

Chemical Reaction and Hall Effects on Visco-Elastic Fluid Flow Past an Inclined Moving Plate in the Presence of Heat Generation/Absorption

P. Latitha
Department of Mathematics,
S. V. University,
Tirupati, A. P.

N. Chaturvedi
Department of Mathematics,
University of Botswana. (Corresponding Author).
Gaborone, Botswana

S.V. K. Varma³
Department of Mathematics,
S. V. University, Tirupati, A.P.

Abstract -The present work analyzes the Hall and Chemical reaction effects on two dimensional MHD flow of a Visco-elastic fluid past an inclined moving plate by taking double diffusive convection in the presence of Heat generation. The governing equations are solved by using a perturbation technique. The effects of the important flow parameters on velocity, temperature and concentration fields as well as Skin-friction, rate of heat transfer and rate of mass transfer have been studied. It has been observed that the concentration decreases with an increase in Chemical reaction parameter, the velocity of flow field decreases due to an increase in the visco-elastic parameter k and the velocity increases with increasing values of modified Grashof number G_m .

Key Words - Hall parameter, Visco-elastic parameter, Chemical reaction and Magnetic parameter.

INTRODUCTION:

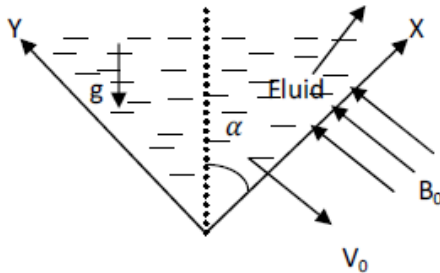
Study of MHD flow with heat and mass transfer plays an important role in biological Sciences. Effects of various parameters on human body can be studied and appropriate suggestions can be given to the persons working in hazardous areas having noticeable effects of magnetism and heat variation. Study of MHD flows also has many other important technological and geothermal applications. Some important applications are cooling of nuclear reactors, liquid metals fluid, power generation system and aero dynamics. An excellent summary of applications is given by Huges and Young [6]. Kim [7] studied the unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Singh et al. [15] have analyzed the heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity. Singh and Gupta [16] have analyzed the MHD free convective flow of a viscous fluid through a porous medium bounded by an oscillating porous plate in slip flow regime with mass transfer. Khandelwal and Jain [8] have discussed the unsteady MHD flow of a stratified fluid through porous medium over a moving plate in slip flow regime. Convective heat transfer from different geometries has received considerable attention in recent

years owing to its importance in various technological applications such as fiber and granular insulation, electronic system cooling, cool combustors, oil extraction, thermal energy storage and flow through filtering devices, porous material regenerative heat exchangers, Bejan and Kraus[2]. Sharma and Singh [17] have reported the unsteady MHD-free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Das *et al.* [4] have studied the mass transfer effects on free convective MHD flow of a viscous fluid bounded by an oscillating porous plate in the slip flow regime with heat source.

Viscoelastic flows and transport phenomena arise in numerous areas of chemical, industrial process, bio-systems, food processing and biomedical engineering. The heat transfer in the forced convection flow of a viscoelastic fluid of Walter model was investigated by Rajagopal [12]. Siddappa *et al.* [14] studied the flow of viscoelastic fluids of the type Walter's liquid B past a stretching sheet. Abel and Veena [1] studied the viscoelasticity on the flow and heat transfer in a porous medium over a stretching sheet. Muthucumaraswamy [10] has studied effects of chemical reaction on a moving isothermal vertical surface with suction. Chaudhary and Jain [3] have found the effect of Hall current and radiation on MHD mixed convection flow of a viscoelastic fluid past an infinite plate. Mahapatra et al. [11] have studied effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface. Chemical reaction and thermal radiation effects on MHD flow of a visco-elastic fluid past a moving porous plate by considering double diffusive convection in presence of heat generation has been studied by Rita Choudhury and PabanDhar [13]. Sahoo et al [18] have studied the unsteady two dimensional MHD flow and heat transfer of an elastic-viscous liquid past an infinite hot vertical porous surface bounded by porous medium with source and sink. The importance of thermal-diffusion and diffusion-thermo effects for various fluid flows has been studied by Eckert and Drake [5]. Kumar et al. [9] have investigated thermal diffusion and radiation effects on

unsteady MHD flow through porous medium with variable temperature and mass diffusion in the presence of heat source or sink.

The aim of the present chapter is to study hall effects on visco-elastic fluid flow past an inclined moving plate in the presence of heat generation/absorption. Approximate solutions have been derived for the mean velocity, mean temperature and mean concentration using multi-parameter perturbation technique and these are presented in graphical form.



PHYSICAL MODEL

FORMULATION OF THE PROBLEM:

The unsteady MHD, Visco-elastic fluid flow due to double diffusive convection past an inclined moving plate with heat generation/absorption has been considered. The flow is two dimensional where x' axis is along the plane of moving plate and y' axis is normal to it, respectively. We assume that the surface is moving continuously with constant velocity in positive x' - direction. A uniform magnetic field of strength B_0 is imposed transversely to the plate. Hall effects are taken into account. Induced magnetic field and applied electric fields are negligible. Taking into consideration the assumptions made above, the governing equations can be written as follows.

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

$$\begin{aligned} \frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} &= \frac{\partial U_{\infty}'}{\partial t'} + g\beta (T' - T_{\infty}') \cos\alpha + g\beta^* (C' - C_{\infty}') \cos\alpha \\ &+ \vartheta \frac{\partial^2 u'}{\partial y'^2} + \frac{\vartheta}{k'} (U_{\infty}' - u' - \frac{k_0}{\rho} \left(\frac{\partial^3 u'}{\partial y'^2 \partial t'} + v' \frac{\partial^3 u'}{\partial y'^3} \right) + \frac{\sigma_e B_0^2}{\rho(1+m^2)} (U_{\infty}' - u') \end{aligned} \tag{2}$$

$$\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'} = \frac{K_T}{\rho C_p} \frac{\partial^2 T'}{\partial y'^2} + \frac{Q_0}{\rho C_p} (T' - T_{\infty}') - \frac{1}{\rho C_p} \frac{\partial q_r'}{\partial y'} \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v' \frac{\partial C'}{\partial y'} = D_M \frac{\partial^2 C'}{\partial y'^2} + D_T \frac{\partial^2 T'}{\partial y'^2} - K_1' (C' - C_{\infty}') \tag{4}$$

The boundary conditions are

$$\begin{aligned} u' &= U_p', T' = T_w' + (T_w' - T_{\infty}') e^{i\omega' t'}, C' \\ &= C_w' + (C_w' - C_{\infty}') e^{i\omega' t'} \text{ at } y' = 0 \end{aligned}$$

$$\begin{aligned} u' \rightarrow U_{\infty}' &= U_0 (1 + \varepsilon e^{i\omega' t'}), T' \rightarrow T_{\infty}', C' \rightarrow C_{\infty}' \text{ as } y' \rightarrow \infty \end{aligned} \tag{5}$$

It is clear from equation (2) that the suction velocity at the plate surface is a function of time only. Hence the suction velocity normal to the plate is assumed in the form

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

where A is the suction parameter such that $\varepsilon A \ll 1$ and V_0 is a scale of suction velocity. The negative sign indicates that the suction is towards the plate.

By using the Rosseland diffusion approximation, the radiative heat flux q_r' is given by

$$q_r' = -\frac{4\sigma^*}{3K_s} \frac{\partial T'^4}{\partial y'} \tag{6}$$

where σ^* and K_s are the Stefan-Boltzmann constant and the Rosseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are 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'^4 and neglecting higher order terms, thus

$$T'^4 \cong 4T_{\infty}'^3 T^* - 3T_{\infty}'^4 \tag{7}$$

Using (6) and (7) in the last term of equation (3), we obtain

$$\frac{\partial q_r'}{\partial y'} = -\frac{16\sigma^* T_{\infty}'^3}{3K_s} \frac{\partial^2 T'}{\partial y'^2} \tag{8}$$

We now introduce the following non dimensional quantities

$$\begin{aligned} y &= \frac{y' V_0}{\vartheta}, t = \frac{t' V_0^2}{\vartheta}, u = \frac{u'}{U_0}, \\ U_{\infty} &= \frac{U_{\infty}'}{U_0}, U_p = \frac{U_p'}{U_0}, \omega = \frac{\omega' \vartheta}{V_0^2} \\ \theta &= \frac{T' - T_{\infty}'}{T_w' - T_{\infty}'}, \phi = \frac{C' - C_{\infty}'}{C_w' - C_{\infty}'}, Gr = \frac{g\beta\vartheta(T_w' - T_{\infty}')}{V_0^2 U_0}, Gm = \frac{g\beta\vartheta(C_w' - C_{\infty}')}{V_0^2 U_0}, \\ Pr &= \frac{\vartheta \rho C_p}{K_T}, Sc = \frac{\vartheta}{D_M}, Q = \frac{Q_0 \vartheta}{\rho C_p V_0^2}, Kr = \frac{K_1' \vartheta}{V_0^2}, So = \frac{D_T(T_w' - T_{\infty}')}{\vartheta(C_w' - C_{\infty}')}, \\ K &= \frac{K' V_0^2}{\vartheta^2}, M^2 = \frac{\sigma B_0^2 \vartheta}{\rho V_0^2}, R = \frac{4\sigma^* T_{\infty}'^3}{K_T K_s}, k = \frac{k_0 V_0^2}{\rho \vartheta^2} \end{aligned} \tag{9}$$

Using equation (9), the governing equations (2), (3) and (4) reduce to the following dimensionless form

The non-dimensional forms of the equation (2) to (4) are given by

$$\frac{\partial u}{\partial t} - (1 + \varepsilon Ae^{i\omega t}) \frac{\partial u}{\partial y} = Gr_1 \theta + Gm_1 \phi + \frac{\partial^2 u}{\partial y^2} + \left(M_1 + \frac{1}{K}\right) (U_\infty - u) + \frac{\partial U_\infty}{\partial t} - k \left(\frac{\partial^3 u}{\partial y^2 \partial t} - (1 + \varepsilon Ae^{i\omega t}) \frac{\partial^3 u}{\partial y^3}\right) \quad (10)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon Ae^{i\omega t}) \frac{\partial \theta}{\partial y} = \frac{1}{Pr} \left(1 + \frac{4R}{3}\right) \frac{\partial^2 \theta}{\partial y^2} - Q\theta \quad (11)$$

$$\frac{\partial \phi}{\partial t} - (1 + \varepsilon Ae^{i\omega t}) \frac{\partial \phi}{\partial y} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} - Kr\phi + So \frac{\partial^2 \phi}{\partial y^2} \quad (12)$$

where $Gr_1 = Gr \cos\alpha$, $Gm_1 = Gm \cos\alpha$

subject to boundary conditions

$$u = U_p, \theta = 1 + \varepsilon e^{i\omega t}, \phi = 1 + \varepsilon e^{i\omega t} \text{ at } y=0$$

$$u = U_\infty(t) = 1 + \varepsilon e^{i\omega t}, \theta \rightarrow 0, \phi \rightarrow 0 \text{ as } y \rightarrow \infty \quad (13)$$

3 SOLUTION OF THE PROBLEM

Equations (10) to (13) are coupled non-linear partial differential equations and these cannot be solved in closed form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. To solve these equations we make the following assumptions for the non-dimensional free stream velocity U_∞ , velocity profile u , temperature profile θ and concentration profile ϕ

$$U_\infty = 1 + \varepsilon e^{i\omega t} + o(\varepsilon^2) \quad (14)$$

$$u(y, t) = u_0(y) + \varepsilon e^{i\omega t} u_1(y) + o(\varepsilon^2) \quad (15)$$

$$\theta(y, t) = \theta_0(y) + \varepsilon e^{i\omega t} \theta_1(y) + o(\varepsilon^2) \quad (16)$$

$$\phi(y, t) = \phi_0(y) + \varepsilon e^{i\omega t} \phi_1(y) + o(\varepsilon^2) \quad (17)$$

On substituting the equation (14) to (17) into the equations (10) to (12) and equating the harmonic and non-harmonic terms, and neglecting the higher order terms $o(\varepsilon^2)$, we obtain

$$ku_0'''' + u_0'' + u_0' - \left(M_1 + \frac{1}{K}\right) u_0 = -Gr\theta_0 - Gm\phi_0 - \left(M_1 + \frac{1}{K}\right) u_0 \quad (18)$$

$$ku_1'''' + u_1'' - i\omega ku_1'' + u_1' - \left(M_1 + \frac{1}{K} + i\omega\right) u_1 = -Gr\theta_1 - Gm\phi_1 - \left(M_1 + \frac{1}{K} + i\omega\right) u_1$$

$$-Au_0' - kAu_0'''' \quad (19)$$

$$\theta_0'' + L\theta_0' + LQ\theta_0 = 0 \quad (20)$$

$$\theta_1'' + L\theta_1' + (Q - i\omega)L\theta_1 = -AL\theta_0' \quad (21)$$

$$\phi_0'' + Sc\phi_0' - KrSc\phi_0 = -ScSo\theta_0'' \quad (22)$$

$$\phi_1'' + Sc\phi_1' - (KrSc + i\omega Sc)\phi_1 = -ASc\phi_0' - ScSo\theta_1'' \quad (23)$$

Here primes denote the differentiation with respect to y

The corresponding boundary conditions reduce to

$$u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, \phi_0 = 1, \phi_1 = 1 \text{ at } y=0$$

$$u_0 \rightarrow 1, u_1 \rightarrow 1, \theta_0 \rightarrow 0, \theta_1 \rightarrow 0, \phi_0 \rightarrow 0, \phi_1 \rightarrow 0 \text{ as } y \rightarrow \infty \quad (24)$$

Solving equations (18) to (23) under the boundary condition (24) we get the zeroth order and first order solutions for temperature and concentration distribution as follows

$$\theta_0(y) = e^{-a_2 y} \quad (25)$$

$$\theta_1(y) = k_1 e^{-a_2 y} + (1 - k_1) e^{-a_4 y} \quad (26)$$

$$\phi_0(y) = -k_2 e^{-a_2 y} + (1 + k_2) e^{-a_6 y} \quad (27)$$

$$\phi_1(y) = k_8 e^{-a_8 y} + k_4 e^{-a_6 y} - k_6 e^{-a_4 y} - (k_5 + k_7) e^{-a_2 y} \quad (28)$$

Using equations (25) to (28) in equations (16) to (17), we get the temperature and concentration distribution as follows

$$\theta = e^{-a_2 y} + \varepsilon e^{i\omega t} [k_1 e^{-a_2 y} + (1 - k_1) e^{-a_4 y}] \quad (29)$$

$$\phi = -k_2 e^{-a_2 y} + (1 + k_2) e^{-a_6 y} + \varepsilon e^{i\omega t} (k_8 e^{-a_8 y} + k_4 e^{-a_6 y} - k_6 e^{-a_4 y} - (k_5 + k_7) e^{-a_2 y}) \quad (30)$$

Again in order to solve the equations (18) and (19), we use multi parameter perturbation technique in terms of Visco-elastic parameter and assuming $k \ll 1$, as visco-elastic parameter is considered to be less than unity for small shear rate, thus we write

$$u_0(y) = u_{00}(y) + ku_{01}(y) + o(k^2) \quad (31)$$

$$u_1(y) = u_{10}(y) + ku_{11}(y) + o(k^2) \quad (32)$$

Using (31) and (32) in the equations (18) to (19) and equating the coefficients of like powers of k, we get the following set of differential equations

$$u_{00}'' + u_{00}' - \left(M_1 + \frac{1}{K}\right)u_{00} = -Gr\theta_0 - Gm\phi_0 - \left(M_1 + \frac{1}{K}\right)u_{00} \quad (33)$$

$$u_{01}'' + u_{01}' - \left(M_1 + \frac{1}{K}\right)u_{01} = -u_{00}''' \quad (34)$$

$$u_{10}'' + u_{10}' - \left(M_1 + \frac{1}{K} + i\omega\right)u_{10} = -Gr\theta_1 - Gm\phi_1 - \left(M_1 + \frac{1}{K} + \frac{i\omega}{4}\right)u_{10} - Au_{00}' \quad (35)$$

$$u_{11}'' + u_{11}' - \left(M_1 + \frac{1}{K} + i\omega\right)u_{11} = i\omega u_{10}'' - u_{10}''' - Au_{01}' - Au_{00}''' \quad (36)$$

The relevant boundary conditions are

$$u_{00} = U_p, u_{01} = 0, u_{10} = 0, u_{11} = 0 \text{ at } y=0$$

$$u_{00} \rightarrow 1, u_{01} \rightarrow 0, u_{10} \rightarrow 1, u_{11} \rightarrow 0 \text{ at } y \rightarrow \infty \quad (37)$$

Now solving the differential equations (33) to (36) subject to the boundary conditions (37), we get the solutions of zeroth order and first order for velocity profile as

$$u_0(y) = (1 + k_{12}e^{-a_{10}y} - (k_9 - k_{11})e^{-a_2y} - k_{10}e^{-a_6y}) + k((k_{14} + k_{15})e^{-a_{10}y} - k_{14}e^{-a_2y} - k_{15}e^{-a_6y}) \quad (38)$$

$$u_1(y) = (1 + k_{25}e^{-a_{12}y} + ((k_{20} - k_{16})e^{-a_4y} - (k_{17} + k_{21} + k_{23})e^{-a_2y} - (k_{19} + k_{24})e^{-a_6y} - k_{18}e^{-a_8y} + k_{22}e^{-a_{10}y}) + k((k_{44} + k_{26} + k_{32})e^{-a_{12}y} + (k_{27} + k_{33})e^{-a_4y} - (k_{28} + k_{34} + k_{39} + k_{42})e^{-a_2y} - (k_{29} + k_{35} + k_{40} + k_{43})e^{-a_6y} - (k_{30} + k_{36})e^{-a_8y} + (k_{31} + k_{37} + k_{38} + k_{41})e^{-a_{10}y})) \quad (39)$$

Using equations (38) and (39) in equation (15), we get the velocity distribution as follows

$$u = (1 + k_{12}e^{-a_{10}y} - (k_9 - k_{11})e^{-a_2y} - k_{10}e^{-a_6y}) + k(((k_{14} + k_{15})e^{-a_{10}y} - k_{14}e^{-a_2y} - k_{15}e^{-a_6y} + \epsilon e^{i\omega t}((1 + k_{25}e^{-a_{12}y} + ((k_{20} - k_{16})e^{-a_4y} - (k_{17} + k_{21} + k_{23})e^{-a_2y} - (k_{19} + k_{24})e^{-a_6y} - k_{18}e^{-a_8y} + k_{22}e^{-a_{10}y})) + (k_{44} + k_{26} + k_{32})e^{-a_{12}y} + (k_{27} + k_{33})e^{-a_4y} - (k_{28} + k_{34} + k_{39} + k_{42})e^{-a_2y} - (k_{29} + k_{35} + k_{40} + k_{43})e^{-a_6y} - (k_{30} + k_{36})e^{-a_8y} + (k_{31} + k_{37} + k_{38} + k_{41})e^{-a_{10}y})))$$

$$-(k_{29} + k_{35} + k_{40} + k_{43})e^{-a_6y} - (k_{30} + k_{36})e^{-a_8y} + (k_{31} + k_{37} + k_{38} + k_{41})e^{-a_{10}y}) \quad (40)$$

Skin friction:

The Skin friction at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = (-a_{10}k_{12} + a_2(k_9 - k_{11}) + a_6k_{10} + k(-a_{10}(k_{14} + k_{15}) + a_2k_{14} + a_6k_{15})) + \epsilon e^{i\omega t}((-a_{12}k_{25} - a_4(k_{20} - k_{16}) + a_2(k_{17} + k_{21} + k_{23}) + a_6(k_{19} + k_{24}) + a_8k_{18} - a_{10}k_{22}) + k(-a_{12}(k_{44} + k_{26} + k_{32}) - a_4(k_{27} + k_{33}) + a_2(k_{28} + k_{34} + k_{38} + k_{42}) + a_6(k_{29} + k_{35} + k_{40} + k_{43}) + a_8(k_{30} + k_{36}) - a_{10}(k_{31} + k_{37} + k_{38} + k_{41}))) \quad (41)$$

Nusselt number:

The rate of heat transfer at the plate in terms of Nusselt number is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -a_2 + \epsilon e^{i\omega t}(-a_4(1 - k_1) - a_2k_1) \quad (42)$$

Sherwood number:

The rate of mass transfer at the plate in terms of Sherwood number is given by

$$Sh = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -a_6(1 + k_2) + a_2k_2 + \epsilon e^{i\omega t}(-a_8k_8 - a_6k_4 + a_4k_6 + a_2(k_5 + k_7)) \quad (43)$$

RESULT AND DISCUSSION:

In order to get physical insight into the problem velocity, temperature and concentration, Skinfriction coefficient τ , Nusselt number Nu, Sherwood number Sh have been discussed by performing numerical calculations for different values of dimensionless parameters and representative set of results is reported graphically in Figures 1-11. These results are obtained to illustrate the influence of the Chemical reaction parameter Kr, Heat source parameter Q, Soret number So, Magnetic field parameter M, Schmidt number Sc, Hall current parameter m, absorption of Radiation parameter R and visco-elastic parameter k on the velocity, temperature and concentration profiles.

Fig.1 represents concentration profiles for different values of Soret number So. It is observed that as Soret number increases concentration decreases. Fig.2 illustrates the concentration profiles for different values of Chemical reaction parameter Kr. It is found that, the concentration decreases with an increase in Chemical reaction parameter.

The effect of Heat source parameter Q on temperature profiles is shown in figure.3. It is seen that temperature decreases with increasing values of Heat source parameter Q . Fig.4. shows the effect of absorption of Radiation parameter R on temperature profiles. It is observed that temperature increases with increasing values of R . Fig.5 depicts the effect of visco-elastic parameter k on the velocity profiles. It is shown that the velocity of flow field decreases due to increase in the visco-elastic parameter k .

Fig.6 illustrates the velocity profiles for different values of Schmidt number Sc . It is obvious that as Schmidt number Sc increases, the velocity increases. The influence of the inclination angle α on the velocity profiles is presented in Fig.7 This shows that the velocity decreases with increasing values of inclination angle α . The influence of Magnetic field parameter M on the velocity field is shown in figure 8. It is observed that as Magnetic field parameter M increases, the velocity decreases.

Fig.9. depicts the effect of Hall current parameter m on the velocity profiles. It is shown that the velocity increases due to increase in the Hall current parameter m . Fig.10 illustrates the effect of Grashof number Gr on velocity profile. It is observed that as the Grashof number Gr increases, the velocity also increases. The velocity profile for different values of modified Grashof number Gm are shown in Fig.11. This shows that the velocity increases with increasing values of modified Grashof number Gm .

Table.1 shows numerical values of the Skin friction coefficient τ , Nusselt number Nu and Sherwood number Sh for various values of Chemical reaction parameter Kr , Soret number So , Heat source parameter Q , absorption of Radiation parameter R , Hall current parameter m and Permeability parameter K . It is observed that as chemical reaction Kr and Soret number So increase, Sherwood number increases. It is observed that Nusselt number decreases with increasing values of Heat source parameter Q and absorption of Radiation parameter R . It is also observed that as Hall current parameter m increases, the skin-friction increases and as Soret number So and Permeability parameter K increases, the skin-friction increases.

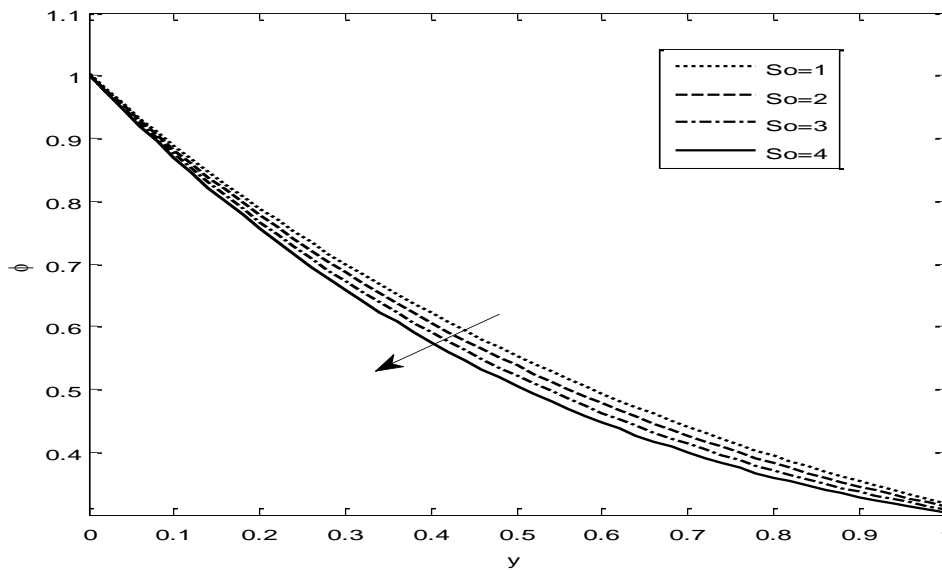


Fig.1. Concentration profiles against y for different values So with $Sc=5$,
 $t=0.5, A=0.5, Kr=2, \epsilon = 0.001, Pr=2, R=3$

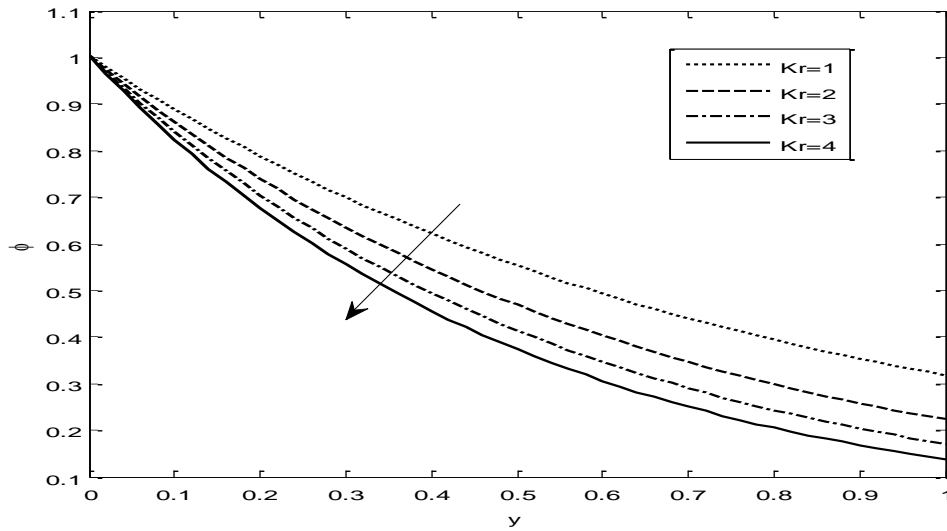


Fig.2. Concentration profiles against y for different values Kr with Sc=5,

t=0.5, A=0.5, So=3, $\epsilon = 0.001$, Pr=2, R=3

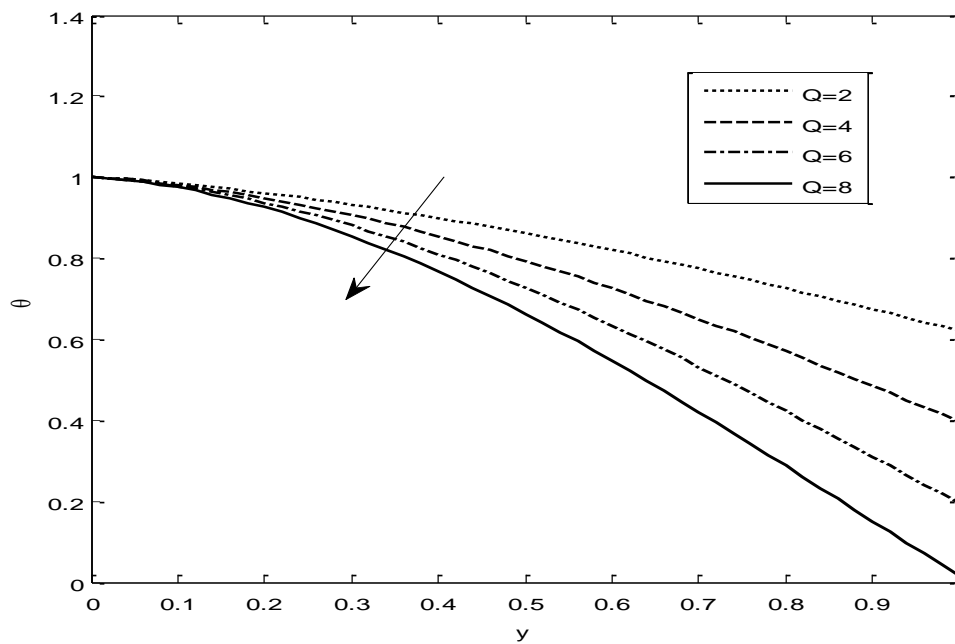


Fig.3. Temperature profiles against y for different values Q with Sc=5,

t=0.5, A=0.5, $\epsilon = 0.001$, R=3, Pr=2

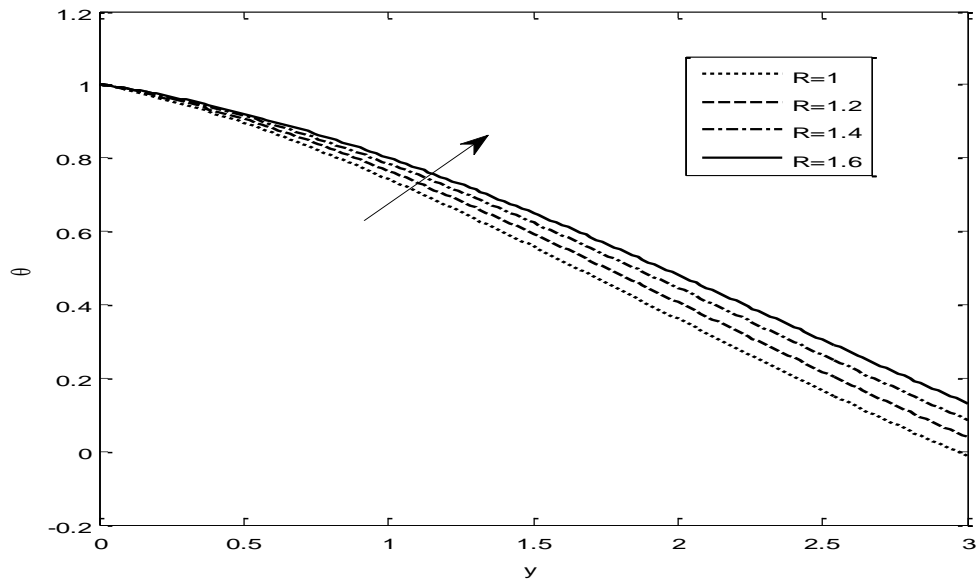


Fig.4. Temperature profiles against y for different values R with Sc=5,

$t=0.5, A=0.5, \varepsilon = 0.001, Pr=2, R=3$

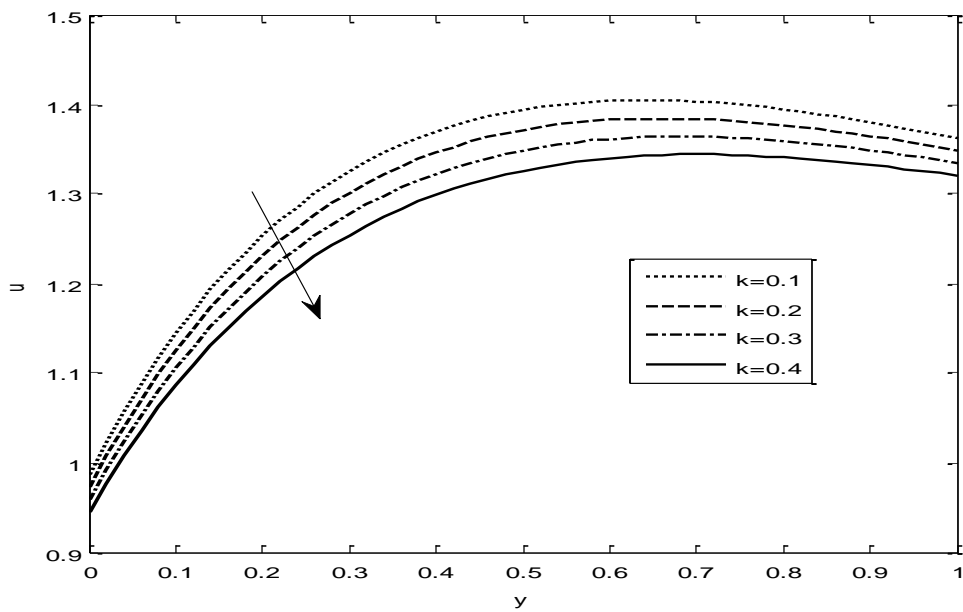


Fig.5. Velocity profiles against y for different values k with Sc=5, So=0.6, Up=1, R=3,

$M=2, m=0.5, k=1, K=0.02, t=0.5, A=0.5, Kr=2, \varepsilon = 0.001, \alpha = \frac{\pi}{3}, \lambda = 1, Pr=2$

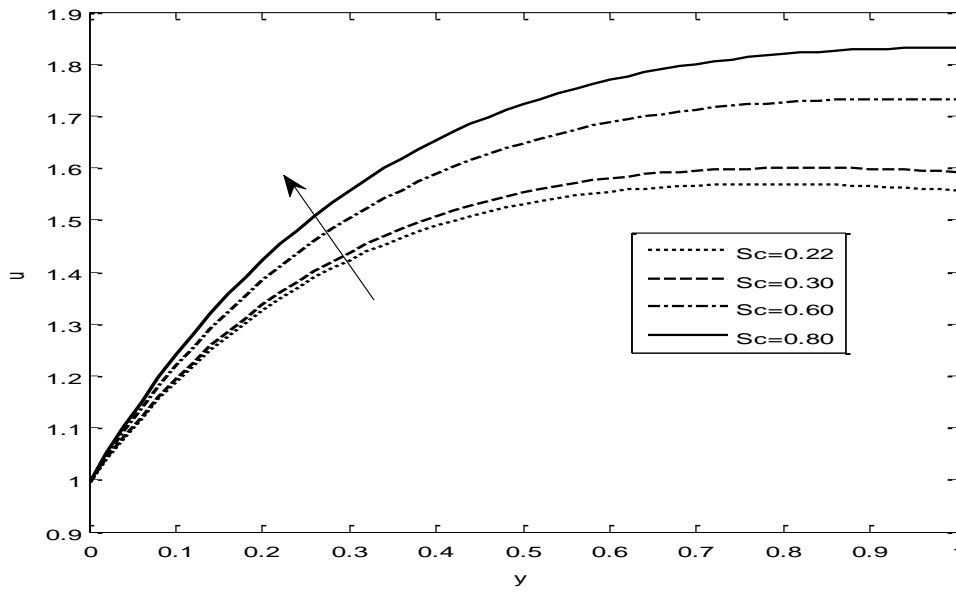


Fig.6. Velocity profiles against y for different values Sc with $k = 0.02, So=3, Up=1, R=3,$

$$M=2, m=0.5, K=1, t=0.5, A=0.5, Kr=2, \varepsilon = 0.001, \alpha = \frac{\pi}{3}, \lambda = 1, Pr=2$$

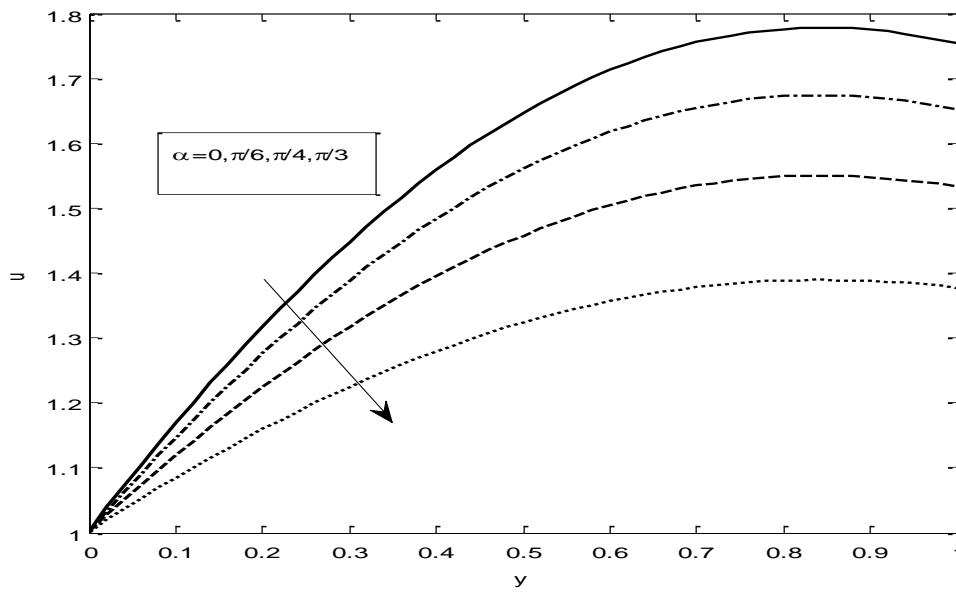


Fig.7. Velocity profiles against y for different values α with $k = 0.02, So=3, Up=1, R=3,$

$$M=2, m=0.5, K=1, t=0.5, Sc=5, A=0.5, Kr=2, \varepsilon = 0.001, \lambda = 1, Pr=2$$

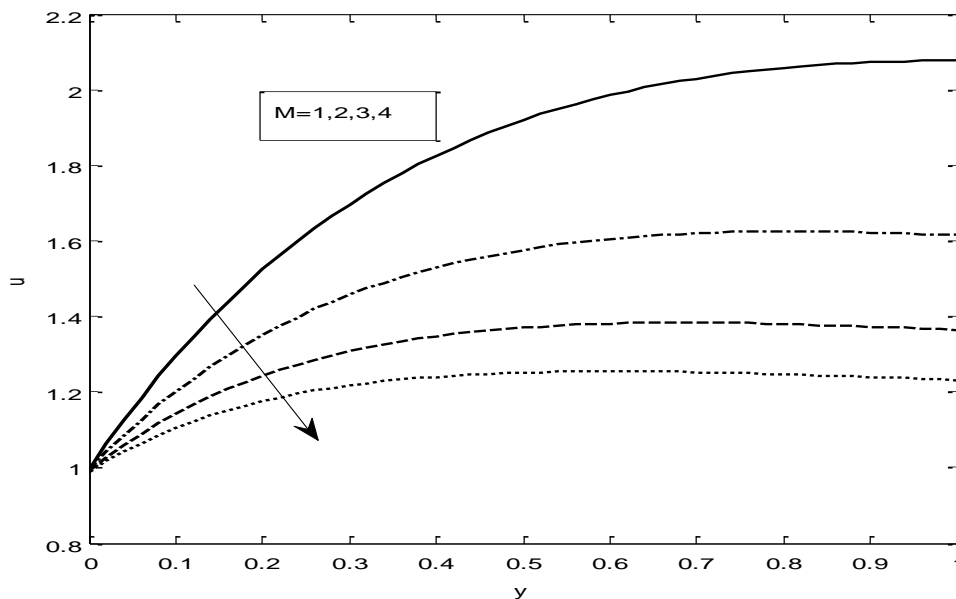


Fig.8. Velocity profiles against y for different values M with $k = 0.02, So=0.5, Up=1, R=3,$

$$M=2, m=0.5, K=1, t=0.5, Sc=0.6, A=0.5, Kr=2, \varepsilon = 0.001, \lambda = 1, \alpha = \frac{\pi}{3}, Pr=2$$

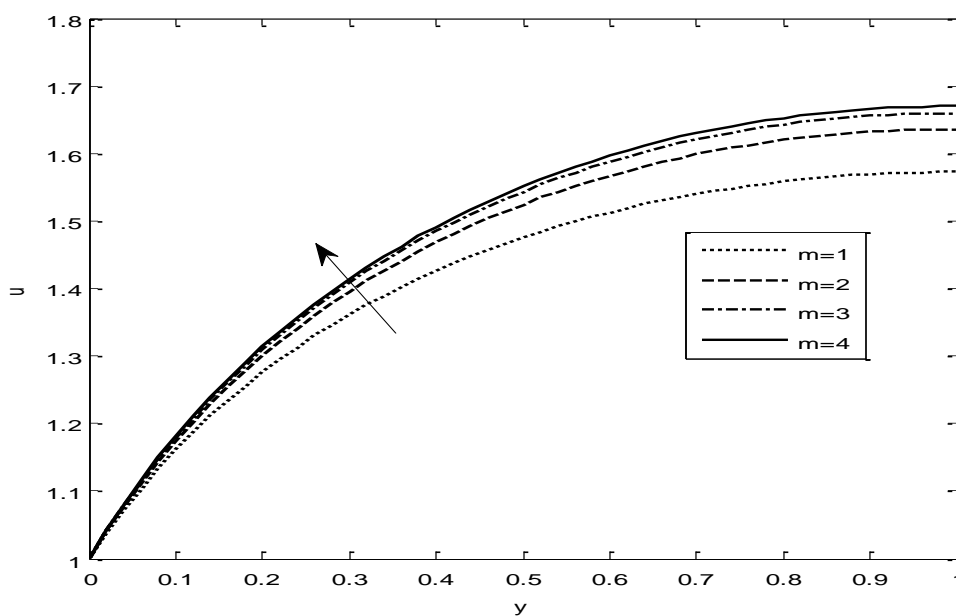


Fig.9. Velocity profiles against y for different values m with $k = 0.02, So=0.5, Up=1, R=3,$

$$M=1, K=1, t=0.5, Sc=0.6, A=0.5, Kr=2, \varepsilon = 0.001, \lambda = 1, \alpha = \frac{\pi}{3}, Pr=2$$

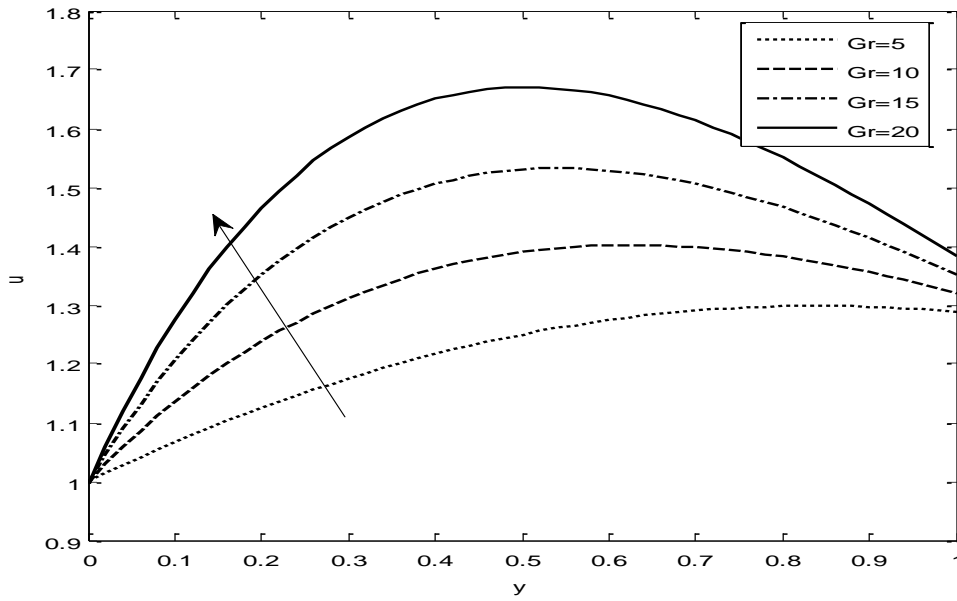


Fig.10. Velocity profiles against y for different values Gr with $k = 0.02, So=3, Up=1, R=3,$

$$M=2, m=0.5, K=1, t=0.5, Sc=5, A=0.5, Kr=2, \varepsilon = 0.001, \lambda = 1, \alpha = \frac{\pi}{3}, Pr=2$$

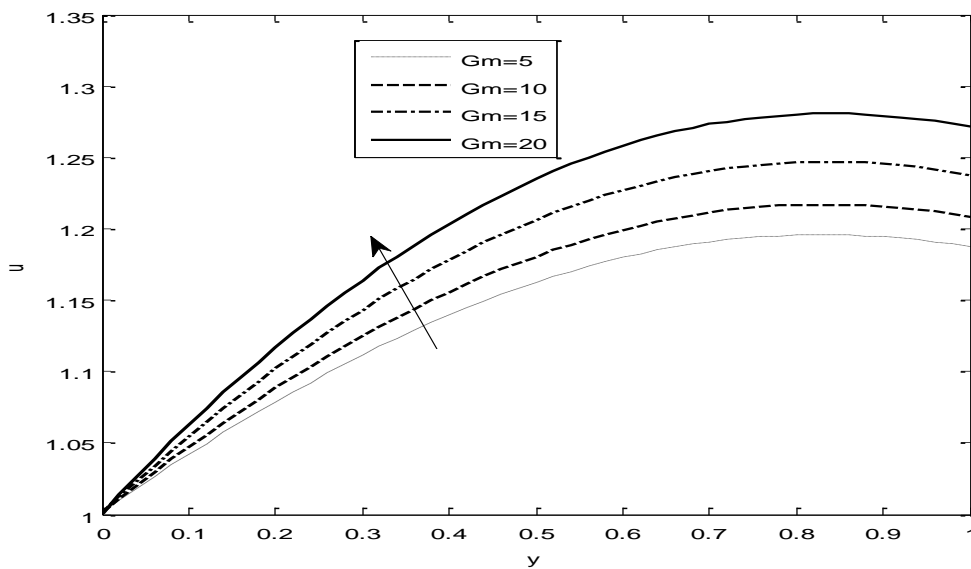


Fig.11. Velocity profiles against y for different values Gm with $k = 0.5, So=1, Up=1,$

$$R=3, M=2, m=1, K=1, t=0.5, Sc=0.6, A=0.5, Kr=2, \varepsilon = 0.001, \lambda = 1, \alpha = \frac{\pi}{3}$$

Comparison study:

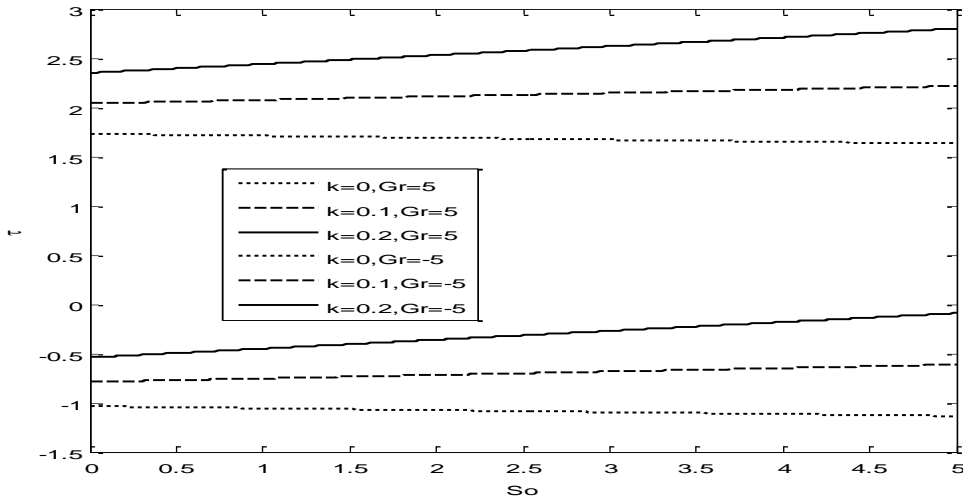


Fig: 12. Effects of visco elastic parameter and Grashof number on skin friction profiles with

$So=3, R=3, M=2, m=1, K=1, Sc=5, A=1, Kr=2, Gm=5, \epsilon = 0.002,$

$$\lambda = 1, \alpha = \frac{\pi}{3}, Gm=5, Q=2$$

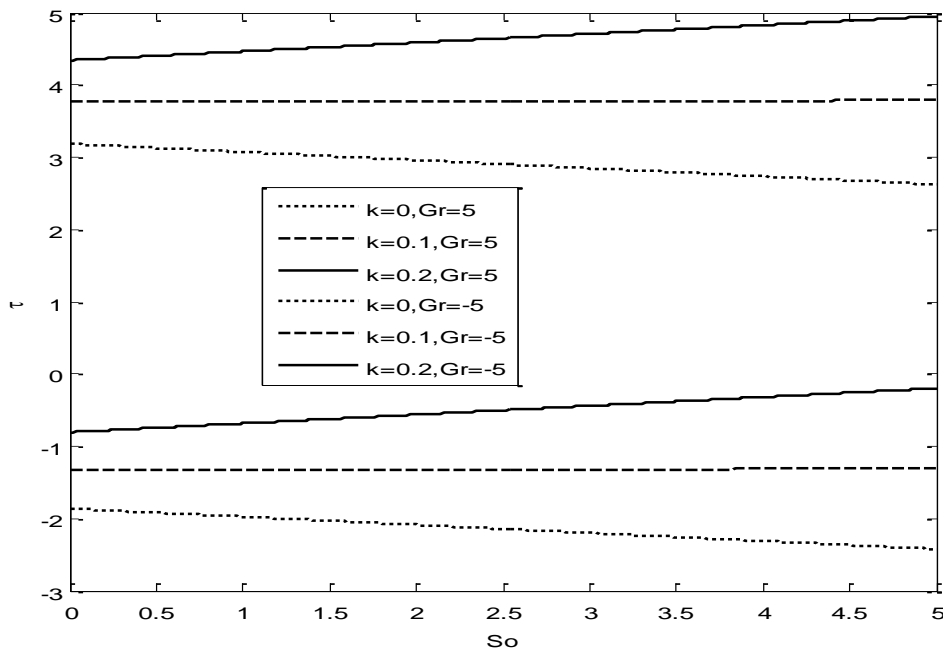


Fig:13. Effects of visco-elastic parameter and Grashof number on skin friction profiles with

$So=3, R=3, M=2, K=1, Sc=5, A=1, Kr=2, Gm=5, \epsilon = 0.002,$

$$\lambda = 1, Gm=5, Q=2$$

From the figures 12 and 13, it is clear that the present results, when the inclination angle(α) is zero and in the absence of Hall effect, are in good agreement with the corresponding results of Rita Choudary and PabhanDhar [13].

TABLE:

Effects of Kr, So, Q, R, m, k on τ , Nu, Sh with M=2, K=1, Sc=5, A=1, Gm=5, $\epsilon = 0.002$,

$$\lambda = 1, Gm=5, Gr=5, \alpha = \frac{\pi}{3}, Pr=2$$

Kr	So	Q	R	m	K	τ	Nu	Sh
1	3	1	1	0.5	0.1	--	--	1.2054
2	3	1	1	0.5	0.1	--	--	1.5193
3	3	1	1	0.5	0.1	--	--	1.7556
2	2	1	1	0.5	0.1	1.9695	--	1.2777
2	3	1	1	0.5	0.1	1.9804	--	1.3499
2	4	1	1	0.5	0.1	1.9913	--	1.4222
2	3	2	1	0.5	0.1	--	0.1523	--
2	3	3	1	0.5	0.1	--	0.1522	--
2	3	4	1	0.5	0.1	--	0.1521	--
2	3	1	2	0.5	0.1	--	0.0979	--
2	3	1	3	0.5	0.1	--	0.0711	--
2	3	1	4	0.5	0.1	--	0.0562	--
2	3	1	1	1	0.1	2.1461	--	--
2	3	1	1	1.5	0.1	2.2862	--	-
2	3	1	1	2	0.1	2.3806	--	-
2	3	1	1	0.5	0.2	2.4476	--	--
2	3	1	1	0.5	0.3	2.9148	--	--
2	3	1	1	0.5	0.4	3.3820	--	--

REFERENCES

[1] S. Abel and P. H. Veena, "Visco-Elastic Fluid Flow and Heat Transfer in Porous Medium over a Stretching Sheet," *International Journal of Non-Linear Mechanics*, Vol. 33, 1998, pp. 531-540.

[2] Bejan. A. and Kraus. A. D., Heat transfer hand book, Wiley, New York, 2003.

[3] Chaudhary . R.C. and Jain .P. (2006):" Hall effect on MHD mixed convection flow of A visco-elastic fluid past and infinite vertical plate with mass transfer and radiation", *Theoretical and Applied Mechanics*, Vol.33,No.4, pp.281-309.

[4] Das S.S., Tripathy R.K., Sahoo S.K. and Dash B.K. , "Mass transfer effects on free convective MHD flow of a viscous fluid bounded by an oscillating porous plate in the slip flow regime with heat source". *J.UltraScientist of Phys Sci.*, vol. 20(1M), pp. 169-176, 2008.

[5] Eckert E. R. G. and Drake R.M., "Analysis of heat and mass transfer", McGraw-Hill, New York

[6] Huges WF and Young FJ (1966). *The Electro-Magneto Dynamics of fluids. John Wiley and Sons, New York.*

[7] Y.J. Kim, Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction, *Int.J.Eng.Sci.*, 38(8) (2000), 833-845.

[8] Khandelwal. A.K. and Jain , N.C. (2005): "Unsteady MHD flow of stratified fluid through porous plate in slip flow regime", *Indian Journal of Theoretical Physics*, Vol.53,No.1, pp 25-35.

[9] Kumar A.G.V., Goud Y. R. and Varma S.V.K." Thermal diffusion and radiation effects on unsteady MHD flow through porous medium with variable temperature and mass diffusion in the presence of heat source/sink", *Advances in Applied Science Research*, vol.3(3), pp.1494-1506, 2012.

[10] R. Muthucumaraswamy, "Effects of a chemical reaction on a moving isothermal vertical surface with suction," *Acta Mechanica*, vol. 155, no. 1-2, pp. 65–70, 2002.

[11] N. Mahapatra. G. C. Dash, S. Panda, and M. Acharya, "Effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface," *Journal of Engineering Physics and Thermophysics*, vol. 83, no. 1, pp. 130–140, 2010

[12] The heat transfer in the forced convection flow of a viscoelastic fluid of Walter model was investigated by Rajagopal (1983).

[13] Rita Choudhury, PabanDhar, " Chemical reaction and thermal radiation effects on MHD flow of a visco-elastic fluid past a moving porous plate by considering double diffusive convection in presence of heat generation. Vol.9.2014, WSEAS TRANSACTIONS ON FLUID MECHANICS.

- [14] B. Siddappa and S. Abel (1985): Non-Newtonian flow past a stretching plate, *Zeitschrift für Angewandte Mathematik und Physik (ZAMP)*, Vol. 36, pp. 890-892.
- [15] A. K. Singh and N. P. Singh, "Heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity," *Indian Journal of Pure and Applied Mathematics*, vol. 34, no. 3, pp. 429-442, 2003.
- [16] Singh P and Gupta C.B. "MHD free convective flow of viscous fluid through a porous medium bounded by an oscillating porous plate in slipflow regime with mass transfer" *Ind. J.Theo. Phys.* Vol. 53(2), pp. 111-120, 2005.
- [17] P. R. Sharma and G. Singh, "Unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation," *International Journal of Applied Mathematics and Mechanics*, vol. 4, no. 5, pp.1-8, 2008.
- [18] Sahoo. S.N., Panda, J.P. and Dash , G.C.(2011) "Unsteady two dimensional MHD flow and heat transfer of an elastic viscous liquid past an infinite hot vertical porous surface bounded by porous medium with source/sink", *A.M.S.E. France*, Vol.80 ,No. 2,pp.26-42.

ACKNOWLEDGEMENTS:

One of the authors (P. Lalitha) acknowledges the support of UGC under the grant RGNF (F1-e) to carry out the research work.