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Chemical Reaction effect on MHD Flow past a Vertical Plate through a Porous Medium under time dependant Permeability and Oscillatory Suction

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ABSTRACT

The model of mass transfer unsteady free convection two-dimensional flow of an incompressible, electrically conducting viscous fluid along an infinite vertical porous plate through porous medium with time dependant Permeability and oscillatory suction in the presence of chemically reacting species has been studied. The dimensionless governing equations are solved using Perturbation technique. The results are obtained for velocity, concentration, Sherwood number and skin friction. The effect of various material parameters are discussed on flow variable and presented by graphs and tables.

Introduction

MHD plays an important role in power generation, space propulsions, cure of diseases, control of thermonuclear reactor, boundary layer control in the field of aerodynamics. In past few years, several simple flow problems associated with classical hydrodynamics have received new attention within the more general context of hydrodynamics. Convection in porous medium has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. The phenomenon of mass transfer is also very common in theory of stellar structure and observable effects are detectable on solar surface. The effect of magnetic field on free convection flow is important in liquid–metals and ionized gases. To study such applications which are closely associated with magneto-chemistry requires a complete understanding of the equation of state and transfer properties such as diffusion, the shear stress, thermal conduction, electrical conduction, etc. Some of these properties will undoubtedly be influenced by the presence of external magnetic field. The phenomena of MHD flow with unsteady oscillatory free convective flows play an important role in aerospace technology and in chemical engineering turbo-machinery. The effects of mass transfer on free convective hydromagnetic oscillatory flow past an infinite vertical unsteady flow of non-Newtonian fluid has been estimated by Koullias et al. [1]. Ashgar et al. [4] have reported the periodic unsteady flows of non-Newtonian fluid. The flow of non-Newtonian fluid induced due to the oscillations of a porous plate has studied by Hayat et al [5]. Singh and Gupta [6] have investigated the MHD free convective flow of a viscous fluid through a porous medium bounded by an oscillating plate in the slip flow regime with mass transfer. Das et al. [7] analyzed the mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction employing numerical methods. Unsteady hydromagnetic convective flow past an infinite vertical porous flat plate in a porous medium has been discussed by Das et al [9]. Mohapatra and Senapati [2, 3] have investigated the unsteady MHD free convection flow with mass transfer through porous medium past a vertical plate. Senapati et.al[8] have studied magnetic effect on mass and heat transfer of a hydrodynamic flow past a vertical oscillating plate in the presence of chemical reaction. Ashraf et. al [10] obtained the solution of MHD flow past a vertical porous plate through a porous medium under oscillatory suction.

It is proposed to study the unsteady free convection two-dimensional flow of an incompressible, electrically conducting viscous fluid along an infinite vertical porous plate through porous medium with time dependant Permeability and oscillatory suction in the presence of chemically reacting species.

Formulation of Problem

Consider the unsteady free convection two-dimensional flow of an incompressible, electrically conducting viscous fluid along an infinite vertical porous plate through porous medium with time dependant Permeability and oscillatory suction in the presence of chemically reacting species. The X' –axis is taken along the plate in the upward direction growing in the direction of motion and Y' –axis is taken normal to the plate. Assume that the fluid has constant properties and the variation in density and

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mass concentration is considered only in the body force term. A magnetic field of uniform field strength B_0 acts normal to the plate. We assume that the plate and the fluid are in the same temperature, but the concentration of species is raised or lowered. The permeability of the porous medium and oscillatory suction velocity are assumed to be $K' = K'_p(1+\epsilon e^{i\omega' t'})$ and $v = -v_0(1+\epsilon e^{i\omega' t'})$ respectively. Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations:

$$\frac{\partial u'}{\partial t'} - v_0\left(1+\epsilon e^{i\omega' t'}\right)\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta_c\left(C' - C'_\infty\right) - \frac{\nu}{K_p\left(1+\epsilon e^{i\omega' t'}\right)}u' - \frac{\sigma B_0^2 u'}{\rho} \tag{1}$$

$$\frac{\partial C'}{\partial t'} - v_0\left(1+\epsilon e^{i\omega' t'}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - R'\left(C' - C'_\infty\right) \tag{2}$$

with boundary conditions

$$\left.\begin{aligned} &u' = v_0\left(1+\epsilon e^{i\omega' t'}\right), \quad C' = C'_\infty + \left(C'_w - C'_\infty\right)\in e^{i\omega' t'} \;\; for\ y' = 0\ and\ t > 0 \\ &u' = 0,\ \ C' = C'_\infty\ as\ y' \to \infty\ and\ y' > 0 \end{aligned}\right\} \tag{3}$$

Let us introduce the dimensionless quantities

$$\left.\begin{aligned} &u = \frac{u'}{v_0},\ t = \frac{t' v_0^2}{\upsilon},\ y = \frac{y' v_0}{\upsilon},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ \omega = \frac{\upsilon\omega'}{v_0^2} \\ &Gm = \frac{g\beta_C \upsilon\left(C'_w - C'_\infty\right)}{v_0^3},\ Sc = \frac{\upsilon}{D},\ M = \frac{\sigma\upsilon B_0^2}{\rho U_0^2} \\ &K_p = \frac{v_0^2 K_p'}{\upsilon^2},\ R = \frac{R' v_0^2}{\upsilon} \end{aligned}\right\} \tag{4}$$

where D is the mass diffusion, Gm is modified Grashof number, K_p is permeability of porous medium, M is magnetic parameter, Sc is Schmidt number, β_c is concentration expansion co-efficient, $B_0 = \mu_e H_0$, ω is the frequency of oscillation and R is chemical reaction parameter.

Therefore, the non-dimensional form of the governing equations for momentum and concentration are

$$u_{yy} + f(t)u_y + CG_m = u_t + \left(M + \frac{1}{K_p f(t)}\right)u \tag{5}$$

$$C_{yy} + f(t)ScC_y = ScC_t + RScC \tag{6}$$

with boundary conditions

$$\left.\begin{aligned} &u(0,t) = C(0,t) = f(t) \\ &u(\infty,t) = C(\infty,t) = 0 \end{aligned}\right\} \tag{7}$$

Method of Solution

In order to solve the problem, we assume the solutions of the following form by taking the amplitude of $\in$ of the permeability variation very small:

$$u(y,t) = u_0(y) + \in u_1(y)e^{i\omega t} \tag{8}$$

$$C(y,t) = C_0(y) + \in C_1(y)e^{i\omega t} \tag{9}$$

Substitute Equations (8) and (9) into Equations (5) and (6) and then equate the harmonic and non-harmonic parts to obtain the following non-dimensional ordinary differential equations:

$$u_0'' + u_0' - \left(M + \frac{1}{K_p}\right)u_0 = -C_0 G_m \tag{10}$$

$$u_1'' + u_1' - \left(i\omega + M + \frac{1}{K_p}\right)u_1 = -\frac{u_0}{K_p} - C_1 G_m \tag{11}$$

$$C_0'' + (Sc - RSc)C_0 = 0 \tag{12}$$

$$C_1'' + ScC_1' - (Sci\omega + ScR)C_1 = -ScC_0' \tag{13}$$

with the following boundary conditions

$$\left.\begin{aligned} &u_0 = u_1 = C_0 = C_1 = 1 \quad for\ \ y = 0 \\ &u_0 = u_1 = C_0 = C_1 = 0 \quad as\ \ y \to \infty \end{aligned}\right\} \tag{14}$$

By solving the equation from (10) to (13) using the boundary conditions (14), we get

$$u = \left(B_{11}e^{-A_{13}y} + B_{12}e^{-A_{11}y}\right) + \in e^{i\omega t}\left(B_{18}e^{-A_{15}y} + B_{15}e^{-A_{13}y} + B_{16}e^{-A_{11}y} + B_{17}e^{-A_{14}y}\right) \tag{15}$$

$$C = e^{-A_{11}y} + \in e^{i\omega t}\left(B_{14}e^{-A_{14}y} + B_{13}e^{-A_{11}y}\right) \tag{16}$$

where

$$A_{11} = \sqrt{Sc(R-1)},\ \ A_{12} = M + \frac{1}{K_p},\ \ A_{13} = \frac{1 + \sqrt{1 + 4\left(M + \frac{1}{K_p}\right)}}{2},\ \ A_{14} = \frac{Sc + \sqrt{Sc^2 + 4(Sci\omega + ScR)}}{2},$$

$$A_{15}=\frac{1+\sqrt{1+4\left(i\omega+M+\frac{1}{K_p}\right)}}{2},\ B_{11}=\frac{A_{11}^2-A_{11}-A_{12}+Gm}{A_{11}^2-A_{11}-A_{12}},\ B_{12}=\frac{-Gm}{A_{11}^2-A_{11}-A_{12}}$$

$$B_{13}=\frac{-A_{11}Sc}{A_{11}^2-(A_{11}+i\omega+R)Sc},B_{14}=1-B_{13},B_{15}=\frac{-B_{11}}{K_p\left(A_{13}^2-A_{13}-\left(i\omega+M+\frac{1}{K_p}\right)\right)}$$

$$B_{16}=\frac{-B_{12}}{K_p\left(A_{11}^2-A_{11}-\left(i\omega+M+\frac{1}{K_p}\right)\right)}+\frac{-B_{13}Gm}{\left(A_{11}^2-A_{11}-\left(i\omega+M+\frac{1}{K_p}\right)\right)}$$

$$B_{17}=\frac{-B_{14}Gm}{\left(A_{14}^2-A_{14}-\left(i\omega+M+\frac{1}{K_p}\right)\right)},B_{18}=1-(B_{15}+B_{16}+B_{17})$$

The real and imaginary parts are separated from Equation (15) and (16). The physical significance of the real parts which are given as follows:

$$\left.\begin{aligned}u_r&=u_0(y)+\in\left(M_r\,Cos\,(\omega t)-M_i sin(\omega t)\right)\\ C_r&=C(y)+\in\left(L_r\,Cos\,(\omega t)-L_i sin(\omega t)\right)\end{aligned}\right\}\tag{17}$$

For $\omega t=\frac{\pi}{2}$ the transient velocity and concentration distribution are given by

$$\left.\begin{aligned}u_r&=u_0(y)-\in M_i sin(\omega t)\\ C_r&=C(y)-\in L_i sin(\omega t)\end{aligned}\right\}\tag{18}$$

The skin friction at the plate is

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=-\{(B_{11}A_{13}+B_{12}A_{11})+\in e^{i\omega t}(B_{18}A_{15}+B_{15}A_{13}+B_{16}A_{11}+B_{17}A_{14})\}\tag{19}$$

The Sherwood Number at the plate is

$$Sh=-\left(\frac{\partial C}{\partial y}\right)_{y=0}=A_{11}+\in e^{i\omega t}(B_{14}A_{14}+B_{13}A_{11})\tag{20}$$

Graphical Results and Discussions

In this paper, the unsteady free convection two-dimensional flow of an incompressible, electrically conducting viscous fluid along an infinite vertical porous plate through porous medium with time dependant Permeability and oscillatory suction in the presence of chemically reacting species have been studied. The effect of the parameters Gm, R, Sc, M, K and ωt on flow characteristics have been studied and shown by means of graphs and tables. In order to have physical correlations, we choose suitable values of flow parameters. The graphs of velocities and mass concentration are taken w.r.t y. Shearing Stress and Sherwood Number at plate are obtained in the tables for different parameters.

Velocity profiles

The velocity profiles are depicted in Figs 1- 4. Figure-(1) shows the effect of the parameters M and K_p on velocity at any point of the fluid, when Sc=0.22, Gm=5, R=10 and $\omega t=\frac{\pi}{2}$. It is noticed that the velocity decreases with the increase in magnetic parameter (M) and, whereas increases with the increase of permeability of porous medium (K_p).

Figure-(2) shows the effect of the parameters Gm and Sc on velocity at any point of the fluid, when $K(K_p)$=5, R=10, M=0.5 and $\omega t=\frac{\pi}{2}$. It is noticed that the velocity increases with the increase of modified Grashoff number (Gm) where as decreases with the increase of Schmidt number (Sc).

Figure-(3) shows the effect of the parameter ωt on velocity at any point of the fluid, when $K(K_p)$=5, Gm=5, M=0.5, R=10 and Sc=0.22. It is noticed that the velocity increases with the increase of Oscillatory parameter (ωt).

Figure-(4) shows the effect of the parameter R on velocity at any point of the fluid, when $K(K_p)$=5, Gm=5, M=0.5, $\omega t=\frac{\pi}{2}$ and Sc=0.22. It is noticed that the velocity decreases with the increase of Chemical reaction parameter (R).

Mass concentration profile: Figure-(5) shows the effect of the parameters Sc and R on mass concentration profile at any point of the fluid when $\omega t=\frac{\pi}{2}$, and in the absence of other parameters. It is noticed that the mass concentration decreases with the increase of Schmidt number (Sc) and Chemical reaction parameter (R).

Table-(1) shows the effects of different parameters on Skin Friction at both the plates. It is noticed that Skin Friction increases with the increase of modified Grashoff number (Gm) and permeability of porous medium (K_p) whereas decreases in the increase of magnetic parameter (M), Schmidt number (Sc) and Chemical reaction parameter (R).

Table-(2) shows the effects of Sc and R on Sherwood Number at both plates. It is noticed that Sherwood Number increases with the increase of Schmidt number (Sc) and Chemical reaction parameter (R).

Table 1. Effect of different parameters on Skin Friction

M	Sc	K	Gm	R	Skin Friction(τ)
0.1	0.22	5	10	10	3.8458
1	0.22	5	10	10	3.0384
2	0.22	5	10	10	1.9848
0.1	0.44	5	10	10	2.5888
0.1	0.88	5	10	10	1.5707
0.1	0.22	7	10	10	3.9610
0.1	0.22	9	10	10	4.0278
0.1	0.22	5	15	10	6.5048
0.1	0.22	5	20	10	9.1634
0.1	0.22	5	10	15	3.0162
0.1	0.22	5	10	20	2.5003

Table 2. Effect of different parameters on Sherwood Number

Sc	R	Sherwood Number(Sh)
0.22	10	1.4064
0.33	10	1.6403
0.44	10	1.9889
0.22	12	1.5549
0.22	15	1.7549

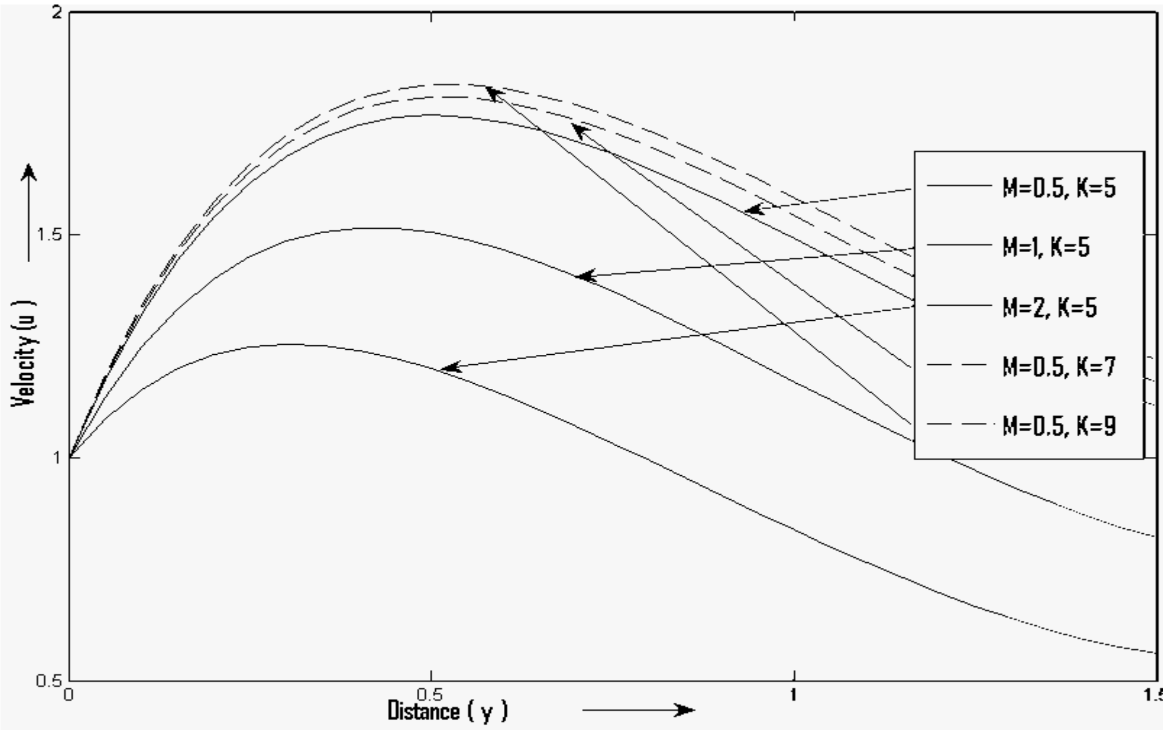

Figure 1. Effect of M and $K(K_p)$ on velocity profile (u), when Sc=0.22, Gm=5, R=10 and $\omega t = \frac{\pi}{2}$.

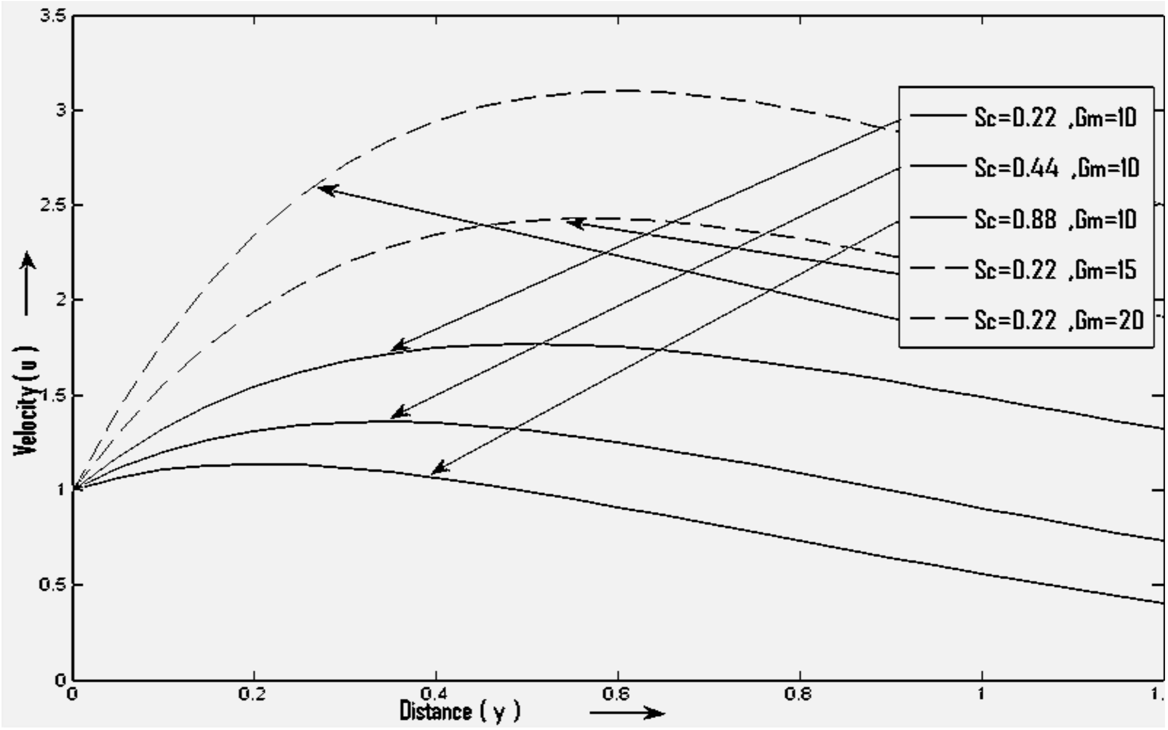

Figure 2. Effect of $Sc\ and\ Gm$ on velocity profile (u), when $K(K_p)$=5, R=10, M=0.5 and $\omega t = \frac{\pi}{2}$.

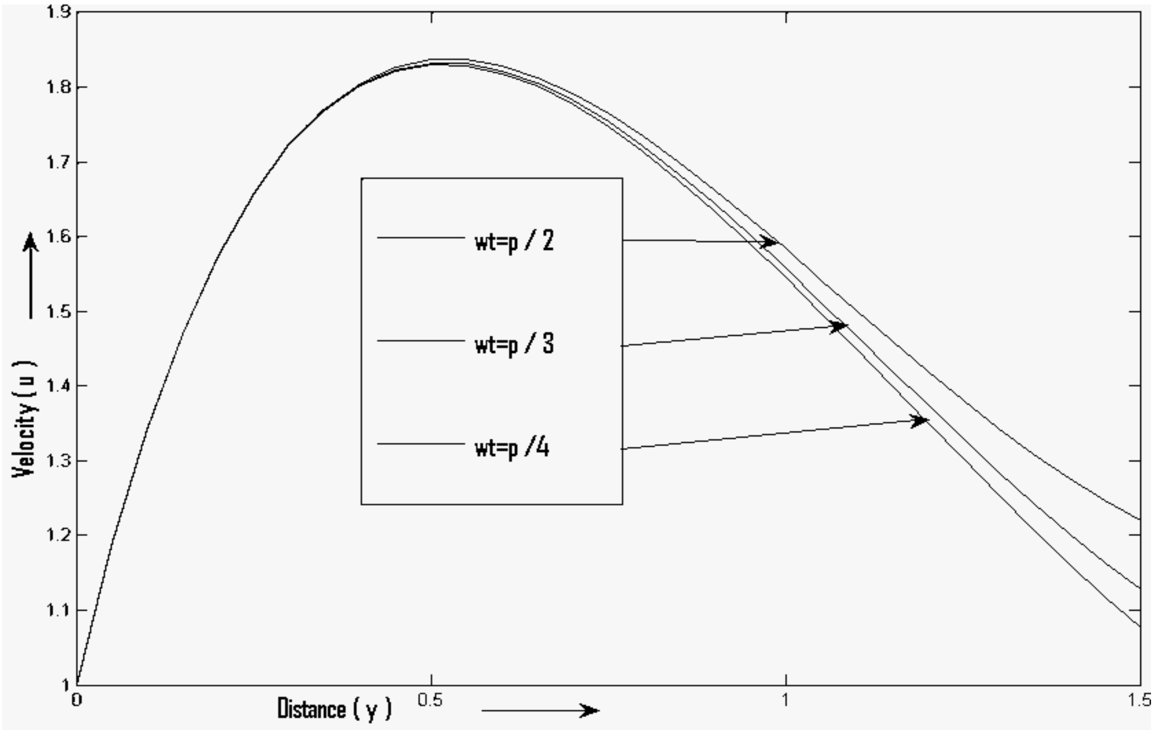

Figure 3. Effect of ωt on velocity profile (u), when $K(K_p)$=5, Gm=5, M=0.5, R=10 and Sc $= 0.22$

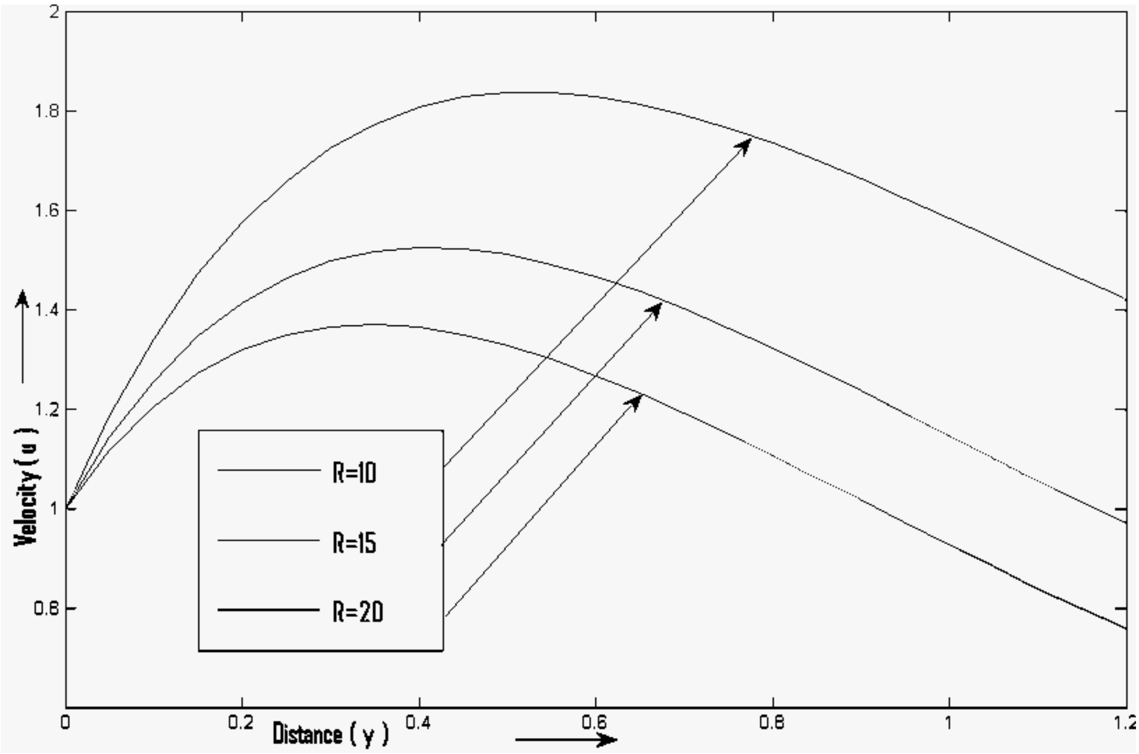

Figure 4. Effect of R on velocity profile (u), when $K(K_p)$=5, Gm=5, M=0.5, $\omega t = \frac{\pi}{2}$ and Sc $= 0.22$

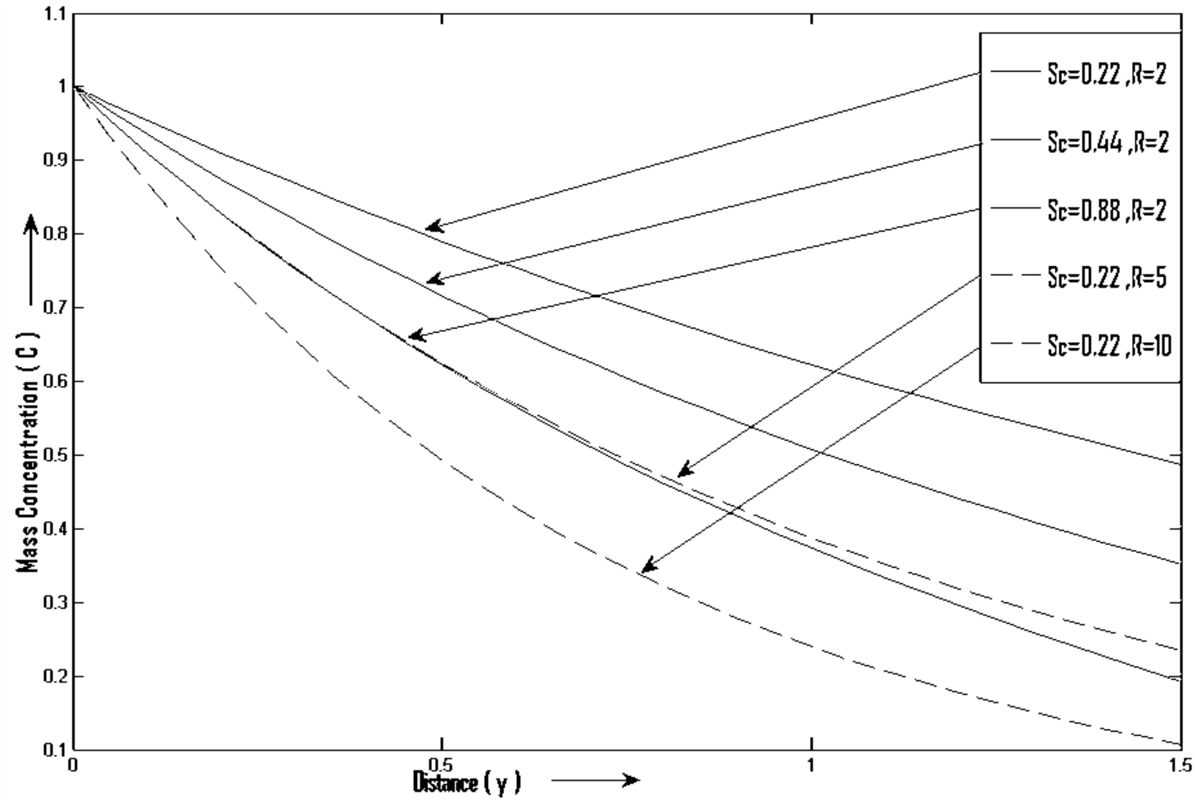

Figure 5. Effect of R and Sc on Mass concentration profile(C) when $\omega t = \frac{\pi}{2}$ and in the absence of other parameters.

Conclusions

The above study shows up the following results of physical interest on velocity and concentration distribution of flow field.

- The magnetic field and Chemical reaction slows down the velocity of fluid due to the magnetic pull of Lorentz force and heavier diffusion of chemical reactive species.
- The velocity of fluid accelerated by modified Grashoff number and enhanced by Porosity parameter.
- Mass concentration decreased by Reactive diffusion species.
- Skin friction at the plate decreases by Lorentz force and Reactive diffusion species

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