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HEAT AND MASS TRANSFER IN MHD VISCO-ELASTIC FLUID FLOW PAST A VERTICAL PLATE IN PRESENCE OF SORET EFFECT AND CHEMICAL REACTION

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Abstract

The analysis of oscillatory MHD fluid flow over a radiative vertical porous plate with Soret effect in presence of variable suction and chemical reaction has been studied. The porous plate is subjected to a transverse sinusoidal suction velocity whose temperature fluctuates with time about a constant non-zero mean value. The governing equations are solved by using perturbation scheme. The approximate solutions for velocity, temperature, concentration fields, shearing stress, rate of heat transfer and rate of mass transfer have been derived. To study the visco-elastic effects with the combination of other flow parameters, the velocity and shearing stress have been discussed through graphs with physical interpretation.

1. Introduction

The combined effect of heat and mass transfer on the electrically

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conducting visco-elastic fluid past a vertical porous plate has been studied for its importance in the flow of the oils through porous rocks, the extraction of energy from geothermal region, drug permeation through human skin, polymer technology, hydrology and chemical engineering, etc. Kim and Vafai [12] and Harris and Ingham [9] have analyzed the problems of natural flow through porous medium past a vertical plate. The combined effect of heat and mass transfer on MHD free convective flow through porous medium was investigated by Chaudhary and Jain [3]. The problem of combined effect of heat and mass transfer along a vertical plate with variable temperature and concentration in presence of magnetic field has been studied by Elbashbeshy [8]. Siddappa and Abel [16] have studied the non-Newtonian flow past a stretching sheet. The problem of MHD natural convection flow of viscous incompressible fluid from a vertical flat plate was investigated by Ahmed and Sarkar [1]. Varshney [17] has studied the oscillatory two-dimensional flow through a porous medium bounded by a porous plate. Chaudhary and Jain [4] have analyzed the combined heat and mass transfer effects on MHD free convection flow past an oscillatory plate embedded in porous medium. Pal and Talukdar [15] have studied the buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and ohmic heating. The problem of radiation effect on mixed convection along a vertical plate with uniform surface temperature was investigated by Hossain and Takhar [10]. Hossain et al. [11] have analyzed the effect of radiation in free convection from a porous vertical plate. Lin and Wu [13] have analyzed the combined heat and mass transfer by laminar natural convection from a vertical plate. Alharbi et al. [2] and Choudhury et al. [5-7] have also contributed their efforts in studying the heat and mass transfer effects for visco-elastic fluids.

In the present paper, we investigate MHD oscillatory flow past a radiative vertical porous plate in presence of Soret effect. Here we have discussed the visco-elastic effects graphically.

The visco-elastic fluid flow is characterized by Walters liquid $(\text{Model } B')$.

The constitutive equation for Walters liquid $(\text{Model } B')$ is

$$\sigma_{ik} = -pg_{ik} + \sigma'_{ik}, \quad \sigma'^{ik} = 2\eta_0 e^{ik} - 2k_0 e'^{ik}, \tag{1.1}$$

where σ^{ik} is the stress tensor, p is an isotropic pressure, g_{ik} is the metric tensor of a fixed coordinate system x^i, v_i is the velocity vector, the contravariant form of e'^{ik} is given by

$$e'^{ik} = \frac{\partial e^{ik}}{\partial t} + v^m e^{ik}_{,m} - v^k_{,m} e^{im} - v^i_{,m} e^{mk}. \tag{1.2}$$

It is the convected derivative of the deformation rate tensor e^{ik} defined by

$$2e^{ik} = v_{i,k} + v_{k,i}. \tag{1.3}$$

Here η_0 is the limiting viscosity at the small rate of shear which is given by

$$\eta_0 = \int_0^\infty N(\tau)d\tau \quad \text{and} \quad k_0 = \int_0^\infty \tau N(\tau)d\tau, \tag{1.4}$$

$N(\tau)$ being the relaxation spectrum. This idealized model is a valid approximation of Walters liquid $(\text{Model } B')$ taking very short memories into account so that terms involving

$$\int_0^\infty t^n N(\tau)d\tau, \quad n \geq 2 \tag{1.5}$$

have been neglected.

2. Mathematical Formulation

We consider an unsteady two-dimensional MHD free convection flow of a visco-elastic incompressible and electrically conducting fluid such that x'-axis is taken along the plate in upward direction and y'-axis is normal to the plate. A transverse magnetic field B_0 is applied normal to the plate. Let

u' and v' be the velocity components in x' and y' directions, respectively. Since the motion is two-dimensional and the plate is of an infinite length therefore all the physical variables are independent of x'. The governing equations are:

$$\frac{\partial v'}{\partial y'} = 0, \tag{2.1}$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial u'}{\partial y'} - \frac{k_0}{\rho}\left[\frac{\partial^3 u'}{\partial t' \partial y'^2} + v'\frac{\partial^3 u'}{\partial y'^3}\right]$$

$$+ g\beta(T' - T'_\infty) + g\beta'(C' - C'_\infty) - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K'}u', \tag{2.2}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{\overline{K}}{\rho c_P}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho c_P}\frac{\partial q'_r}{\partial y'}, \tag{2.3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D_M\frac{\partial^2 C'}{\partial y'^2} + D_T\frac{\partial^2 T'}{\partial y'^2} - K_1(C' - C'_\infty). \tag{2.4}$$

The boundary conditions are:

$$\left.\begin{aligned} &y' = 0: u' = u,\ T' = T'_w + \varepsilon(T'_w - T'_\infty)e^{i\omega' t'},\ C' = C'_w + \varepsilon(C'_w - C'_\infty)e^{i\omega' t'} \\ &y' \to \infty: u' = 0,\ T' \to T'_\infty,\ C' \to C'_\infty \end{aligned}\right\}. \tag{2.5}$$

Equation (2.1) yields that the suction velocity at the plate is either a constant or a function of time and here the suction velocity is taken normal to the plate in the form

$$v' = -V_0(1 + \varepsilon A e^{i\omega' t'}), \tag{2.6}$$

where A is a real positive constant, $\varepsilon \ll 1$, V_0 is a scale of suction velocity which is a non-zero positive constant.

We introduce the non-dimensional parameters as

$$\left.\begin{aligned}
&u = \frac{u'}{V_0},\ y = \frac{V_0 y'}{v},\ t = \frac{V_0^2 t'}{v},\ Pr = \frac{\mu c_P}{\overline{K}},\ Sc = \frac{v}{D},\ \theta = \frac{T' - T'_\infty}{T'_W - T'_\infty},\\
&\phi = \frac{C' - C'_\infty}{C'_W - C'_\infty},\ Gr = \frac{g\beta(T'_W - T'_\infty)v}{V_0^3},\ Gm = \frac{g\beta'(C'_W - C'_\infty)v}{V_0^3},\\
&\omega = \frac{v\omega'}{V_0^2},\ K = \frac{K' V_0^2}{v^2},\ M = \frac{\sigma B_0^2 v}{\rho V_0^2},\ Sr = \frac{D_T (T'_W - T'_\infty)}{v(C'_W - C'_\infty)},\\
&F = \frac{4vI'}{\rho c_P},\ U = \frac{u'}{V_0},\ Kr = \frac{vK_1}{V_0^2},\ k = \frac{k_0 V_0^2}{\rho v^2}
\end{aligned}\right\}, \quad (2.7)$$

where Pr is the Prandtl number, Gr is the Grashof number for heat transfer, Gm is the Grashof number for mass transfer, K is the permeability parameter, M is the magnetic parameter, Sc is the Schmidt number, Sr is the Soret number, F is the radiation parameter, Kr is the chemical reaction parameter, k is the visco-elastic parameter.

The radiative heat flux is given by

$$\frac{\partial q'_r}{\partial y'} = 4(T' - T'_\infty)I',$$

where $I' = \int_0^\infty k_e \frac{\partial e_{b\lambda}}{\partial T'} d\lambda$, k_e is the absorption coefficient at the wall and $e_{b\lambda}$ is the Planck's function.

In view of equations (2.6) and (2.7), equations (2.2)-(2.4) transform to following dimensionless forms:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial u}{\partial y}$$

$$= \frac{\partial^2 u}{\partial y^2} - k\left[\frac{\partial^3 u}{\partial t \partial y^2} - (1 + \varepsilon A e^{i\omega t})\frac{\partial^3 u}{\partial y^3}\right] + Gr\theta + Gm\phi - \left(M + \frac{1}{K}\right)u, \quad (2.8)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - F\theta, \quad (2.9)$$

$$\frac{\partial\phi}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial\phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2} + Sr\frac{\partial^2\theta}{\partial y^2} - Kr\phi. \tag{2.10}$$

The modified boundary conditions are:

$$\left.\begin{array}{l} y = 0: u = U,\ \theta = 1 + \varepsilon e^{i\omega t},\ \phi = 1 + \varepsilon e^{i\omega t},\ \phi = 1 + \varepsilon e^{i\omega t} \\ y \to \infty: u = 0,\ \theta \to 0,\ \phi \to 0 \end{array}\right\}. \tag{2.11}$$

3. Solution of the Problem

To solve equations (2.8)-(2.10), we represent the velocity, temperature and concentration of the fluid in the neighbourhood of the plate as

$$\left.\begin{array}{l} u = u_0(y) + \varepsilon e^{i\omega t} u_1(y) \\ \theta = \theta_0(y) + \varepsilon e^{i\omega t} \theta_1(y) \\ \phi = \phi_0(y) + \varepsilon e^{i\omega t} \phi_1(y) \end{array}\right\}. \tag{3.1}$$

Substituting (3.1) in equations (2.8)-(2.10), equating the harmonic and non-harmonic terms and neglecting the higher order terms of $O(\varepsilon^2)$, we obtain

$$k u_0''' + u_0'' + u_0' - \left(M + \frac{1}{K}\right) u_0 = -Gr\theta_0 - Gm\phi_0, \tag{3.2}$$

$$kA u_0''' + k u_1''' - ik\omega u_1'' + u_1'' + u_1' - \left(M + \frac{1}{K} + i\omega\right) u_1 = -Gr\theta_1 - Gm\phi_1 - A u_0', \tag{3.3}$$

$$\theta_0'' + Pr\theta_0' - PrF\theta_0 = 0, \tag{3.4}$$

$$\theta_1'' + Pr\theta_1' - (F + i\omega) Pr\theta_1 = -APr\theta_0', \tag{3.5}$$

$$\phi_0'' + Sc\phi_0' - KrSc\phi_0 = -SrSc\theta_0'', \tag{3.6}$$

$$\phi_1'' + Sc\phi_1' - (Kr + i\omega) Sc\phi_1 = -SrSc\theta_1'' - ASc\phi_0', \tag{3.7}$$

where primes denote differentiation with respect to *y*.

The corresponding boundary conditions are:

$$\left.\begin{array}{l} y = 0: u_0 = U,\ u_1 = 0,\ \theta_0 = 1,\ \phi_0 = 1,\ \phi_1 = 1 \\ y \to \infty: u_0 = 0,\ u_1 = 0,\ \theta_0 = 0,\ \theta_1 = 0,\ \phi_0 = 0,\ \phi_1 = 0 \end{array}\right\}. \tag{3.8}$$

The solutions of equations (3.4)-(3.7) subject to boundary condition (3.8) are given by

$$\theta_0 = e^{-\alpha_2 y},$$

$$\theta_1 = A_1 e^{-\alpha_2 y} + A_2 e^{-\alpha_4 y},$$

$$\phi_0 = A_3 e^{-\alpha_2 y} + A_4 e^{-\alpha_6 y},$$

$$\phi_1 = A_6 e^{-\alpha_2 y} - A_7 e^{-\alpha_4 y} + A_8 e^{-\alpha_6 y} + A_9 e^{-\alpha_8 y}.$$

To solve equations (3.2) and (3.3), we consider

$$\left.\begin{array}{l} u_0 = u_{00} + k u_{01} \\ u_1 = u_{10} + k u_{11} \end{array}\right\}, \tag{3.9}$$

where $k \ll 1$ for small shear rate as given by Nowinski and Ismail [14].

Using (3.9) in equations (3.2), (3.3), equating the coefficients of like powers of k and neglecting higher order terms of k, we obtain

$$u''_{00} + u'_{00} - \left(M + \frac{1}{K}\right)u_{00} = A_{10} e^{-\alpha_2 y} - A_4 Gm e^{-\alpha_6 y}, \tag{3.10}$$

$$u''_{01} + u'_{01} - \left(M + \frac{1}{K}\right)u_{01} = -u'''_{00}, \tag{3.11}$$

$$u''_{10} + u'_{10} - \left(M + \frac{1}{K} + i\omega\right)u_{10} = A_{18} e^{-\alpha_2 y} + A_{19} e^{-\alpha_4 y} + A_{20} e^{-\alpha_6 y} - Gm A_9 e^{-\alpha_8 y} + A A_{13} \alpha_{10} e^{-\alpha_{10} y}, \tag{3.12}$$

$$u''_{11} + u'_{11} - \left(M + \frac{1}{K} + i\omega\right)u_{11} = -A u'''_{00} - u'''_{10} + i\omega u''_{10} + A A_{14} \alpha_2 e^{-\alpha_2 y} - A A_{15} \alpha_6 e^{-\alpha_6 y} + A A_{17} \alpha_{10} e^{-\alpha_{10} y}. \tag{3.13}$$

The relevant boundary conditions are:

$$\left.\begin{array}{l} y = 0:\ u_{00} = U,\ u_{01} = 0,\ u_{10} = 0,\ u_{11} = 0 \\ y \to \infty:\ u_{00} = 0,\ u_{01} = 0,\ u_{10} = 0,\ u_{11} = 0 \end{array}\right\}. \tag{3.14}$$

Solving equations (3.10) and (3.11), using boundary condition (3.14) and substituting these values in equation (3.9), we get

$$u_0 = A_{11}e^{-\alpha_2 y} - A_{12}e^{-\alpha_6 y} + A_{13}e^{-\alpha_{10} y}$$
$$+ k(A_{14}e^{-\alpha_2 y} - A_{15}e^{-\alpha_6 y} + A_{17}e^{-\alpha_{10} y}).$$

Solving equations (3.12) and (3.13), using boundary condition (3.14) and substituting these values in equation (3.9), we get

$$u_1 = A_{21}e^{-\alpha_2 y} + A_{22}e^{-\alpha_4 y} + A_{23}e^{-\alpha_6 y} - A_{24}e^{-\alpha_8 y} + A_{25}e^{-\alpha_{10} y}$$
$$+ A_{26}e^{-\alpha_{12} y} + k(N_1e^{-\alpha_2 y} + N_2e^{-\alpha_4 y} + N_3e^{-\alpha_6 y}$$
$$+ N_4e^{-\alpha_8 y} + N_5e^{-\alpha_{10} y} + N_8e^{-\alpha_{12} y}).$$

4. Result and Discussion

The fluid velocity is given by

$$u = u_0 + \varepsilon e^{i\omega t}u_1$$
$$= A_{11}e^{-\alpha_2 y} - A_{12}e^{-\alpha_6 y} + A_{13}e^{-\alpha_{10} y} + k(A_{14}e^{-\alpha_2 y} - A_{15}e^{-\alpha_6 y} + A_{17}e^{-\alpha_{10} y})$$
$$+ \varepsilon[(A_{21}e^{-\alpha_2 y} + A_{22}e^{-\alpha_4 y} + A_{23}e^{-\alpha_6 y} - A_{24}e^{-\alpha_8 y} + A_{25}e^{-\alpha_{10} y}$$
$$+ A_{26}e^{-\alpha_{12} y}) + k(N_1e^{-\alpha_2 y} + N_2e^{-\alpha_4 y} + N_3e^{-\alpha_6 y} + N_4e^{-\alpha_8 y}$$
$$+ N_5e^{-\alpha_{10} y} + N_8e^{-\alpha_{12} y})]e^{i\omega t}. \tag{4.1}$$

The shearing stress at the plate is given by

$$\sigma = \left(\frac{\partial u}{\partial y}\right)_{y=0} - \left[\frac{\partial^2 u}{\partial y \partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial^2 u}{\partial y^2}\right]_{y=0}. \tag{4.2}$$

The non-dimensional form of the rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0}. \tag{4.3}$$

The non-dimensional form of the rate of mass transfer in terms of Sherwood number at the plate is given by

$$Sh = \left(\frac{\partial\phi}{\partial y}\right)_{y=0}. \tag{4.4}$$

In order to get physical insight into the problem, the numerical evaluation has been carried out for non-dimensional fluid velocity, shearing stress, Nusselt number, Sherwood number at the plate, by assigning some specific arbitrary values to the physical parameters viz. Prandtl number *Pr*, Grashof number *Gr* for heat transfer, Grashof number *Gm* for mass transfer, Permeability parameter *K*, Magnetic parameter *M*, Schmidt number *Sc*, Soret number *Sr*, Radiation parameter *F*, Chemical reaction parameter *Kr*, which are involved in the solutions. Graphical illustrations are made for fluid velocity and shearing stress at the plate. The visco-elastic parameter $k = 0$ represents Newtonian fluid and non-zero values of *k* characterize non-Newtonian fluid flow mechanics. Throughout the discussion, $\omega = 1$, $U = 1$, $A = 1$, $\varepsilon = 0.001$ are kept fixed.

Figures 1-11 exhibit fluid velocity *u* against *y* under the influence of various physical parameters, the velocity component *u* accelerates near the plate and decelerates away from the plate. The variations of parameters do not alter the patterns of the fluid velocity in both Newtonian and non-Newtonian cases. In all the cases, the growth of visco-elasticity depicts on accelerating trend of the fluid velocity at all points of the fluid flow region in comparison with Newtonian fluid flow phenomenon.

From technological point of view, it is very important to know the effects of visco-elastic effects on the shearing stress at the wall and consequently the viscous drag. Figures 12-19 depict the behaviour of shearing stress σ against different parameters having interest from the physical point of view.

The shearing stress experiences a rising trend during the growth of the parameters Grashof number heat transfer *Gr*, Grashof number for mass transfer *Gm*, permeability parameter *K*, and Soret number *Sr* (Figures 13-15, 19) but opposite trend is observed in case of the parameters Prandtl number

Pr, Chemical reaction parameter *Kr*, Radiation parameter *F* and Magnetic parameter *M* (Figures 12, 16-18) in both Newtonian and visco-elastic fluid flow phenomena.

The Prandtl number helps to study simultaneous effects of momentum and thermal diffusion in fluid flow. Figure 12 illustrates that the growth of visco-elasticity enhances the shearing stress in comparison with the simple fluid.

Grashof number for heat transfer (*Gr*) is defined as the ratio of buoyancy force to viscous force and it characterizes the free convection parameter whereas the Grashof number for mass transfer (*Gm*) characterizes the free convection parameter for mass transfer. Both the parameters play significant role in heat and mass transfer problems. In this study, the rising trend of visco-elasticity enhances the shearing stress in compared to Newtonian fluid (Figures 13, 14). Here the results are discussed for the flow past an externally cooled plate, i.e., $Gr > 0$, also $Gm > 0$ indicates that the free stream concentration less than the concentration at the buoyancy surface. The shearing stress experiences an accelerating trend during the growth of visco-elasticity as well as permeability parameter *K* but the opposite pattern is observed in case of chemical reaction parameter *Kr* in comparison with the Newtonian fluid. The effect of Lorentz force on viscous drag is illustrated in Figure 18. The shearing stress experienced by the non-Newtonian fluid reveals on accelerating trend in the fluid flow region in compared to simple Newtonian fluid. When heat and mass are transferred simultaneously in a moving fluid, the relation between the fluxes and the driving potentials is more intricate in nature. It has been found that an energy flux can be generated not only by temperature gradient but also by composition gradients. The energy flux caused by composition gradient is called the *Dufour* or *diffusion thermo effect*. On the other hand, mass fluxes can also be created by temperature gradient known as the Soret or thermal diffusion effect. Figure 19 demonstrates that the shearing stress enhances due to the rise of visco-elasticity as well as Soret number in comparison with Newtonian fluid flow phenomenon.

The rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are not significantly affected by the visco-elastic parameter.

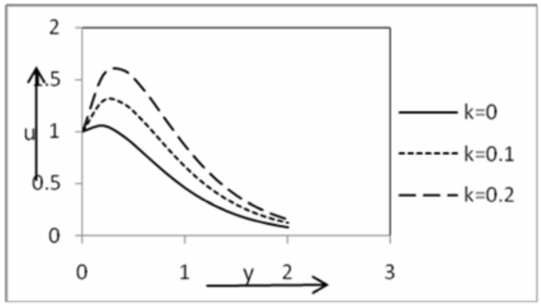

Figure 1. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

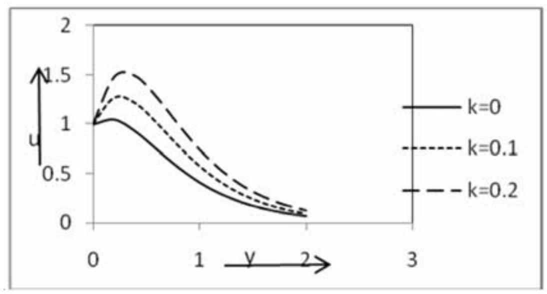

Figure 2. Velocity u versus y for $Pr = 5$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

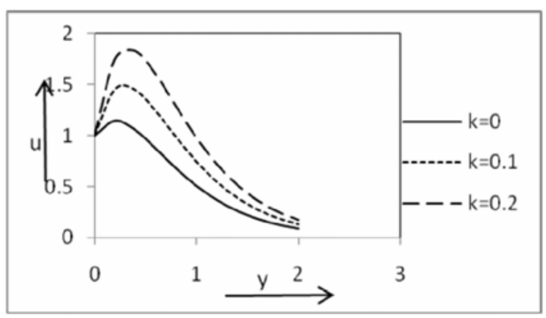

Figure 3. Velocity u versus y for $Pr = 3$, $Gr = 6$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

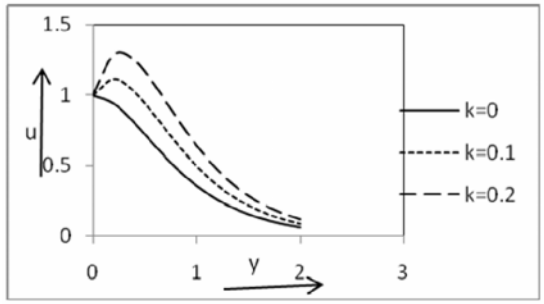

Figure 4. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 4$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

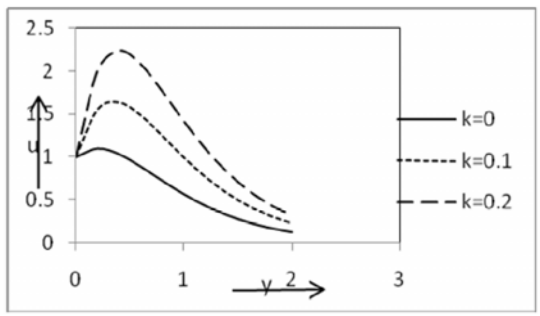

Figure 5. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 2$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

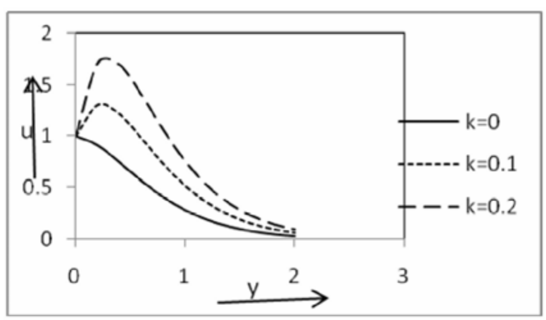

Figure 6. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 3$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

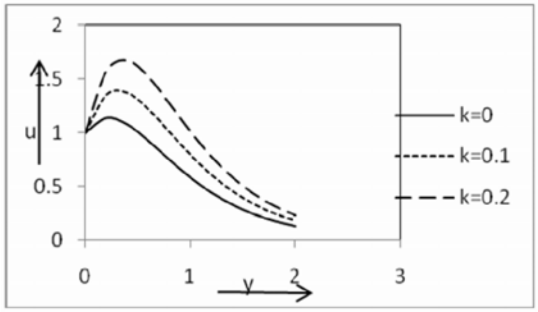

Figure 7. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 4$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

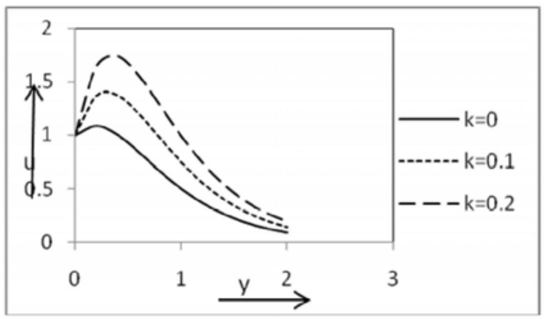

Figure 8. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.3$, $Sr = 0.4$, $F = 1$.

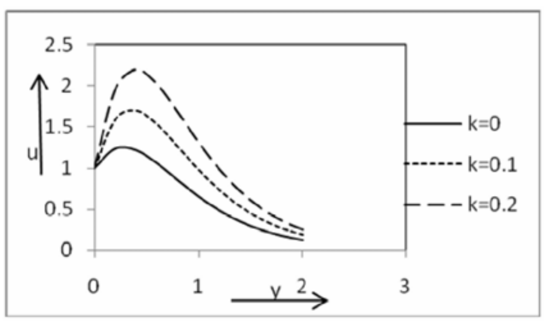

Figure 9. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.8$, $F = 1$.

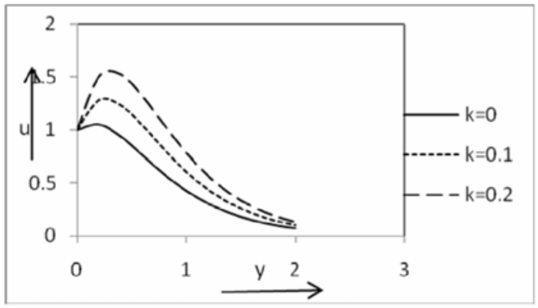

Figure 10. Velocity u versus y for $Pr = 3$, $Gr = 2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 3$.

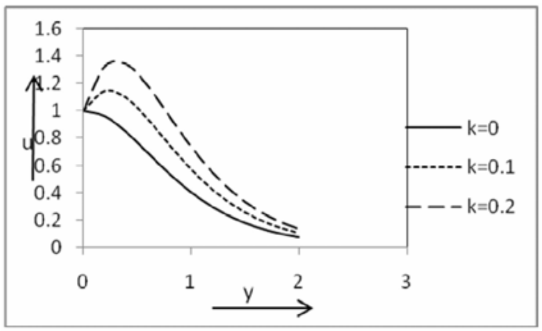

Figure 11. Velocity u versus y for $Pr = 3$, $Gr = -2$, $Gm = 6$, $Sc = 3$, $M = 1$, $K = 1$, $Kr = 0.6$, $Sr = 0.4$, $F = 1$.

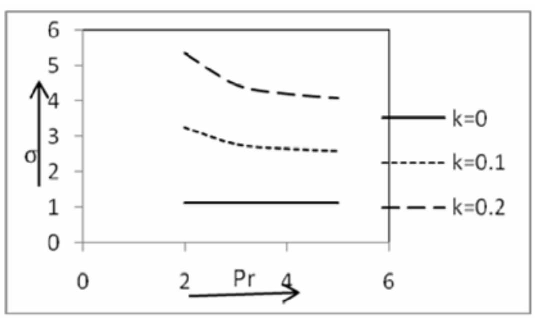

Figure 12. Shearing stress σ vs Pr.

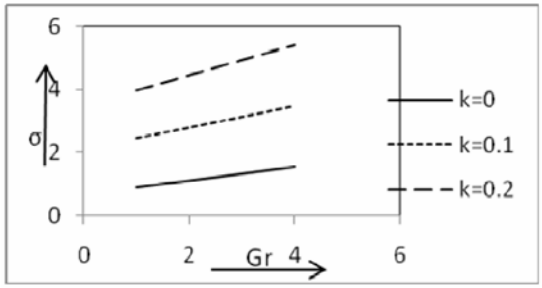

Figure 13. Shearing stress σ vs *Gr*.

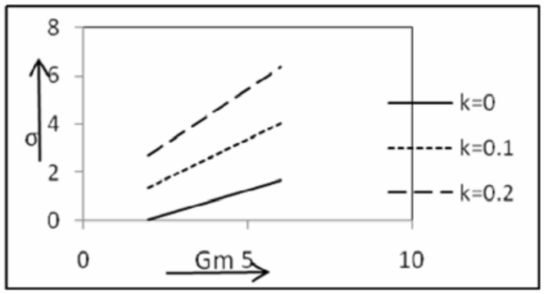

Figure 14. Shearing stress σ vs *Gm*.

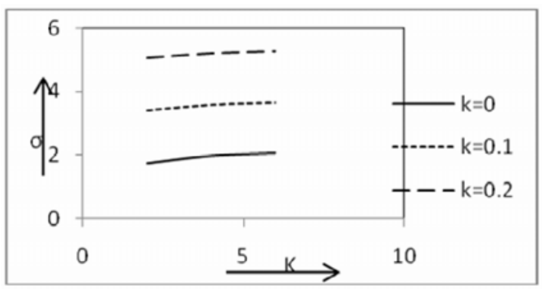

Figure 15. Shearing stress σ vs *K*.

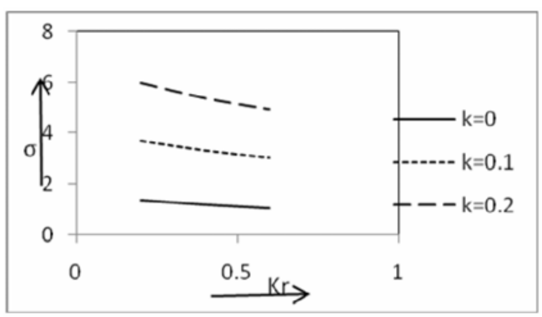

Figure 16. Shearing stress σ vs *Kr*.

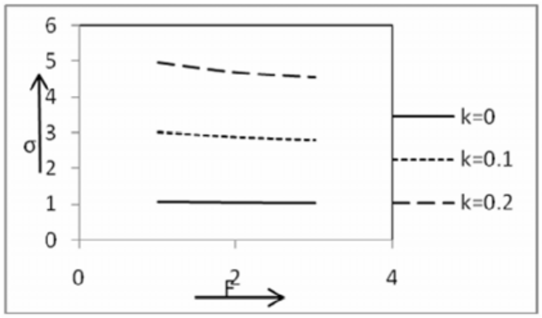

Figure 17. Shearing stress σ vs *F*.

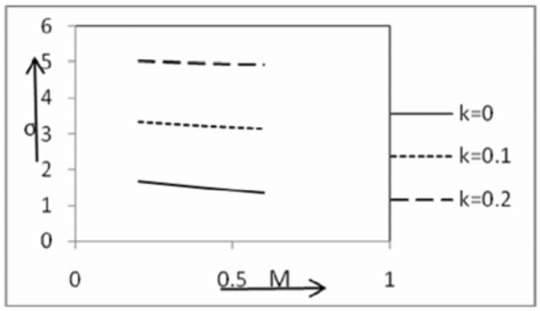

Figure 18. Shearing stress σ vs *M*.

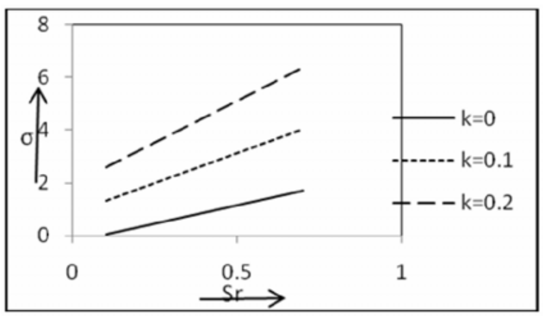

Figure 19. Shearing stress σ vs *Sr*.

5. Conclusion

This study leads to the following conclusions:

- The velocity field is considerably affected by the visco-elastic parameter at all points of the fluid flow region in combination of other flow parameters.

• The fluid velocity first rises adjacent to plate and thereafter descends towards the free stream velocity in both Newtonian and non-Newtonian cases.

• The shearing stress at the plate is found to be reduced under the influence of Prandtl number, radiation parameter, chemical reaction parameter and magnetic parameter whereas a reverse effect has been observed for Grashof number for heat transfer, permeability parameter, Grashof number for mass transfer and Soret parameter.

• The visco-elastic parameter has no significant effect on the temperature and the mass concentration fields.

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