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MHD Viscoelastic Fluid Flow Past an Infinite Vertical Plate in the Presence of Radiation and Chemical Reaction

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Abstract

A study has been carried out to analyse an unsteady free convective chemically reacting, MHD Visco-elastic fluid flow pastan infinite vertical plate in the presence of thermal radiation with uniform temperature and species diffusion. The dimensionless governing partialdifferential equations are solved by using closed analytical method. Numerical results for the velocity, temperature, concentration and the rates of heat and mass transfer are shown graphicallyfor different values of physical parameters involved.

Keywords: Chemical reaction, MHD, viscoelastic fluid, Heat and Mass transfer, free convection.

INTRODUCTION

Several industrial applications involve the flow of non-Newtonian fluids, and thus the flow behaviour of such fluids finds a great relevance. Moltenmetal's, plastic, pulps, emulsions, slurries and raw materials in fluid stateare some examples to mention. Non-Newtonian flow also finds practicalapplications in bio-engineering, wherein blood circulation inhuman/animal artery is explained by an appropriate Visco-elastic fluidmodel of small elasticity. The study of a visco-elastic pulsatile flow helps in understanding the mechanism of dialysis of blood through an artificialkidney.

The flow of viscous incompressible fluid past an impulsively started infinite horizontal plate in its own plane was first studied by Stokes [1] . Using this equation several researchers studied the severalproblems related to the flow of Walter's Liquid B. The constitutive equations of certain class of non-Newtonianfluids with short memories have been proposed by Walters [2] andBeard and Walters [3] for elastic-viscous fluid, referred to as WaltersLiquid 'B'. Bestman[5] have studied free convection heat transfer to steady radiating Non-NewtonianMHD flow past a vertical porous plate. Jha[7] has discussedMHD free-convection and mass transfer flow of an elasto-viscous fluid. Choubey and Yadav [6] investigated Magneto hydrodynamicflow of a Non-Newtonian fluid past a porous plate. Das and Panda[11]analyzed magneto hydrodynamic steady free convective flow andmass transfer in a rotating elastic-viscous fluid past an infinite verticalporous flat plate with constant suction. Damesh and Shannak [12] studied visco-elastic fluid flow past an infinite vertical porous plate inthe presence of first order chemical reaction. Hameed and Nadeem [10] discussed Unsteady MHD flow of a Non-Newtonian fluid on aporous plate. Nayak et al. [17] investigated MHD flow of a viscoelasticfluid along vertical porous surface with chemical reaction.Rajagopal and Gupta [4] was investigated an exact solution for theflow of a non-Newtonian fluid past an infinite porous plate. Samria et al. [8] studied MHD free convection flow of a viscoelasticfluid past an infinite vertical plate. Rajesh [13] studied heatsource and mass transfer effects on MHD flow of an elasto-viscous fluid through a porous medium. Kumar and Varma [14] investigatedthermal diffusion and radiation effects on unsteady MHD flow past animpulsively started exponentially accelerated vertical plate with variabletemperature and variable mass diffusion. Nabil et al.[15] discussednumerical study of viscous dissipation effects on free convection heatand mass transfer of MHD non-Newtonian fluid flow through a porousmedium. Ramana Murthy [16] studied unsteady MHD Free Convective visco elastic flow and mass transfer through Porous medium.Umamaheswar et al.[18] investigated unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclinedporous plate in the presence of heat source, viscous dissipation and ohmicheat. Attia [19] studied unsteady flow of a non-Newtonian fluid abovea rotating disk with heat transfer. Ramesh et al.[20]analyzed double diffusive convection in a layer of Maxwell viscoelastic fluid in porous medium in the presence of Soret and Dufour effects. Rashidi et al. [21] investigated mixed convective heat transfer forMHD viscoelastic fluid flow over a porous wedge with thermal radiation.Jha et al. [22] studied influence of Soret effect on MHD mixed convection flow of visco-elastic fluid past a vertical surface with Halleffect. Prakash et al.[23] investigated the Effects of chemical reactionand radiation absorption on MHD flow of dusty viscoelastic fluid.Ravikumar et al. [24] discussed theoretical investigation of anunsteady MHD free convection heat and mass transfer flow of a non-Newtonian fluid flow past a permeable moving vertical plate in thepresence of thermal diffusion and heat sink. Rushi Kumar et al.[25]studied thermal diffusion effects on MHD heat and mass transfer flowpast a moving vertical plate when the magnetic field relative to the fluidor to the plate. Ramana Murthy [26] discussed the effects of Magneto hydrodynamics on the peristaltic flow of fourth grade fluid in an inclined channel with permeable walls. Ramana Murthy et.al. [27] studied Magnetohydrodynamics Rivlin-Ericksen flow through porous medium in slip flow regime.Motivated by these investigations mentioned above, thepurpose of the present work is to consider unsteady MHD free convectivechemically reacting viscoelastic fluid flow past an infinite vertical platewith uniform temperature and species concentration.The governing equations are solved by using closed analytical method.Numerical results for the velocity, temperature, concentration and the rates of heat and mass transfer are shown graphically for different values of physical parameters involved.

MATHEMATICAL ANALYSIS

The unsteady free convection and mass transfer flow of an electrically conducting visco-elastic fluid past an infinite vertical plate in the presence of heat source has been considered. A transverse magnetic field of uniform strength B_0 is applied normal to the direction of the flow. The induced magnetic field is neglected in comparison to the applied magnetic field as the magnetic Reynolds number of the flow is taken to be very small. The flow is assumed to be in $x'-$ direction which is taken along the vertical plate in upward direction against to the gravitational field and the y'-axis is taken to be normal to the plate. Initially the plate and the surrounding fluid are at the same temperature T'_∞ with concentration level C'_∞ at all points in stationary condition. At time $t>0$, the plate is given an impulsive motion with a velocity $u=u_0$ in its own plane and all at once the plate temperature and spices concentration are up stretched to T'_w and C'_w respectively. For free convection flow, it is also assumed that the viscous dissipation is neglected in the energy. The effects of variation in density (ρ) with temperature and species concentration are considered only in the body force term in accordance with usual Boussinesq's approximation. The fluid considered here is gray, absorbing / eliminating radiation but a non-scattering medium.Since the flow of the fluid is assumed to be in the direction of x' axis, so the physical quantities are functions of the coordinates y' and t' only.Then by usual Boussinesq's approximation, the unsteady visco-elastic fluid flow is governed by the following equations

$$\frac{\partial u'}{\partial t'} = \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{K_0}{\rho}\frac{\partial^3 u'}{\partial y'^2\partial t'} - \frac{\sigma B_0^2 u'}{\rho} + g\beta\left(T'-T'_\infty\right) + g\beta^*\left(C'-C'_\infty\right) \tag{1}$$

$$\rho C_P\frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K_r\left(C'-C'_\infty\right) \tag{3}$$

with the initial boundary conditions:

$$\begin{aligned} &t'\le 0: u'=0,\ T'=T'_\infty,\ C'=C'_\infty \quad \text{for all } y' \\ &t'>0:\ u'=u_0,\ T'=T'_w,\ C'=C'_w \quad \text{at } y'=0 \\ &u'=0,\ T'\to T'_\infty, C'\to C'_\infty \quad \text{as } y'\to\infty, \end{aligned} \tag{4}$$

where $A=\frac{u_0^2}{\nu}$. The local radiant for the case of an optically thin grayGasis expressed by $\frac{\partial q_r}{\partial y'} = -4a^*\sigma\left(T'_\infty - T'^4\right)$ (5)

It is assumed that the temperature differences within the flow are sufficiently small and that T'^4 may be expressed as a linear function of the temperature .This is obtained by expanding T'^4 in a Taylor series about T'_∞ and neglecting the higher order terms, thus, we get

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{6}$$

From equations (5) and (6), equation (2) reduces to

$$\rho C_P\frac{\partial T'}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} + 16a^*\sigma T'^3_\infty\left(T'_\infty - T'\right) \tag{7}$$

On introducing the following non-dimensional quantities:

$$\begin{aligned} &u=\frac{u'}{u_0}, t=\frac{t'u_0^2}{\nu}, y=\frac{y'u_0}{\nu}, \theta=\frac{T'-T'_\infty}{T'_w-T'_\infty}, \\ &G_r=\frac{g\beta\nu\left(T'_w-T'_\infty\right)}{u_0^3}, C=\frac{C'-C'_\infty}{C'_w-C'_\infty}, k=\frac{\nu K_r}{u_0^2}, \\ &\Pr=\frac{\mu C_P}{k}, Sc=\frac{\nu}{D}, M=\frac{\sigma B_0^2\nu}{\rho u_0^2}, \\ &R=\frac{16a^*\nu^2\sigma T'^3_\infty}{k u_0^2}, S=\frac{K_0^2 u_0^2}{\rho\nu^2}, G_m=\frac{g\beta^*\left(C'_w-C'_\infty\right)}{u_0^3}, \end{aligned} \tag{8}$$

In equations (1) to (4), leads to

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}-S\frac{\partial^3 u}{\partial y^2\partial t}-Mu+G_r\theta+G_mC \tag{9}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}-\frac{R}{\Pr}\theta \tag{10}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-Kr\,C \tag{11}$$

with the initial and boundary conditions:

$$\begin{aligned} &t\le 0;\ u=0,\ \theta=0,\ C=0 \quad \text{for all } y\\ &t>0;\ u=1,\ \theta=1\ \ C=1 \quad \text{at } y=0\\ &\qquad u\to 0,\ \theta\to 0\ \ C\to 0 \ \text{as } y\to\infty \end{aligned} \tag{12}$$

SOLUTION OF THE PROBLEM

The governing equations along with the boundary conditions cannot be solved numerically. So, the numerical solution remains the only possible solution one could take. This was based on the discretization of the governing equations using the central differencing in space. The discretization equations were solved by numerically using closed analytical method.

we assume the trial solution for the velocity and temperature as:

$$u(y,t)=u_0(y)e^{i\omega t} \tag{13}$$

$$\theta(y,t)=\theta_0(y)e^{i\omega t} \tag{14}$$

$$\phi(y,t)=\phi_0(y)e^{i\omega t} \tag{15}$$

Substituting Equations (9) and (11) in Equations (13), (14) and (15), we obtain OD equations

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0=e^{-i\omega t},\ \ \theta_0=e^{-i\omega t},\ \phi_0=e^{-i\omega t} \quad \text{at} \quad y=0\\ &u_0\to 0,\ \ \theta_0\to 0,\ \ \phi_0\to 0, \quad \text{as} \quad y\to\infty \end{aligned} \tag{16}$$

The analytical solutions of OD equations with satisfying the boundary conditions (16) are given by

$$u(y,t)=A_3e^{-k_5y}+A_1e^{-k_2y}+A_2e^{-k_1y} \tag{17}$$

$$\theta(y,t)=e^{-k2y} \tag{18}$$

$$\phi(y,t)=e^{-k1y} \tag{19}$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –dimensional form is given by

$$C_f=-\left(\frac{\partial u}{\partial y}\right)_{z=0}=-\left(\frac{\partial u_0}{\partial y}+\varepsilon e^{i\omega t}\frac{\partial u_1}{\partial y}\right)_{y=0}$$
$$=A_3k_5e^{-k_5y}+A_1k_2e^{-k_2y}+A_2k_1e^{-k_1y}$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non –dimensional form is given, in terms of the Nusselt number, is given by

$$N_u=-\left(\frac{\partial \theta}{\partial y}\right)_{y=0}=\left(\frac{\partial \theta_0}{\partial y}+\varepsilon e^{i\omega t}\frac{\partial \theta_1}{\partial y}\right)_{z=0}=k_2e^{-k_2y}$$

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non –dimensional form, in terms of the Sherwood number, is given by

$$S_h=-\left(\frac{\partial \varphi}{\partial y}\right)_{y=0}=\left(\frac{\partial \varphi_0}{\partial y}+\varepsilon e^{i\omega t}\frac{\partial \varphi_1}{\partial y}\right)_{y=0}=k_1e^{-k_1y}$$

RESULT AND DISCUSSIONS

A closed analytical solution to the problem of unsteady MHD free convective chemically reacting visco-elastic fluid flow past a moving vertical plate in the presence of thermal radiation have been presented in the preceding section. In order to get the physical insight into the problem, thenumerical values of the velocity field is computed for different values of the system parameters such as magnetic parameter (M), viscoelastic parameter (Γ), solutal Grashof number (Gm), thermal Grashof number (Gr), radiation parameter (R), Prandtl number (Pr), chemical reaction parameter (Kr) respectively. Throughout the computations we employ G=0.5; Kr=5; Gr=10; Gm=5; Sc=0.78; R=4; w=0.1; M=3, Pr=0.71.

Figure 2 reveals that the velocity variations with the help of the viscoelastic parameter (Γ) in case of cooling and heating of the plate at time t=0.4. It is observed that the elasticity of the fluid increases and then decreases in case of cooling ofthe plate, whereas it decreases in the case of heating of the plate,

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finally takes asymptotic values1.3 for both the cases. It may be concluded that the energy due elastic property of the fluid increases the velocity and then gets dissipated.Figure 2 in case of cooling and heating of the plate. It is observed that the velocity of the fluid decreases with the increase of the magnetic parameter values for cooling of the plate at time 0.4. As expected, the velocity decreases with an increase in the magnetic parameter. It is because the application of the transverse magnetic field will result in a resistive type force (Lorentz force) similar to the drag force which tends to resist the fluid flow and thus reducing its velocity. Also, the boundary layer thickness decreases with an increase in the magnetic parameter. We also see that velocity profiles decrease with the increase of the magnetic effect indicating that the magnetic field tends to retard the motion of the fluid. The magnetic field may control the flow characteristics. The reverse phenomenon is found in the case of heating of the plate. Fig. 4 presents the plot of increase in channel porous permeability on the velocity profile. As observed, as the permeability of the medium increases there is increase in the fluid velocity since barriers placed on the flow path reduce as Da increases allowing for free flow thus increasingthe velocity.Figure (5) and (6) shows the effects of thermal Grashof number Gr and mass Grashof number Gm on the velocity profiles. From this figure it is found that the velocity increases in case of cooling of the plate. It is because that increase in the values of thermal Grashof number and mass Grashof number has the tendency to increase the thermal and mass buoyancy effect. This gives rise to an increase in the induced flow transport and a reverse effect is identified in case of heating of the plate.The effect of the chemical reaction parameter (Kr) has shown Figure 8 in the case cooling and heating of the plate. As expected, the presence of the chemical reaction significantly affects both profiles. It should be mentioned that the case studied relates to a destructive chemical reaction.In fact, as the chemical reaction parameter increases, a considerable reduction in the velocity occurs, and the presence of the peak indicates that the maximum velocity takes place in the fluid body close to the surface, but not at the surface itself. It is evident that an increase in this parameter significantly alters the concentration boundary-layer thickness but does not change the momentum one.The effect of concentration, temperature profiles for different values of chemical reaction parameter is illustrated in Figure (7) and (9) it is found that the concentration decreases as chemical reaction parameter.Figure 10 and (11)shows the effect of Schmidt number Sc on the velocity and concentration profiles forSc = 0:22 (hydrogen), 0:6 (water vapor), and 0:78 (ammonia). It is observed thatthe velocity and concentration decreases with increasing Schmidt number values due to the decrease inthe molecular diffusivity, which results in a decrease in the concentration and velocityboundary layer thickness. Figure (12) shows the effect of Prandtl number (Pr) on the velocity profiles. It is observer that the velocity increases with increasing values of Prandtl number (Pr). Figure (13) shows the effect of Prandtl number (Pr) on the temperature profiles. It is observer that the temperature increases with increasing values of Prandtl number (Pr).

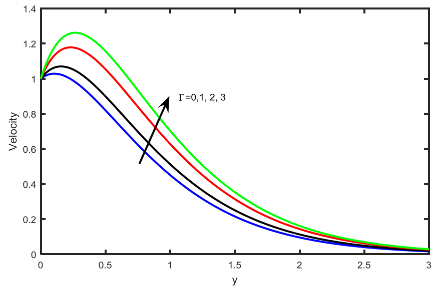

Fig.2. Velocity profiles for different values of visco-elastic parameter (Γ).

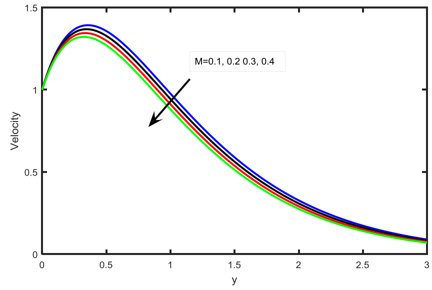

Fig.3. Velocity profiles for different values of magnetic parameter (M).

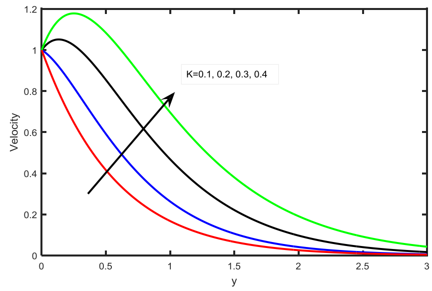

Fig.4. Velocity profiles for different values of permeability parameter (K).

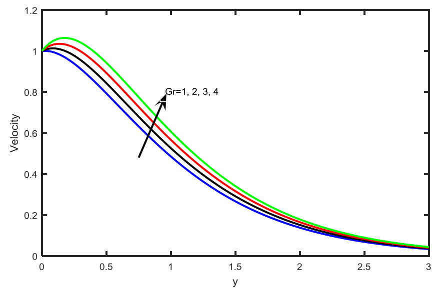

Fig.5. Velocity profiles for different values of Grashof number (Gr).

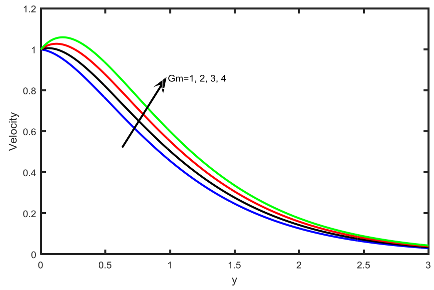

Fig.6. Velocity profiles for different values of modified Grashof number

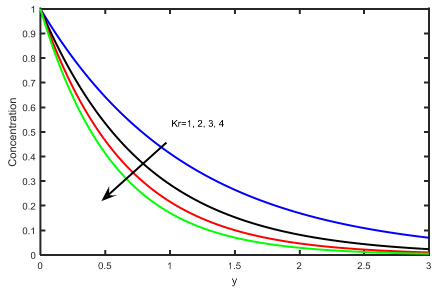

Fig.7. Concentration profiles for different values of chemical reaction parameter (Kr).

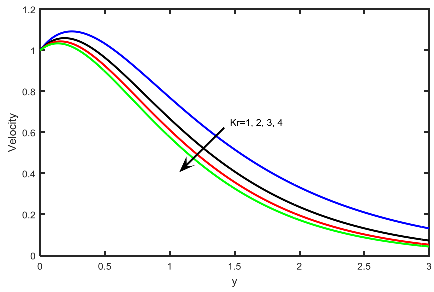

Fig.8. Velocity profiles for different values of chemical reaction parameter (Kr).

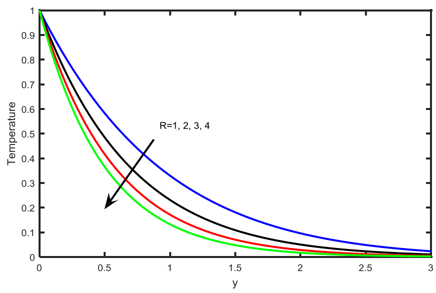

Fig.9. Temperature profiles for different values of radiation parameter (R).

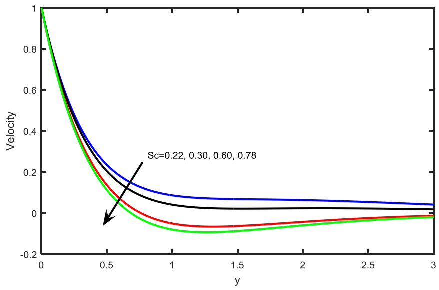

Fig.10. Velocity profiles for different values of Schmidt number (Sc).

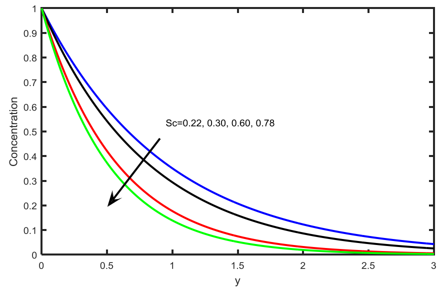

Fig.11. Concentration profiles for different values of Schmidt number (Sc).

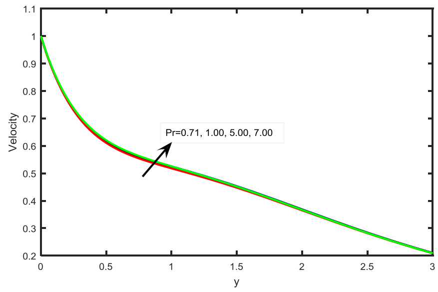

Fig.12. Velocity profiles for different values of Prandtl number (Pr).

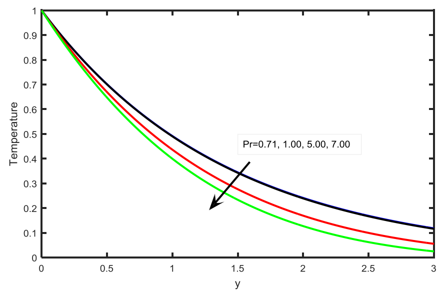

Fig.13. Temperature profiles for different values of Prandtl number (Pr).

Table for Skin friction, Nusselt number and Sherwood number values different values of Pr=0.71;G=0.5;Kr=10;Gr=10;Gm=5;Sc=0.78;R=4;i=1;w=0.1;M=3 at y=0;

Pr	Γ	Kr	Gr	Gm	Sc	R	i	w	M	Cf	Nu	Sh
0.71	0.5	5	10	5	0.78	4	1	0.1	3	-2.3729	2.0352	2.0140
0.72										-2.3726	2.0357	2.0140
0.73										-2.3722	2.0362	2.0140
0.74										-2.3719	2.0367	2.0140
0.71	0.1	5	10	5	0.78	4	1	0.1	3	-2.1840	2.0352	2.0140
	0.2									-2.2287	2.0352	2.0140
	0.3									-2.2750	2.0352	2.0140
	0.4									-2.3230	2.0352	2.0140
0.71	0.5	1	10	5	0.78	4	1	0.1	3	-2.8955	2.0352	0.9675
		2								-2.6868	2.0352	1.3100
		3								-2.5514	2.0352	1.5799
		4								-2.4516	2.0352	1.8100
0.71	0.5	5	2	5	0.78	4	1	0.1	3	0.1384	2.0352	2.8206
			4							-0.4284	2.0352	2.8206
			6							-0.9952	2.0352	2.8206
			8							-1.5619	2.0352	2.8206
0.71	0.5	5	10	2	0.78	4	1	0.1	3	-1.4204	2.0352	2.8206
				4						-1.8926	2.0352	2.8206
				6						-2.3648	2.0352	2.8206
				8						-2.8370	2.0352	2.8206
0.71	0.5	5	10	5	0.72	4	1	0.1	3	-2.1572	2.0352	2.7100
					0.74					-2.1474	2.0352	2.7474
					0.76					-2.1379	2.0352	2.7842
					0.78					-2.1287	2.0352	2.8206
0.71	0.5	5	10	5	0.78	1	1	0.1	3	-3.0559	1.0686	2.8206
						2				-2.6124	1.4636	2.8206
						3				-2.3322	1.7726	2.8206
						4				-2.1287	2.0352	2.8206
0.71	0.5	5	10	5	0.78	4	0.2	0.1	3	-2.0589	2.0035	2.7956
							0.4			-2.0655	2.0071	2.7984
							0.6			-2.0724	2.0106	2.8012
							0.8			-2.0796	2.0141	2.8040
0.71	0.5	5	10	5	0.78	4	1	0.1	3	-2.0871	2.0177	2.8068
								0.2		-2.1287	2.0352	2.8206
								0.3		-2.1783	2.0526	2.8344
								0.4		-2.2371	2.0698	2.8482
0.71	0.5	5	10	5	0.78	4	1	0.1	1	-3.6819	2.0177	2.8068
									2	-2.7427	2.0177	2.8068
									3	-2.0871	2.0177	2.8068
									4	-1.5706	2.0177	2.8068

5. CONCLUSIONS

We have examined the unsteady free convective chemically reacting, MHD visco-elastic fluid (Walter's liquid-B model) flow past an infinitevertical plate with uniform temperature and also with uniform massdiffusion in the presence of thermal radiation. The dimensionlessgoverning partial differential equations are solved by usual closed analytical method, we can conclude the following:

- The fluid velocity increases with increasing parameters Γ ,K, Gr, Gm and Pr for cooling of the plate whereas the reverse effectis found in the case of heating of the plate.
- The fluid velocity decreases with increasing values of theparameters M , *Kr*and Sc for cooling of the plate, for heating ofthe plate.

- The fluid temperature decreases with increasing values of *R*(radiation parameter) or *Pr* (Prandtl number) while it increaseswith *t* (time).
- The fluid concentration decreases with increase in *kr*(chemical reaction parameter) and *Sc* (Schmidt number) whileit increases with *t* (time).

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