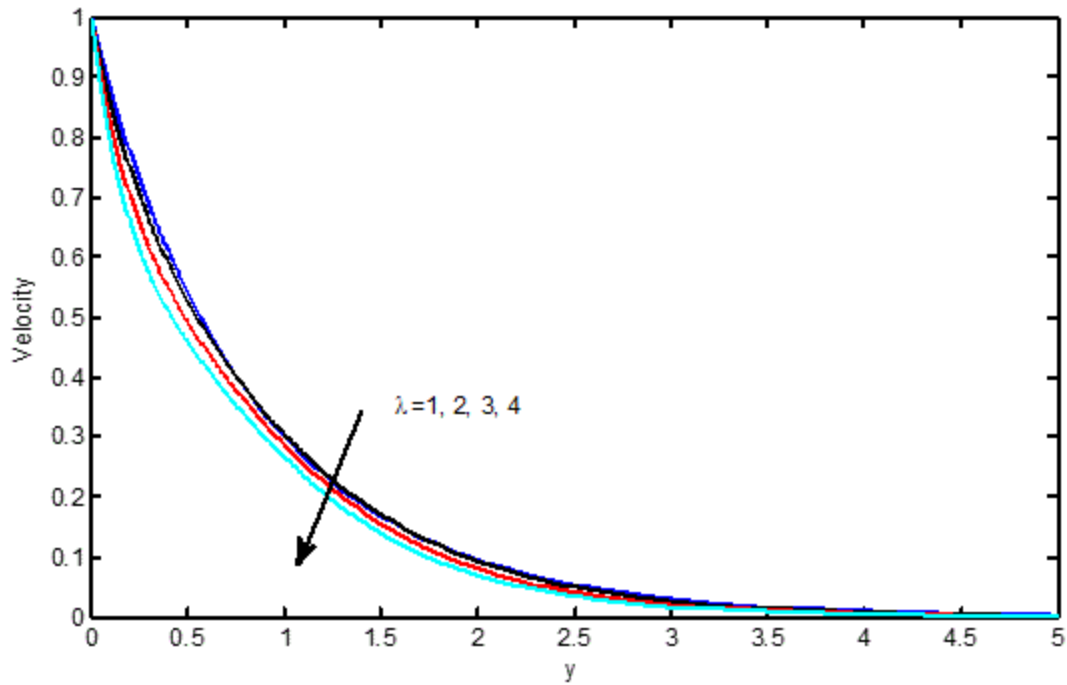


FIG. 10. Effects of velocity profiles for different values of visco-elastic parameter ( $\lambda$ ).

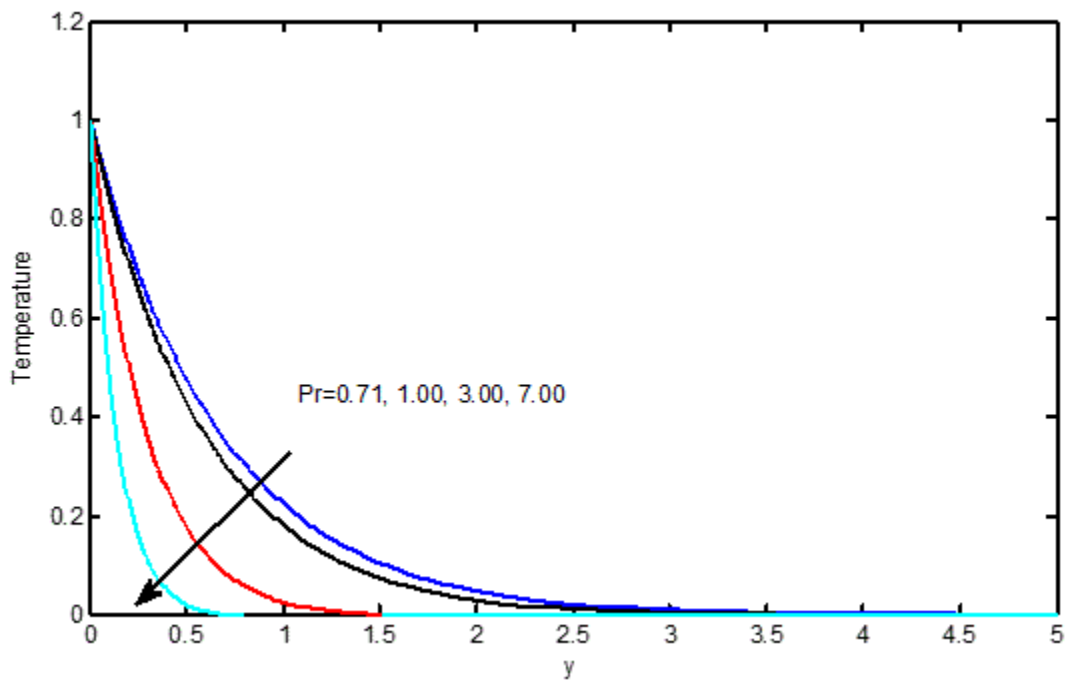


FIG. 11. Effects of temperature profiles for different values of Prandtl number ( $Pr$ ).

FIG. 12 has been plotted to depict the variation of temperature profiles against for different values of heat source parameter (R) by fixing other physical parameters (FIG. 13-17). From this graph, we observe that temperature decrease with increase in the Heat source parameter (R).

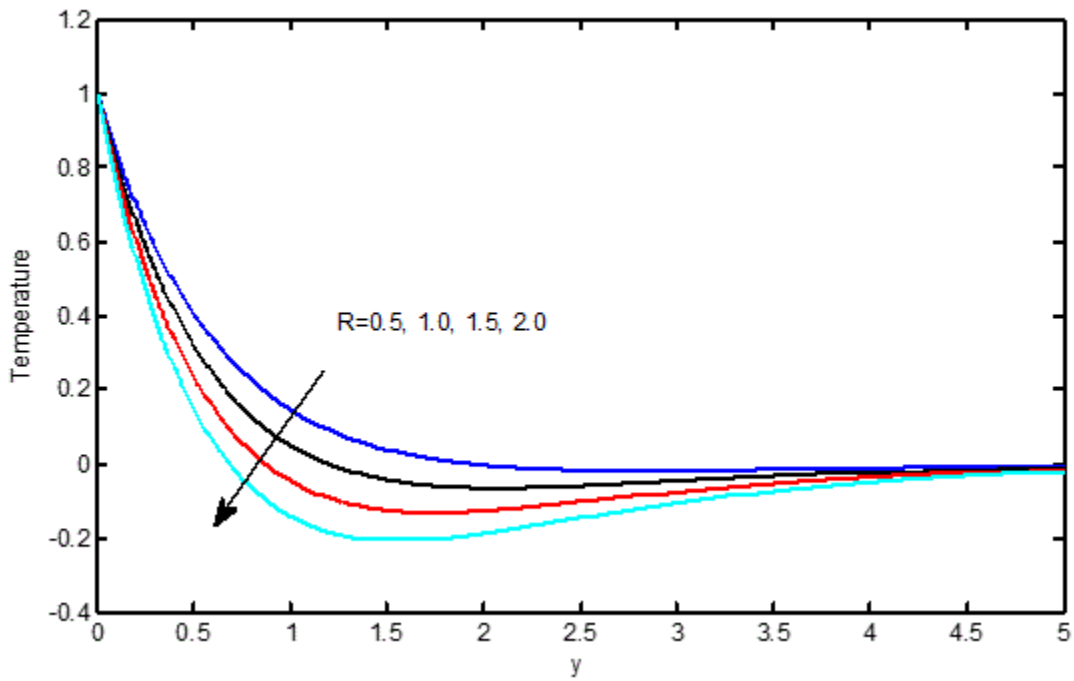


FIG. 12. Effects of temperature profiles for different values of heat absorption parameter (R).

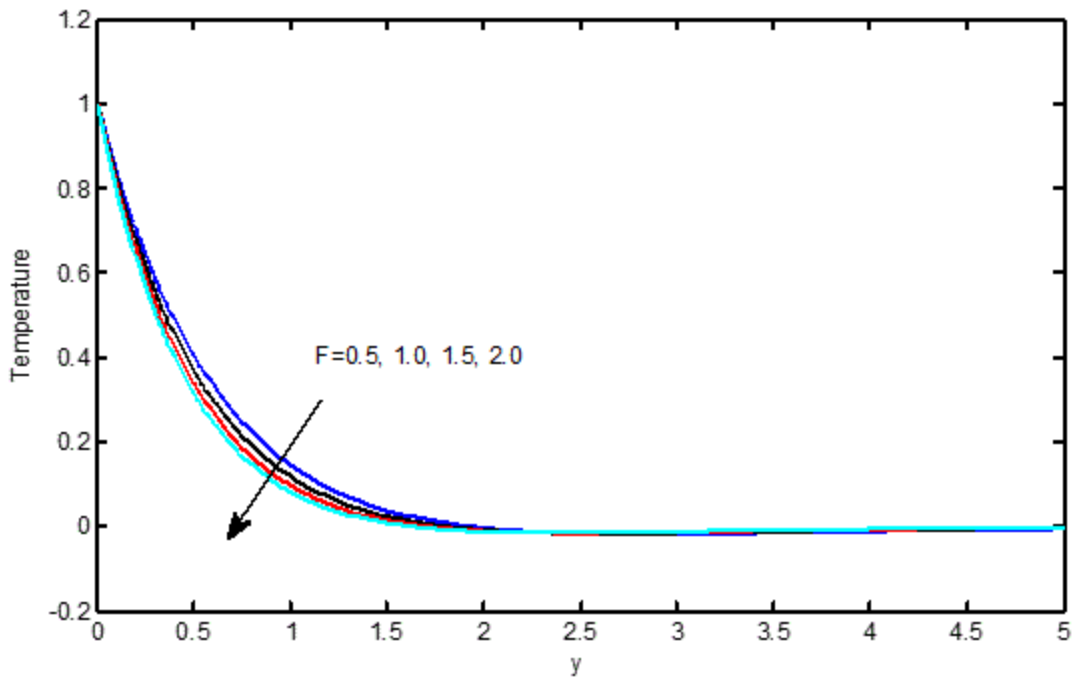


FIG. 13. Effects of temperature profiles for different values of radiation parameter (F).

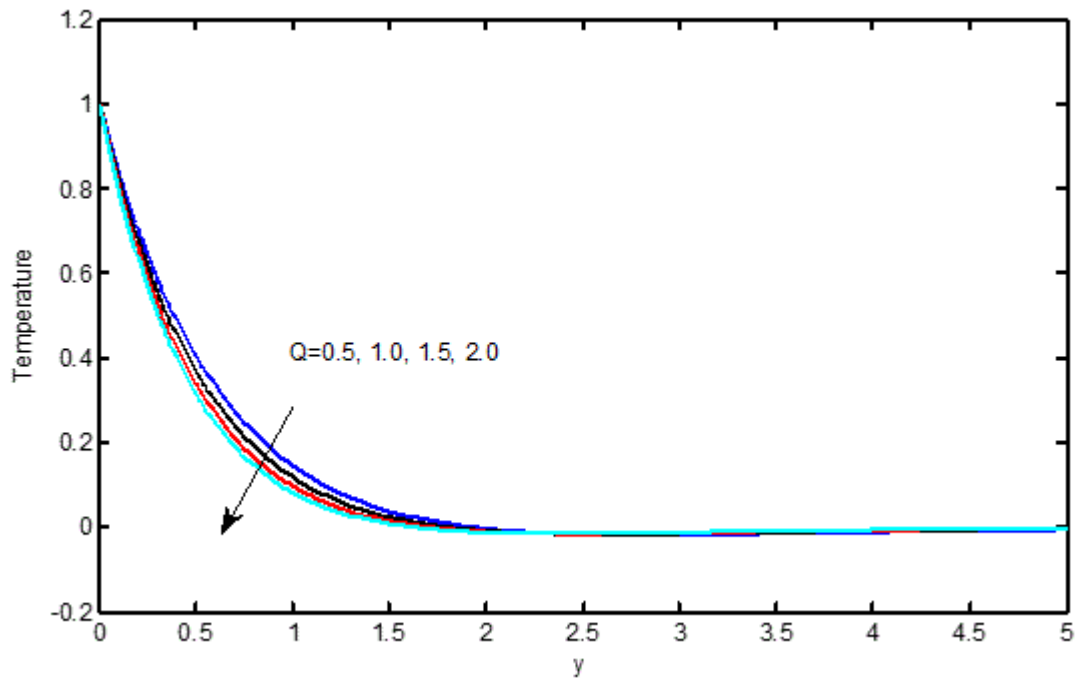


FIG. 14. Effects of temperature profiles for different values of heat source ( $Q$ ).

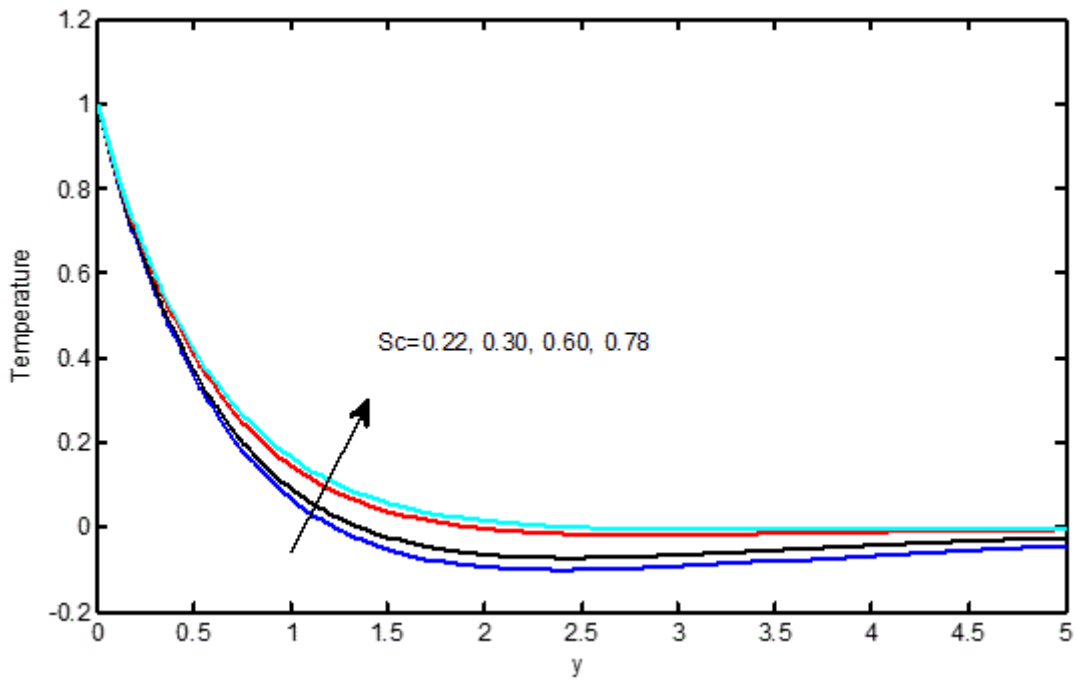


FIG. 15. Effects of temperature profiles for different values of Schmidt number ( $Sc$ ).

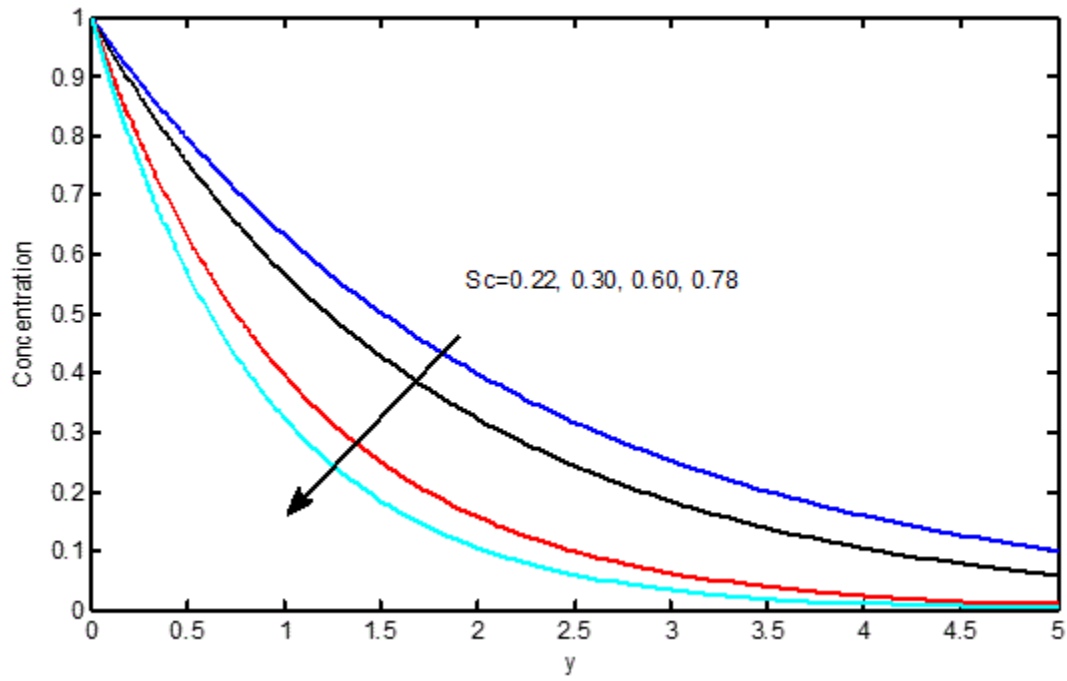


FIG. 16. Effects of concentration profiles for different values of Schmidt number ( $Sc$ ).

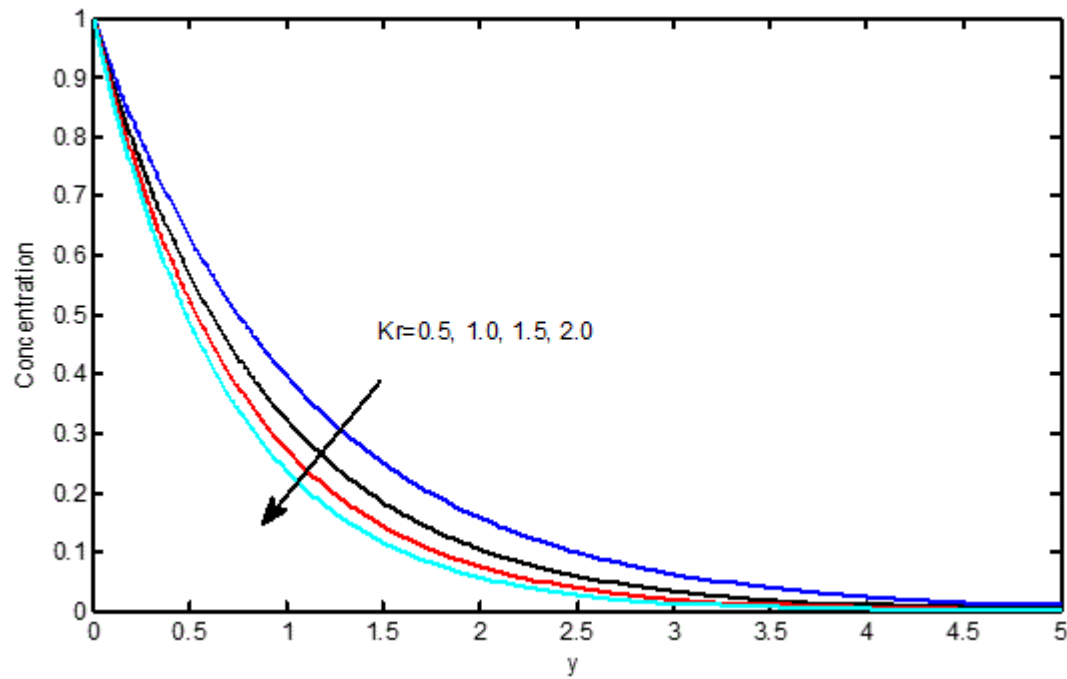


FIG. 17. Effects of concentration profiles for different values of chemical reaction parameter ( $Kr$ ).

## Conclusion

In this study, an analytical solution of unsteady hydromagnetic free convective heat and mass transfer flow of viscous, incompressible, electrically conducting viscoelastic fluid through porous medium bounded by 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 Grashof 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, whereas secondary velocity increases with an increase in heat source parameter and radiation absorption parameter.
- (vii) The viscoelastic parameter has the influence of decreasing the primary and secondary velocity.

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