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Unsteady MHD Walter's-B Viscoelastic Flow Past a Vertical Porous Plate

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ABSTRACT

The present paper intended to analyse an unsteady MHD Walter's-B viscoelastic flow past a vertical porous plate embedded in a porous medium in the presence of the radiation and chemical reaction effects. The dimensionless partial differential equations of governing equations of the flow field are solved numerically using closed analytical method. The velocity, temperature and concentration profiles are discussed graphically and discussed qualitatively.

1. Introduction

In recent years, large number of mathematicians has been attracted towards investigation of unsteady MHD flow of non-Newtonian fluid because of study on heat and mass transfer of the boundary layer flow fields, in view of its numerous applications in various fields such as like milk processing, blood oxygenators, mixing mechanism, dissolution process and polymer processing industry in manufacturing processes. There exist many viscoelastic fluids and their models to study non-Newtonian fluids like second grade viscoelastic fluids, third grade viscoelastic fluids, micropolar fluids, Rivlin Erickson model, Maxwell model and Walter's-B model etc. Sakiadis [1, 2] first studied the boundary layer problem assuming velocity of a bounding surface as constant.

The convection problem in porous medium has also important applications in geothermal reservoirs and geothermal energy extractions. Crane [3] computed an exact similarity solution for the boundary layer flow of a Newtonian fluid toward an elastic sheet which is stretched with the velocity proportional to the distance from the origin. An unsteady free convective flow with mass transfer phenomenon past an infinite vertical porous plate with constant suction was studied by

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Soundalgekar and Wavre [4]. Soundalgekar [5] analyzed the effects of mass transfer and free convection currents on the flow past an impulsively started vertical plate. Lai and Kulacki [6] studied the coupled heat and mass transfer with natural convection from vertical surface in a porous medium. Hiremath and Patil [7] studied the effect on free convection currents on the oscillatory flow through a porous medium which is bounded by vertical plane surface of constant temperature.

Subhashini *et al.,* [8] analyzed the effect of mass transfer on the flow past a vertical porous plate. Elbashbeshy and Ibrahim [9] investigated the effect of steady free convection flow with variable viscosity and thermal diffusivity along a vertical plate. Kafoussias and Williams [10] studied the thermal-diffusion and diffusion-thermo effects on the mixed free-forced convective and mass transfer steady laminar boundary layer flow over a vertical plate, with temperature dependent viscosity. A comprehensive review of the studies of convective heat transfer mechanism through porous media has been made by Nield and Bejan [11]. Sajid and Hayat [12] investigated the radiation effects on the mixed convection flow over an exponentially stretching sheet and solved the problem analytically using homotopy analysis method. Fluctuating heat and mass transfer on an unsteady free convective MHD flow through a porous media in a rotating system has been discussed by Dash *et al.,* [13] In these studies the magnetohydrodynamic effect has been ignored. The numerical solution for the same problem was then given by Bidin and Nazar [14]. Anwar Beg *et al.,* [15] obtained the numerical solutions for the free convective flow induced by a stretching surface in the presence of Dufour and Soret effects. Tsai and Huang [16] analyzed Dufour and Soret effects on the Hiemenz flow over a stretching surface immersed in a porous medium. Afify [17] studied Dufour and Soret effects in heat and mass transfer in the flow induced by a stretching surface. Turkyilmazoglu [18] studied multiple solutions of heat and mass transfer of MHD slip flow for the viscoelastic fluid over a stretching sheet. Turkyilmazoglu [19] Studied Multiple analytic solution of heat and mass transfer of MHD slip flow for two types of viscoelastic fluids over a stretching/shrinking surface. Reddy *et al.,* [20] studied the radiation and chemical reaction effects on MHD flow along a moving vertical porous plate. Rashidi and Erfani [21] applied an analytical method for solvi1g steady MHD convective and slip flow due to a rotating disk with viscous dissipation and Ohmic heating. Further, Rashidi *et al.,* [22] studied an analytic approximate solution for MHD boundary layer viscoelastic fluid flow over continuously moving stretching surface by HAM with two auxiliary parameters. Sivaraj and Kumar [23] have analyzed an unsteady MHD dusty viscoelastic fluid Couette flow in an irregular channel with varying mass diffusion. Recently, Poornima and Bhaskar Reddy [24] presented an analysis of the radiation effects on MHD free convective boundary layer flow of nanofluid over a nonlinear stretching sheet. However, the interaction of radiation with mass transfer due to a stretching sheet has received little attention. Mishra [25] analyzed the effect of free convection and mass transfer on the flow of an elastico-viscous fluid (Walters B0 model) in a vertical channel. The diffusion thermo effect has been considered on the fully developed laminar flow with uniform plate temperature and concentration. Conductivity Further, Prakash *et al.,* [26] contributed through their publication entitled radiation and Dufour effects on an unsteady MHD mixed convective flow in an accelerated vertical wavy plate with varying temperature and mass diffusion. Abolbashari *et al.,* [27] studied entropy analysis for an unsteady MHD flow past a stretching permeable surface in nanofluid. Mixed convective heat transfer for MHD viscoelastic fluid flow over a porous wedge with thermal radiation is studied by Rashidi *et al.,* [28]. Benazir *et al.,* [29] have studied unsteady MHD Casson fluid flow over a vertical cone and flat plate with non-uniform heat source/sink. Reddy *et al.,* [30] analyzed the heat and mass transfer effects on MHD free convection flow over an inclined plate embedded in a porous medium. Khan *et al.,* [31] have analysed the natural convection simulation of Prabhakar-like fractional Maxwell fluid flowing on inclined plane with generalized thermal flux. Seethamahalakshmi *et al.,* [32] were studied the computational study of MHD nanofluid flow with effects of variable viscosity and non-uniform heat generation. Falodun *et al.,* [33] was investigated the heat and mass transfer effects on MHD Casson fluid flow of blood in stretching permeable vessel. Soret and Dufour mechanisms on unsteady boundary layer flow of tangent hyperbolic and Walters-B nano liquid was studied by Reddy *et al.,* [34]. Riaz at al [35] have examined the unsteady MJHD flow of tangent hyperbolic liquid past a vertical porous plate. Rani *et al.,* [36] were investigated the significance of Cattaneo-Christov heat flux on chemically reacting nanofluids flow past a stretching sheet with joule heating effect. Reddy, K. V., *et al.,* [37] have analysed an outlining the impact of melting on MHD Casson fluid flow past a stretching sheet in a porous medium with radiation. Leelavathi *et al.,* [38] have been examined the MHD Casson fluid flow in stagnation-point over an inclined porous surface. Ramesh *et al.,* [39] demonstrated the magneto-hydrodynamic effects on heat and mass transfer in hybrid nanofluid flow over a stretched sheet with Cattaneo-Christov model. Rao *et al.,* [40] discussed the MHD slip flow of upper-convected Casson and Maxwell nanofluid over a porous stretched sheet: impacts of heat and mass transfer.

In the present study we have considered an unsteady MHD Walter's-B viscoelastic flow past a vertical porous plate embedded in a porous medium in the presence of the radiation and chemical reaction effects. The dimensionless partial differential equations of governing equations of the flow field are solved numerically using closed analytical method. The velocity, temperature and concentration profiles are discussed through graphically and discussed qualitatively.

2. Methodology

We consider an unsteady magnetohydrodynamic Casson fluid flow of a viscoelastic incompressible electrically conducting fluid past an impulsively started infinite vertical porous plate with variable temperature and mass diffusion with the effect of thermal radiation is considered. The plate is embedded in a porous medium, x^* - axis and y^* -axis are taken along and normal to the plate respectively. Initially the plate and fluid are the same temperature and concentration T_∞^* and C_∞^* respectively. At the time $t^* > 0$ plate is given in motion along x^* direction with constant velocity u_0. A transverse magnetic field B_0 is considered normal to the direction of flow. Magnetic Reynolds number and transversely applied magnetic field are very small, therefore induced magnetic fields is negligible. The fluid concentration is an exponential and the first order chemical reaction is considered. Due to infinite length in $x^* -$ direction the flow variables are functions of y^* and t^* only.

The Casson fluid properties are as:

$$\tau_{ij} = \begin{cases} 2\left(\mu_B + p_y / \sqrt{2\pi}\right)e_{ij}, \ \pi > \pi_c \\ 2\left(\mu_B + p_y / \sqrt{2\pi_c}\right)e_{ij}, \ \pi < \pi_c \end{cases} \tag{1}$$

Where $\mu_B, \pi = e_{ij}e_{ij}, \ e_{ij}, \pi, \pi_c, p_y$ be the non-Newtonian fluid's dynamic viscosity, the rate of deformation at the $(i, j)^{th}$ component, the component product of rate of deformation by itself, the critical value of π and the fluid's yield stress, respectively.

Under the above assumptions, the governing boundary layer equations with Boussinesq's approximation are:

Continuity equation:

$$\frac{\partial v^*}{\partial y^*}=0 \Rightarrow v^* = -v_0\,(\text{constant}) \tag{2}$$

Momentum equation:

$$\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}=\begin{bmatrix} \nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u^*}{\partial y^{*2}}-\lambda\frac{\partial^3 u^*}{\partial y^{*2}\partial t^*}+g\beta_T(T^*-T_\infty^*)\cos\alpha \\ +g\beta_C(C^*-C_\infty^*)\cos\alpha-\frac{\sigma B_0^2 u^*}{\rho}-\frac{\nu u^*}{K^*} \end{bmatrix} \tag{3}$$

Energy equation:

$$\rho C_p\left(\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}\right)=k\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{\partial q_r}{\partial y^*} \tag{4}$$

Equation of continuity for mass transfer:

$$\frac{\partial C^*}{\partial t^*}+v^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-k_r(C^*-C_\infty^*) \tag{5}$$

Where g is gravitational acceleration, β is the Casson fluid parameter, β_T is the volumetric coefficient of thermal expansion, β_C is the coefficient of volume expansion for mass transfer, K^* is the permeability of porous medium, σ is the electrical conductivity of the fluid, T^* is the dimensional temperature, ν is the kinematic viscosity, μ is the viscosity, ρ is the fluid density, B_0 is the magnetic induction, q_r is the radiative heat flux in y^* -direction, D is the mass diffusion coefficient, Kr is the chemical reaction rate of constant, λ Walter's-B is the visco-elasticity parameter, C_p is the specific heat at constant pressure, k is the thermal conductivity of the fluid.

The appropriate boundary conditions are

$$\begin{cases} t^*\le 0 \;\; u^*=0, T^*=T_\infty^*, C^*=C_\infty^* \quad \forall y^* \\ t^*>0 \;\; u^*=u_0, v^*=-v_0, T^*=T_\infty^*+(T_w^*-T_\infty^*)\,e^{At^*} \\ \quad C^*=C_\infty^*+(C_w^*-C_\infty^*)\,e^{At^*} \quad \text{At } y^*=0 \\ u^*=0, T^*\to\infty, C^*\to\infty, \qquad y^*\to\infty, \end{cases} \tag{6}$$

Where, $A=\frac{v_0^2}{\nu}, T_w^* \text{ and } C_w^*$ are temperature and concentration of place respectively.

For an optically thick gray fluid, the radiative heat flux q_r is approximated by the Roseland approximation which is given by

$$q_r=-\frac{4\sigma}{3k_m}\frac{\partial T^{*4}}{\partial y^*} \tag{7}$$

Where σ and k_m are Stefan Boltzmann constant and mean absorption coefficients respectively. It is assumed that the temperature difference within the flow is sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about T_∞^* and neglecting the higher order terms,

$$T^{*4} \cong 4T_\infty^{*3}T^* - 3T_\infty^{*4} \tag{8}$$

Using Eq. (7) and Eq. (8) in Eq. (4), we get

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{16\sigma T_\infty^{*2}}{3k_1 \rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} \tag{9}$$

In order to acquire non-dimensional partial differential equations, introducing following dimensionless quantities:

$$\begin{cases} u = \dfrac{u^*}{u_0}, y = \dfrac{y^* v_0}{v}, t = \dfrac{t^* v_0^2}{v}, \theta = \dfrac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \\ \Gamma = \dfrac{\lambda v_0^2}{v^2}, C = \dfrac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, Gm = \dfrac{v g \beta^* (C_w^* - C_\infty^*)}{u_0 v_0^2}, Gr = \dfrac{v g \beta (T_w^* - T_\infty^*)}{u_0 v_0^2}, \\ Kr = \dfrac{krv}{v_0^2}, K = \dfrac{v_0^2 K^*}{v^2}, \Pr = \dfrac{\rho Cp}{k}, M = \dfrac{\sigma B_0^2 v}{\rho v_0^2}, R = \dfrac{4\sigma T_\infty^{*3}}{k_1 k}, Sc = \dfrac{v}{D} \end{cases} \tag{10}$$

By virtue of Eq. (10), we get non-dimensional form of Eq. (3), Eq. (4) and Eq. (9) respectively:

$$\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \left(1 + \frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2} - \Gamma \frac{\partial^3 u}{\partial y^2 \partial t} + Gr\theta + GmC - (M + \frac{1}{K})u \tag{11}$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1 + \frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} \tag{12}$$

$$\frac{\partial C}{\partial t} - \frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 c}{\partial y^2} - KrC \tag{13}$$

The corresponding initial and boundary conditions in non-dimensional form are:

$$\begin{cases} t \le 0 \quad u = 0, \theta = 0, C = 0 \quad \forall y \\ t > 0 \quad u = 1, \theta = e^t, C = e^t \quad \text{at } y = 0 \\ \qquad\quad u = 0, u \to 0, C \to 0, y \to \infty \end{cases} \tag{14}$$

Solution of the Problem

In order to reduce the above system of partial differential equations to a system of ordinary equations in dimensionless form, we may represent the velocity, temperature and concentration as

$$u(y,t)=u_0(y)e^{i\omega t} \tag{15}$$

$$\theta(y,t)=\theta_0(y)e^{i\omega t} \tag{16}$$

$$C(y,t)=C_0(y)e^{i\omega t} \tag{17}$$

Substituting Eq. (15), Eq. (16) and Eq. (17) in Eq. (11), Eq. (12) and Eq. (13), we obtain:

$$\left(1+\frac{1}{\beta}-i\omega\Gamma\right)u_0''+u_0'-k_3u_0=-\left[Gr\theta_0+GmC_0\right]\cos\alpha \tag{18}$$

$$k_1\theta_0''+\theta_0'-i\omega\theta_0=0 \tag{19}$$

$$C_0''+ScC_0'-\left(Kr+i\omega\right)C_0=0 \tag{20}$$

Here the primes denote the differentiation with respect to y.

The corresponding boundary conditions can be written as

$$\begin{cases} t\le 0, u_0=0, \theta_0=0, \mathrm{C}_0=0 \quad \forall\, y \\ t>0,\ u_0=e^{-i\omega t} \quad \theta_0=e^{(1-i\omega)t},\ C_0=e^{(1-i\omega)t} \quad \text{at} \quad y=0 \\ t>0,\ u_0\to 0, \quad \theta_0\to 0, \quad \phi_0\to 0 \quad \text{as} \quad y\to\infty \end{cases} \tag{21}$$

The analytical solutions of Eq. (18) – Eq. (20) with satisfying the boundary conditions Eq. (21) are given by

$$u_0(y)=\left(\left(1-\left(A_1+A_2\right)e^t\right)e^{-i\omega t}\right)e^{-m_5y}+\left(A_1e^{-m_3y}+A_2e^{-m_1y}\right)e^{(1-i\omega)t} \tag{22}$$

$$\theta_0\left(y\right)=e^{(1-i\omega)t-m_3y} \tag{23}$$

$$C_0(y)=e^{(1-i\omega)t-m_1y} \tag{24}$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$u(y,t)=\left[\left(1-\left(A_1+A_2\right)e^t\right)e^{-m_5y}+\left(A_1e^{-m_3y}+A_2e^{-m_1y}\right)e^t\right] \tag{25}$$

$$\theta\left(y,t\right)=e^{(t-m_3y)} \tag{26}$$

$$C(y,t)=e^{(t-m_1y)} \tag{27}$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, the local surface heat, and mass flux. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin- friction) is given by

$$C_f = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = \left[\left(1-\left(A_1+A_2\right)e^t\right)m_5 + \left(m_3A_1 + m_1A_2\right)e^t\right]$$

From temperature field, now we study the rate of heat transfer which is given in non -dimensional form as:

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_3 e^t$$

From concentration field, now we study the rate of mass transfer which is given in non -dimensional form as:

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = m_1 e^t$$

3. Results and Discussion

The problem of an unsteady MHD Walter's-B viscoelastic flow past a vertical porous plate embedded in a porous medium in the presence of the radiation and chemical reaction is addressed in this study. Numerical solutions have been carried out for the non-dimensional temperature, concentration, velocity keeping the other parameters of the problem fixed. Numerical calculations of these results are presented graphically in the Figure 1 to Figure 14. These results show the effect of different parameters on the velocity, temperature distribution and concentration profiles at the wall. To find out the solution of this problem, we have placed an infinite vertical plate in a finite length in the flow. Hence, we solve the entire problem in a finite boundary. However, in the graphs, the y values vary from 0 to 4 and the velocity, temperature, and concentration tend to zero as y tends to 5. This is true for any value of y. Thus, we have considered finite length. In the present study we adopted the following default parameter values of finite element method. Gm=3;Gr=3;K=0.9; R=2;Pr=0.71;t=0.2;Γ=0.005;Sc=0.66;n=1;M=5.

Figure 1 and Figure 2 are exhibits the effect of chemical reaction on the velocity and concentration distribution. It is seen that the chemical reaction increases, the velocity and concentration profiles decrease. Thus, it is concluded that the magnitude of coefficient of chemical reaction plays a vital role on velocity distribution. The effect of the Schmidt number on the velocity and concentration profiles is shown in Figure 3 and Figure 4 respectively. It is noticed that as the Schmidt number increases, the velocity and concentration profiles decrease. This is because of concentration buoyancy effects that often retard the fluid velocity.

Figure 4 and Figure 5 represent the velocity and temperature profiles for different values of the radiation parameter. We observed that thermal radiation enhances convective flow such that as thermal radiation intensity R increases, flow velocity and temperature distribution decreases within the thermal buoyancy layer very close to the plate. Figure 7 and Figure 8 present the effect of Prandtl number on the velocity and temperature profiles. As Prandtl number increases the velocity profiles decreases.

Figure 9 illustrates that the velocity distribution for different values visco-elastic parameter (Γ). It is noticed that the velocity profiles decrease with an increasing visco-elastic parameter. The effect of the permeability parameter (K) on the velocity field is shown in Figure 10. As depicted in this figure, the effects of increasing the values of porous permeability parameter is to increase the value of the velocity component in the boundary layer due to the fact that drag is reduced by increasing the values of the porous permeability on the fluid flow which results in increased velocity. The trend shows that the velocity is accelerated with increasing porosity parameter. For various values of the magnetic parameter (M), the velocity profiles are plotted in Figure 11. As M increases, the velocity decreases. This result qualitatively agrees with the expectations, since the magnetic field exerts a retarding force on the flow. Figure 12, Figure 13 and Figure 14 shows the effect of the velocity, temperature and concentration profiles for different values of time (t) respectively. It is observed that the velocity, temperature and concentration profiles are increases with an increasing the time (t).

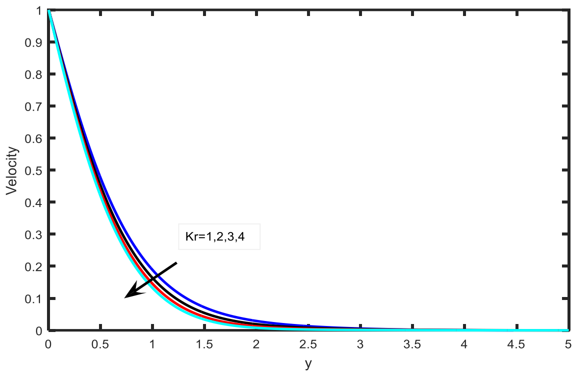

Fig. 1. Velocity profiles for different values of chemical reaction parameter (Kr)

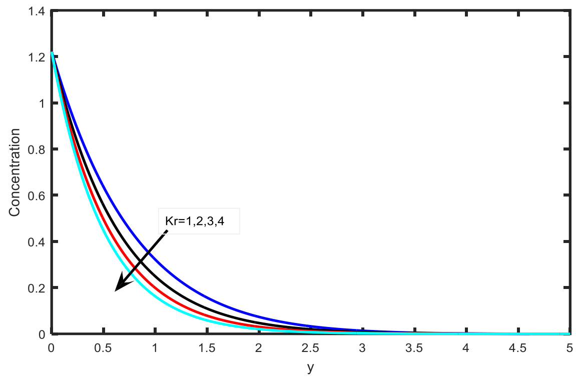

Fig. 2. Concentration profiles for different values of chemical reaction parameter (Kr)

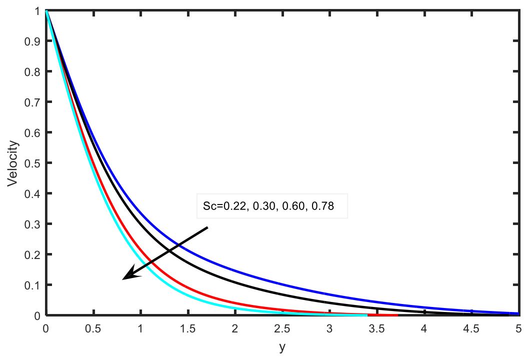

Fig. 3. Velocity profiles for different values of Schmidt number (Sc)

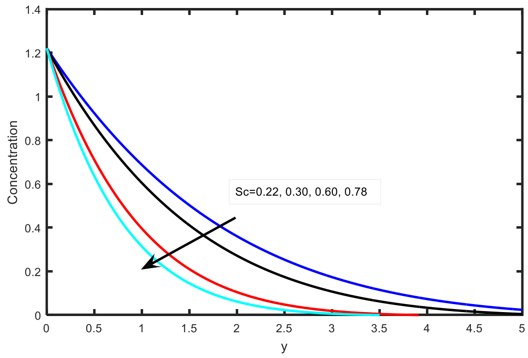

Fig. 4. Concentration profiles for different values of Schmidt number (Sc)

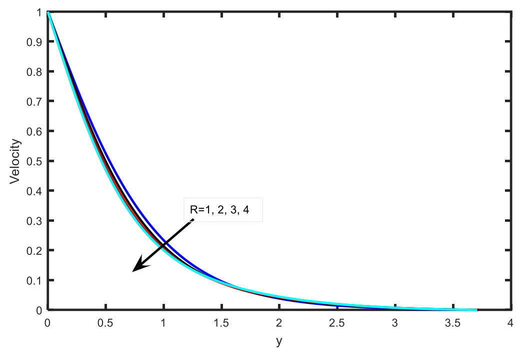

Fig. 5. Velocity profiles for different values of radiation parameter (R)

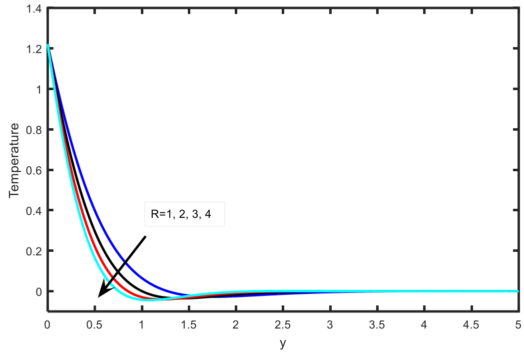

Fig. 6. Temperature profiles for different values of radiation parameter (R)

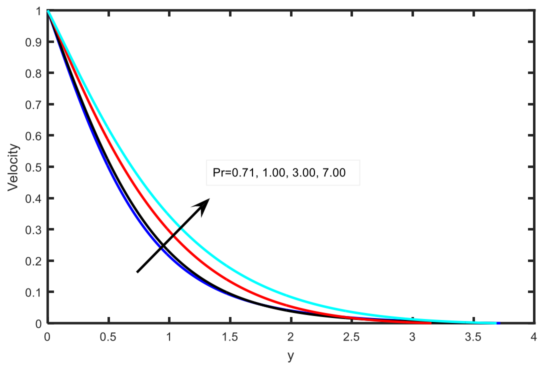

Fig. 7. Velocity profiles for different values of Prandtl number (Pr)

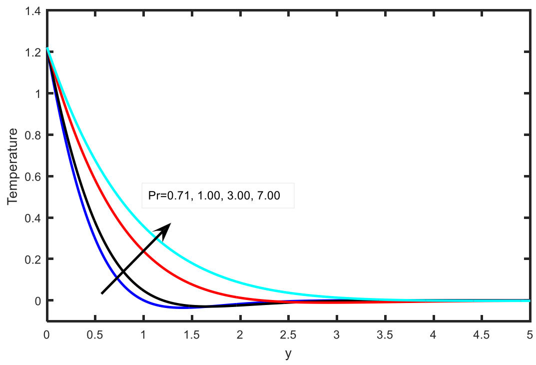

Fig. 8. Temperature profiles for different values of Prandtl number (Pr)

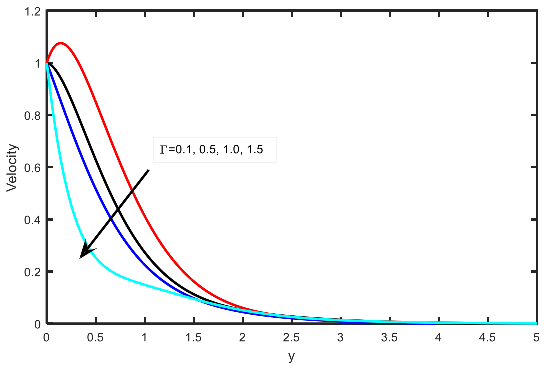

Fig. 9. Velocity profiles for different values of visco-elastic parameter (Γ)

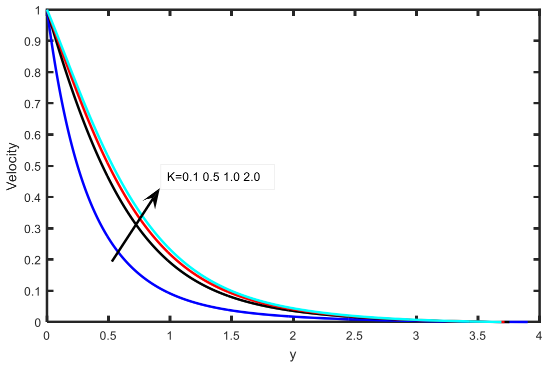

Fig. 10. Velocity profiles for different values permeability parameter (K)

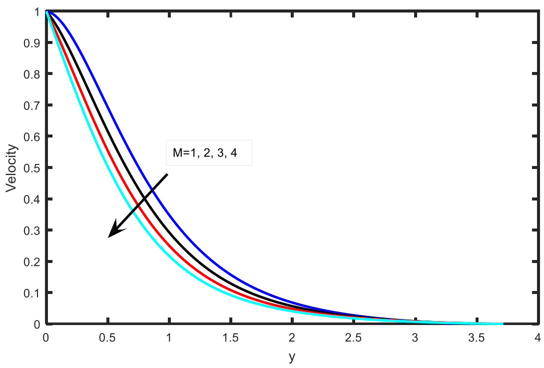

Fig. 11. Velocity profiles for different values of magnetic parameter (M)

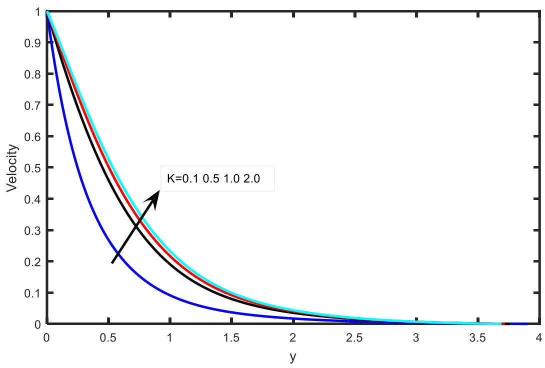

Fig. 12. Velocity profiles for different values of time (t)

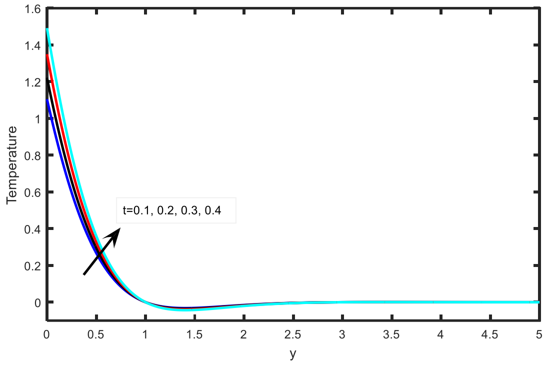

Fig. 13. Temperature profiles for different values of time (t)

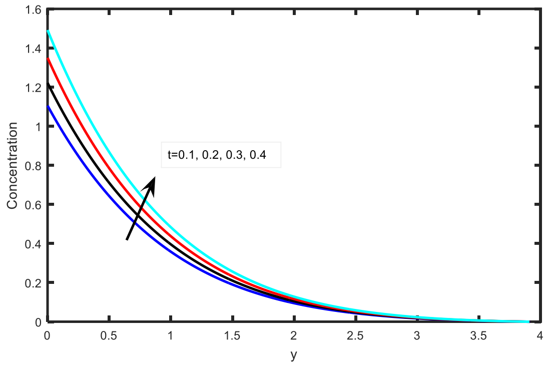

Fig. 14. Concentration profiles for different values of time (t)

4. Conclusions

In this paper we have studied numerical analysis of Walter's-B viscoelastic MHD flow past a vertical porous plate in the presence of radiation and chemical reaction. The numerical results have been performed through graphically with various parameters. Form the graphical representation, we have the following observations.

i. With the increase in the value of Kr, Sc, R, Γ and M, the velocity decrease.
ii. With the increase in the value of Pr, K and t, the velocity increase.
iii. With the increase in the value of R, the Temperature decrease.
iv. With the increase in the value of Pr and t, the Temperature increase.
v. With the increase in the value of Kr and Sc, the concentration decrease.

With the increase in the value of t, the concentration increase.

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