Radiation Effects on Unsteady MHD Flow of A Visco-Elastic Fluid Along Vertical Porous Surface With Heat Source and Chemical Reaction

Pavan , G. S. S. Raju

***Abstract*—An unsteady two dimensional magnetohydrodynamic flow of a visco-elastic incompressible fluid (Walters B_0 fluid model) along an infinite hot vertical porous surface bounded by porous medium with free stream as well as suction velocity in the presence of Thermal radiation, heat surface and chemical reaction has been investigated. The governing equations of motion, energy and concentration are solved by the successive perturbation technique. The variations in the fluid velocity, temperature and concentration are shown graphically where as numerical values of skin-friction; Nusselt number and Sherwood number are presented in tabular form.**

***Index Terms*— chemical reaction. Heat source, MHD flow, Porous medium, Walter's 'B'model.**

I. Introduction

The study of magneto hydrodynamics heat and mass transfer processes over a moving surface is of interest in engineering and geophysical applications such as geothermal reservoirs, thermal insulation, enhanced oil recovery, packed-bed catalytic reaction and cooling of nuclear reactors. Heat and mass transfer analysis with chemical reaction has a great interest to engineers and scientist because of its universal applications in many branches of sciences and engineering. In many chemical processes, a chemical processes, a chemical reaction occurs between a foreign mass and a fluid in which a plate is moving .These processes have numerous applications such as polymer production, manufacturing of ceramics or glassware and food processing. Besides, the magneto hydrodynamic laminar boundary layer behaviour over a stretching surface is a significant type of flow having considerable practical applications in chemical engineering, electrochemistry and polymer processingProcedure for Paper Submission

Flows through porous media are frequently used in filtering of gasses, liquid and drying of bulk materials. In electrochemical engineering, porous electrodes and permeable, semi permeable diaphragms are used to obtain improved current efficiencies. When fluid passes through a properly focus magnetic field, the magnetic process keeps minerals in the water rather than precipitated out. This is known as magnetic field conditioning .Further, magnetically treated fuel has a tendency to attract oxygen molecules when mixed with air in a combustion cylinder. This results a more efficient and complete combustion of the fuel generating more power from same amount of fuel.

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Several researchers have studied the two dimensional free convection, heat and mass transfer flow of an elastic-viscous fluid through porous medium. Sharma and Mathura [1] have studied the steady laminar free convections flow of an electrically conducting fluid along a porous hot vertical plate in the presence of heat source/sink. Dash and Rath [2] have studied the problem of laminar flow and heat transfer of an electrically conducting fluid between parallel porous plates by applying explicit finite difference scheme. Walters [3] has studied the Non-Newtonian effects in some elastic-viscous liquids whose behaviour at small rates of shear is characterized by general linear equation of state.

Soundalgekar and Takhar [4] analyzed the radiation effects on free convection flow past a semi-infinite vertical plate. Das et.al [5] studied the radiation effects on flow past an impulsively started vertical infinite plate. Hossain and Takhar [6] analyzed the effects of radiation on mixed boundary layer flow near a vertical plate with uniform surface temperature using Rosseland flux model. Unsteady two dimensional laminar flow of a viscous incompressible electrically conducting fluid in the vicinity of semi-infinite vertical porous moving plate was discussed by Kim [7].

Flow and heat transfer of an electrically conducting viscous-elastic fluid between two horizontal squeezing/stretching plates has been studied by Rath et al. [8]. Unsteady MHD free convection and mass transfer flow past an infinite heated porous vertical plate with time dependent suction was discussed by Cookey and Sigalo[9]. Free convection heat and mass transfer from a horizontal cylinder of elliptic cross section in micro polar fluids as been studied by Yang[10].Unsteady flow and heat transfer through an elastic-viscous liquid along an infinite hot vertical porous moving plate with variable free stream suction have been studied by Sharma and Pareek [11]. Toki and Tokis [12] studied exact solution for the unsteady free convection flows on a porous plate with time-dependent heating. MHD flow through a porous medium past a stretched vertical permeable effect of Hall current and chemical reaction on MHD flow along an exponentially porous flat plate with internal heat absorption/generation was studied by Rath.et al.[13]. Sharma and Sharma[14] have studied the unsteady two-dimensional flow and heat transfer through an elastic-viscous liquid along an infinite heat vertical porous surface bounded by porous medium.
The main objective of the present investigation is to study the

combined effect of transverse magnetic field, Thermal radiation, heat source and chemical reaction in the presence of oscillatory suction and free streem velocity on the flow , heat and mass transfer phenomena of an electrically conducting visco-elastic fluid.

II. MATH

An unsteady two dimensional MHD flow past a vertical infinite surface through a porous medium of a visco-elastic fluid (Walters fluid (model B')) has been considered. The time dependent fluctuating suction velocity has been introduced with an oscillatory free stream velocity. A uniform transverse magnetic field B_0 is applied normal to the direction of the fluid flow. The x^*- axis is taken along the surface in upward direction i.e opposite to the direction of gravity and y^* - axis is taken normal to the surface.

The equations of continuity, motion, energy and diffusion for flow of a viscous-elastic fluid through porous medium bounded by an infinite, hot vertical porous surface with oscillatory suction velocity are given by

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

$$\rho\left(\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*}\right) = \rho \frac{\partial U^*}{\partial t^*} + \mu \frac{\partial^2 u^*}{\partial y^{*2}} + -K_0^*\left(\frac{\partial^3 u^*}{\partial t^* \partial y^{*2}} + v^* \frac{\partial^3 u^*}{\partial y^{*3}}\right) + \frac{\mu}{K_p^*}(U^* - u^*) + \sigma B_0^2(U^* - u^*) +$$
$$g\beta\rho(T^* - T_\infty) + g\beta^*\rho(C^* - C_\infty),$$

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} + S^*(T^* - T_\infty) - \frac{1}{\rho C_p}\frac{\partial q^*}{\partial y^*}$$

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C}{\partial y^{*2}} - K_c^*(C^* - C_\infty)$$

Where u^*,v^* are the velocity component along x^* and y^* direction respectively, ρ the density of the fluid, g the acceleration due to gravity, μ the dynamic viscosity, K_p^* the permeability parameter, K_O^* the non-Newtonian parameter, K the termal conductivity of the fluid, C_P the specific heat of fluid at constant pressure, K_C^* the chemical reaction parameter, S^* the heat source parameter, T^* the temperature of the fluid, β and $β^*$ are the volumetric coefficient of thermal and concentration of the fluid, D the mass diffusion co-efficient and t^* the time.

The boundary conditions are:

$$y^* = 0 : u^* = 0, T^* = T_w, C^* = C_w$$

$$y^* \to \infty : u^* \to U^*(t^*), T^* \to T_\infty, C^* \to C_\infty$$

Where T_w is the surface temperature, $U^*(t^*)$ the free stream velocity, T_∞ is the free stream temperature, C_w is the concentration at the wall and C∞ is the concentration of the fluid far away from the wall.

From equation of continuity (1) it is clear that the suction velocity normal to the plate v* is either a constant or a function of time. Hence, it is assumed that v* is in the form of

$$v^* = -v_0(1 + \varepsilon e^{-n^* t^*})$$

Where ω^* is the frequency of vibrations, ε is the small parameter i.e (0<ε<1) and ϑ_0 is the postitive suction velocity. The negative sign indicates that the suction is towards the plate.

To reduce the governing equations into non dimensional form, let us consider the following transformations.

$$\frac{y^* v_0}{\upsilon}, t = \frac{t^* v_0^2}{4\upsilon}, u = \frac{u^*}{U}, \omega = \frac{4\upsilon\omega^*}{v_0^2}, U(t) = \frac{U^*(t^*)}{U}, T = \frac{T^* - T_\infty}{T_w - T_\infty}, P_r = \frac{\mu C_p}{K}, K_p = \frac{K^* v_0^2}{\upsilon^2},$$

$$K_0 = \frac{K^* v_0^2}{\rho\upsilon^2}, K_c = \frac{K_c^*\upsilon}{v_0^2}, S_c = \frac{\upsilon}{D}, M = \frac{B_0}{v_0}\sqrt{\frac{\sigma}{\upsilon\rho}}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, S = \frac{S^*\upsilon}{v_0^2}, G_r = \frac{\upsilon g\beta(T_w - T_\infty)}{U v_0^2}$$

Where G_r, G_c, P_r , S_c, K_p, K_c, M and K_0 are the Grashoff number for heat transfer, the Grashoff number for mass transfer, the Prandlt number, Schmidt number, the porosity parameter, the chemical reaction parameter, the magnetic parameter and the non-dimensional non-Newtonian parameter.

Using the transformation (7) equation (6) reduces to:

$$v^* = -v_o(1 + \varepsilon e^{-nt})$$

Where ω is the frequency of the suction velocity.

In view of equation (7), equation (2)-(4) become

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1 + \varepsilon e^{-nt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + M(1 + \varepsilon e^{-nt}) - K_0\left\{\frac{1}{4}\frac{\partial^3 u}{\partial t \partial y^2} - (1 + \varepsilon e^{-nt})\frac{\partial^3 u}{\partial y^3}\right\} - \frac{1}{4}\varepsilon n e^{-nt}$$
$$+ G_r\theta + G_c C$$

$$\frac{P_r}{4}\frac{\partial T}{\partial t} - P_r(1 + \varepsilon e^{-nt})\frac{\partial \theta}{\partial y} = \frac{\partial^2 \theta}{\partial y^2} + (S\theta P_r - RP_r\theta)$$

$$\frac{S_c}{4}\frac{\partial C}{\partial t} - S_c(1 + \varepsilon e^{-nt})\frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} - K_c S_c C$$

Where N = M+$\frac{1}{K_P}$(say)

The corresponding boundary conditions in non-dimensional form are:

$$y = 0 : u = 0, T = 1, C = 1$$
$$y \to \infty : u \to U(t), T \to 0, C \to 0$$

In the neighbourhood of the surface it is assumed that

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{-nt}$$
$$\theta(y,t) = \theta_0(y) + \varepsilon\theta_1(y)e^{-nt}$$
$$C(y,t) = C_0(y) + \varepsilon C_1(y)e^{-nt}$$

And for the free stream $U(t) = 1 + \varepsilon e^{-nt}$

Now, substituting (13) in the equations (9)-(11) and equating the coefficients of like power of ε we get the following zeroth-order equations:

$$K_0 u_0''' + u_0'' + u_0' - Nu_0 = G_r\theta_0 - G_c C_0 - N$$

$$\theta_0^{''} + P_r\theta_0^{'} + P_r S_1\theta_0 = 0$$

$$C_0^{''} + S_c C_0^{'} - K_0 S_c C_0 = 0$$

Where $S_1 = S - R$

First order equations are:

$$K_0 u_1^{'''} + n_1 u_1^{''} + u_1^{'} - N_1 u_1 = -G_r\theta_1 - G_C C_1 - K_0 u_0^{'''} - u_0^{'} - N$$

$$\theta_1^{''} + P_r\theta_1^{'} + P_r S_2\theta_1 = -P_r\theta_0^{'}$$

$$C_1^{''} + S_C C_1^{'} - S_C S_3 C_1 = -S_C C_0^{'}$$

Where

$$n_1 = (1 + \frac{K_0 n}{4}), N_1 = (N - \frac{n}{4}), S_2 = (S_1 + \frac{n}{4}), S_3 = (K_C - \frac{n}{4})$$

Where prime denotes the differentiation with respect to y

The corresponding boundary conditions are changed to

$$y = 0 : u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0$$

$$y \to \infty : u_0 \to 1, u_1 \to 1, T_0 \to 0, T_1 \to 0, C_0 \to 0, C_1 \to 0$$

Solving equations (15), (16), (18), (19) using the boundary conditions (20) , we get

$$\theta_0 = e^{-m_1 y}$$

$$C_0 = e^{-m_2 y}$$

$$\theta_1 = A_1(e^{-m_1 y} - e^{-m_3 y})$$

$$C_1 = A_2(e^{-m_2 y} - e^{-m_4 y})$$

But equation (14) and (17) are of third order equation when $K_0 \neq 0$ and these equations reduce to second order equation when $K_0 = 0$ (for Newtonian fluid).Hence the presence of non-Newtonian parameter increases the order of the differential equation. As the non-Newtonian parameter (K_0) is very small for incompressible fluid (Walters) therefore u_0 and u_1 Can be expanded in powers of K_0 which are given by

$$u_0(y) = u_{00}(y) + K_0 u_{01}(y) + o(k^2)$$

$$u_1(y) = u_{10}(y) + K_0 u_{11}(y) + o(k^2)$$

Introducing (25) into the equations (14) and (17) and equating like powers of K_0 in both sides we get

$$u_{00}^{''} + u_{00}^{'} - N u_{00} = -G_r\theta_0 - G_C C_0 - N$$

$$u_{10}^{''} + u_{10}^{'} - N_1 u_{10} = -G_r\theta_1 - G_C C_1 - u_{00}^{'} - N$$

$$u_{10}^{''} + u_{10}^{'} - N_1 u_{10} = -G_r\theta_1 - G_C C_1 - u_{00}^{'} - N$$

$$u_{01}^{''} + u_{01}^{'} - N u_{01} = -u_{00}$$

$$u_{11}^{''} + u_{11}^{'} - N_1 u_{11} = -u_{10}^{'''} - \frac{n}{4}u_{10}^{''} - u_{00}^{'''} - u$$

The boundary conditions are

$$y = 0 : u_{00} = 0, u_{01} = 0, u_{10} = 0, u_{11} = 0$$

$$y \to \infty : u_{00} \to 1, u_{01} \to 0, u_{10} \to 1, u_{11} \to 0$$

Solving equations (26)-(29) using the boundary condition (30), we get

$$u_{00} = A_5 e^{-m_5 y} - A_4 e^{-m_2 y} - A_3 e^{-m_1 y} + 1$$

$$u_{01} = A_9 e^{-m_5 y} + A_8 y e^{-m_5 y} - A_7 e^{-m_2 y} - A_6 e^{-m_1 y}$$

$$u_{10} = A_{19} e^{-m_6 y} + A_{18} e^{-m_1 y} + A_{17} e^{-m_2 y} + A_{15} e^{-m_3 y} + A_{13} e^{-m_4 y} + A_{12} e^{-m_5 y} + 1$$

$$u_{11} = A_{46} e^{-m_6 y} + A_{45} y e^{-m_6 y} + A_{42} e^{-m_5 y} + A_{35} e^{-m_4 y} + A_{32} e^{-m_3 y} + A_{29} e^{-m_2 y} + A_{24} e^{-m_1 y}$$

Hence the velocity u(y, t) is given by

$$u(y,t) = A_5 e^{-m_5 y} - A_4 e^{-m_2 y} - A_3 e^{-m_1 y} + 1 + K_0\left\{A_9 e^{-m_5 y} + A_8 y e^{-m_5 y} - A_7 e^{-m_2 y} - A_6 e^{-m_1 y}\right\}$$
$$+ \varepsilon[A_{19} e^{-m_6 y} + A_{18} e^{-m_1 y} + A_{17} e^{-m_2 y} + A_{15} e^{-m_3 y} + A_{13} e^{-m_4 y} + A_{12} e^{-m_5 y} + 1$$
$$+ K_0\left\{A_{46} e^{-m_6 y} + A_{45} y e^{-m_6 y} + A_{42} e^{-m_5 y} + A_{35} e^{-m_4 y} + A_{32} e^{-m_3 y} + A_{29} e^{-m_2 y} + A_{24} e^{-m_1 y}\right\}]$$

Skin friction

$$S_f = \left\{\frac{\partial u}{\partial y} - K_0\left[\frac{1}{4}\frac{\partial^2 u}{\partial y \partial t} - \left(1 + \varepsilon e^{-nt}\right)\frac{\partial^2 u}{\partial y^2}\right]\right\}_{y=0}$$

Nusselt Number (N_u)

$$N_u = -\left.\frac{\partial \theta}{\partial y}\right]_{y=0} = \left[m_1 - \varepsilon e^{-nt} A_1(m_3 - m_1)\right]$$

Sherwood Number (S_h)

$$S_h = -\left.\frac{\partial C}{\partial y}\right]_{y=0} = \left[m_2 - \varepsilon e^{-nt} A_2(m_4 - m_2)\right]$$

III.RESULTS AND DISSCUSSIONS

The non linear coupled equations (15), (16), (18), (19) and (26)-(29) subject to boundary conditions (20) and (30), which illustrate an unsteady two dimensional magnetohydrodynamic flow of a visco-elastic incompressible fluid along an infinite hot vertical porous surface bounded by porous medium with free stream as well as suction velocity in the presence of Thermal radiation, heat surface and chemical reaction has been investigated. The governing equations of motion, energy and concentration are solved by the successive perturbation technique. The variations in the fluid velocity, temperature and concentration are shown graphically where as numerical values of skin-friction; Nusselt number and Sherwood number are presented in tabular form.

The velocity profile for the different values of Prandtl number (Pr), magnetic parameter (M), Grashoff number for heat transfer (Gr), Grashoff number for mass transfer (Gc), Schmidt number (Sc), porosity parameter (Kp), radiation parameter (R), heat source parameter (S) and time (t) are shown in the figures 1-9 respectively. From these figures it is observed that the velocity increases as Gr, Kp, Gc and S increases, while velocity decreases as M, Pr, R, t and Sc increases.

Figures 10-12 show that the temperature profiles for different values of Prandtl number (Pr), radiation parameter (R) and heat source parameter (S). It is noticed that temperature increases as S increases, while temperature decreases as Pr and R increase.

The concentration profiles for different values of Schmidt number (Sc) and chemical reaction parameter (Kc) are shown in figures 13 and 14 respectively. It is noticed that the concentration decreases as Sc and Kc increase.

From table 1 it is noticed that an increasing in Grashoff number for mass transfer (Gc), Prandtl number (Pr) and heat source parameter (S) results an increase in Skin friction, while it decreases with an increase in magnetic parameter (M), Grashoff number for heat transfer (G_r), elastic parameter (K_0), radiation parameter (R), chemical reaction parameter (Kc) and Schmidt number (Sc) respectively.

Table 2 shows the effects of Prandtl number (Pr), radiation parameter (R), heat source parameter (S), n and time (t) numerically on rate of heat transfer (Nu). It is noticed that the rate of heat transfer increases with increasing values of Pr and R. While it decreases with increasing values of S, n and time (t) respectively.

Table 3 shows the effects of Schmidt number (Sc), chemical reaction parameter (Kc), n and time (t) on rate of mass transfer (Sh) numerically. It is observed that the rate of mass transfer increases with increasing values of Sc and Kc, while it decreases in the case of n and t respectively.

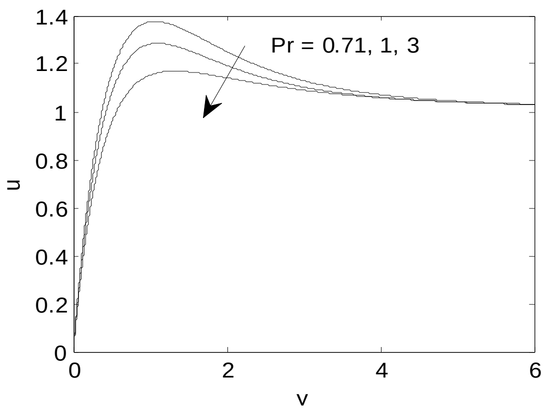

Fig.1velocity profile for different values of P_r

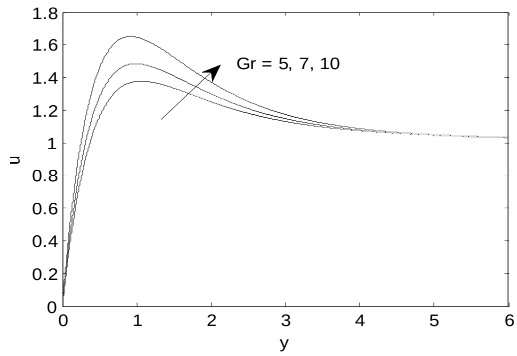

Fig.2 velocity profile for different values of G_r

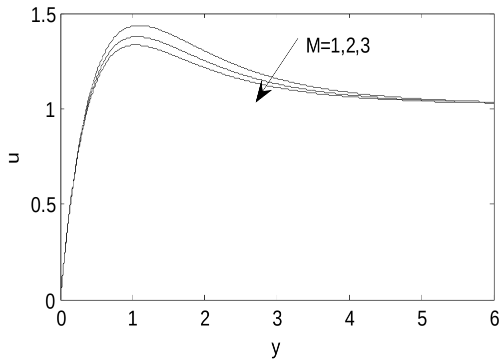

Fig.3 velocity profile for different values of M

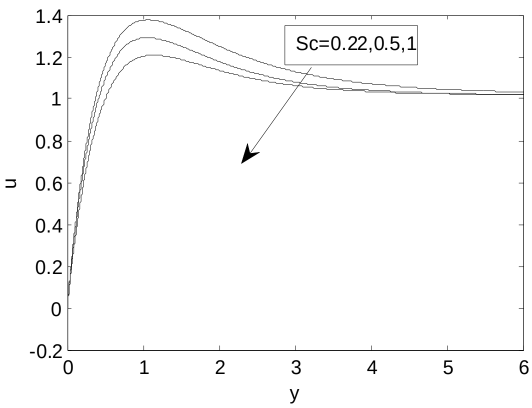

Fig.4 velocity profile for different values of S_c

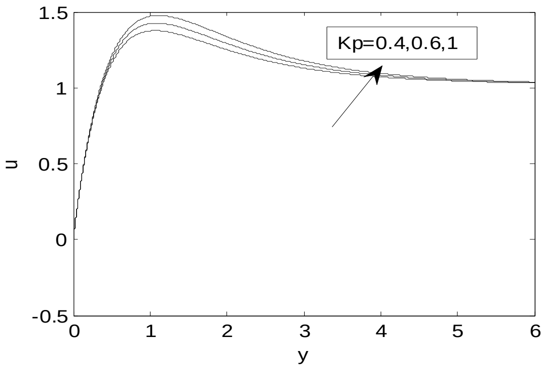

Fig.5 velocity profile for different values of K_p

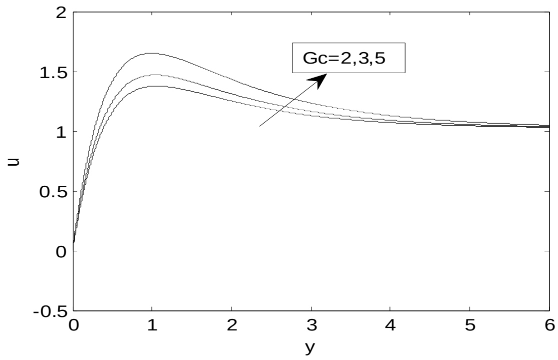

Fig.6 velocity profile for different values of G_c

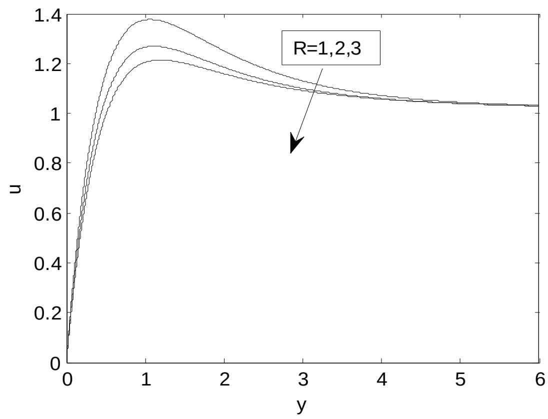

Fig.7 velocity profile for different values of R

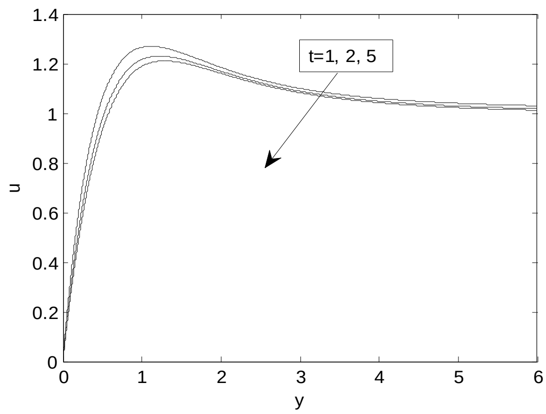

Fig.8 velocity profile for different values of t

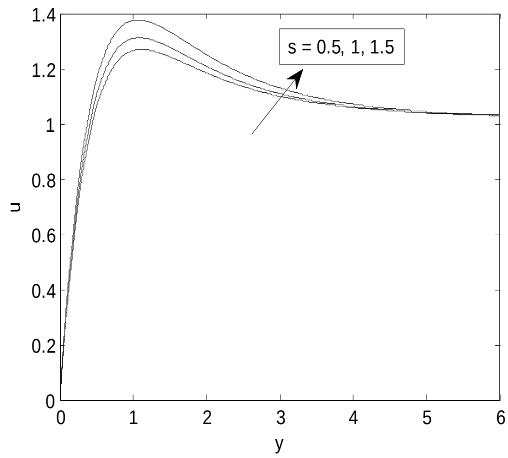

Fig.9 velocity profile for different values of S

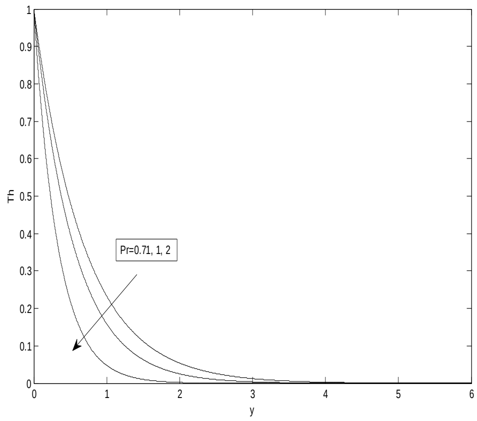

Fig.10 velocity profile for different values of P_r

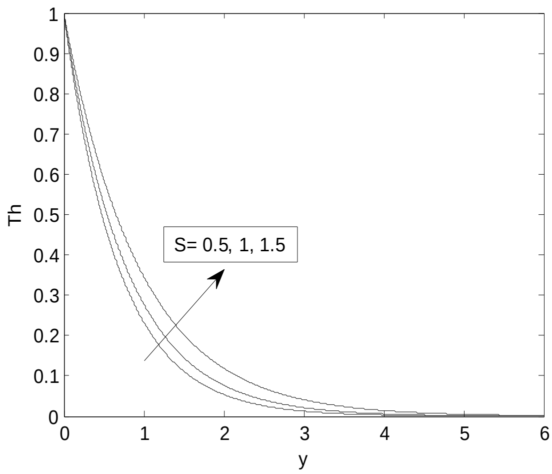

Fig.11 Temperature profile for different values of S

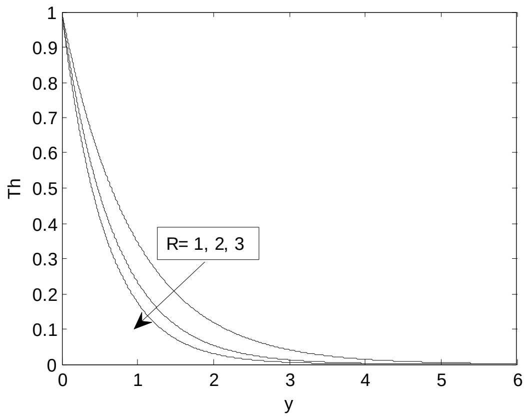

Fig.12Temperature profile for different values of R

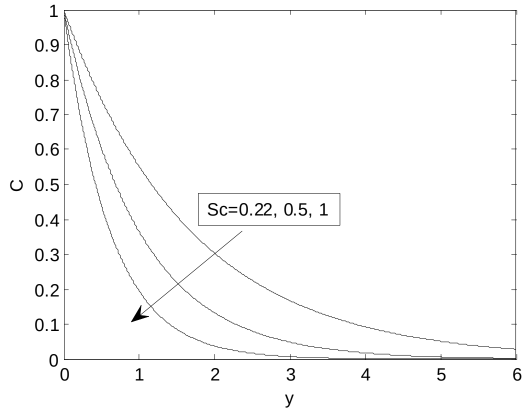

Fig.13 Temperature profile for different values of S_c

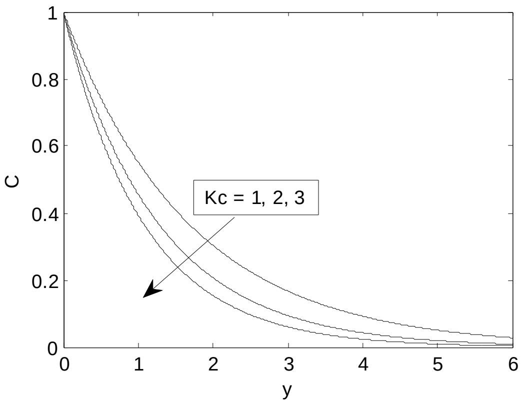

Fig.14 Temperature profile for different values of K_c

Table I: Skin friction (S_f)

Pr	M	Gr	Gc	Sc	S	R	K_0	Kc	S_f
0.71	1.00	5.00	2.00	0.22	0.50	2.00	0.22	1.00	**1.15**
5.00	1.00	5.00	2.00	0.22	0.50	2.00	0.22	1.00	4.55
0.71	**5.00**	5.00	2.00	0.22	0.50	2.00	0.22	1.00	-2.50
0.71	1.00	**10.00**	2.00	0.22	0.50	2.00	0.22	1.00	1.08
0.71	1.00	5.00	**5.00**	0.22	0.50	2.00	0.22	1.00	1.46
0.71	1.00	5.00	2.00	**0.50**	0.50	2.00	0.22	1.00	0.98
0.71	1.00	5.00	2.00	0.22	**1.00**	2.00	0.22	1.00	1.25
0.71	1.00	5.00	2.00	0.22	0.50	**3.00**	0.22	1.00	0.99
0.71	1.00	5.00	2.00	0.22	0.50	2.00	**0.50**	1.00	-16.27
0.71	1.00	5.00	2.00	0.22	0.50	2.00	0.22	**3.00**	1.01

Table II: Nusselt number (Nu)

Sc	Kc	n	t	Sh
0.22	1.00	0.50	1.00	**0.60**
1.00	1.00	0.50	1.00	1.67
0.22	**3.00**	0.50	1.00	0.94
0.22	1.00	**3.00**	1.00	0.59
0.22	1.00	0.50	**5.00**	0.59

TableIII:Sherwood number(S_h)

Pr	S	R	n	t	Nu
0.71	0.50	2.00	0.50	1.00	**1.48**
7.00	0.50	2.00	0.50	1.00	8.68
0.71	**1.00**	2.00	0.50	1.00	1.30
0.71	0.50	**3.00**	0.50	1.00	1.76
0.71	0.50	2.00	**3.00**	1.00	1.45
0.71	0.50	2.00	0.50	**5.00**	1.45

IV.CONCLUSION

The Mathematical analysis has been presented on unsteady two dimensional magnetohydrodynamic flow of a visco-elastic incompressible fluid along an infinite hot vertical porous surface bounded by porous medium with free stream as well as suction velocity in the presence of Thermal radiation, heat surface and chemical reaction has been investigated. The governing equations of motion, energy and concentration are solved by the successive perturbation technique. The variations in the fluid velocity, temperature and concentration profiles to observe the effects of Prandtl number (Pr), magnetic parameter (M), Grashoff number for heat transfer (Gr), Grashoff number for mass transfer (Gc), chemical reaction parameter (Kc), Schmidt number (Sc), porosity parameter (Kp), radiation parameter (R), heat source parameter (S) and time (t). Also the numerical results are presented for skin friction, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number through tables. From the steady the following conclusions are drawn:

- The velocity profile increases with increasing Gr, Kp, Gc, and S. While it decreases with increasing M, R, t, Pr and Sc.
- The temperature decreases with increasing the values of Pr and R, while it increases with increasing S.
- The concentration decreases with increasing Sc and Kc.
- Velocity on skin friction increases with increasing Pr, Gc and S, while it decreases with increasing M, Gr, Sc, R, Ko and Kc.
- The rate of heat transfer increases with increasing Pr and R. While it decreases with increasing S, n and time (t).
- The rate of mass transfer in terms of Sherwood number increases with increasing Scand Kc. While it decreases with increasing n and time (t).

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