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Archives of Applied Science Research, 2013, 5 (5):169-181
(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Effect of chemical reaction on unsteady hydromagnetic mass transfer flow past a semi-infinite vertical porous moving plate with time dependent suction and radiative heat source

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ABSTRACT

The present study considers the chemical reaction effect on mass transfer of an unsteady flow past a semi infinite vertical porous moving plate with time dependent suction and radiative heat source in presence of transverse magnetic field. The novelty of this study is to analyze the effect of chemical reaction on mass transfer of fluid flow in the porous plate. The analytical solutions for velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number are obtained by solving the governing equations of the flow field using multi parameters perturbation technique. The effects of the material parameters on the temperature, velocity and concentration profiles are discussed quantitatively.

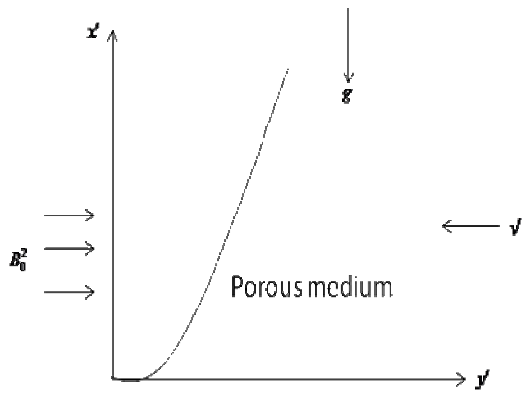
Key words: Chemical reaction, hydromagnetic flow, mass transfer, porous plate, time dependent suction**.**

INTRODUCTION

Flow through porous medium past infinite vertical plate is common in nature and has many applications in engineering and science. The study of heat and mass transfer with chemical reaction is of great importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. A chemical reaction is said to be first – order if the rate of reaction is directly proportional to the concentration itself. In many chemical processes a reaction occurs between a foreign mass and a fluid in which a plate is moving. These processes are found in many industrial applications such as food processing, manufacturing of chemicals and polymer production. Recently, many researchers have given attention to the effects of transversely applied magnetic field and thermal perturbation on the flow of electrically conducting viscous fluids. Various properties associated with the interplay of magnetic fields and thermal perturbation in porous medium past vertical plate find useful applications in astrophysics, geophysical fluid dynamics and engineering.

Several researchers have analyzed the chemical reaction effect on mass & heat transfer of hydromagnetic flow. Chambre and Young have studied the flow of chemically reacting species at the boundary [1]. Recent developments of heat and Mass Transfer in hydromagnetic flows are discussed by P.C.Ram [2]. Das et al. have analyzed effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction [3]. Rapits has investigated the radiation and free convection flow through porous medium [4].Hussain & Takhar have discussed the radiation effects on mixed convection along an isothermal plate [5]. Raptis and Peridikis have studied the above kind of flow through a moving plate [6]. Kim has studied the unsteady MHD convective heat transfer past a semi infinite vertical porous moving plate with variable suction [7]. Muthukumaraswamy and Ganesan have solved the problem of the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate [8]. Chamkha et al. studied the effects of radiation on free convection flow past a semi infinite vertical plate with mass transfer [9]. Cookey et al. have a work on the influence of viscous dissipation and radiation on unsteady MHD free-convection flow past an infinite heated vertical plate in a porous medium with time dependent suction[10]. Devi and Kandasamy studied the problem of effects of chemical reaction, heat and mass transfer on non-linear MHD flow over an accelerating surface with heat source and thermal stratification in the presence of suction or injection [11].Prakash and Ogulu in their study have discussed unsteady two dimensional flow of a radiating and chemically reacting MHD fluid time-dependent suction [12]. The problem of the radiation effects on flow past an impulsively started infinite vertical plate with variable temperature has been analyzed by Muthucumarswamy and Ganesan [13] Molla and Hossain have discussed the chemical reaction, heat and mass diffusion effect in natural convection flow [14]. Prasad et al. used an implicit finite difference scheme of Crank-Nicolson type to solve the problem of radiation and mass transfer effects on two dimensional flow past an impulsively started infinite vertical plate [15]. Prasad and Reddy analyzed radiation and mass transfer effects on an unsteady permeable moving plate embedded in a porous medium with viscous dissipation [16]. Das et al. have discussed the effects of mass transfer on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source [17]. Hayat et al. studied unsteady flow with heat and mass transfer of a third grade fluid over a stretching surface in the presence of chemical reaction [18]. Rao and Shivaiah have discussed on a similar topic using implicit finite difference method [19]. K.Das analyzed the chemical reaction effect on micropolar fluid [20]. Mishra et al. studied the mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source [21].

The objective of the present study is to analyze the chemical reaction effect on unsteady hydromagnetic mass transfer flow past a semi-infinite vertical porous moving plate with time varying suction and radiative heat source.



The Physical Model and the Co-ordinate System of the Problem

5. Formulation of the Problem:-

We consider the unsteady MHD flow of an electrically conducting fluid past a semi-infinite vertical porous moving plate with time dependent suction and radiative heat source. At time $t' = 0$, the plate is maintained at a temperature T'_w which initiates radiative heat transfer. A constant magnetic field B_0^2 is maintained in the y' direction. There is a chemical reaction between the diffusing species and the fluid. The plate moves uniformly along the '+ve' x' direction with velocity U_0. Under Boussinesq's approximation the flow is governed by the following equations.

Continuity Equation

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

Momentum equation

$$\frac{\partial u'}{\partial t'}+v'\frac{\partial u'}{\partial y'}=g\beta(T'-T'_\infty)+g\beta(C-C_\infty)+v\frac{\partial^2 u'}{\partial y'^2}-\frac{\sigma B_0^2}{\rho}u'-\frac{\upsilon u'}{K^*} \quad (2)$$

Energy Equation

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\alpha\frac{\partial^2 T'}{\partial y'^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'}+\frac{\upsilon}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \quad (3)$$

Concentration Equation

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}-K_r'^2(C'-C'_\infty) \quad (4)$$

The boundary conditions are

$$u'=U_0,\ T'=T_w'+\varepsilon e^{n't'}\left(T_w'-T_\infty'\right), C'=C_w'+\varepsilon e^{n't'}\left(C_w'-C_\infty's\right)\ \text{at}\ y'=0 \quad (5a)$$

$$u'\to U^*(t'),\ T\to T_\infty,\ C\to C_\infty\ \text{at}\ y'\to\infty \quad (5b)$$

Assuming Rossland approximation which leads to the radiative heat flux q_r is given by

$$q_r=-\frac{4\sigma_s}{3k_e}\frac{\partial T'^4}{\partial y'} \quad (6)$$

where, $\sigma_s \to$ Stefan-Boltzmann constant and k_e is the mean absorption coefficient. If temperature differences within the flow are sufficiently small, equation (6) can be linearized by expanding T'^4 into the Taylor series about T'_∞, which after neglecting higher order terms takes the form:

$$T'^4 \cong 4T_\infty'^3 T-3T_\infty'^4 \quad (7)$$

Considering equation (6) and equation (7), equation (3) reduces to

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\alpha\frac{\partial^2 T'}{\partial y^2}+\frac{16\sigma_s T_\infty'^2}{3k_e\rho C_\rho}\frac{\partial^2 T'}{\partial y'^2}+\frac{\upsilon}{C_\rho}\left(\frac{\partial u'}{\partial y'}\right)^2 \quad (8)$$

From equation (1) it is clear that v' is a constant or a function of time only. We assume that

$$v'=-V_0\left(1+\varepsilon e^{n't'}\right) \quad (9)$$

Such that, $V_0>1$ and $\varepsilon<<1$ and the negative sign indicates that the suction velocity is towards the plate. Introducing the non-dimensional quantities

$$\left.\begin{aligned}
&y=\frac{y'V_0}{\upsilon},\ t=\frac{t'V_0^2}{\upsilon},\ u=\frac{u'}{U_0},\ V=\frac{\upsilon}{U_0},\ U(t)=\frac{U^*(t')}{U_0}\\
&n=\frac{n'\upsilon}{V_0^2},\ G_r=\frac{\upsilon g\beta(T_w-T_\infty)}{U_0V_0^2},\ G_c=\frac{\upsilon g\beta^*(C_w-C_\infty)}{U_0V_0^2}\\
&M=\frac{\sigma B_0^2\upsilon}{\rho V_0^2},\ R=\frac{16\sigma_s T_\infty{}^2}{3k_e k},\ \mathrm{T}'=\frac{T-T_\infty}{T_w-T_\infty},\ \mathrm{C}'=\frac{C-C_\infty}{C_w-C_\infty}\\
&P_r=\frac{\upsilon}{\alpha},\ S_c=\frac{\upsilon}{D},\ E_c=\frac{U_0^2}{C_p(T_w-T_\infty)}\\
&K_p=\frac{K^*V_0^2}{\upsilon^2},\ K_r^2=\frac{K_r'^2\upsilon}{V_0^2}
\end{aligned}\right\}\tag{10}$$

Now, the equations (2), (8), and (4) reduce to the following non-dimensional form

$$\frac{\partial u}{\partial t}-\left(1+\varepsilon e^{nt}\right)\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}+G_rT+G_cC-\left(M+\frac{1}{K_p}\right)u\tag{11}$$

$$\frac{\partial T}{\partial t}-\left(1+\varepsilon e^{nt}\right)\frac{\partial T}{\partial y}=\frac{1}{P_r}\left(1+\frac{4}{3R}\right)\frac{\partial^2 T}{\partial y^2}+E_C\left(\frac{\partial u}{\partial y}\right)^2\tag{12}$$

$$\frac{\partial C}{\partial t}-\left(1+\varepsilon e^{nt}\right)\frac{\partial C}{\partial y}=\frac{1}{S_C}\frac{\partial^2 C}{\partial y^2}-K_r{}^2\left(C-C_\infty\right)\tag{13}$$

The corresponding boundary conditions are:

$$\left.\begin{aligned}
&u=1,\ \mathrm{T}=1+\varepsilon e^{nt},\ C=1+\varepsilon e^{nt}\ \text{ at } y=0\\
&u\to U(t),\ \mathrm{T}\to 0,\ C\to 0 \text{ at } y\to\infty
\end{aligned}\right\}\tag{14}$$

6. Method of Solution:-

The problems posed in equation (11), (12) & (13) subject to the boundary conditions presented in equation (14) are highly non-linear equations and generally numerical solution is obtained by the finite difference scheme. However, analytical solutions to above equations could be possible. Since ε is small we can advance by adopting regular perturbation expansion of the form $u(y,t)=u_0(y)+\varepsilon u_1(y)e^{nt}$

$$\left.\begin{aligned}
&T(y,t)=T_0(y)+\varepsilon T_1(y)e^{nt}\\
&C(y,t)=C_0(y)+\varepsilon C_1 e^{nt}\\
&\text{Also,}\quad U(t)=1+\varepsilon e^{nt}
\end{aligned}\right\}\tag{15}$$

Substituting equation (15) in equation (11) – equation (13) and equating the non-harmonic (coefficient of ε^0), harmonic (coefficient of ε) terms we get

$$u_0'' + u_0' - \left(M + \frac{1}{K_p}\right)u_0 = -G_r T_0 - G_c C_0 \tag{16}$$

$$u_1'' + u_1' - N_1 u_1 = -G_r T_1 - G_c C_1 \tag{17}$$

$$T_0'' + N_2 T_0' = -E_C N_2 \left(\frac{\partial u_0}{\partial y}\right)^2 \tag{18}$$

$$T_1'' + N_2 T_1' - N_3 T_1 = -N_2 T_0' - 2N_2 E_C u_0' u_1' \tag{19}$$

$$C_0'' + S_C C_0' - K_r^2 S_C C_0 = 0 \tag{20}$$

$$C_1'' + S_C C_1' - \left(K_r^2 + n\right) S_C C_1 = -S_C C_0' \tag{21}$$

where, $N_1 = M + \frac{1}{K_p} + n,\ N_2 = \frac{3RP_r}{3R+4},\ N_3 = \frac{3RP_r n}{3R+4}$

it should be noted that single primes and double primes of 'u', 'T' and 'C' in equation(16) onwards represent their first and second derivatives with respect to the 'y'.

The boundary conditions now reduce to

$$\left.\begin{aligned} &u_0 = 1,\ T_0 = 1,\ C_0 = 1,\ u_1 = 0,\ \mathrm{T}_1 = 1,\ \mathrm{C}_1 = 1 \text{ at } y = 0 \\ &u_0 \to 1,\ T_0 \to 0,\ C_0 \to 0,\ u_1 \to 1,\ \mathrm{T}_1 \to 0,\ \mathrm{C}_1 \to 0 \text{ at } y \to \infty \end{aligned}\right\} \tag{22}$$

To solve the non-linear-coupled Equations (16) – (21) subject to boundary conditions given in equation (22), we assume that the viscous dissipation parameter (Eckert number E_C) is small. So, it is used as the perturbation parameter.

$$\left.\begin{aligned} u_0(y') &= u_{01}(y') + E_C u_{02}(y') \\ T_0(y') &= T_{01}(y') + E_C T_{02}(y') \\ C_0(y') &= C_{01}(y') + E_C C_{02}(y') \\ u_1(y') &= u_{11}(y') + E_C u_{12}(y') \\ T_1(y') &= T_{11}(y') + E_C T_{12}(y') \\ C_1(y') &= C_{11}(y') + E_C C_{12}(y') \end{aligned}\right\} \tag{23}$$

Substituting equation (23) in equation (16) - (21) we obtain the following sequence of approximations:-

$$u_{01}'' + u_0' - N_1 u_{01} = -G_r T_{01} - G_C C_{01} \tag{24}$$

$$u_{02}'' + u_{02}' - N_1 u_{02} = -G_r T_{01} - G_C C_{02} \tag{25}$$

$$T_{01}'' + N_2 T_{01}' = 0 \tag{26}$$

$$T_{02}'' + N_2 T_{02}' = -N_2 \left(\frac{\partial u_{01}}{\partial y} \right)^2 \tag{27}$$

$$C_{01}'' + S_C C_{01}' - K_r^2 S_C C_{01} = 0 \tag{28}$$

$$C_{02}'' + S_C C_{02}' - K_r^2 S_C C_{02} = 0 \tag{29}$$

Subject to $\rightarrow$

$$\left.\begin{array}{l} u_{01} = 1,\ u_{02} = 0,\ T_{01} = 1,\ T_{02} = 0,\ C_{01} = 1,\ C_{02} = 1 \ \text{ at } y = 0 \\ u_{01} \to 1,\ u_{02} \to 0,\ T_{01} \to 1,\ T_{02} \to 0,\ C_{01} \to 1,\ C_{02} \to 1 \ \text{ at } y \to \infty \end{array}\right\} \tag{30}$$

for 0 (1) equations, and

$$u_{11}'' + u_{11}' - N_1 u_{11} = -G_r T_{11} - G_C C_{11} \tag{31}$$

$$u_{12}'' + u_{12}' - N_1 u_{12} = -G_r T_{12} - G_C C_{12} \tag{32}$$

$$T_{11}'' + N_2 T_{11}' - N_3 T_{11} = 0 \tag{33}$$

$$T_{12}'' + N_2 T_{12}' - N_3 T_{12} = -N_2 C_{02}' - 2 N_2 u_{01}' u_{11}' \tag{34}$$

$$C_{11}'' + S_C C_{11}' - \left(K_r^2 + n \right) S_C C_{11} = -S_C C_{01}' \tag{35}$$

$$C_{12}'' + S_C C_{12}' - \left(K_r^2 + n \right) S_C C_{12} = -S_C C_{02}' \tag{36}$$

Subject to $\rightarrow$

$$\begin{array}{l} u_{11} = 0,\ u_{12} = 0,\ T_{11} = 1,\ T_{12} = 0,\ C_{11} = 1,\ C_{12} = 0 \ \text{ at } y = 0 \\ u_{11} \to 1,\ u_{12} \to 0,\ T_{11} \to 0,\ T_{12} \to 0,\ C_{11} \to 0,\ C_{12} \to 0 \ \text{ at } y \to \infty \end{array} \tag{37}$$

for O (E_C) equations where $N_1 = M + \frac{1}{K_p} + n,\ N_2 = \frac{3RP_r}{3R+4}$ & $N_3 = \frac{3RP_r n}{3R+4}$

Solving equations (24) – (29) with boundary conditions (30) and solving Equations (31) – (36) satisfying boundary condition equation(37) and substituting into equation (23) and using equation (15) we obtain the concentration, temperature and velocity of the flow field respectively as:

$$C = e^{-m_1 y} + E_C e^{-m_1 y} + \varepsilon e^{nt}\left[(1-D)e^{-m_6 y} + De^{-m_1 y} + E_C\left\{D\left(e^{-m_1 y} - e^{-m_6 y}\right)\right\}\right]$$
$$= (1+E_C)e^{-m_1 y} + \varepsilon e^{nt}\left[(1-D-E_C D)e^{-m_6 y} + D(1+E_C)e^{-m_1 y}\right] \quad (38)$$

$$T = 1 + E_C\left\{-(\beta_1+\beta_2+\beta_3)e^{-N_2 y} + \beta_1 e^{-2m_1 y} + \beta_2 e^{-2m_2 y} + \beta_3 e^{-(m_1+m_2)y}\right\}$$
$$+\varepsilon e^{nt}\left[e^{-m_3 y} + E_C\left\{-(j_1+j_2+j_3+j_4+j_5+j_6+j_7+j_8+j_8)e^{-m_5 y}\right.\right.$$
$$j_1 e^{-m_1 y} + j_2 e^{-(m_1+m_4)y} + j_3 e^{-(m_1+m_3)y} + j_4 e^{-(m_1+m_6)y} + j_5 e^{-2m_1 y} + j_6 e^{-(m_2+m_4)y}$$
$$\left.\left.+j_7 e^{-(m_2+m_3)y} + j_8 e^{-(m_2+m_6)y} + + j_9 e^{-(m_1+m_2)y}\right\}\right] \quad (39)$$

$$u = \left[1 + \alpha\left(e^{-m_1 y} - e^{-m_2 y}\right) - E_C\left(K_1+K_2+K_3+K_4+K_5\right)e^{-m_2 y}\right.$$
$$+E_C\left\{K_1 e^{-N_2 y} + K_2 e^{-2m_1 y} + K_3 e^{-2m_2 y} + K_4 e^{(m_1+m_2)y} + K_5 e^{-m_1 y}\right\} + \varepsilon e^{nt}\left\{-(\gamma_1+\gamma_2+\gamma_3)e^{-m_4 y}\right.$$
$$+\gamma_1 e^{-m_3 y} + \gamma_2 e^{-m_6 y} + \gamma_3 e^{-m_1 y} - E_C\left(t_1+t_2+t_3+t_4+t_5+t_6+t_7+t_8+t_9+t_{10}+t_{11}\right)e^{-m_4 y}$$
$$+E_C t_1 e^{-m_5 y} + E_C t_2 e^{-m_1 y} + E_C t_3 e^{-(m_1+m_4)y} + E_C t_4 e^{-(m_1+m_3)y} + E_C t_5 e^{-(m_1+m_6)y} + E_C t_6 e^{-2m_1 y} + E_C t_7 e^{-(m_2+m_4)y}$$
$$\left.\left.+E_C t_8^{-(m_2+m_3)y} + E_C t_9 e^{-(m_2+m_6)y} + E_C t_{10} e^{-(m_1+m_2)y} + E_C t_{11} e^{-m_6 y}\right\}\right] \quad (40)$$

where constants are given in the Appendix.

Appendix:

$$N_1 = (M + n + \frac{1}{K_p}),\ N_2 = \frac{3RP_r}{3R+4},\ N_3 = \frac{3RP_r n}{3R+4}$$

$$m_1 = \frac{S_C + \sqrt{S_C^{\ 2} + 4K_r^{\ 2} S_C}}{2},\ m_2 = \frac{1 + \sqrt{1 + 4\left(M + \frac{1}{K}\right)}}{2},\ m_5 = m_3 = \frac{N_2 + \sqrt{N_2^{\ 2} + 4N_3}}{2}$$

$$m_4 = \frac{1 + \sqrt{1 + 4N_1}}{2}, \qquad m_6 = \frac{S_C + \sqrt{S_C^{\ 2} + 4\left(K_r^{\ 2} + n\right)S_C}}{2}$$

$$\alpha = \frac{G_C}{\left(M + \frac{1}{K}\right) + m_4 - m_4^{\ 2}}, \qquad K_1 = \frac{-G_r\left(\beta_1+\beta_2+\beta_3\right)}{N_2^{\ 2} - N_2 - \left(M + \frac{1}{K}\right)}$$

$$K_2 = \frac{-G_r \beta_1}{4m_1^{\ 2} - 2m_1 - \left(M + \frac{1}{K}\right)}, \qquad K_3 = \frac{-G_r \beta_2}{4m_2^{\ 2} - 2m_2 - \left(M + \frac{1}{K}\right)}$$

$$K_4 = \frac{-G_r \beta_3}{\left(m_1+m_2\right)^2 - \left(m_1+m_2\right) - \left(M + \frac{1}{K}\right)}, \qquad K_5 = \frac{-G_C}{m_1^{\ 2} - m_1 - \left(M + \frac{1}{K}\right)}$$

$$\beta_1=\frac{-N_2m_1^2\alpha^2}{\left(4m_1^2-2N_2m_1\right)}\ ,\beta_2=\frac{-N_2m_2^2\alpha^2}{\left(4m_2^2-2N_2m_2\right)},\beta_3=\frac{2N_2m_1m_2\alpha^2}{\left(m_1+m_2\right)^2-N_2\left(m_1+m_2\right)}$$

$$\gamma_1=\frac{-G_r}{\left(m_3^2-m_3-N_1\right)},\gamma_2=\frac{-G_C\left(1+D\right)}{\left(m_6^2-m_6-N_1\right)}\ ,\gamma_3=\frac{-G_C\left(1+D\right)}{\left(m_1^2-m_1-N_1\right)},\ \gamma_3=\frac{-G_c\,D}{m_1^2\_m_1\_N_1}$$

$$t_1=\frac{G_r(j_1+j_2+j_3+j_4+j_5+j_6+j_7+j_8+j_9}{m_5^2\_m_5\_N_1},t_2=\frac{-\left(G_rj_1+G_CE\right)}{m_1^2-m_1-N_1}$$

$$t_3=\frac{-G_rj_2}{\left(m_1+m_4\right)^2-\left(m_1+m_4\right)-N_1},t_4=\frac{-G_rj_3}{\left(m_1+m_3\right)^2-\left(m_1+m_3\right)-N_1}$$

$$t_5=\frac{-G_rj_4}{(m_1+m_6)^2\_(m_1+m_6)\_N_1},t_6=\frac{-G_rj_5}{4m_1^2-2m_1-N_1},t_7=\frac{-G_rj_6}{\left(m_2+m_4\right)^2-\left(m_2+m_4\right)-N_1}$$

$$t_8=\frac{-G_rj_7}{\left(m_2+m_3\right)^2-\left(m_2+m_3\right)-N_1},\qquad t_9=\frac{-G_rj_8}{\left(m_2+m_6\right)^2-\left(m_2+m_6\right)-N_1}$$

$$t_{10}=\frac{-G_rj_9}{\left(m_2+m_2\right)^2-\left(m_1+m_2\right)-N_1},\quad t_{11}=\frac{G_C}{m_6^2-m_6-N_1},D=E=\frac{m_1S_C}{m_1^2-m_1S_C-\left(K_r^2+n\right)S_C}$$

$$j_1=\frac{N_2m_1}{m_1^2-N_2m_1-N_3},\qquad j_2=\frac{2N_2\alpha m_1m_4\left(\gamma_1+\gamma_2+\gamma_3\right)}{\left(m_1+m_4\right)^2-N_2\left(m_1+m_4\right)-N_3}$$

$$j_3=\frac{-2N_2\alpha m_1m_3\gamma_1}{\left(m_1+m_3\right)^2-N_2\left(m_1+m_3\right)-N_3},\ j_4=\frac{-2N_2\alpha m_1m_6\gamma_2}{\left(m_1+m_6\right)^2-N_2\left(m_1+m_6\right)-N_3}$$

$$j_5=\frac{-2N_2\,\alpha m_1^2\,\gamma_3}{(4m_1^2-2m_1\,N_2-N_3)},\ j_6=\frac{-2N_2\alpha m_2m_4\left(\gamma_1+\gamma_2+\gamma_3\right)}{\left(m_2+m_4\right)^2-N_2\left(m_2+m_4\right)-N_3}$$

$$j_7=\frac{2N_2\alpha m_2m_3\gamma_1}{\left(m_2+m_3\right)^2-N_2\left(m_2+m_3\right)-N_3},\ j_8=\frac{2N_2\alpha m_2m_6\gamma_2}{\left(m_2+m_6\right)^2-N_2\left(m_2+m_6\right)-N_3},\ j_9=\frac{2N_2\alpha m_1m_2\gamma_3}{\left(m_1+m_2\right)^2-N_2\left(m_1+m_2\right)-N_3}$$

NOMENCLATURE:

g	Acceleration due to gravity
ν	Kinematic viscosity
B_0	Magnetic field of uniform strength
σ	Electrical conductivity
ρ	Density of the fluid

C_P	Thermal conductivity specific heat at constant pressure
$C^{/}$	Species concentration
D	Molecular diffusivity
Gr	Grashof number for heat transfer
K^*	Permeability of the medium
α	Thermal diffusivity
Nu	Nusselt number
E_c	Eckert number
q_r	Radiative heat flux
S_h	Sherwood number
T	Non dimensional temperature
$T^{'}$	Non dimensional time
$Y^{'}$	Non dimensional distance along y-axis
G_c	Grashof number for mass transfer
K_p	Porosity parameter
m	Magnetic parameter
P_r	Prandtl number
S_c	Schmidt number
T'	Temperature of the field
t'	Time
u'	Velocity component along X-axis
v	Suction velocity
ε	A small positive constant
n'	Non dimensional frequency of oscillation
n	frequency of oscillation
τ	Skin friction
K_r	Chemical reaction parameter
C	Non-dimensional species concentration
y'	Distance along y-axis
T_w	Temperature at the wall
T_∞	Temperature at fan from the plate
R	Radiation parameter

RESULTS AND DISCUSSION

The problem presents the effect of chemical reaction on unsteady mass transfer flow past a semi-infinite vertical porous moving plate with time dependent suction and radiative heat source in presence of transverse magnetic field. The governing equations of the flow field are set and solved using multi-parameter perturbation technique and approximate solutions are obtained for velocity field, temperature field and concentration field. The effects of pertinent parameters on the flow field are analyzed and discussed with the help of velocity profiles in the Fig-I to Fig.-IV, temperature profiles in the Fig.- V and Fig.-VI and the concentration profiles in the Fig.-VII and Fig.-VIII. The variation in the value of skin friction coefficient, Nusselt number (rate of heat transfer co-efficient) and Schimdt number (rate of mass transfer co-efficient) are shown in Tables 1 to 4.

Velocity Field- The velocity of the flow field suffers a substantial change with the variation of magnetic parameter M and permeability parameter K_p .The effects of these parameters on the velocity field are analyzed with the aid of Fig-.I and II.

In Fig-I, we discuss the effect of the magnetic parameter M on the velocity field. The curve with M=0 corresponds to non-MHD flow. A study of the curves of the said figures shows that the growing magnetic parameter retards the velocity of the flow field all points due to the influence of Lorentz force on the flow field. Figure-II depicts the effect of the permeability parameter on the flow field. The permeability parameter K_p increases the transient velocity of the flow field at all points. Fig-III explains the variation of the velocity of the flow field with respect to the change in Grashof number for mass transfer, G_c. It is observed that the velocity of the flow field increases with the increase in G_c. In figure-IV, the variation of the velocity with the change in chemical reaction parameter is shown. It is found that small value of chemical reaction parameter K_r results in greater velocity of the flow and vice-versa.

Temperature Field- The temperature of the flow field depends on time, Prandtl number and chemical reaction parameter etc. Figure-V depicts the effect of the time on the temperature. It is observed that temperature falls rapidly for small value of time and with increase in the value of time it decreases gradually. Temperature rises with growing time. Fig-VI shows the change in the temperature field with the variation in Prandtl number. This graph indicates that higher value of Prandtl number reduces the temperature of the field.

Concentration Field- Fig-VII and VIII show the change in concentration with Schimdt number and chemical reaction parameter .From figure fig-VII it is observed that rise in the value of Schimdt number decreases the concentration field and vice-versa. Again, very sharp fall in concentration is found with higher value of it. Fig-VIII depicts the effect of chemical reaction parameter on the concentration distribution of the field. It shows that a growing chemical reaction parameter reduces the concentration field.

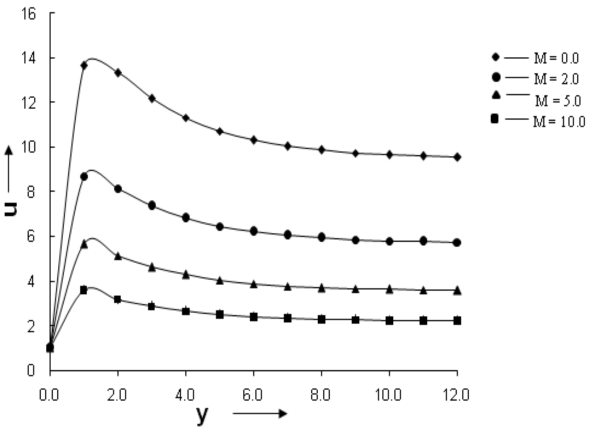


Fig-1 Velocity(u) profile for R=2, $\varepsilon = 0.02$, $P_r = 0.71$, t = 1, $S_c = 0.24$, $E_c = 0.01$, $G_r = 5$, $G_c = 6$, $K_r = 0.5$, n = 0.5, $K_p = 1.0$

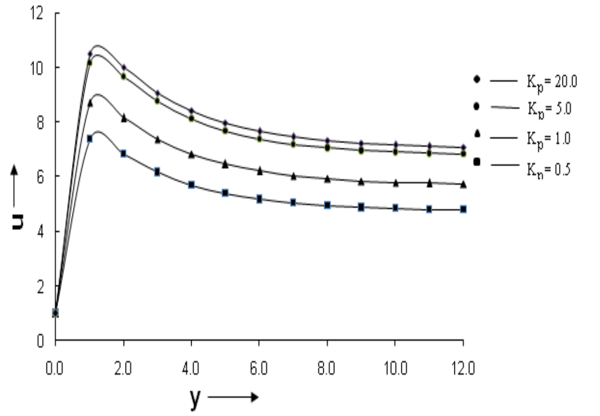


Fig-2 Velocity(u) profile for R=2, $\varepsilon = 0.02$, $P_r = 0.71$, t = 1, $S_c = 0.24$, $E_c = 0.01$, $G_r = 5$, $G_c = 6$, $K_r = 0.5$, n = 0.5, M = 2.0

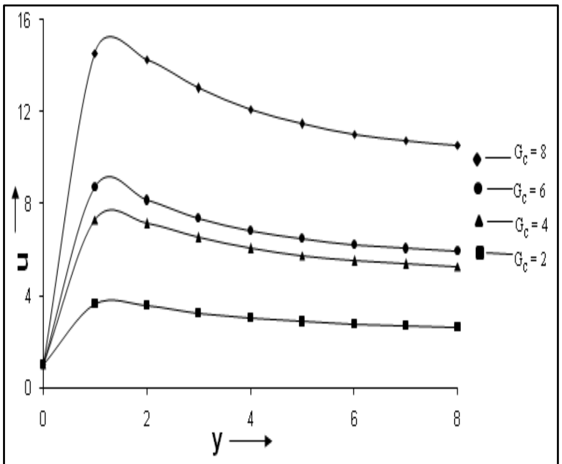


Fig-3 Velocity(u) profile for R=2, $\varepsilon = 0.02$, $P_r = 0.71$, t = 1, $S_c = 0.24$, $E_c = 0.01$, $G_r = 5$, $K_p = 1$, $K_r = 0.5$, n = 0.5, M = 2.0

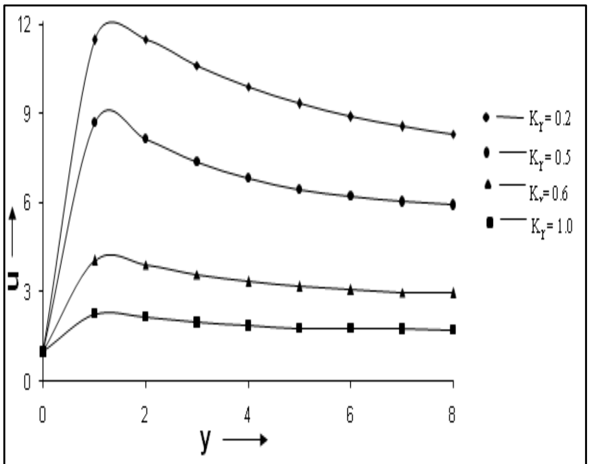


Fig-4 Velocity(u) profile for R=2, $\varepsilon = 0.02$, $P_r = 0.71$, t = 1, $S_c = 0.24$, $E_c = 0.01$, $G_r = 5$, $K_p = 1$, $G_c = 6$, n = 0.5, M = 2.0

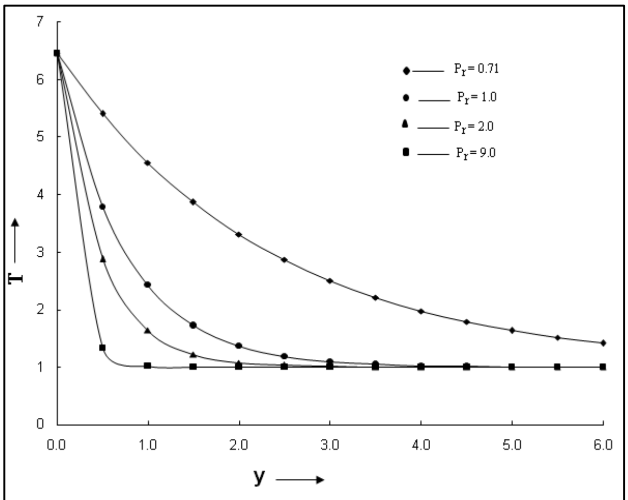


Fig- 5 Temperature(T) profile for R=2, ε = 0.1, K_r = 0.5, t = 2, S_c = 0.24, E_c = 0.01, G_r = 2, K_p = 1, G_c = 1, n = 2.0, M = 2.0

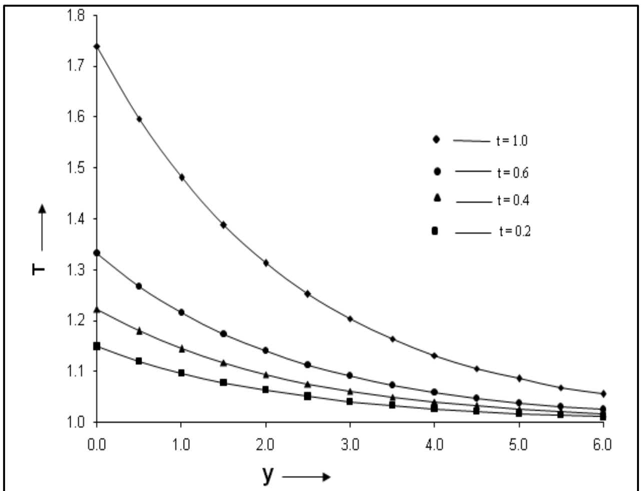


Fig- 6 Temperature (T) profile for R=2, ε = 0.1, K_r = 0.5, P_r = 0.71, S_c = 0.24, E_c = 0.01, G_r = 2, K_p = 1, G_c = 1, n = 2.0, M = 2.0

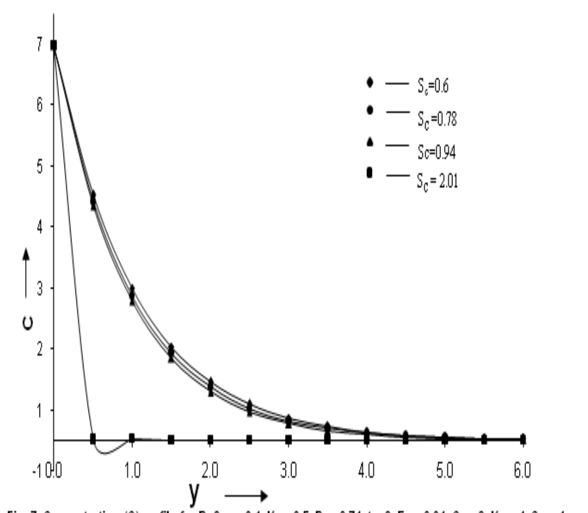


Fig- 7 Concentration (C) profile for R=2, ε = 0.1, K_r = 0.5, P_r = 0.71, t = 2, E_c = 0.01, G_r = 2, K_p = 1, G_c = 1, n = 2.0, M = 0

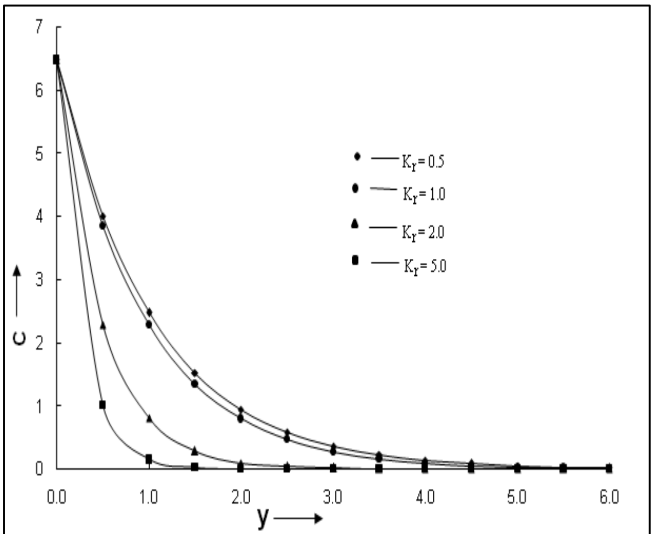


Fig- 8 Concentration (C) profile for R=2, ε = 0.1, S_c = 0.6, P_r = 0.71, t = 2, E_c = 0.01, G_r = 2, K_p = 1, G_c = 1, n = 2.0, M = 0

TABLE – 1: Variation in the value of skin friction t and the rate of heat transfer, Nu against K_p for different values of M with E_c = 0.01, R = 2.0 , K_r = 0.5 , G_r = 5.0 , G_c = 6.0

K_p	M = 1.0		M = 2.0		M = 5.0		M = 10.0	
0.5	10.5009	0.3994	5.2148	0.4728	2.0521	0.6554	1.0025	0.8936
1.0	8.4617	0.3151	4.1903	0.3994	1.6384	0.5992	0.7923	0.8503
5.0	6.3193	0.2350	3.1097	0.3331	1.1948	0.5513	0.5602	0.8143
20.0	5.8231	0.2181	2.8601	0.3196	1.0925	0.5419	0.5066	0.8074

TABLE - 2 : Effect of G_r, G_c & K_r on Skin-friction coefficient, τ for M = 2.0 & K_p = 1.0

G_r	G_c	K_r	τ
5.0	6.0	0.2	4.48623
5.0	6.0	0.5	4.19031
5.0	6.0	0.6	4.07728
5.0	6.0	1.0	3.60148
2.0	6.0	0.2	4.55510
3.0	6.0	0.2	4.53214
2.0	6.0	0.2	4.64692
5.0	6.0	0.2	4.48623
5.0	2.0	0.2	1.41890
5.0	3.0	0.2	2.19347
5.0	2.0	0.2	1.64844

TABLE – 3: Effect of P_r on Rate of heat Transfer, Nu for M = 2.0, K_r = 0.5 & t = 1.0

K_r	P_r	K_p	Nu
0.5	0.71	1.0	0.39938
0.5	1.00	1.0	0.56441
0.5	2.00	1.0	1.14055
0.5	9.00	1.0	5.09506

TABLE – 4: Effect of S_c & K_r on S_h

S_c	K_r	S_h
0.30	0.5	0.1223
0.60	0.5	6.7152
0.78	0.5	6.5050
0.94	0.5	6.1580
2.01	0.5	23.3515
0.60	1.0	6.1944
0.60	2.0	13.4482
0.60	5.0	23.9360

CONCLUSION

The above analysis brings out the following results of physical interest on velocity, temperature, and concentration distribution of the flow field.

1) The magnetic parameter M retards the velocity of the flow field at all points due to the magnetic pull of the Lorentz force acting on the flow field.
2) The Grashof numbers for heat transfer, G_r and mass transfer G_c accelerates the velocity of the flow field.
3) The effect of porosity parameter K_p is to enhance the velocity of the flow field at all points.
4) The chemical reaction parameter, K_r decelerates the flow field.
5) The Prandtl number, P_r reduces the temperature of the flow field at all points. Higher the Prandtl number, the sharper is the reduction in temperature of the flow field.
6) The concentration distribution of the flow field decreases at all points as the Schimdt number S_c increases This means the heavier diffusing species have a greater retarding effect on the concentration distribution of the flow field.
7) The chemical reaction parameter, K_r also reduces the concentration distribution of the flow field remarkably.
8) A growing M or K_p leads to a decrease in the value of skin friction coefficient.
9) Rate of heat transfer, N_u increases with increase in P_r .
10)The chemical reaction parameter, Kr and Schimdt number, S_c also affect the mass transfer coefficient S_h.

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