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Unsteady MHD Free Convection Flow of a Viscoelastic Fluid Past a Vertical Porous Plate

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Abstract

Aan analytical investigation of unsteady MHD free convection flow of a viscoelastic fluid past a vertical porous plate through a porous medium with time dependent oscillatory permeability and suction in presence of a uniform transverse magnetic field is considered. The coupled nonlinear partial differential equation are turned to ordinary by super imposing a solutions with steady and time dependent transient part. Finally, the set of ordinary differential equations are solved with a perturbation scheme to meet the inadequacy of boundary condition. Elasticity of the fluid and the Lorentz force reduce the velocity and it is more pronounced in case of heavier species. Most interesting observation is the fluctuation of velocity appears near the plate due to the presence of sink and presences of elastic element as well as heat source reduce the skin friction.

Keywords: Visco elastic fluid**,** oscillatory flow, thermal radiation, chemical reaction, heat and mass transfer, radiation absorption, porous plate.

1. INTRODUCTION

An important class of two dimensional time dependent flow problem dealing with the response of boundary layer to external unsteady fluctuations of the free stream velocity about a mean value attracted the attention of many researchers. Besides that convective flow through porous medium has applications in geothermal energy recovery, thermal energy storage, oil extraction, and flow through filtering devices. Now a days magnetohydrodynamics is very much attracting the attention of the many authors due to its applications in geophysics and engineering. MHD flow with heat and mass transfer has been a subject of interest of many researchers because of its various applications in science and technology. Such phenomena are observed in buoyancy induced motions in the atmosphere, in water bodies, quasi solid bodies such as earth, etc. Heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink was considered by Reddy et al. [1]. Unsteady MHD radiative, chemically reactive and rotating fluid flow past an impulsively started vertical plate with variable temperature and mass diffusion was addressed by Raju et al. [2]. MHD rotating heat and mass transfer free convective flow past an exponentially accelerated isothermal plate with fluctuating mass diffusion was investigated by Philip et al. [3]. Hall current effects on unsteady MHD flow in a rotating parallel plate channel bounded by porous bed on the lower half Darcy lap wood model was considered by Harikrishna et al. [4]. Natural convection boundary layer flow of a double diffusive and rotating fluid past a vertical porous plate was addressed by Reddy et al. [5, 6]. Chemical reaction and radiation effects on unsteady MHD free convection flow near a moving vertical plate with variable properties were studied by Redyy et al. [7, 8, 9, 26, 27, and 31]. The effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source were considered by Seshaiah et al. [10]. Unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption, radiation, chemical reaction and Soret effects were discussed by Rao et al. [11, 12]. Unsteady MHD free convection flow past an exponentially accelerated vertical plate with mass transfer, chemical reaction and thermal radiation was addressed by Chamkha et al. [13]. Analytical study of MHD free convictive, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction was conducted by Raju et al. [14]. Unsteady MHD free convection flow of a Kuvshinski fluid past a vertical porous plate in the presence of chemical reaction and heat source/sink was considered by Reddy et al. [15]. MHD convective heat and mass transfer flow of a Newtonian fluid past a vertical porous plate with chemical reaction, radiation absorption and thermal diffusion was investigated by Umamaheswar et al. [16, 17]. Soret effect due to mixed convection on unsteady magnetohydrodynamic flow past a semi-infinite vertical permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction was investigated by Raju et al. [18]. Thermal diffusion effect on MHD heat and mass transfer flow past a semi-infinite moving vertical porous plate with heat generation and chemical reaction was studied by Reddy et al. [19]. Radiation absorption and chemical reaction effects on MHD flow of heat generating Casson fluid past oscillating vertical porous plate was considered by Reddy et al. [20]. Unsteady MHD free convection flow of a visco-elastic fluid past a vertical porous plate in the presence of thermal radiation, radiation absorption, heat generation/absorption and chemical reaction and also chemical reaction and thermal radiation effects on MHD micropolar fluid past a stretching sheet embedded in a non-Darcian porous medium were studied by Reddy et al. [21, 22]. Effects of unsteady free convective MHD non Newtonian flow through a porous medium bounded by an infinite inclined porous plate were considered by Reddy et al. [23]. Unsteady MHD free convection oscillatory Couette flow through a porous medium with periodic wall temperature and MHD thermal diffusion natural convection flow between heated inclined plates in porous medium was addressed by Raju et al. [24, 25]. Heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source were considered by Ravikumar et al. [28]. Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface were investigated by Raju et al. [29]. Unsteady MHD thermal diffusive, radiative and free convective flow past a vertical porous plate through non-homogeneous porous medium and MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom wall in the presence of viscous dissipation and Joule's heating were addressed by Raju et al. [30, 33]. Unsteady MHD mixed convection flow of a viscous double diffusive fluid over a vertical plate in porous medium with chemical reaction, thermal radiation and Joule heating was considered by Rao et al. [32]. Unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium was considered by Vidyasagar et al. [34]. Magneto convective flow of a non-Newtonian fluid through non-homogeneous porous medium past a vertical porous plate with variable suction was considered by Reddy et al. [35].

2. FORMULATION OF THE PROBLEM

The unsteady free convective flow of a radiative, chemically reactive, heat absorbing, visco-elastic fluid past an infinite vertical porous plate in a porous medium with time dependent oscillatory suction as well as porosity parameter in the presence of radiation absorption and a transverse magnetic field is considered. Let x^1-axis be taken along the plate in the direction of the flow and y^1-axis normal to it. Let us consider the magnetic Reynolds number much less than unity so that induced magnetic field is neglected in comparison with the applied transverse magnetic field.

The basic flow in the medium is, therefore, entirely due to the buoyancy force caused by the temperature difference between the wall and the medium. It is assumed that initially, at $t^1 \le 0$, the plates as well as fluids are at the same temperature and also concentration of the species is very low so that the Soret and Dofour effects are neglected. When $t^1 > 0$, the temperature of the plate is instantaneously raised to $T_w^1 = T_\infty + \varepsilon(T_W - T_\infty)e^{i\omega^1 t^1}$ and the concentration of the species is set to $C_w^1 = C_\infty + \varepsilon(C_W - C_\infty)e^{i\omega^1 t^1}$.

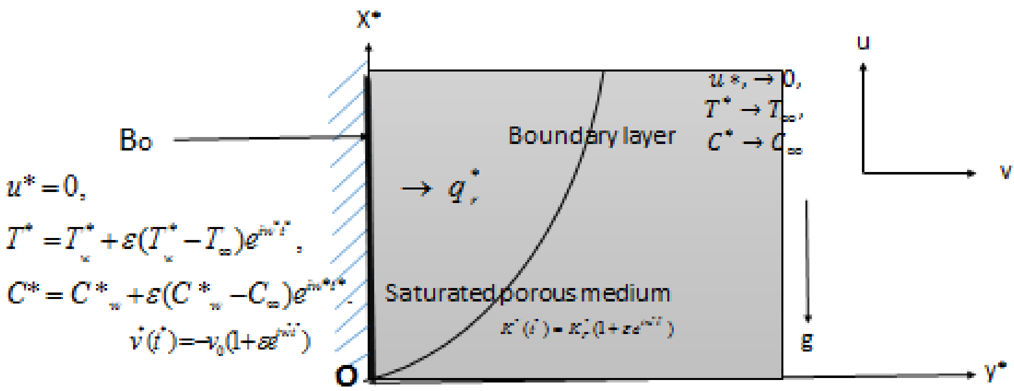

Fig. 1: Flow geometry and the coordinate system

Under the above hypothesis with usual Boussinesq's approximation, followed by Reddy et al. [21] the dimensionless governing equations and boundary conditions are given by

$$\frac{1}{4}\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r T + G_m C - \left(M^2 + \frac{1}{K_p}\right)u - \frac{1}{4}\gamma\left\{\frac{\partial^3 u}{\partial t\,\partial y^2} - 4\frac{\partial^3 u}{\partial y^3}\right\} \tag{1}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} = \frac{1}{P_r}\frac{\partial^2 T}{\partial y^2} - (N_r + Q)T + RC \tag{2}$$

$$\frac{1}{4}\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K_c C \tag{3}$$

$$\begin{aligned} &u = 0, \quad T = e^{i\omega t}, \quad C = e^{i\omega t} \quad \text{at } y = 0, \\ &u \to 0, \quad T \to 0, \quad C \to 0 \quad \text{as } y \to \infty \end{aligned} \tag{4}$$

3. SOLUTION OF THE PROBLEM

In view of periodic suction, temperature and concentration at the plate let us assume the velocity, temperature, concentration the neighborhood of the plate be

$$u(y,t)=u_0(y)e^{i\omega t}, \qquad T(y,t)=T_0(y)e^{i\omega t} \text{and } C(y,t)=C_0(y)e^{i\omega t} \tag{5}$$

The above method of solution has been adopted by Reddy et al. [21] to have the periodically fluctuating flow problems. Substituting equations (5) into (1)-(3) and comparing the non-harmonic and harmonic terms we get the following set of equations are obtained.

$$\gamma u_0^{111}+u_0^{11}(1-\frac{\gamma i\omega}{4})-(M^2+\frac{1}{K_P}+\frac{i\omega}{4})u_0=-G_mC_0-G_rT_0 \tag{5}$$

$$T_0^{11}-(N_r+Q+\frac{i\omega}{4})P_rT_0=-RP_rC_0 \tag{6}$$

$$C_0^{11}-(K_c+\frac{i\omega}{4})S_cC_0=0 \tag{7}$$

The boundary conditions reduce to the following form

$$\begin{aligned} &u_0=0, \quad \mathrm{T}_0=1, \quad \mathrm{C}_0=1 \quad \text{at y = 0} \\ &u_0\to 0, \quad \mathrm{T}_0\to 0, \quad \mathrm{C}_0\to 0 \text{ as y} \to\infty \end{aligned} \tag{8}$$

Equation (5) is of third order but only two boundary conditions are available. Therefore Perturbation method has been applied using (γ<<1), the elastic parameter as the perturbation parameter.

$$u_0=u_{00}(y)+\gamma u_{01}(y)+o(\gamma^2) \tag{9}$$

Inserting eq.(4.17) into (4.13) equating the coefficients of γ^0 and γ to zero, we have the following set of ordinary differential equations zeroth order equations are

First order equations

$$u_{00}^{11}-(M^2+\frac{1}{K_P}+\frac{i\omega}{4})u_{00}=-G_mC_0-G_rT_0 \tag{10}$$

$$u_{01}^{11}(1-\frac{iw}{4})-(M^2+\frac{1}{K_P}+\frac{i\omega}{4})u_{01}=-u_{00}^{111} \tag{11}$$

The corresponding boundary conditions are;

$$u_{00} = 0, \quad \text{as y } = 0$$
$$u_{10} \to 0, \quad \text{as y} \to \infty \tag{12}$$

Solving these differential equations (4.18)-(4.19) with the help of above boundary conditions (4.20) we get the following solutions

$$u(y,t) = \{(a_6 - a_7)e^{-\sqrt{a_4 y}} + a_6 e^{-\sqrt{a_2 y}} - a_7 e^{-\sqrt{a_1 y}}\} + \gamma\{(a_{13} - a_{12} - a_{14})e^{-\sqrt{a_8 y}} + a_{12}e^{-\sqrt{a_4 y}} - a_{13}e^{-\sqrt{a_2 y}} + a_{14}e^{-\sqrt{a_1 y}})e^{-\sqrt{a_1 y}}\}]e^{iwt} \tag{13}$$

$$T(y,t) = ((1-a_3)e^{-\sqrt{a_2 y}} + a_3 e^{-\sqrt{a_1 y}})e^{i\omega t} \tag{14}$$

$$C(y,t) = e^{-\sqrt{a_1 y}} e^{i\omega t} \tag{15}$$

The skin friction at the plate in terms of amplitude and phase angle is given by

$$\tau = e^{i\omega t} \left.\frac{\partial u_0}{\partial y}\right|_{y=0} = \left.\frac{\partial u_0}{\partial y}\right|_{y=0} + N\cos(\omega t + \alpha) \tag{16}$$

$$N = N_j + iN_i \text{ , } \tan\alpha = \frac{N_i}{N_j}$$

The rate of heat transfer, i.e. heat flux (N_u) at the plate in terms of amplitude and phase is given by,

$$N_u = -[e^{i\omega t} \left.\frac{\partial T_0}{\partial y}\right|_{y=0}] = -[\left.\frac{\partial T_0}{\partial y}\right|_{y=0} + R_1\cos(\omega t + \delta)] \tag{17}$$

$$R_1 = R_j + iR_i \text{ , } \tan\delta = \frac{R_i}{R_j}$$

The mass transfer coefficient, i.e. the Sherwood number (S_h) at the plate in terms of amplitude and phase is given by

$$S_h = -[e^{i\omega t} \left.\frac{\partial C_0}{\partial y}\right|_{y=0} = -[\left.\frac{\partial C_0}{\partial y}\right|_{y=0} + Q_1\cos(\omega t + \phi)] \tag{18}$$

$$Q_1 = Q_j + iQ_i \ , \ \tan\phi = \frac{Q_i}{Q_j}$$

4. RESULTS AND DISCUSSION

In order to assess the influence of the dimensionless thermo physical parameters on the flow regime, calculations have been carried out on velocity, temperature, and concentration fields for various physical parameters The results are represented through graphs in figures 2 -9. Figure 2 displays the velocity profiles for various values of magnetic parameter. It is noticed that velocity decreases with an increase in magnetic parameter. This is due to the fact that the applied magnetic field is known as Lorentz force, acts as a retarding force that condenses the momentum boundary layer. This result is in good agreement with the results of Reddy et al. [21]. Figure 3 depicts the effects of visco-elastic parameter on velocity. From this figure, it is noticed that velocity decreases with an increase in visco-elastic parameter. Influence of the frequency of oscillations on velocity is presented in figure 4. From this figure, it is observed that velocity increases with an increase in frequency of oscillation parameter. Effect of radiation absorption parameter on velocity is presented in figure 5. From this figure, it is noticed that velocity decreases with an increase in radiation absorption parameter. Effect of heat absorption parameter on temperature is shown in figure 6, from which it is concluded that the temperature decreases as heat absorption parameter increases. Effect of heat generation parameter on temperature is shown in figure 7, from which it is observed that temperature increases as heat generation parameter increases. From figure 8, it is concluded that temperature boundary layer increases as radiation absorption parameter increases. Effect of chemical reaction parameter on concentration is presented in figure 9, which witnesses that concentration boundary layer decreases as the values of chemical reaction parameter increase.

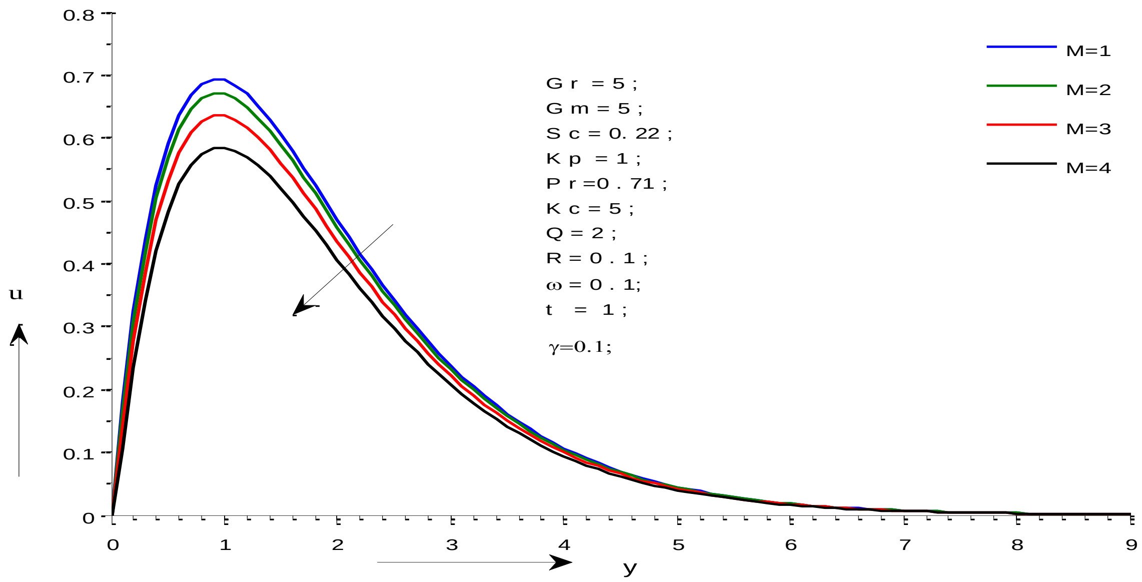

Fig.2: Effect of magnetic parameter (M) on velocity

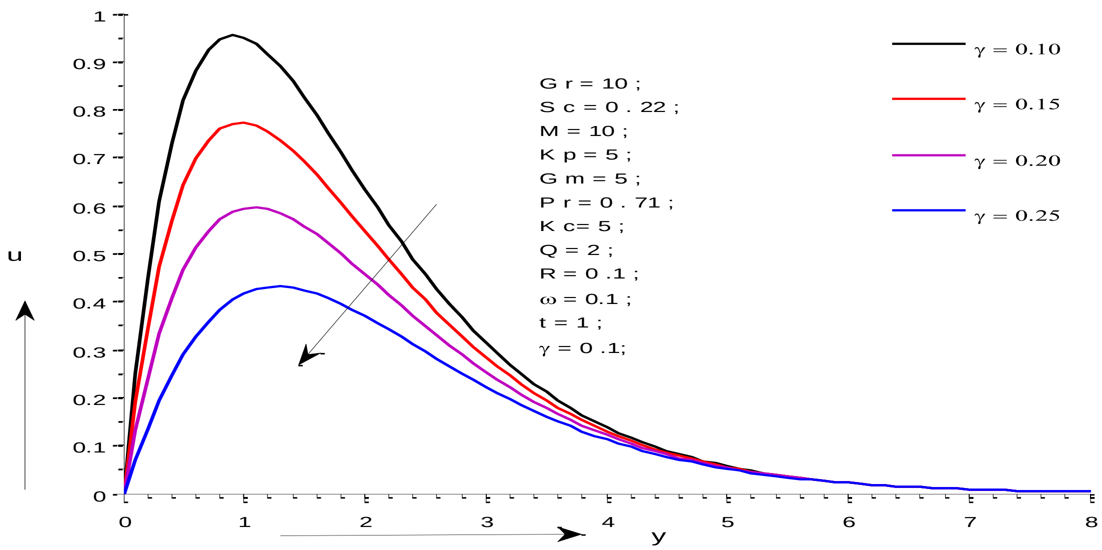

Fig. 3. Effect of Visco-elastic parameter γ on velocity

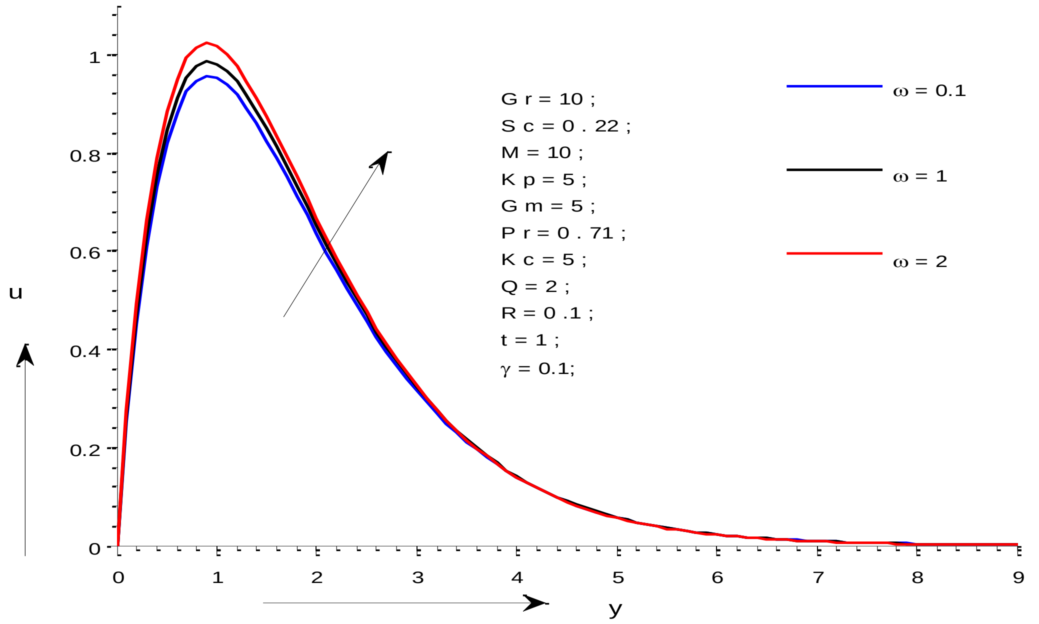

Fig.4. Effect of frequency of oscillations parameter (ω) on velocity

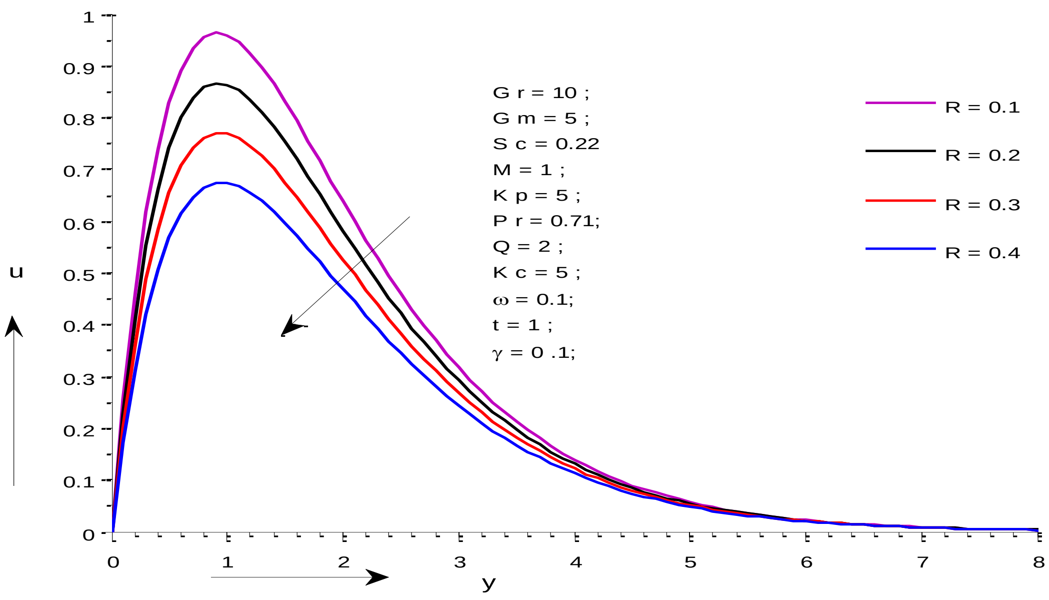

Fig.5. Effect of radiation absorption parameter (R) on velocity

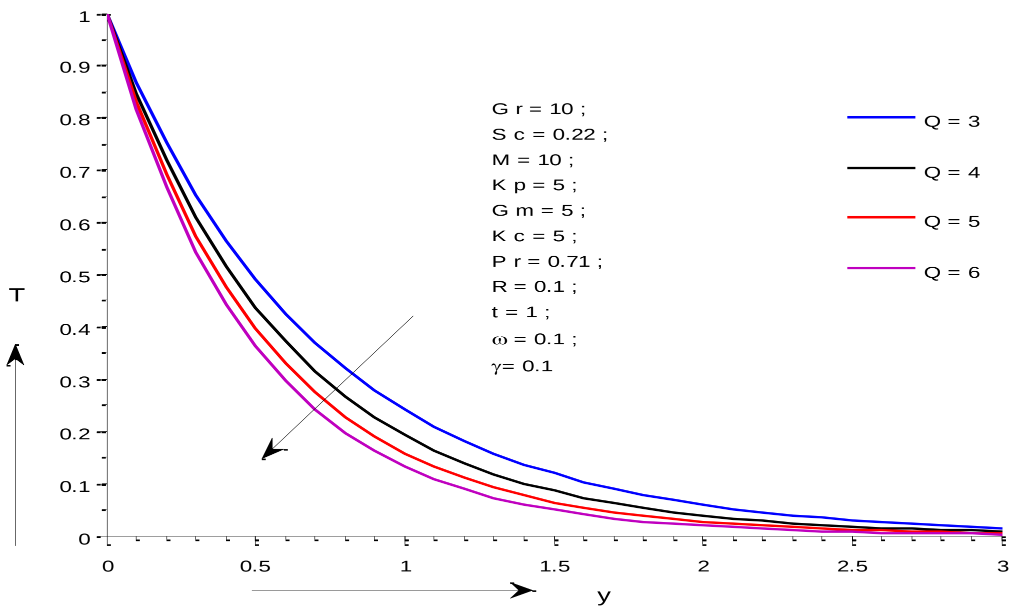

Fig.6. Effect of heat absorption parameter (Q) on temperature

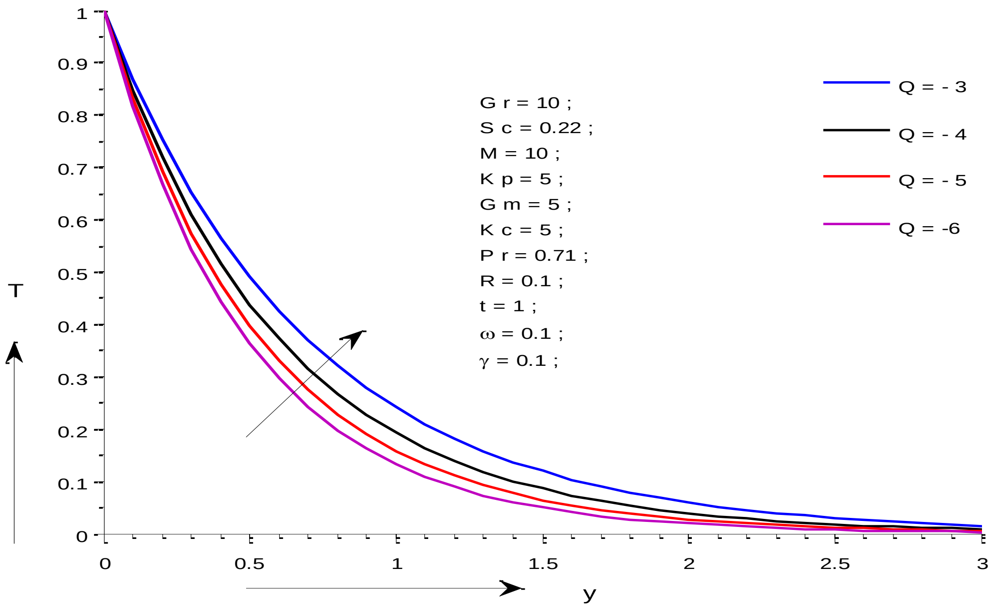

Fig.7. Effect of heat generation parameter (Q) on temperature

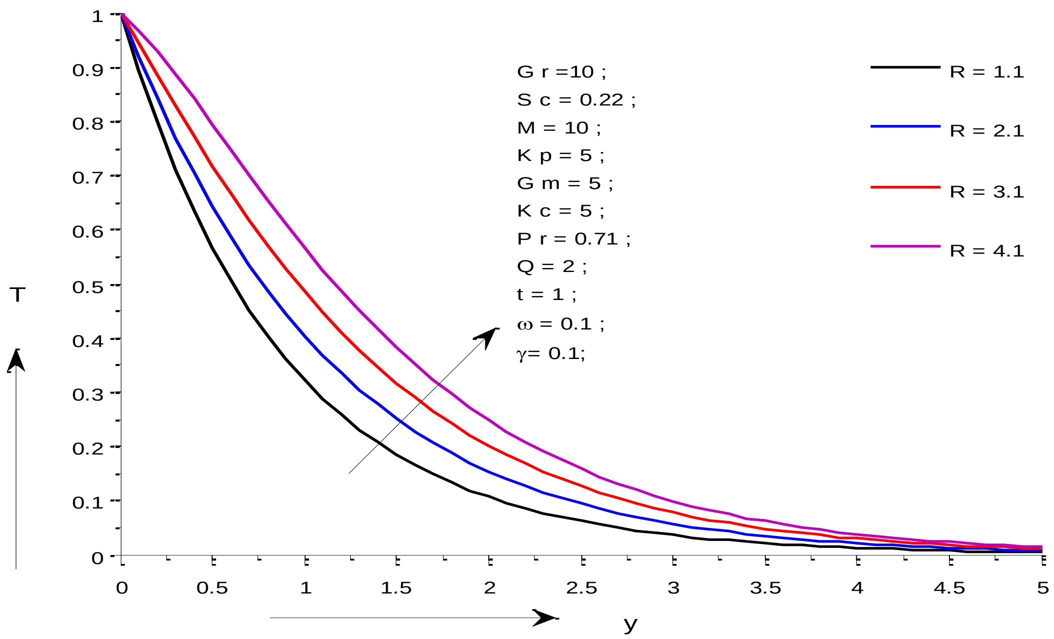

Fig.8. Effect of radiation absorption parameter (R) on temperature

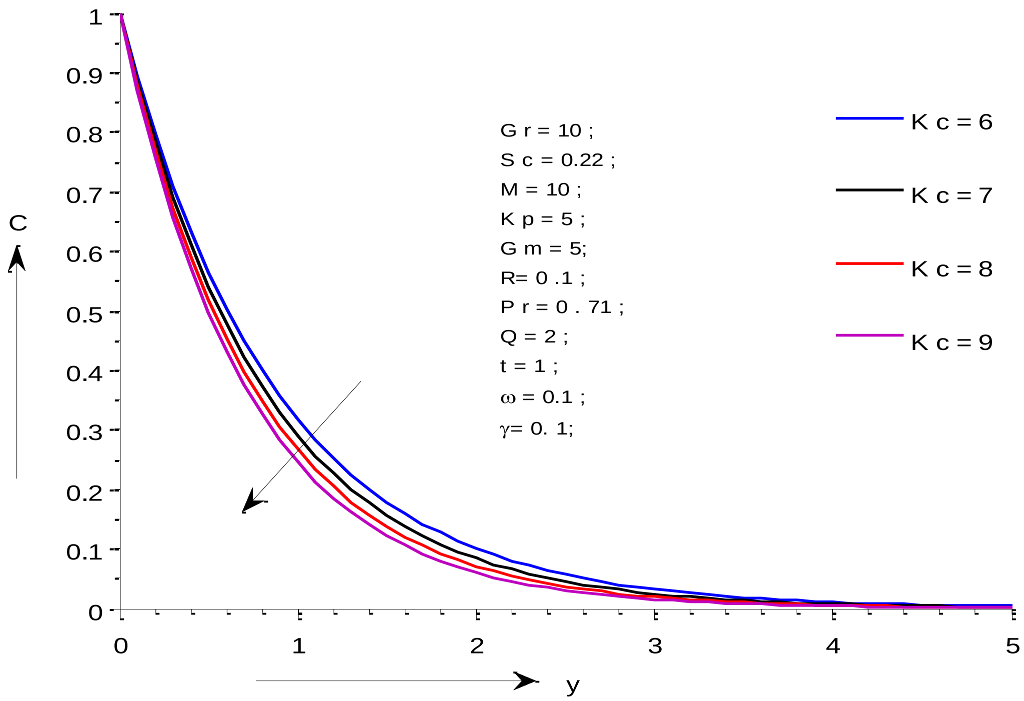

Fig.9. Effect of chemical reaction parameter (Kc) on concentration

Effects of various parameters on skin friction, rate of heat transfer and rate of mass transfer are presented in tables 1- 3. From table 1, it is noted that skin friction decreases due to an increase in magnetic parameter. From this table, it is also observed that the skin friction increases due to an increase in porosity parameter. From table 2, it is observed that skin friction increases for increasing values of radiation absorption parameter whereas Nusselt number decreases with the increasing values of radiation absorption parameter. Of course skin friction as well as Nusselt number increase for increasing values of Prandtl number and also heat absorption parameter but skin friction as well as Nusselt number decrease for increasing values of heat generation parameter. From table 3, it is found that skin friction decreases with increase values of chemical reaction parameter, but a reverse effect is noticed in the case of Sherwood number.

Table 1: Effects of Gr, Gm, M and Kp on skin friction coefficient

Gr	**Gm**	**M**	**Kp**	τ
10	5	2.0	1.0	13.4816
10	5	2.5	1.0	13.3871
10	5	3.0	1.0	13.2776
10	5	3.5	1.0	13.1591
10	5	1.0	0.2	8.8277
10	5	1.0	0.4	8.8304
10	5	1.0	0.6	8.8312
10	5	1.0	0.8	8.8317

Table 2: Effect of R, Pr and Q on skin friction coefficient and Nusselt number

R	**Q**	τ	**Nu**
1.1	2	87.7150	0.8439
2.1	2	151.7686	0.5267
3.1	2	220.8222	0.2095
4.1	2	289.8758	-0.1078
1.1	3	8.8328	1.4326
1.1	4	10.3228	1.6609
1.1	5	12.4940	1.8618
1.1	6	15.0108	2.0432
1.1	-3	10.2312	3.2321
1.1	-4	8.2442	2.3642
1.1	-5	6.3456	1.5432

Table 3: Effect of Sc and Kc on skin friction coefficient and Sherwood number

Kc	τ	Sh
6	88.7471	1.1499
7	73.9932	1.2420
8	16.9541	1.3276
9	11.4068	1.4081

CONCLUSIONS

An unsteady MHD free convection flow of a viscoelastic, incompressible, electrically conducting fluid past a vertical porous plate through a porous medium with time dependent oscillatory permeability and suction in presence of a uniform transverse magnetic field is investigated. Some of the notable conclusions are given below.

a) Application of magnetic field decelerates the fluid flow.
b) The heavier species with low conductivity reduces the flow within the boundary layer.
c) An increase in elasticity of the fluid leads to decrease the velocity which is an established result.

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