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Research Article

Combined Radiation and Ohmic Heating Effects on MHD Free Convective Visco-Elastic Fluid Flow Past a Porous Plate with Viscous Dissipation

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Abstract

In this paper, we investigated the combined radiation and Ohmic heating effects on MHD free convective Visco-elastic fluid flow past a porous plate with viscous dissipation. The governing equations are solved for the velocity profile, temperature and concentration by using double perturbation technique. The effects of magnetic parameter M, Grashof number Gr, modified Grashof number Gm on velocity u are shown in the graphs while the effects of these parameters on skin friction are numerically discussed through tables.

Keywords: *Grashof number; modified Grashof number; MHD; Ohmic heating; Visco-elastic fluid; viscous dissipation.*

1. Introduction

The MHD viscous flow containing heat and mass transfer has attracted many researchers for its applications in various areas like power and cooling systems, cooling of nuclear reactor, magneto-hydrodynamic power generation systems.The effect of ohmic heating on the MHD free convective heat transfer has been studied for Newtonian fluid by Hossain (M. A. Hossain, 1992). Chen (Chien-Hsin-Chen, 2004) has studied the problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface with Ohmic heating. The effect of Ohmic heating and viscous dissipation on MHD mixed convection heat and mass transfer about a vertical plate are calculated numerically by Aydin and Kaya (O. Aydin and A. Kaya, 2009). Siddappa (Siddappa et al. 185) discussed the flow of Visco elastic fluids of the type Walter's liquid B past a stretching sheet. Andersson (H. I. Andersson, 1992) studied the flow problem of electrically conducting Visco elastic fluid past a flat and incompressible elastic sheet. Magyari (Magyari et al. 2004) investigated an analytical solutions for unsteady free convection in porous media. Lahurikar (Lahurikar et al. 1995) considered mass transfer effects on flow past a oscillating plate. Soundalgekar (Soundalgekar et al., 1997) gave an exact solution for magnetic free convection flow past an oscillating plate. Sreekanth (Sreekanth et al., 2001) discussed transient MHD free convection flow of an incompressible viscous dissipative fluid. Ganesan (Ganesan et al., 2002) studied radiation and mass transfer effects on fluid flow an incompressible viscous fluid past a moving vertical cylinder. Rao (V.V.R. Rao, 1971) discussed the unsteady magnetohydrodynamic convection heat transfer past an infinite plane. Pop (I. Pop, 1969) has reported on transient buoyancy-driven convective hydrodynamics from a vertical plate. Beg (Beg et al., 2006) have analyzed the free convective MHD flow from a spinning sphere with impulsive motion using the Blottner difference method. Raptis and Massalas (A. Raptis and C. V. Massalas, 1998) studied induced magnetic field effects in their study of unsteady hydromagnetic-radiative free convection. Aziz (M. Abd-El Aziz, 2006) considered the thermal radiation flux effects on unsteady MHD microplar fluid convection. Rahman and Sarkar (M. M. Rahman and M.S.A. Sarkar 2004) have studied unsteady MHD flow of a dusty Visco-elastic oldroyd fluid under time varying body force through a rectangular channel. Makinde and Osalusi (OD. Makinde and E. Osalusi, 2006) have considered a MHD steady flow in a channel with a slip at permeable boundaries. Mishra (Mishra et al., 2008) investigated a flow and heat transfer of a MHD Visco-elastic fluid in channel with stretching walls. Takhar and Soundalgekar (V. M. Soundalgekhar and H. S. Takhar , 1992) discussed the effect of radiation on the natural convection flow of a gas past a semi-infinite plate using the Cogly-Vincentine-Gilles equilibrium model. Muthucumaraswamy (Muthucumaraswamy et al., 2009) studied unsteady flow past an accelerated infinite vertical plate with variable temperature and uniform mass diffusion. Prasad (Prasad et al., 2007) studied radiation and mass transfer effects on two dimensional flow past an impulsively started infinite vertical plate. Kim (J. Kim Youn, 2000) has considered an unsteady MHD convective heat transfer past a semi-

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infinite vertical porous moving plate with variable suction. Chamkha (Chamkha et al., 2001) studied radiation effects on free convection flow past a semi-infinite vertical plate with mass transfer. Raju (Raju et al., 2012) discussed the radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Raju (Raju et al., 2012) studied MHD thermal diffusion natural convection between inclined plates in porous medium. Several authors (Ravi Kumar et al., 2012&2013, T.S.Reddy et al., 2013, Raju et al., 2011&2013), reported the similar work. In this paper, the combined radiation and Ohmic heating effects on MHD free convective flow with heat and mass transfer from a vertical porous plate in the presence of viscous dissipation has been studied.

2. Mathematical Formulation of the Problem

The convective MHD flow with heat and mass transfer over a vertical porous plate in the presence of viscous dissipation and Ohmic heating has been considered. The $\bar{x}$ -axis is taken along the length of the porous plate and $\bar{y}$ -axis is normal to it. Let $\bar{u}$ and $\bar{v}$ be the velocities of the fluid along $\bar{x}$ and $\bar{y}$ directions respectively. The equations governing the fluid flow are:

Equation of continuity

$$\frac{\partial \bar{v}}{\partial \bar{y}} = 0 \Rightarrow \bar{v} = -v_0 \tag{1}$$

Also $\frac{\partial \bar{P}}{\partial \bar{y}} = 0 \Rightarrow \bar{P}$ is independent of $\bar{y}$

Momentum equation:

$$\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{k_0}{\rho}\bar{v}\frac{\partial^3 \bar{u}}{\partial \bar{t}\,\partial \bar{y}^2} + g\beta(\bar{T} - \bar{T}_\infty) - \frac{\sigma B_0^2 \bar{u}}{\rho} + g\bar{\beta}(\bar{C} - \bar{C}_\infty) - \frac{\nu}{\bar{K}}\bar{u} \tag{2}$$

Energy equation:

$$\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}} = \frac{\kappa}{\rho C_p}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + \frac{\nu}{C_p}\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 - \frac{k_0}{\rho C_p}\left(\bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right) + \frac{\sigma B_0^2 \bar{u}^2}{\rho C_p} + Q\left(\bar{T}_\infty - \bar{T}\right) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial \bar{y}} \tag{3}$$

Concentration equation:

$$\bar{v}\frac{\partial \bar{C}}{\partial \bar{y}} = D\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} \tag{4}$$

The radiative heat flux q_r is given by

$$\frac{\partial q_r}{\partial \bar{y}} = 4(\bar{T} - T_\infty)I$$

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

The intial boundary conditions are

$$\begin{aligned} &\bar{y} = 0 : \bar{u} = 0, \bar{T} = T_w, \bar{C} = C_w \\ &\bar{y} = \infty : \bar{u} \to 0, \bar{T} \to T_{\infty,} \bar{C} \to C_\infty \end{aligned} \tag{5}$$

On introducing of the non-dimensional quantities

$$\begin{aligned} &y = \frac{v_0\bar{y}}{\nu}, u = \frac{\bar{u}}{v_0}, T = \frac{\bar{T} - \bar{T}_\infty}{T_w - T_\infty} C = \frac{\bar{C} - \bar{C}_\infty}{C_w - C_\infty}, \Pr = \frac{\mu C_P}{\kappa}, \\ &M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, Gr = \frac{g\beta\nu\left(T_w - T_\infty\right)}{v_0^3}, Gm = \frac{g\beta\nu\left(C_w - C_\infty\right)}{v_0^3}, \\ &Ec = \frac{v_0^2}{C_p\left(T_w - T_\infty\right)}, N = \frac{4\nu I}{\rho C_p v_0^2}, H = \frac{Q\nu}{\rho C_p v_0^2}, Sc = \frac{\nu}{D}, \\ &K = \frac{\bar{K}v_0^2}{\nu^2},. \end{aligned} \tag{6}$$

Equations (2), (3) and (4) become

$$k_1\frac{\partial^3 u}{\partial t\partial y^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - \left(M + \frac{1}{K}\right)u = -GrT - GmC \tag{7}$$

$$\frac{\partial^2 T}{\partial y^2} + \Pr\frac{\partial T}{\partial y} - \Pr\left(N + H\right)T = -\Pr Ec\left(\frac{\partial u}{\partial y}\right)^2 - \Pr MEcu^2 - k_1\Pr Ec\frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial y^2} \tag{8}$$

$$\frac{\partial^2 c}{\partial y^2} + Sc\frac{\partial c}{\partial y} = 0 \tag{9}$$

Where $k_1 = \frac{k_0 v_0^2}{\rho\nu^2}$

The modified boundary conditions are

$$\begin{aligned} &y = 0 : u = 0, T = 1, C = 1 \\ &Y \to \infty : u \to 0, T \to 0, C \to 0 \end{aligned} \tag{10}$$

3. Method of solution

To solve the equations (7) to (9), the perturbation scheme forEc<<1 is introduced as follows:

$$\begin{aligned} &u\left(y,t\right) = u_0\left(y\right) + Ece^{i\omega t}u_1\left(y\right) + o(Ec^2) \\ &T\left(y,t\right) = T_0\left(y\right) + Ece^{i\omega t}T_1\left(y\right) + o(Ec^2) \\ &C\left(y,t\right) = C_0\left(y\right) + Ece^{i\omega t}C_1\left(y\right) + o(Ec^2) \end{aligned} \tag{11}$$

On substituting relations (11) in equations (7) to (9) and neglecting the second and higher

Powers of Ec, the zeroth and first equations are obtained as follows:

Zeroth order equations:

$$\frac{\partial^2 u_0}{\partial y^2} + \frac{\partial u_0}{\partial y} - \left(M + \frac{1}{K}\right)u_0 = -GrT_0 - GmC_0 \tag{12}$$

$$\frac{\partial^2 T_0}{\partial y^2} + \Pr\frac{\partial T_0}{\partial y} - \Pr(N + H)T_0 = 0 \tag{13}$$

$$\frac{\partial^2 C_0}{\partial y^2} + Sc\frac{\partial C_0}{\partial y} = 0 \tag{14}$$

First order equations:

$$\left(k_1 i\omega + 1\right)\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial u_1}{\partial y} - \left(M + \frac{1}{K}\right)u_1 = -GrT_1 - GmC_1 \tag{15}$$

$$\frac{\partial^2 T_1}{\partial y^2} + \Pr\frac{\partial T_1}{\partial y} - \Pr(N+H)T_1 = -\Pr\left(\frac{\partial u_0}{\partial y}\right)^2 - \Pr Mu_0 - k_1 \Pr\frac{\partial u_0}{\partial y}\frac{\partial^2 u_0}{\partial y^2} \quad (16)$$

$$\frac{\partial^2 C_1}{\partial y^2} + Sc\frac{\partial C_1}{\partial y} = 0 \quad (17)$$

The modified boundary conditions are

$$y = 0: u_0 = 0, u_1 = 0, T_0 = 1, T_1 = 0, C_0 = 1, C_1 = 0$$
$$y \to \infty: u_0 \to 0, u_1 \to 0, T_0 \to 1, T_1 \to 0, C_0 \to 1, C_1 \to 0 \quad (18)$$

In order to solve the equations (12) to (18), the multi-perturbation scheme

For k_1 <<1(for low shear stress) has been introduced as follows:

$$\begin{aligned} u_0(y) &= u_{00} + k_1 u_{01} + o(k_1^2) \\ u_1(y) &= u_{10} + k_1 u_{11} + o(k_1^2) \\ T_0(y) &= T_{00} + k_1 T_{01} + o(k_1^2) \\ T_1(y) &= T_{10} + k_1 T_{11} + o(k_1^2) \\ C_0(y) &= C_{00} + k_1 C_{01} + o(k_1^2) \\ C_1(y) &= C_{10} + k_1 C_{11} + o(k_1^2) \end{aligned} \quad (19)$$

Using relations (19) in the equations from (12) to (18) and neglecting the second and

Higher powers of k_1,the zeroth and first order equations are obtained as:

Zero order equations:

$$\frac{\partial^2 u_{00}}{\partial y^2} + \frac{\partial u_{00}}{\partial y} - \left(M + \frac{1}{K}\right)u_{00} = -GrT_{00} - GmC_{00} \quad (20)$$

$$\frac{\partial^2 u_{10}}{\partial y^2} + \frac{\partial u_{10}}{\partial y} - \left(M + \frac{1}{K}\right)u_{10} = -GrT_{10} - GmC_{10} \quad (21)$$

$$\frac{\partial^2 T_{00}}{\partial y^2} + \Pr\frac{\partial T_{00}}{\partial y} - \Pr(N+H)T_{00} = 0 \quad (22)$$

$$\frac{\partial^2 T_{10}}{\partial y^2} + \Pr\frac{\partial T_{10}}{\partial y} - \Pr(N+H)T_{10} = -\Pr\left(\frac{\partial u_{00}}{\partial y}\right)^2 - \Pr Mu_{00} \quad (23)$$

$$\frac{\partial^2 C_{00}}{\partial y^2} + Sc\frac{\partial C_{00}}{\partial y} = 0 \quad (24)$$

$$\frac{\partial^2 C_{10}}{\partial y^2} + Sc\frac{\partial C_{10}}{\partial y} = 0 \quad (25)$$

First order equations:

$$\frac{\partial^2 u_{01}}{\partial y^2} + \frac{\partial u_{01}}{\partial y} - \left(M + \frac{1}{K}\right)u_{01} = -GrT_{01} - GmC_{01} \quad (26)$$

$$i\omega\frac{\partial^2 u_{11}}{\partial y^2} + \frac{\partial u_{11}}{\partial y} - \left(M + \frac{1}{K}\right)u_{11} = -GrT_{11} - GmC_{11} \quad (27)$$

$$\frac{\partial^2 T_{01}}{\partial y^2} + \Pr\frac{\partial T_{01}}{\partial y} - \Pr(N+H)T_{01} = 0 \quad (28)$$

$$\frac{\partial^2 T_{11}}{\partial y^2} + \Pr\frac{\partial T_{11}}{\partial y} - \Pr(N+H)T_{11} = -2\Pr\frac{\partial u_{00}}{\partial y}\frac{\partial u_{01}}{\partial y} - \Pr Mu_{01} - \Pr\frac{\partial u_{00}}{\partial y}\frac{\partial^2 u_{00}}{\partial y^2} \quad (29)$$

$$\frac{\partial^2 C_{01}}{\partial y^2} + Sc\frac{\partial C_{01}}{\partial y} = 0 \quad (30)$$

$$\frac{\partial^2 C_{11}}{\partial y^2} + Sc\frac{\partial C_{11}}{\partial y} = 0 \quad (31)$$

The corresponding boundary conditions are :

$$\begin{aligned} &y = 0: u_{00} = 0, u_{01} = 0, u_{10} = 0, u_{11} = 0, \\ &T_{00} = 1, T_{01} = 0, T_{10} = 0, T_{11} = 0, C_{00} = 1, \\ &C_{01} = 0, C_{10} = 0, C_{11} = 0 \\ &y \to \infty: u_{00} \to 0, u_{01} \to 0, u_{10} \to 0, u_{11} \to 0, \\ &T_{00} \to 0, T_{01} \to 0, T_{10} \to 0, T_{11} \to 0, C_{00} \to 0, \\ &C_{01} \to 0, C_{10} \to 0, C_{11} \to 0 \end{aligned} \quad (32)$$

The solutions of the equations from (20) to (31) subject to boundary conditions (32) are obtained as follows:

$$C_0 = e^{-Scy} \quad (33)$$

$$C_1 = 0 \quad (34)$$

$$T_0 = e^{-q_1 y} \quad (35)$$

$$T_1 = A_1 e^{-q_1 y} + A_2 e^{-2r_1 y} + A_3 e^{-2q_1 y} + A_4 e^{-2s_c y} + A_5 e^{-(r_1+q_1)y} + A_6 e^{-(q_1+s_c)y} + A_7 e^{-(r_1+s_c)y} + A_8 e^{-r_1 y} + A_9 e^{-s_c y} \quad (36)$$

$$u_{00} = t_1 e^{-r_1 y} + t_2 e^{-q_1 y} + t_3 e^{-Scy} \quad (37)$$

$$u_{01} = 0 \quad (38)$$

$$u_{10} = a_{22} e^{-r_1 y} + a_{12} e^{-q_1 y} + a_{13} e^{-2r_1 y} + a_{14} e^{-2q_1 y} + a_{15} e^{-2Scy} + a_{16} e^{-(r_1+q_1)y} + a_{17} e^{-(q_1+Sc)y} + a_{18} e^{-(r_1+Sc)y} + a_{20} e^{-Scy} \quad (39)$$

$$u_{11} = N_{20} e^{-r_1 y} + N_{11} e^{-q_1 y} + N_{12} e^{-Scy} + N_{13} e^{-2q_1 y} + N_{14} e^{-2r_1 y} + N_{15} e^{-2Scy} + N_{16} e^{-(r_1+q_1)y} + N_{17} e^{-(q_1+Sc)y} + N_{18} e^{-(r_1+Sc)y} \quad (40)$$

4. Results and discussion

The expressions for velocity, temperature and concentration for the flow field are given by

$$u = u_{00} + k_1 u_{01} + E_c\left(u_{10} + k_1 u_{11}\right) \quad (41)$$

$$T = T_0 + E_c T_1 \quad (42)$$

$$C = C_0 + E_c C_1 \quad (43)$$

The non-dimensional form of the rate of heat transfer in the form of Skin friction τ is given by

$$\tau = \left(\frac{\partial u}{\partial y} + k_1\frac{\partial^2 u}{\partial y^2}\right)_{y=0}$$

$$
\begin{aligned}
&= \left(M_1 + M_2\right) r_1 \left(1 - k_1 r_1\right) + M_1 q_1 \left(-1 + k_1 q_1\right) \\
&+ M_2 s_c \left(-1 + k_1 s_c\right) + \\
&E_c \begin{pmatrix}
\left(a_{22} + k_1 A_{20}\right) r_1 \left(-1 + k_1 r_1\right) \\
+\left(a_{12} + k_1 A_{11}\right) q_1 \left(-1 + k_1 q_1\right) \\
+2\left(a_{13} + k_1 A_{14}\right) r_1 \left(-1 + 2k_1 r_1\right) \\
+2\left(a_{14} + k_1 A_{13}\right) q_1 \left(-1 + 2k_1 q_1\right) \\
+2\left(a_{15} + k_1 A_{15}\right) s_c \left(-1 + 2k_1 s_c\right) \\
+\left(a_{16} + k_1 A_{16}\right)\left(q_1 + r_1\right)\left(-1 + k_1\left(q_1 + r1\right)\right) \\
+\left(a_{17} + k_1 A_{17}\right)\left(q_1 + s_c\right)\left(-1 + k_1\left(q_1 + s_c\right)\right) \\
+\left(a_{18} + k_1 A_{18}\right)\left(r_1 + s_c\right)\left(-1 + k_1\left(r_1 + s_c\right)\right) \\
+a_{20} s_c \left(-1 + k_1 s_c\right)
\end{pmatrix}
\end{aligned} \tag{44}
$$

Nusselt number N_u is given by,

$$
\begin{aligned}
N_u &= \left(\frac{\partial T}{\partial y}\right)_{y=0} \\
&= -q_1 \\
&+ E_c e^{iwt} \begin{pmatrix}
-q_1\left(a_{11} + 2a_2 + 2k_1 b_8 + k_1 b_{13}\right) \\
-\left(2a_1 + a_7 + 2k_1 b_7\right) r_1 \\
-\left(2a_3 + a_9 + 2k_1 b_9\right) s_c - \\
\left(a_4 + k_1 b_{10}\right)\left(r_1 + q_1\right) \\
-\left(a_5 + k_1 b_{11}\right)\left(q_1 + s_c\right) \\
-\left(a_6 + k_1 b_{11}\right)\left(r_1 + s_c\right)
\end{pmatrix}
\end{aligned} \tag{45}
$$

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

$$
S_h = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -s_c \tag{46}
$$

Discussions

In this problem, the velocity field u, temperature field T, mass transfer C,skin friction τ and rate of heat transfer Nu, Sherwood number S_h are obtained from the equations (41)-((46).The velocity field u and skin friction have been studied numerically by giving numerical values for M, Gr, Gm while keeping the remaining parameters are constant. The results obtained are illustrated through figure 1 to 3 and tables 1to 3.

Figure 1 depicts the velocity profile u against y for different values of m. from this figure, we observe that as m increases, the velocity u decreases. it indicates that magnetic field suppresses the free convection. from figure 2, it is observe that as Gm increases, velocity field u increases. In figure 3, it is clear that as Gr increases, velocity field u increases. From tables 1 to 3 skin friction increases with an increase in Gm but it shows the reverse effects in case of M and Gr.

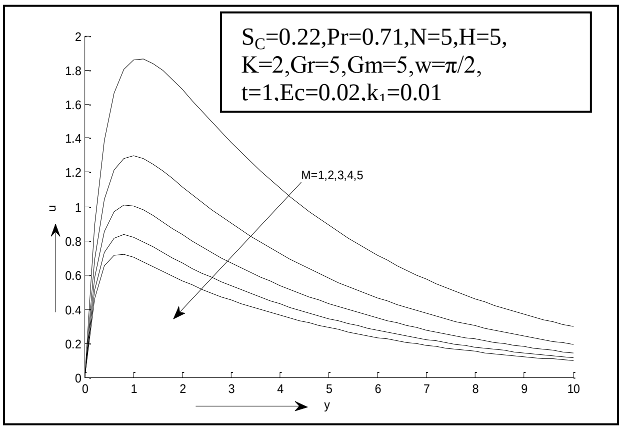

Fig1. Effect of M on velocity u

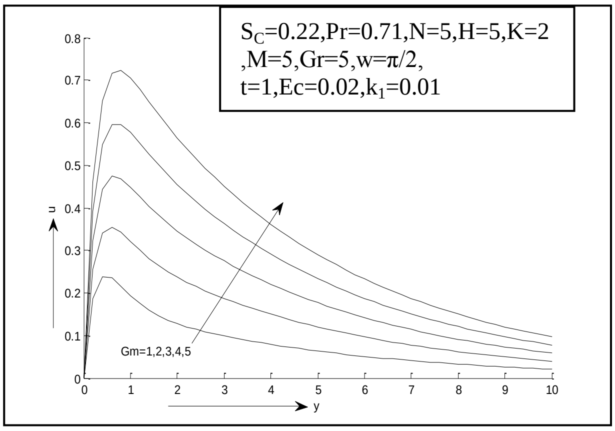

Fig 2. Effect of Gm on velocity u

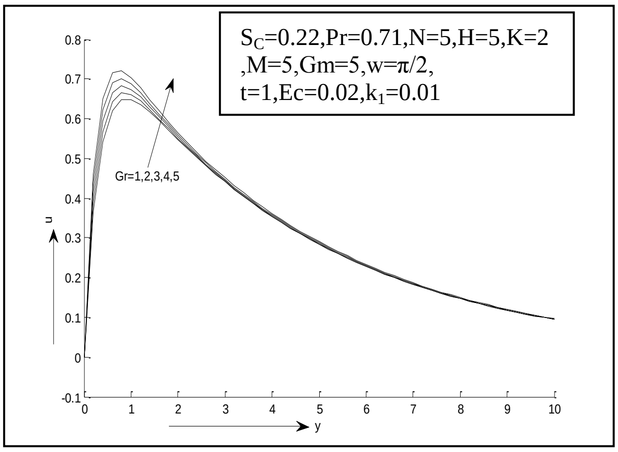

Fig 3. Effect of Gr on velocity u

Table1: Effect of M on Skin friction

M	τ
1	5.5768
2	4.5056
3	3.9024
4	3.4739
5	-6.0431

Table2: Effect of Gr on Skin friction

Gm	τ
1	-8.8752
2	-7.8475
3	-7.4578
4	-6.4237
5	-6.0276

Table3: Effect of Gm on Skin friction

Gr	τ
1	2.1876
2	1.3732
3	-0.1526
4	-2.5341
5	-6.0276

5. Conclusion

In this paper, the effects on MHD free convective Visco-elastic fluid flow past a porous plate in the presence of Ohmic heating and viscous dissipation has been studied. The governing equations are solved for the velocity field, temperature and concentration by using perturbation technique in terms of dimensionless parameters. In the analysis of the flow the following conclusions are made:

- Velocity increases with an increase in Gm and Gr but it shows the reverse effects in case of M.
- Skin friction increases with an increase in Gm but it shows the reverse effects in case Gr and M.

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