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Visco-elastic Flow with Heat and Mass Transfer Past a Vertical Porous Plate in Presence of Hall Current and Radiation

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Abstract

The effects of Hall current and radiation on unsteady MHD free convective visco-elastic flow past an infinite vertical porous plate in presence of heat and mass transfer subjected to wall slip condition have been analyzed analytically. The highly non-linear equations are solved analytically by using multi parameter perturbation technique. The expressions for velocity field, temperature field, shearing stress and rate of heat transfer as well as mass transfer have been obtained. To study the visco-elastic effects with the combination of other flow parameters, the velocity and shearing stress have been illustrated graphically with physical interpretation.

Keywords: Free convection, Radiation, Perturbation scheme, Walters liquid (Model B$^{'}$).

2010 Mathematics Subject Classification: 76A10.

1. Introduction

Analytical approach of the problem of unsteady free convective flow of an electrically conducting fluid past an infinite vertical porous plate under the influence of magnetic field has attracted the interest of many researchers because of its application in different fields such as polymer industries, chemical engineering, paper industries, plastic engineering etc. In addition, recent developments in modern technology have intensified more interest of many researchers in studies of heat and mass transfer in visco-elastic fluids along with the Hall current and radiation due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical and astrophysical studies. where the density is low and (or) the magnetic field is very strong , the conductivity normal to the magnetic field is reduced due to the free spiralling of electrons and ions about the magnetic lines of force before suffering collisions; also a current is induced in a direction normal to both electric and magnetic field. This phenomenon is well known in the literature and is called the Hall effect. Hall current has important engineering applications in problem of magnetohydrodynamic generators and Hall accelerators as well as in flight magnetohydronamic. Sato [1] and Sherman and Satton [2] were the first authors who investigated the hydromagnetic flow of ionized gas between two parallel plates taking Hall effect into account. The effect of Hall current for MHD free convection flow along a vertical surface and in presence of transverse magnetic field with or without heat and mass transfer have been studied by number of authors; Beard et al. [3], Katagiri [4], Pop [5], Raptis [6], Attia [7,10], Biswal et al. [8], Takhar et al. [9]. Also, Kumar et al. [11] have analyzed the combined effect of slip condition and Hall current on unsteady MHD flow of a visco-elastic fluid through porous medium. Singh et al. [12] have studied an exact solution of an oscillatory MHD flow through a porous medium bounded by rotating porous channel in presence of Hall current. Raju et al. [13] have investigated Hall current effects on unsteady MHD flow between stretching sheet and an oscillating porous upper parallel plate with constant suction whereas Ahmed et al. [14] have studied the transient MHD free convection from an infinite vertical porous plate in a rotating system with mass transfer and hall current. Also, visco-elastic unsteady MHD flow between two horizontal parallel plates with Hall current have been investigated by Choudhury et al. [15].

The objective of the present paper is to investigate the unsteady free convective MHD flow with heat and mass transfer characterized by Walters liquid (Model B^{-}) over an infinite vertical porous plate in presence of Hall current and radiation.
The constitutive equation for Walters liquid (Model B$^{'}$) is

$$\sigma_{ik} = -p g_{ik} + \sigma'_{ik} ,$$

$$\sigma'^{ik} = 2\eta_0 e^{ik} - 2k_0 e'^{ik} \tag{1.1}$$

where σ^{ik} is the stress tensor, p is isotropic pressure, g_{ik} is the metric tensor of a fixed co-ordinate system x^i, v_i is the velocity vector, the contravarient 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

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

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

$$\int_0^\infty t^n N(\tau)d\tau,\ n \geq 2 \qquad (1.5)$$

have been neglected.

2. Mathematical Formulation

We consider a temperature and species concentration to study Hall and radiation effects on unsteady MHD free convection flow of a viscous incompressible, electrically conducting fluid past an infinite vertical porous plate in presence of transverse magnetic field. The x'-axis is assumed to be oriented vertically upwards along the plate and y'-axis is taken normal to the plane of the plate. Since the plate is of infinite length, all the physical variables are function of y' and t' only. A uniform magnetic field B_0 is applied normal to the plate with constant suction V_0. It is assumed that induced magnetic field produced by fluid motion is negligible in comparison with the applied one. This assumption is valid because magnetic Reynolds number is very small for liquid metals and partially ionized fluids. Also no external electric field is applied so polarization effect is negligible. With the foregoing assumptions and under the usual boundary layer and Boussinesq approximations the flow is governed by the following set of equations:

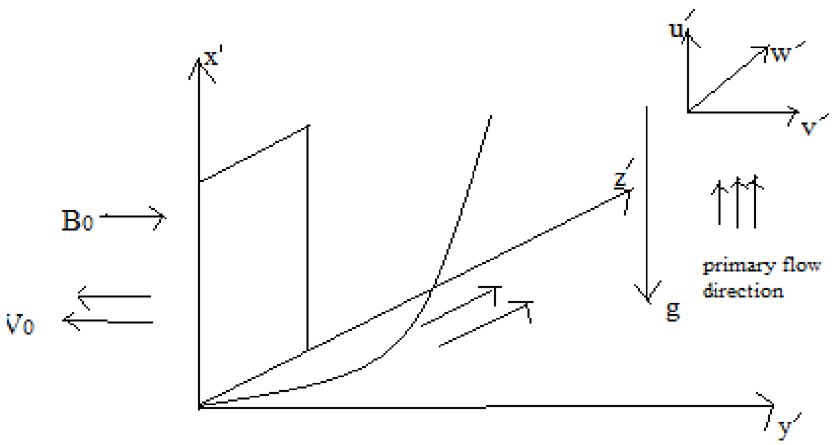

Figure 1: Physical configuration of the problem.

Continuity equation:

$$\frac{\partial v'}{\partial y'} = 0 \Rightarrow v' = -V_0 \tag{2.1}$$

Momentum equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \frac{\eta_0}{\rho}\frac{\partial^2 u'}{\partial y'^2} - \frac{k_0}{\rho}\left(\frac{\partial^3 u'}{\partial t' \partial y'^2} + v'\frac{\partial^3 u'}{\partial y'^3}\right) + g\beta(T' - T'_\infty)$$

$$+ g\beta'(c' - c'_\infty) - \frac{\sigma B_0^2}{\rho(1+m^2)}(u' + mw') - \frac{\upsilon u'}{K'} \tag{2.2}$$

$$\frac{\partial w'}{\partial t'} + v'\frac{\partial w'}{\partial y'} = \frac{\eta_0}{\rho}\frac{\partial^2 w'}{\partial y'^2} - \frac{k_0}{\rho}\left(\frac{\partial^3 w'}{\partial t' \partial y'^2} + v'\frac{\partial^3 w'}{\partial y'^3}\right) - \frac{\sigma B_0^2}{\rho(1+m^2)}(w' - mu') - \frac{\upsilon w'}{K'} \tag{2.3}$$

Energy equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{K_T}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q'_r}{\partial y'} \tag{2.4}$$

Concentration equation:

$$\frac{\partial c'}{\partial t'} + v'\frac{\partial c'}{\partial y'} = D\frac{\partial^2 c'}{\partial y'^2} \tag{2.5}$$

$$\left.\begin{aligned} & y' = 0:\ u' = L'\left(\frac{\partial u'}{\partial y'}\right),\ w' = L'\left(\frac{\partial w'}{\partial y'}\right),\ T' = T'_\infty + (T'_w - T'_\infty)e^{i\omega' t'} \\ & y' \to \infty:\ u' \to 0,\ w' \to 0,\ T' \to T'_\infty \end{aligned}\right\} \tag{2.6}$$

For the sake of normalisation of the flow model, we introduce the following non-dimensional quantities.

$$\left.\begin{aligned} & \eta = \frac{V_0}{\nu}y',\ t = \frac{V_0^2 t'}{4\nu},\ u = \frac{u'}{V_0},\ w = \frac{w'}{V_0},\ \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ Pr = \frac{\rho\nu C_p}{K_T}, \\ & Gr = \frac{g\beta\nu(T' - T'_\infty)}{V_0^3},\ M = \frac{\sigma\nu B_0^2}{\rho V_0^2},\ K = \frac{K' V_0^2}{\nu^2},\ h = \frac{V_0 L'}{\nu},\ F = \frac{4\nu I'}{\rho C_p V_0^2}, \\ & k = \frac{k_0 V_0^2}{\rho\nu^2},\ Sc = \frac{\nu}{D},\ Gm = \frac{g\beta'\nu(C' - C'_\infty)}{V_0^3} \end{aligned}\right\} \tag{2.7}$$

where Pr is the Prandtl number, Gr is Grashof number for heat transfer, Gm is Grashof number for mass transfer, M is the Hartmann number, k is the visco-elastic parameter, h is the slip parameter, K is the permeability parameter, K_T is the thermal conductivity, F is the radiation parameter, Sc is the Schmidt number, T' denotes the temperature of the fluid, T'_∞ denote the temperature of the fluid far away from the plate, g is the acceleration due to gravity, β is the co-efficient of volume expansion for heat

transfer, β' is the co-efficient of volume expansion for mass transfer, C' is the species concentration.
The radiative heat flux is given by

$$\frac{\partial q_r'}{\partial y'} = 4(T' - T_\infty)I'$$

where $I' = \int_0^\infty K \frac{\partial e_{b\lambda}}{\partial T'} d\lambda$, K is absorption coefficient at the wall and $e_{b\lambda}$ is the Plank's function.
In view of (2.7), the Equations (2.2) ,(2.3) ,(2.4) and (2.5) reduces to

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial \eta} = \frac{\partial^2 u}{\partial \eta^2} - k\left[\frac{1}{4}\frac{\partial^3 u}{\partial t \partial \eta^2} - \frac{\partial^3 u}{\partial \eta^3}\right] - \frac{M}{1+m^2}(u + mw) - \frac{u}{K} + Gr\theta + GmC \quad (2.8)$$

$$\frac{1}{4}\frac{\partial w}{\partial t} - \frac{\partial w}{\partial \eta} = \frac{\partial^2 w}{\partial \eta^2} - k\left[\frac{1}{4}\frac{\partial^3 w}{\partial t \partial \eta^2} - \frac{\partial^3 w}{\partial \eta^3}\right] - \frac{M}{1+m^2}(w - mu) - \frac{w}{K} \quad (2.9)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial \eta} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial \eta^2} - F\theta \quad (2.10)$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - \frac{\partial c}{\partial \eta} = \frac{1}{Sc}\frac{\partial^2 C}{\partial \eta^2} \quad (3.1)$$

The corresponding boundary conditions are

$$\eta \to 0 : u = h\left(\frac{\partial u}{\partial \eta}\right), w = h\left(\frac{\partial w}{\partial \eta}\right), \theta = e^{i\omega t}, C = e^{i\omega t}$$

$$\eta \to \infty : u \to 0 , w \to 0, \theta \to 0 , C \to 0 \quad (3.2)$$

3. Method of Solution

Introducing the complex variable

$q = u(\eta, t) + iw(\eta, t)$, where $i = \sqrt{-1}$ equations (2.8) and (2.9) transform to single partial differential equation

$$\frac{1}{4}\frac{\partial q}{\partial t} - \frac{\partial q}{\partial \eta} = \frac{\partial^2 q}{\partial \eta^2} - k\left[\frac{1}{4}\frac{\partial^3 q}{\partial t \partial \eta^2} - \frac{\partial^3 q}{\partial \eta^3}\right] - \frac{Mq}{1+m^2}(1 - im) - \frac{q}{K} + Gr\theta + GmC \quad (3.3)$$

relevant to boundary conditions

$$\left.\begin{aligned} &\eta \to 0 : q = h\left(\frac{\partial q}{\partial \eta}\right), , \theta = e^{i\omega t}, c = e^{i\omega t} \\ &\eta \to \infty : q \to 0 , \theta \to 0 , c \to 0 \end{aligned}\right\} \quad (3.4)$$

In order to solve equations (2.10), (3.1) and (3.3) under the boundary conditions of equations (3.4), we assume that

$$q(\eta,t) = q_0(\eta)e^{iwt} \tag{3.5}$$

$$\theta(\eta,t) = \theta_0(\eta)e^{iwt} \tag{3.6}$$

$$c(\eta,t) = c_0(\eta)e^{iwt} \tag{3.7}$$

subject to boundary conditions

$$\eta \to 0 : q_0 = h\left(\frac{\partial q_0}{\partial \eta}\right), \theta_0 = 1, c_0 = 1$$

$$\eta \to \infty: q_0 \to 0\,, \theta_0 \to 0\,, c_0 \to 0 \tag{3.8}$$

Using (3.6) and (3.7) into the equations (2.10) and (3.1), we get

$$\theta_0 = e^{-\frac{\eta}{2}\left(Pr+\sqrt{Pr^2+Pr(i\omega+4F)}\right)}$$

$$c_0 = e^{-\frac{\eta}{2}(Sc+\sqrt{Sc^2+i\omega Sc})}$$

From (3.6) and (3.7), the solution for the temperature and the concentration fields are obtained as:

$$\theta = e^{i\omega t--\frac{\eta}{2}\left(Pr+\sqrt{Pr^2+Pr(i\omega+4F)}\right)} \tag{3.9}$$

$$c = e^{i\omega t--\frac{\eta}{2}(Sc+\sqrt{Sc^2+i\omega Sc})} \tag{3.10}$$

Substituting the values of (3.5) in equation (3.3) we get,

$$kq_0''' + \left(1 - ik\frac{\omega}{4}\right)q_0'' + q_0' - (a_1 - ia_2)q_0 = -Gre^{-\alpha_4\eta} - Gme^{-\alpha_2\eta} \tag{4.1}$$

where primes denote differentiation with respect to η.
The corresponding transformed boundary conditions are

$$\text{At } \eta \to 0\,, q_0 = h\frac{\partial q_0}{\partial \eta}$$

$$At\, \eta \to \infty\,, q_0 = 0 \tag{4.2}$$

To solve the equation (4.1), we assume

$$q_0 = q_{00}(\eta) + kq_{01}(\eta) \tag{4.3}$$

as k<<1 due to small shear rate.

Using (4.3) in (4.1) and equating the coefficients of like powers of k , we get

$$q_{00}'' + q_{00}' - (a_1 - ia_2)q_{00} = -Gre^{-\alpha_4\eta} - Gme^{-\alpha_2\eta} \tag{4.4}$$

$$q_{01}'' + q_{01}' - (a_1 - ia_2)q_{01} = -\frac{i\omega}{4}q_{00}'' - q_{00}''' \tag{4.5}$$

subject to modified boundary conditions

$$\text{At } \eta = 0, q_{00} = h\frac{\partial q_{00}}{\partial \eta}, q_{01} = h\frac{\partial q_{01}}{\partial \eta}$$

$$\text{At } \eta \to \infty,\ q_{00} = 0, q_{01} = 0 \tag{4.6}$$

Solving the equations (4.4), (4.5) under the boundary conditions (4.6) ,we get

$$q_{00} = (a_7 - ia_8)e^{-\alpha_6\eta} + (a_3 + ia_4)Gre^{-\alpha_4\eta} + (a_5 + ia_6)Gme^{-\alpha_2\eta} \tag{4.7}$$

$$q_{01} = (B_1 - iB_2)e^{-\alpha_6\eta} + (a_9 + ia_{10})e^{-\alpha_6\eta} + (a_{11} + ia_{12})e^{-\alpha_4\eta} + (a_{13} + ia_{14})e^{-\alpha_2\eta} \tag{4.8}$$

Using (4.7) and (4.8) in equation (4.3) , we get

$$q_0 = (c_1e^{-\alpha_6\eta} + c_3e^{-\alpha_4\eta} + c_5e^{-\alpha_2\eta}) + i(c_2e^{-\alpha_6\eta} + c_4e^{-\alpha_4\eta} + c_6e^{-\alpha_2\eta}) \tag{4.9}$$

From (3.5), we get

$$q = q_0e^{i\omega t} = \{(c_1e^{-\alpha_6\eta} + c_3e^{-\alpha_4\eta} + c_5e^{-\alpha_2\eta}) + i(c_2e^{-\alpha_6\eta} + c_4e^{-\alpha_4\eta} + c_6e^{-\alpha_2\eta})\}e^{i\omega t} \tag{4.10}$$

Now, equating the real and imaginary parts, we get the axial and transverse components of velocities as the constants of the solution of differential equations are obtained but not presented here for the sake of brevity.

$$u = (c_1e^{-\alpha_6\eta} + c_3e^{-\alpha_4\eta} + c_5e^{-\alpha_2\eta})\cos\omega t - (c_2e^{-\alpha_6\eta} + c_4e^{-\alpha_4\eta} + c_6e^{-\alpha_2\eta})\sin\omega t$$

$$w = (c_2e^{-\alpha_6\eta} + c_4e^{-\alpha_4\eta} + c_6e^{-\alpha_2\eta})\cos\omega t + (c_1e^{-\alpha_6\eta} + c_3e^{-\alpha_4\eta} + c_5e^{-\alpha_2\eta})\sin\omega t$$

4. Skin friction

Thee axial component of the skin friction at the plate for primary velocity is

$$\sigma_1 = \left(\frac{\partial u}{\partial \eta} - k\left[\frac{1}{4}\frac{\partial^2 u}{\partial t \partial \eta} - \frac{\partial^2 u}{\partial \eta^2}\right]\right)_{\eta=0}$$

$$= -(c_1\alpha_6 + c_3\alpha_4 + c_5\alpha_2)\cos\omega t + (c_2\alpha_6 + c_4\alpha_4 + c_6\alpha_2)\sin\omega t +$$
$$k[(c_1\alpha_6^2 + c_3\alpha_4^2 + c_5\alpha_2^2)\cos\omega t - (c_2\alpha_6^2 + c_4\alpha_4^2 + c_6\alpha_2^2)\sin\omega t]$$

The transverse component of the skin friction at the plate for secondary velocity is

$$\sigma_2 = \left(\frac{\partial w}{\partial \eta} - k\left[\frac{1}{4}\frac{\partial^2 w}{\partial t \partial \eta} - \frac{\partial^2 w}{\partial \eta^2}\right]\right)_{\eta=0}$$

$$= -(c_2\alpha_6 + c_4\alpha_4 + c_6\alpha_2)\cos\omega t - (c_1\alpha_6 + c_3\alpha_4 + c_5\alpha_2)\sin\omega t +$$
$$k[(c_2\alpha_6^2 + c_4\alpha_4^2 + c_6\alpha_2^2)\cos\omega t + (c_1\alpha_6^2 + c_3\alpha_4^2 + c_5\alpha_2^2)\sin\omega t]$$

The rate of heat transfer in term of the Nusselt number is given by

$$N_u = -\left(\frac{\partial \theta}{\partial \eta}\right)_{\eta=0}$$
$$= \frac{1}{2}\left(Pr + \sqrt{Pr^2}(i\omega + 4F)\right)e^{i\omega t}$$

The rate of mass transfer co-efficient in term of the Sherwood number is given by

$$S_h = \left(\frac{\partial c}{\partial \eta}\right)_{\eta=0}$$

$$= -\frac{1}{2}\left(Sc + \sqrt{Sc^2 + i\omega Sc}\right)e^{i\omega t}$$

The constants are obtained but not presented here for the sake of brevity.

5. Result And Discussion

The purpose of this study is to bring out the effects of visco-elastic parameter on the fluid flow past an infinite vertical porous plate with heat and mass transfer by considering Hall current and radiation. The visco-elastic effect is exhibited through the non-dimensional parameter k. The non-zero values of the parameter k characterize the visco-elastic fluid and k=0 represents the Newtonian fluid flow phenomenon. It is observed from the velocity profile graphs that the flow nature of the visco-elastic fluid grows throughout the surface under the effects of various flow parameter in comparison with the Newtonian fluid.

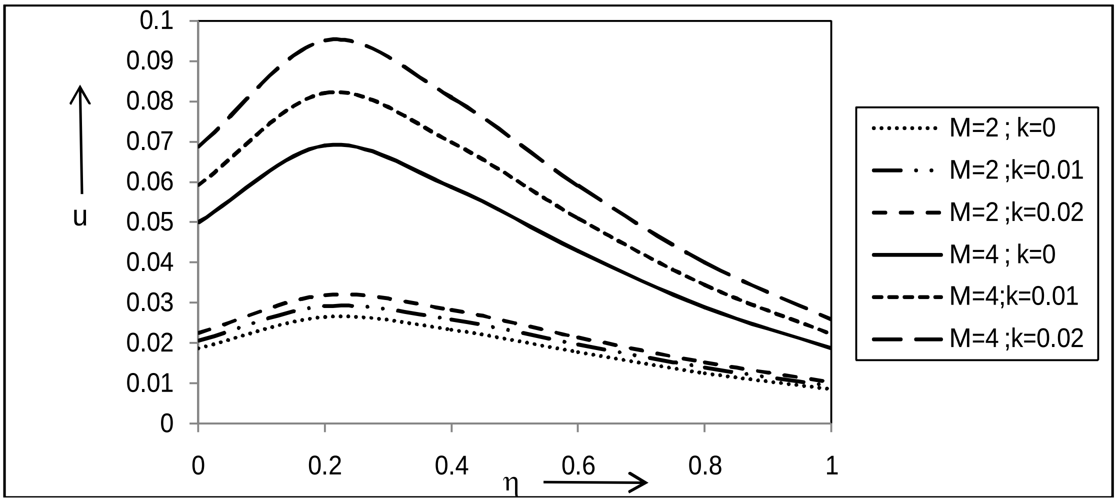

Figure 2: variation of primary velocity u against η

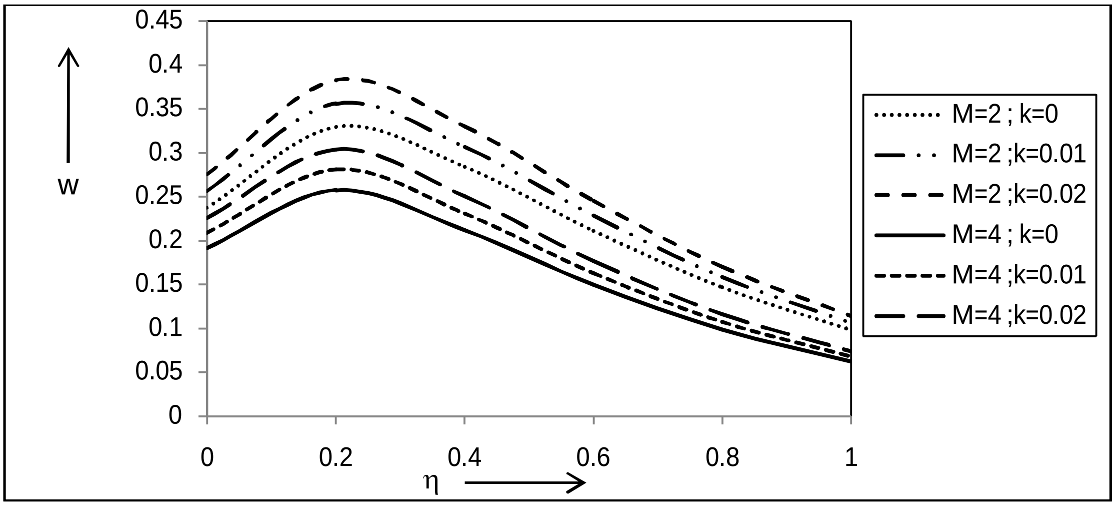

Figure 3: variation of secondary velocity w against η

Figure 2 to 9 show the variations of primary velocity u and secondary velocity w against η. The behaviour of fluid flow under the effect of magnetic parameter (M) is illustrated by figures 2 and 3.It is noticed from these figures that the rising values of magnetic parameter modifies the speed of the fluid flow system along with the increasing values of visco-elastic parameter in primary velocity but a reverse trend is occurred in case of secondary velocity.

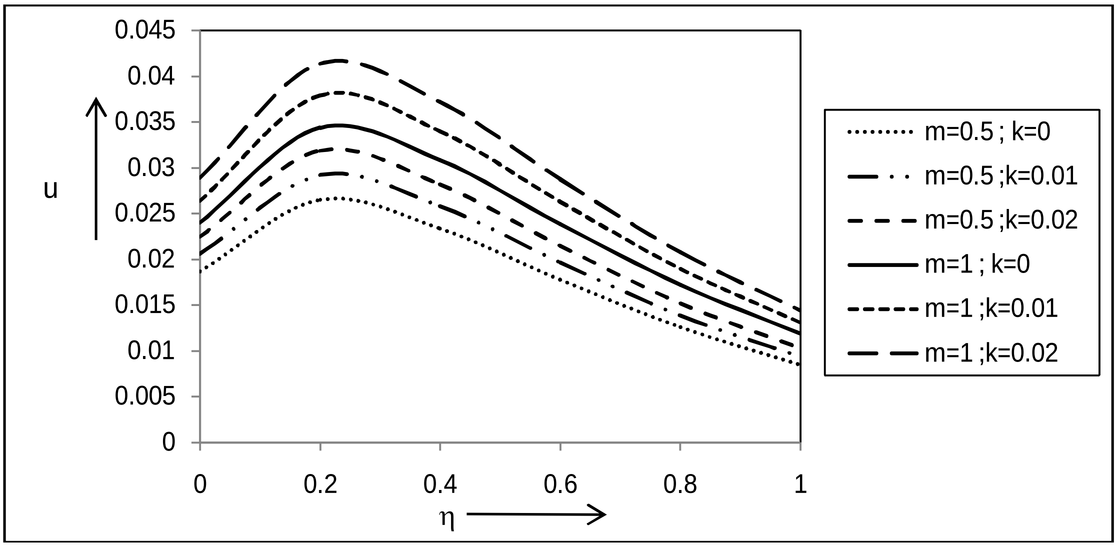

Figure 4: variation of primary velocity u against η

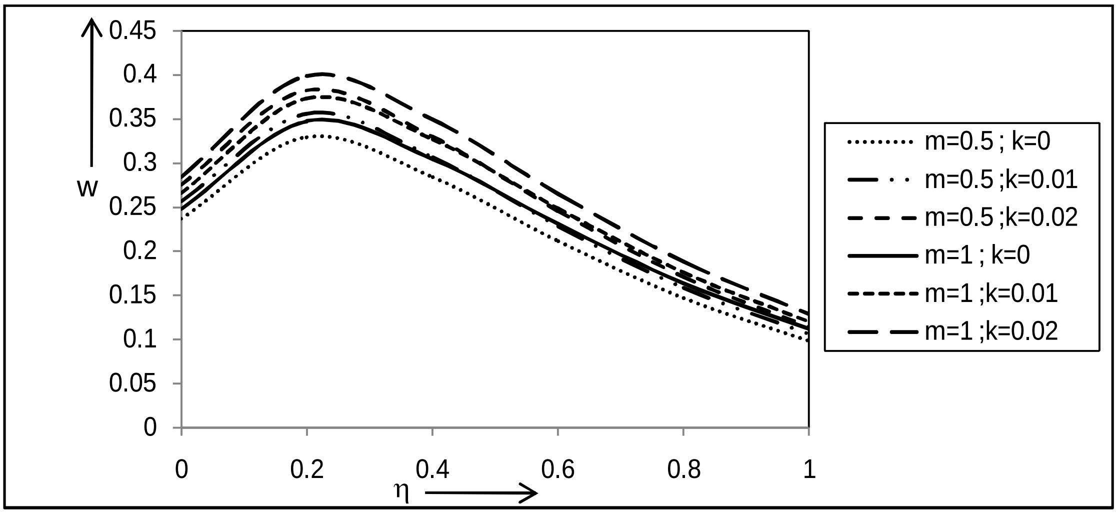

Figure 5: variation of secondary velocity w against η

The effects of Hall current on primary velocity u and secondary velocity *w* against η is revealed by figures 4 and 5. From these figures it can be concluded that the rising values of Hall current enhanced the pattern of both primary and secondary velocity along with the modification of visco-elastic parameter.

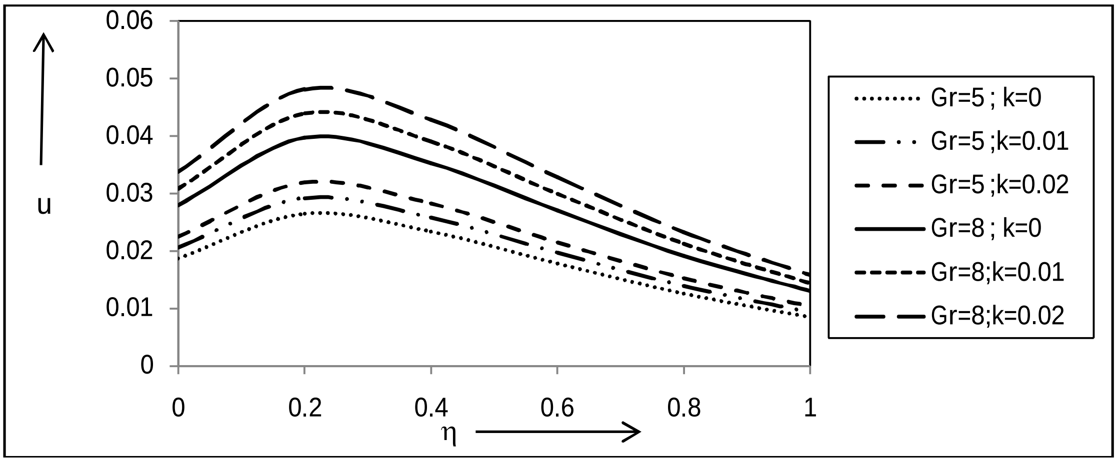

Figure 6: variation of primary velocity u against η

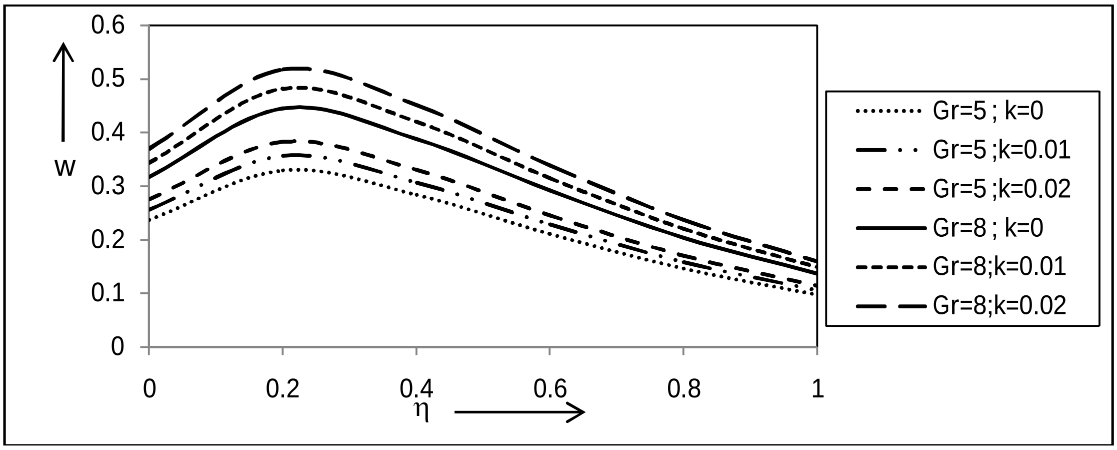

Figure 7: variation of secondary velocity w against η

Grashof number plays an important rule in heat and mass transfer problem. In this study, the graphs are depicted for the flow past an externally cooled plate $(Gr > 0)$.

Figures 6 and 7 reveal that the growing nature of Grashof number for heat transfer amplifies the fluid flow system for primary and secondary velocity with enhancement of visco-elastic parameter.

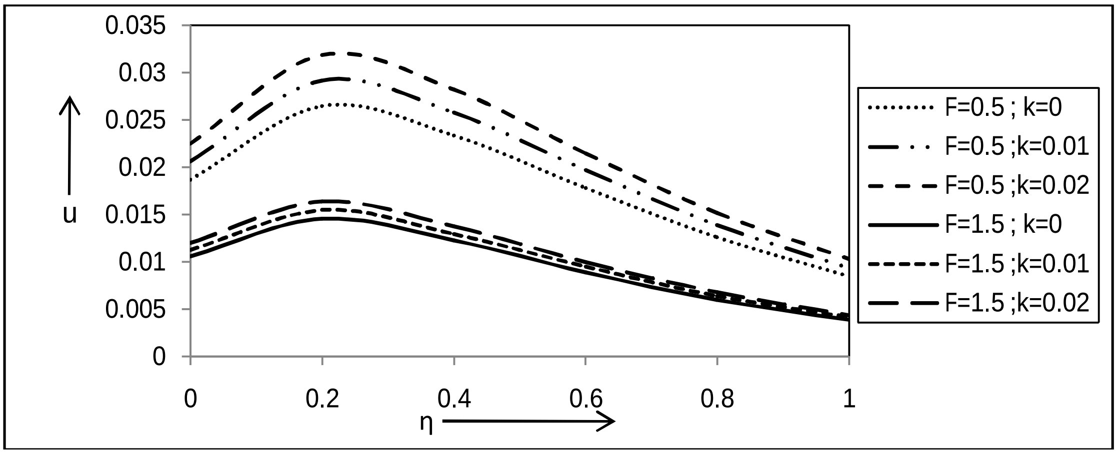

Figure 8: Variation of primary velocity u against η

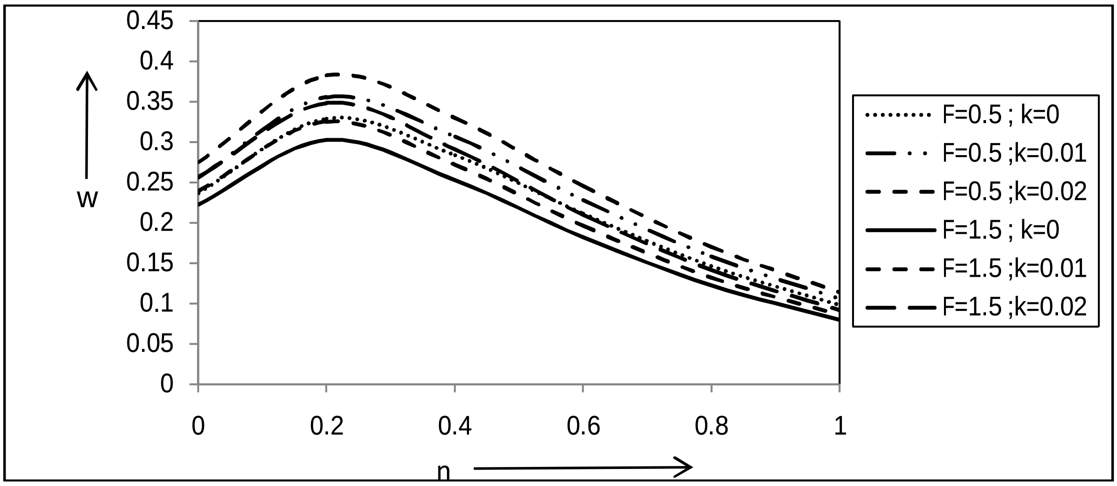

Figure 9: Variation of secondary velocity w against η

The effects of radiation parameter on velocity profile have been cited in figures 8 and 9. The declined trend is observed for both kinds of velocity profiles with the growing nature of radiation parameter F along with the growth of visco-elasticity.

Figures 10 to 17 reveal the variation of axial and transverse skin friction component σ and σ' against various flow parameters such as Prandtl number Pr, Magnetic parameterM, radiation parameter F, and permeability parameter K .In addition to this, the visco-elastic effects on both types of skin frictions are also measured in these graphs.

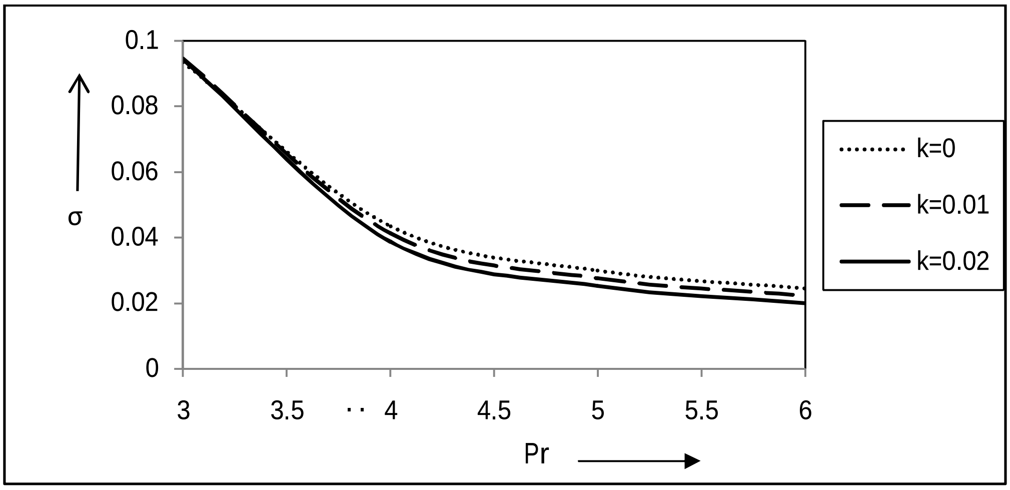

Figure 10: variation of axial skin friction σ against Pr.

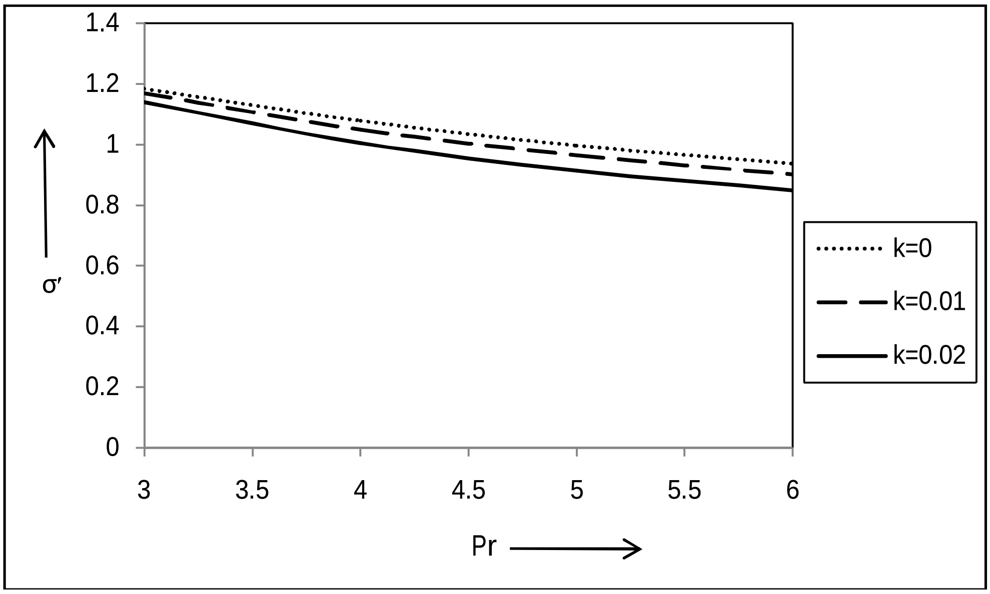

Figure 11: variation of transverse skin friction σ' against Pr.

Figures 10 and 11 show that the magnitude of skin friction of both kinds reduce along with the amplified values of Prandtl number for Newtonian as well as non-Newtonian cases.

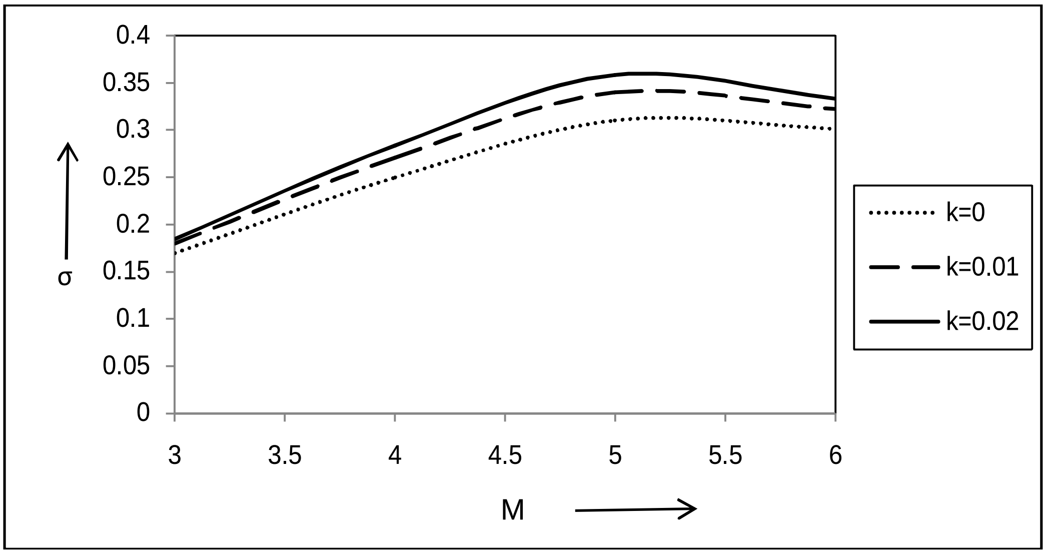

Figure 12: variation of axial skin friction σ against M.

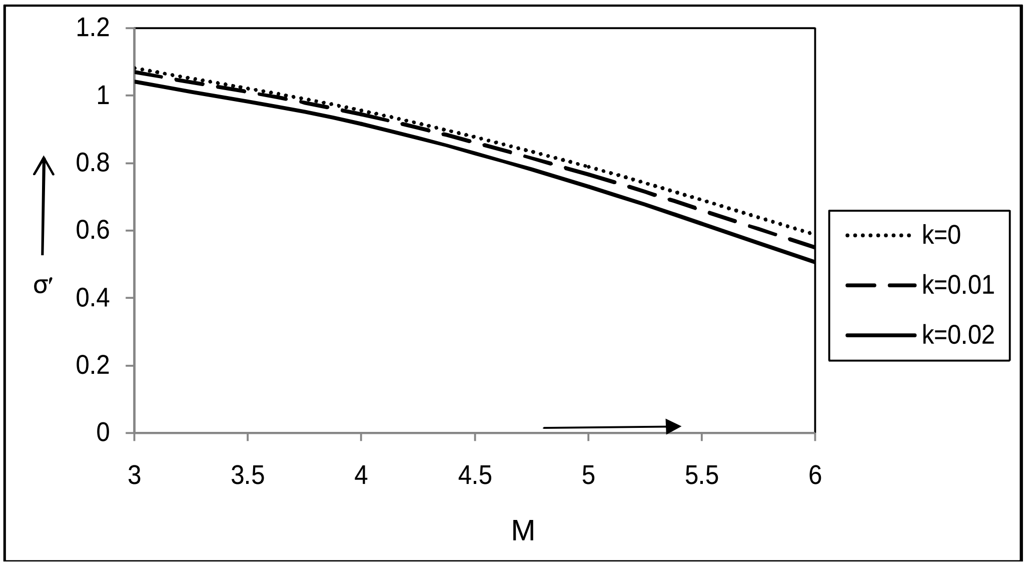

Figure 13: variation of transverse skin friction σ' against M.

Figures 12 and 13 depict the effects of Magnetic parameter on the axial skin friction and transverse skin friction. It is noticed that the magnitude of axial skin friction increases with the increasing value of Magnetic parameter but a opposite behaviour is observed in case of transversal skin friction along with modification of visco-elastic parameter.

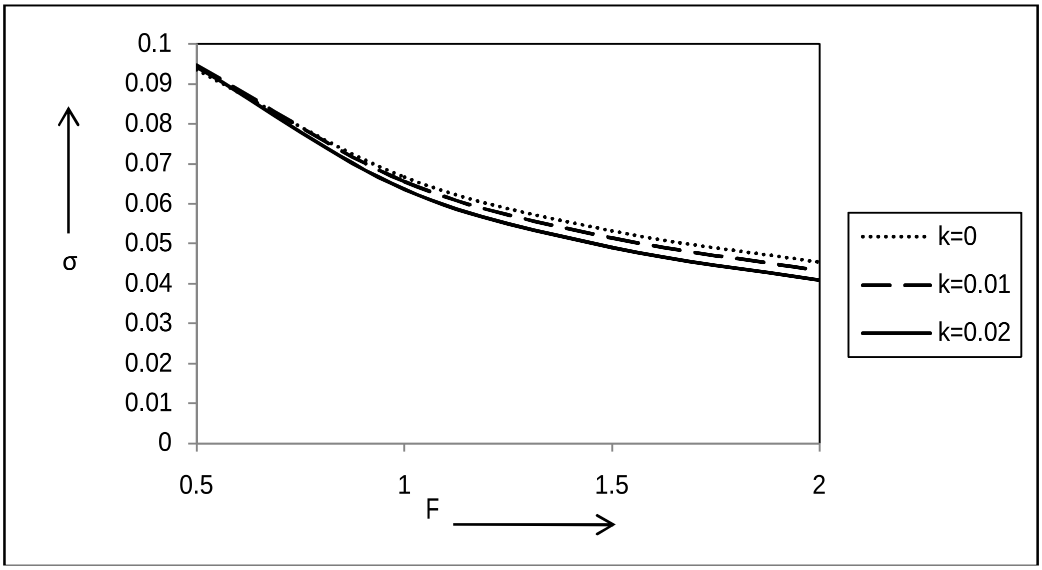

Figure 14: variation of axial skin friction σ against F.

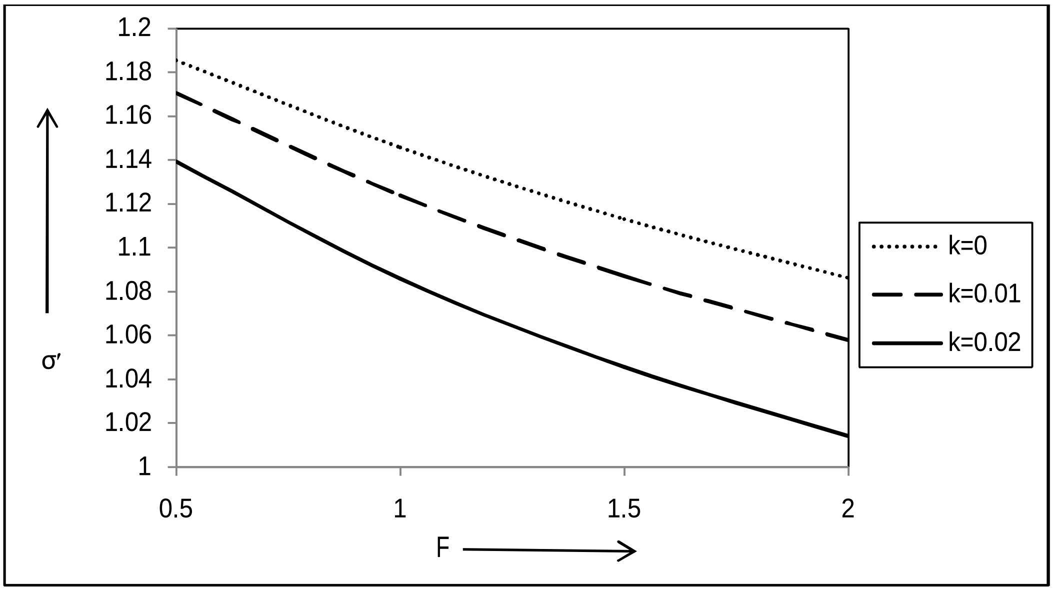

Figure 15: variation of transverse skin friction σ' against F.

The effects of radiation parameter on both kinds of skin friction are revealed in figures 14 and 15. The figures show that growing values of visco-elastic parameter decreases axial as well as transverse skin friction with the increasing values of radiation parameter.

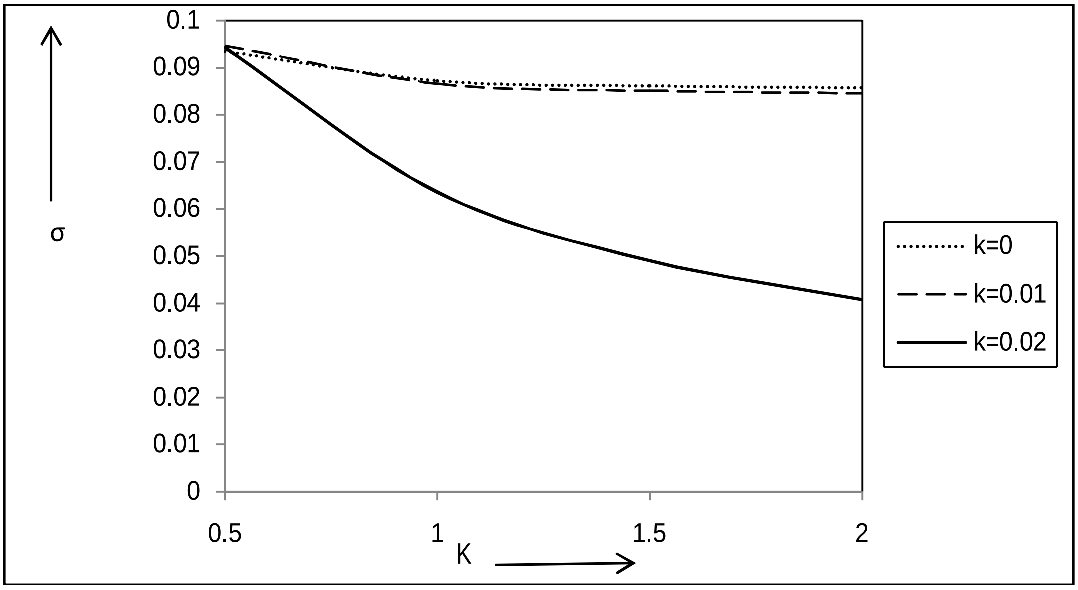

Figure 16: variation of axial skin friction σ against K.

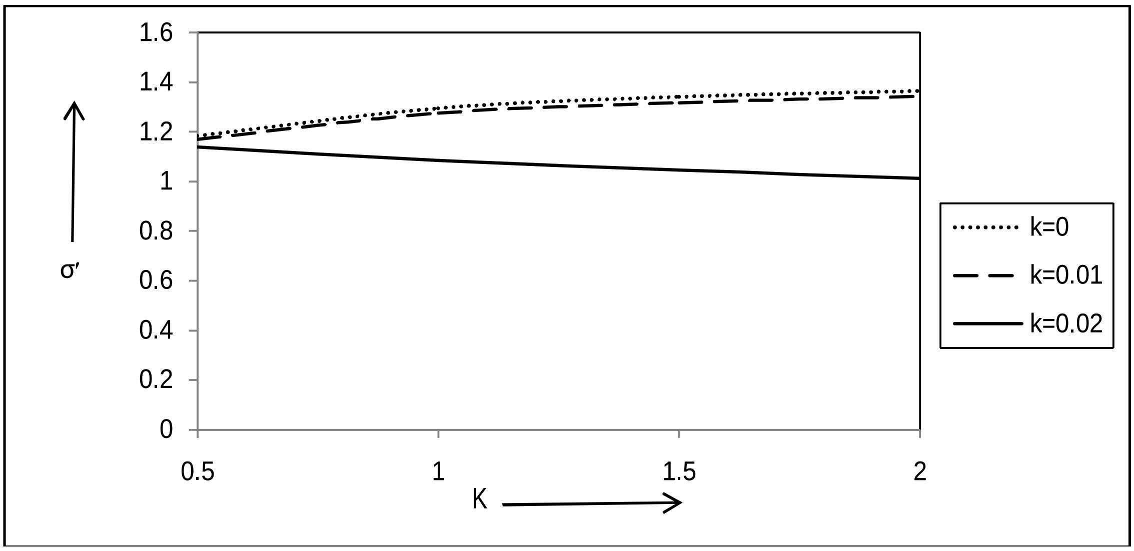

Figure 17: variation of transverse skin friction σ' against K.

Figures 16 and 17 illustrate the appearance of skin friction field against permeability parameter during the fluid flow motion. Rising values of visco-elastic parameter decline both axial and transverse skin friction along with the increasing values of permeability parameter.

It has also been observed that the heat and mass transfer fields are not significantly affected by the non-Newtonian parameter.

Conclusion

An analytical approach is carried out to investigate the influence of Hall current and radiation effects with heat and mass transfer of an electrically conducting visco-elastic fluid flow through a porous medium over a vertical surface. Some of the important points are concluded as below:

- The effect of visco-elasticity is prominent at every point of the fluid flow region under the influence of other flow parameters involved in the solution.
- The presence of Magnetic field modifies the visco-elastic fluid in comparison with the Newtonian fluid in case of primary velocity but a reverse pattern is noticed in case of secondary velocity.
- The rising value of Hall parameter and thermal Grashof number modify both primary as well as secondary velocity. On the contrary a diminished pattern is observed in case of radiation parameter for both kinds of velocity.
- The magnitude of both axial and transverse skin friction reduce with rising values of visco-elastic parameter against Prandtl number, radiation parameter and permeability parameter but in case of Magnetic parameter the magnitude of the axial skin friction rises .Diminishing trend of transverse skin friction is noticed with modification of visco-elastic parameter against Magnetic parameter.
- The rate of heat transfer and rate of mass transfer are not significantly affected by the visco-elasticity throughout the fluid flow motion.

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