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Chemical reaction effect on MHD Free Convection and Mass Transfer Flow past a Vertical Flat Plate with porous medium

Dr.R.K.Dhal[1] & Dr.A.K.Mohanty[2]

J.N.V. Paralakhemundi, Gajapati, Orissa-761201(India)[1]
Principal ,V.N. College,J.K.Road ,Orissa-755019(INDIA) [2]

Abstract: **-** The two dimensional free convection and mass transfer flow of an incompressible, viscous and electrically conducting fluid past a continuously moving vertical flat plate through porous medium in the presence of heat source, thermal diffusion, large suction, Chemical reaction and the influence of uniform magnetic field applied normal to the flow has been studied. Usual similarity transformations are introduced to solve the momentum, energy and concentration equations. To obtain the solutions of the problem, the ordinary differential equations are solved by using perturbation technique. The expressions for velocity field, temperature field, concentration field, skin friction, rate of heat and mass transfer have been obtained. The results are discussed in detailed with the help of graphs and tables to observe the effect of different parameters.

Keywords*:* **-** *MHD, Free convection, Flate plate, Heat Transfer, Mass transfer and Variable Temperature, Porous medium, chemical reaction.*

I. INTRODUCTION

Magneto-hydrodynamic (MHD) is the branch of continuum mechanics which deals with the flow of electrically conducting fluids in electric and magnetic fields. Many natural phenomena and engineering problems are worth being subjected to an MHD analysis. Furthermore, Magneto-hydrodynamic (MHD) has attracted the attention of a large number of scholars due to its diverse application to geophysics, astrophysics and many engineering problems, such as cooling of nuclear reactors, the boundary layer control in aerodynamics, cooling towers, MHD pumps, MHD bearings etc.

Convection in porous media has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. The phenomena of mass transfer are also very common in theory of stellar structure and observable effects are detectable, at least on the solar surface. The study of effects of magnetic field on free convection flow is important in liquid-metal, electrolytes and ionized gases. The thermal physics of hydro-magnetic problems with mass transfer is of interest in power engineering and metallurgy. The study of flows through porous media became of great interest due to its wide application in many scientific and engineering problems. Such type of flows can be observed in the movement of underground water resources, for filtration and water purification processes, the motion of natural gases and oil through oil reservoirs in petroleum engineering and so on. A large amount of research work has been done in the field of chemical reaction, heat and mass transfer. The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many braches of science and engineering.

An extensive contribution on heat and mass transfer flow has been made by Gebhart [1] to highlight the insight on the phenomena. Gebhart and Pera [2] studied heat and mass transfer flow under various flow situations. Therefore several authors, viz. Raptis and Soundalgekar [3], Agrawal et. al. [4], Jha and Singh [5], Jha and Prasad [6] have paid attention to the study of MHD free convection and mass transfer flows. Abdusattar [7] and Soundalgekar et. al. [8] also analyzed about MHD free convection through an infinite vertical plate. A numerical solution of unsteady free convection and mass transfer flow is presented by Alam and Rahman [9] when a viscous, incompressible fluid flows along an infinite vertical porous plate embedded in a porous medium is considered.Senapati and Dhal [10] have studied magnetic effect on mass and heat transfer of a hydrodynamic flow past a vertical oscillating plate in presence of chemical reaction. Senapati et al.[11] have discussed the mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink .

It is proposed to study the Chemical reaction effect on MHD Free Convection and Mass Transfer Flow past a Vertical Flat Plate with porous medium.

II. FORMULATION OF PROBLEM

Consider a two dimensional steady free convection heat and mass transfer flow of an incompressible, electrically conducting and viscous fluid past an electrically non-conducting continuously moving vertical flat plate through porous medium in presence chemically reaction species . Introducing a Cartesian co-ordinate system, *x*-axis is chosen along the plate in the direction of flow and *y*-axis normal to it. A uniform magnetic field $B_0(x)$ is applied normally to the flow region. The plate is maintained at a constant temperature T_w and the concentration is maintained at a constant value C_w. The temperature of ambient flow is T_∞ and the concentration of uniform flow is C_∞. Considering the magnetic Reynold's number to be very small, the induced magnetic field is assumed to be negligible, Considering the Joule heating and viscous dissipation terms to negligible and that the magnetic field is not enough to cause Joule heating, the term due to electrical dissipation is neglected in the energy equation. The density is considered a linear function of temperature and species concentration so that by usual Boussinesq's approximation, the steady flow is governed by the following equations:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta_c(C-C_\infty)-\frac{\sigma B_0^2 u}{\rho}-\frac{u}{K'} \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{K}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+Q(T-T_\infty) \qquad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_M\frac{\partial^2 T}{\partial y^2}+D_T\frac{\partial^2 T}{\partial y^2}-R'(C-C_\infty) \qquad (4)$$

with boundary conditions

$$\left.\begin{aligned} &u=U_0\ ,v=V_0(x).\ \mathrm{T}=\mathrm{T}_w\ ,C=C_w\ \text{ at y=0}\\ &u=0\,,v=0\,,T=T_\infty\ ,C=C_\infty\ as\ \ y\to\infty\end{aligned}\right\} \qquad (5)$$

where u and v are velocity components along x-axis and y-axis respectively, g is acceleration due to gravity, T is the temperature. k is thermal conductivity, σ is the electrical conductivity, D_M is the molecular diffusivity,U_0 is the uniform velocity, C is the concentration of species, $B_0(x)$ is the uniform magnetic field, C_P is the specific heat at constant pressure, Q is the constant heat source(absorption type), D_T is the thermal diffusivity, C(x) is variable concentration at the plate, $V_0(x)$ is the suction velocity, ρ is the density, ν is the kinematic viscosity, β is the volumetric coefficient of thermal expansion and β_c is the volumetric coefficient of thermal expansion with concentration and the other symbols have their usual meaning. For similarity solution, the plate concentration C(x) is considered to be $C(x)=C_\infty+(C_w-C_\infty)x$.

Let us introduce the following local similarity variables in equation

$$\psi=\sqrt{2\nu x U_0}\ f(\eta)\ ,\eta=y\sqrt{\frac{U_0}{2\nu x}}\ ,\theta=\frac{T-T_\infty}{T_w-T_\infty}\ ,\phi=\frac{C-C_\infty}{C_w-C_\infty} \qquad (6)$$

$$Pr=\frac{\mu C_p}{k}\ ,Gr=\frac{2xg\beta(T_w-T_\infty)}{U_0^2}\ ,Gm=\frac{2xg\beta_c(C_w-C_\infty)}{U_0^2}\ ,Sc=\frac{\nu}{D_M y}\ ,M=\frac{2x\sigma B_0^2}{U_0\rho}$$

$$\frac{1}{K}=\frac{2x}{U_0K'}\ ,S=\frac{2xQ}{U_0}\ ,R=\frac{2x\nu R'}{U_0}\ ,S_0=\frac{(T_w-T_\infty)}{(C_w-C_\infty)}\ ,f_w=V_0(x)\sqrt{\frac{2x}{\nu U_0}}$$

In equations (2) to (4) with boundary conditions (5) ,we get

$$f'''+ff''-\left(M+\frac{1}{K}\right)f'+Gr\theta+Gm\phi=0 \qquad (7)$$

$$\theta''+Prf\theta'-SPr\theta=0 \qquad (8)$$

$$\phi''+Scf\phi'-(2Scf'-R)\phi+S_0Sc\theta''=0 \qquad (9)$$

with boundary conditions

$$\left.\begin{aligned} &f=f_w,f'=1,\theta=1,\phi=1\quad at\ \ \eta=0\\ &f'=0\,,\theta=0,\phi=0\ as\ \eta\to\infty\end{aligned}\right\} \qquad (10)$$

where Gr is Grashof number, Gm modified Grashof number, M is magnetic number, Pr is prandtl number, Sc is Schmidt number, K permeability parameter porous medium ,S is heat source parameter ,S_0 is the Soret number, R chemical reaction parameter and f_w is the suction parameter.

III. METHOD OF SOLUTION

To introduce the new variable ξ in place of η ,let us substitute the following

$$\xi = \eta f_w \,, f(\eta) = f_w X(\xi), \theta(\eta) = f_w^2 Y(\xi)\ \phi(\eta) = f_w^2 Z(\xi) \tag{11}$$

In equations (7) – (9) with boundary condition (10),We get

$$X'''(\xi) + X''(\xi)X(\xi) = \epsilon\left(\left(M + \frac{1}{K}\right)X'(\xi) - GrY(\xi) - GmZ(\xi)\right) \tag{12}$$

$$Y''(\xi) + PrX(\xi)Y'(\xi) = \epsilon SPrY \tag{13}$$

$$Z''(\xi) + ScX(\xi)Z'(\xi) - 2ScX'(\xi)Z(\xi) + ScS_0Y''(\xi) = -\epsilon RZ(\xi) \tag{14}$$

with boundary conditions

$$\left.\begin{array}{l} X = 0, X' = \epsilon, Y = \epsilon, Z = \epsilon \ \ at\ \xi = 0 \\ X' = 0\,, Y = 0, Z = 0 \quad as\ \ \xi \to \infty \end{array}\right\} \tag{15}$$

where $\epsilon = \frac{1}{f_w^2}$ is very small as suction is very large.

let us substitute the following series in equations (12) to(14) with boundary condition(15)

$$\left.\begin{array}{l} X = 1 + \epsilon X_1 + \epsilon^2 X_2 + \epsilon^3 X_3 + \cdots. \\ Y = \epsilon Y_1 + \epsilon^2 Y_2 + \epsilon^3 Y_3 + \cdots. \\ Z = \epsilon Z_1 + \epsilon^2 Z_2 + \epsilon^3 Z_3 + \cdots. \end{array}\right\} \tag{16}$$

and by comparing the co-efficient of ϵ ,ϵ^2 and ϵ^3 ,we get

First order equations

$$\left.\begin{array}{l} X_1''' + X_1'' = 0 \\ Y_1'' + prY_1' = 0 \\ Z_1'' + ScZ_1' + ScS_0\ Y_1'' = 0 \end{array}\right\} \tag{17}$$

with boundry conditions

$$\left.\begin{array}{l} X_1 = 0, X_1' = 1, Y_1 = 1, Z_1 = 1 \text{ at } \xi = 0 \\ X_1' = 0, Y_1 = 0, Z_1 = 0\ \ as\ \xi \to \infty \end{array}\right\} \tag{18}$$

Second order equations

$$\left.\begin{array}{l} X_2''' + X_2'' + X_1X_1'' = \left(M + \frac{1}{K}\right)X_1' - GrY_1 - GmZ_1 \\ Y_2'' + Pr(Y_2' + X_1Y_1') = SPrY_1 \\ Z_2'' + Sc(Z_2' + X_1Z_1') - 2ScX_1'\,Z_1 + ScS_0X_2'' = -RZ_1 \end{array}\right\} \tag{19}$$

with boundry conditions

$$\left.\begin{array}{l} X_2 = 0, X_2' = 0, Y_2 = 0, Z_2 = 0 \text{ at } \xi = 0 \\ X_2' = 0, Y_2 = 0, Z_2 = 0\ \ as\ \xi \to \infty \end{array}\right\} \tag{20}$$

Third order equations

$$\left.\begin{array}{l} X_3''' + X_3'' + X_1X_2'' + X_1''X_2 = \left(M + \frac{1}{K}\right)X_2' - GrY_2 - GmZ_2 \\ Y_3'' + +Pr(X_2Y_1' + Y_2'X_1 + Y_3') = SPrY_2 \\ Z_3'' + Sc(Z_3' + Z_2'X_1 + Z_1'X_2) - 2Sc(Z_2X_1' + Z_1X_2') + ScS_0Y_3'' = -RZ_2 \end{array}\right\} \tag{21}$$

with boundry conditions

$$\left.\begin{array}{l} X_3 = 0, X_3' = 0, Y_3 = 0, Z_3 = 0 \text{ at } \xi = 0 \\ X_3' = 0, Y_3 = 0, Z_3 = 0\ \ as\ \xi \to \infty \end{array}\right\} \tag{22}$$

By solving (17) with boundary condition (18) we get

$$\left.\begin{array}{l} X_1 = 1 - e^{-\xi} \\ Y_1 = e^{-Pr\xi} \\ Z_1 = (1 - A_1)e^{-Sc\xi} + A_1 e^{-Pr\xi} \end{array}\right\} \tag{23}$$

By solving (19) with boundary condition (20) we get

$$X_2 = A_5 + (A_4 + \xi A_6)e^{-\xi} + \frac{e^{-2\xi}}{4} + A_2 e^{-Sc\xi} + A_3 e^{-Pr\xi}$$
$$Y_2 = (A_6 + \xi A_7)e^{-Pr\xi} + A_8 e^{-(1+Pr)\xi}$$
$$Z_2 = B_8 e^{-Sc\xi} + B_1 \xi e^{-Sc\xi} + B_2 e^{-Pr\xi} + B_3 e^{-(Sc+1)\xi} + B_4 e^{-(Pr+1)\xi} + B_5 e^{-2\xi} + B_6 e^{-\xi} + B_7 \xi e^{-\xi} \tag{24}$$

By solving (21) with boundary condition (22) we get

$$X_3 = A_{17} + A_{16} e^{-\xi} + A_9 e^{-(Pr+1)\xi} + A_{10} e^{-(Sc+1)\xi} + A_{11} e^{-Pr\xi} + A_{12} e^{-Sc\xi} + \frac{2}{45} e^{-3\xi} + A_{13} e^{-2\xi} + A_{14} \xi e^{-\xi} + A_{15} \xi^2 e^{-\xi}$$

$$Y_3 = A_{18} e^{-Pr\xi} + A_{19} e^{-(Sr+Pr)\xi} + A_{20} e^{-(2+Pr)\xi} + \frac{A_3}{2} e^{-2Pr\xi} + A_{21} e^{-(1+Pr)\xi} + A_{22} \xi e^{-Pr\xi} + A_{23} \xi^2 e^{-Pr\xi} + A_{24} \xi e^{-(1+Pr)\xi}$$

$$Z_3 = B_9 \xi e^{-Sc\xi} + B_{10} e^{-Pr\xi} + B_{11} e^{-(1+Sc)\xi} + B_{12} e^{-(1+Pr)\xi} + B_{13} e^{-(Pr+Sc)\xi} + B_{14} e^{-(2+Pr)\xi} + B_{15} e^{-(2+Sc)\xi} + B_{16} e^{-2Pr\xi} + B_{17} e^{-2\xi Sc} + B_{18} e^{-2\xi} + B_{20} e^{-\xi} + B_{21} \xi e^{-\xi} + B_{22} \xi e^{-2\xi} + B_{23} \xi^2 e^{-Sc\xi} + B_{24} \xi e^{-Pr\xi} + B_{25} \xi e^{-(1+Sc)\xi} + B_{26} \xi e^{-(1+Pr)\xi} + B_{27} \xi^2 e^{-Pr\xi} + B_{28} \xi e^{-Pr\xi} + B_{29} e^{-Sc\xi} \tag{25}$$

Using equations (16) in equation (11) with the help of equations (23) to (25) we have obtained the velocity, the temperature and concentration fields as follows

Velocity Distribution

$$u = U_0 f'(\eta) = U_0 f_w^2 X'(\xi) = U_0[X_1'(\xi) + \epsilon X_2'(\xi) + \epsilon^2 X_3'(\xi)] \tag{26}$$

Temperature Distribution

$$\theta = f_w^2 Y(\xi) = Y_1(\xi) + \epsilon Y_2(\xi) + \epsilon^2 Y_3(\xi) \tag{27}$$

and mass concentration Distribution

$$\phi = f_w^2 Z(\xi) = Z_1(\xi) + \epsilon Z_2(\xi) + \epsilon^2 Z_3(\xi) \tag{28}$$

The main quantities of physical interest are the local skin-friction, local Nusselt number and the local Sherwood number. The equation defining the wall skin-friction as

$$\mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$$

So the dimensionless skin friction is

$$\tau = 1 + \epsilon\left(A_6 - A_4 - PrA_3 - ScA_2 - \frac{1}{2}\right) + \epsilon^2\left(A_{17} - A_{16} - (Pr+1)A_9 - (Sc+1)A_{10} - PrA_{11} - ScA_{12} - 2A_{13} + A_{14} - \frac{2}{15}\right)$$

The local Nusselt number is defined as $-\left(\frac{\partial T}{\partial y}\right)_{y=0}$

So the dimensionless Nusselt Number is

$$Nu = -Pr + \epsilon\big((-A_6 Pr + A_7) - (1+Pr)A_8\big) + \epsilon^2(-PrA_{18} - (Sr+Pr)A_{19} - (2+Pr)A_{20} - 2PrA_3 - (1+Pr)A_{21} + A_{22} + A_{24})$$

The local Sherwood number is defined as $-\left(\frac{\partial C}{\partial y}\right)_{y=0}$

So the dimensionless Sherwood number

$$Sh = -Sc(1-A_1) - PrA_1 + \epsilon(-ScB_8 + B_1 - PrB_2 - (Sc+1)B_3 - (Pr+1)B_4 - 2B_5 - B_6 + B_7) + \epsilon^2(B_9 - PrB_{10} - (1+Sc)B_{11} - (1+Pr)B_{12} - (Pr+Sc)B_{13} - (2+Pr)B_{14} - (2+Sc)B_{15} - 2PrB_{16} - 2ScB_{17} - 2B_{18} - B_{20} + B_{21} + B_{22} + B_{24} + B_{25} + B_{26} + B_{28} - ScB_{29})$$

where

$A_1 = \frac{ScS_0Pr^2}{ScPr - Pr^2}$, $A_2 = \frac{Gm(1-A_1)}{Sc^3 - Sc^2}$, $A_3 = \frac{Gr + GmA_1}{Pr^3 - Pr^2}$, $A_4 = \frac{1}{2} + M + \frac{1}{K} - PrA_2 - ScA_1$,
$A_5 = -\left(A_4 + A_2 + A_3 + \frac{1}{4}\right)$, $A_6 = \frac{Pr^2}{(1+Pr)}$, $A_7 = \frac{Pr^2 + SPr}{Pr}$, $A_8 = -\frac{Pr^2}{(1+Pr)}$

$$, A_9 = \frac{A_3+A_8Gr+GmB_9-A_3Pr^2}{(Pr+1)^3-(Pr+1)^2}, A_{10} = \frac{A_2+GmB_3-A_2Sc^2}{(Sc+1)^3-(Sc+1)^2}, A_{11} = \frac{A_3Pr^2+Gr\ A_6+GmB_2+\left(M+\frac{1}{K}\right)PrA_3}{Pr^3-Pr^2},$$

$$A_{12} = \frac{A_2Sc^2+Sc\left(M+\frac{1}{K}\right)A_2+GmA_8}{Sc^3-Sc^2}, A_{13} = \frac{-2A_6+1+GmB_5+\left(M+\frac{1}{K}\right)/2}{4},$$

$$A_{14} = -\left(A_5 + A_4 + 2A_6 + GmB_6 - \left(M + \frac{1}{K}\right)A_6A_4\right) - 2\left(A_6 + GmB_1 + A_6\left(M + \frac{1}{K}\right)\right),$$

$$A_{15} = \frac{\left(A_6+GmB_1+A_6\left(M+\frac{1}{K}\right)\right)}{-2},$$

$$A_{16} = -A_9(Pr + 1) - A_1(Sc + 1) - PrA_{11} - ScA_{12} - 2A_{13} + A_{14} + 2A_{15} - \frac{2}{15},$$

$$A_{17} = -\left(A_{16} + A_9 + A_{10} + A_{11} + A_{12} + A_{13} + \frac{2}{45}\right)$$

$$A_{19} = \frac{Pr^2A_2}{(Sc+Pr)^2-Pr(Sc+Pr)}, A_{20} = \frac{Pr^2-4PrA_8(Pr+1)}{4((2+Pr)^2-Pr(2+Pr))},$$

$$A_{21} = \frac{SPrA_8+Pr^2A_9+PrA_8(1+Pr)-Pr^2A_6+PrA_7}{(1+Pr)^2-Pr(1+Pr)} + \frac{Pr^2A_6-Pr^2A_7}{(1+Pr)},$$

$$A_{22} = \frac{SPrA_6+Pr^2A_5+Pr^2A_6-PrA_7}{-Pr} + \frac{SPrA_7+Pr^2A_7}{-Pr^2},$$

$$A_{23} = \frac{SPrA_7+Pr^2A_7}{2}, A_{24} = \frac{Pr^2(A_6-A_7)}{1+Pr}, A_{18} = -\left(A_{19} + A_{20} + A_{21} + \frac{A_3}{2}\right)$$

$$B_1 = \left(Sc(A_1 - 1) + A_2Sc^2 + \frac{R(1-A_1)}{Sc}\right), B_2 = \frac{ScPrA_1-ScS_0A_3Pr^2-RA_1}{Pr^2-PrSc},$$

$$B_3 = \frac{2Sc(1-A_1)+Sc^2(A_1-1)}{(Sc+1)^2-Sc(Sc+1)}, B_4 = \frac{2ScA_1-ScPrA_1}{(Pr+1)^2-Sc(Pr+1)}, B_5 = \frac{ScS_0}{4-2Sc},$$

$$B_6 = \frac{2A_6ScS_0-ScS_0A_6}{1-Sc} + \frac{ScS_0A_6(Sc-2)}{(1-Sc)^2}, B_7 = -\frac{ScS_0A_6}{1-Sc},$$

$$B_8 = -(B_2 + B_3 + B_4 + B_5 + B_6)$$

$$B_9 = \frac{-RB_8+Sc^2B_8+Sc^2(1-A_1)A_5}{-Sc} + \frac{-RB_1+Sc^2B_1}{-Sc^2},$$

$$B_{10} = \frac{-RB_2-ScS_0A_{18}Pr^2+2PrScS_0A_{22}-2ScS_0A_{23}+PrScA_1A_5+ScPrB_2}{Pr^2-ScPr} + \frac{(2Pr-Sc)\left(2A_{23}PrScS_0-ScS_0A_{22}Pr^2\right)}{Pr^2(Pr-Sc)^2} + \frac{-ScS_0A_{23}}{(Pr+Sc)^2}$$

$$B_{11} = \frac{(2+3Sc)\left(2ScB_1-Sc^2B_1-Sc^2(A_1-1)A_6-2Sc(1-A_1)A_6\right)}{(1+Sc)^2(1+2Sc)^2} + \frac{-RB_3+2ScB_8+2Sc(1-A_1)(A_6-A_4)-A_4Sc^2(A_1-1-B_8)+Sc(Sc+1)B_3}{(Sc+1)^2-Sc(Sc+1)}$$

$$B_{12} = \frac{-RB_4-(ScS_0A_{21}+ScS_0A_{24})(1+Pr)^2+ScB_4(Pr+1)-ScPr(B_2-A_4A_1)+2Sc(B_2+A_6-A_4)}{(Pr+1)^2-Sc(Pr+1)} + \frac{(2+2Pr+Sc)\left(ScA_1A_6(Pr-2)-2ScS_0A_{24}(Pr+1)\right)}{(1+Pr)(1+Pr+Sc)^2}$$

$$B_{13} = \frac{-ScS_0A_{19}(Sc+Pr)^2+(Sc-2Pr)ScA_3(1-A_1)+ScA_1A_2(Pr-2Sc)}{(Pr+Sc)^2-Sc(Pr+Sc)}$$

$$B_{14} = \frac{-ScS_0A_{20}(2+Pr)^2+2ScB_4-Sc(1+Pr)B_4-ScA_1+\left(\frac{ScPr\ A_1}{4}\right)}{(Pr+2)^2-Sc(Pr+2)}$$

$$B_{15} = \frac{ScB_3(1-Sc)+(1-A_1)\left(\frac{Sc^2}{4}-Sc\right)}{(Sc+2)^2-Sc(Sc+2)}, B_{16} = \frac{-2ScS_0Pr^2A_3-ScPrA_1A_3}{4Pr^2-2PrSc},$$

$$B_{17} = \frac{A_2(A_1-1)}{2}, B_{18} = \frac{-RB_5+Sc(B_6+2B_5+B_7)}{4-2Sc} + \frac{ScB_7(4-Sc)}{4(2-Sc)^2}$$

$$B_{20} = \frac{-RB_6+Sc(B_6-B_7)}{1-Sc} + \frac{(2+Sc)(-RB_7+3ScB_7)}{(1+Sc)^2}$$

$$B_{21} = \frac{B_7(Sc-R)}{1+Sc}, B_{22} = \frac{ScB_7}{2(2-Sc)}, B_{23} = \frac{B_1(Sc^2-R)}{-2Sc},$$

$$B_{24} = \frac{2PrScS_0A_{23}-ScS_0Pr^2A_{22}}{Pr(Pr-Sc)}, B_{25} = \frac{(2Sc-Sc^2)(B_1+A_6(A_1-1))}{(1+Sc)(1+2Sc)}$$

$$B_{26} = \frac{-ScS_0A_{24}(Pr+1)+(ScPr-2Sc)A_6A_1}{(1+pr)(1+Pr+Sc)}, B_{27} = \frac{-ScS_0A_{23}Pr^2}{Pr(Pr+Sc)}$$

$$B_{28} = \frac{-ScS_0A_{23}Pr^2(4Pr+2Sc)}{Pr^2(Pr+Sc)^2}$$

$$B_{29} = -(B_{10} + B_{11} + B_{12} + B_{13} + B_{14} + B_{15} + B_{16} + B_{17} + B_{18} + B_{20})$$

IV. RESULTS AND DISCUSSION

In this paper we have studied the Chemical reaction effect on MHD Free Convection and Mass Transfer Flow past a Vertical Flat Plate with porous medium. The effect of the parameters Gr, Gm, M, K, R, Pr, S,So,fw, and Sc 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, heat and mass concentration are taken w.r.t. η and the values of Skin friction, Nusselt number and Sherwood Number are shown in the table for different values of flow parameters

Velocity profiles: The velocity profiles are depicted in Figs 1-4. Figure-(1) shows the effect of the parameters Gr and Gm on velocity at any point of the fluid, when Sc=0.22,Pr=0.71,M=2,K=2,R=2 ,So=0.5 ,S=0.5 and fw=0.5.It is noticed that the velocity decreases with the increase Grashof number (Gr), where as increases with the increase of Modified Grashof number (Gm).

Figure-(2) shows the effect of the parameters M,K and R on velocity at any point of the fluid , when Sc=0.22,Pr=0.71, Gm=15,Gr=10 ,So=0.5 ,S=0.5 and fw=0.5. . It is noticed that the velocity increases with the increase of permeability of porous medium (K) and Chemical reaction parameter (R),where as decreases with the increase of magnetic parameter (M).

Figure-(3) shows the effect of the parameters So,Sc and fw on velocity at any point of the fluid, when Pr=0.71,M=2,K=2,R=2 ,Gr=10 and Gm=15 .It is noticed that the velocity decreases with the increase of Soret number (So) where as increases with Schmidt number (Sc) and suction parameter (fw).

Figure-(4) shows the effect of the parameters S and Pr on velocity at any point of the fluid, when Sc=0.22,Gr=10,M=2,K=2,R=2 ,So=0.5 ,Gm=15 and fw=0.5.It is noticed that the velocity decreases with the increase of source parameter (S),where as increases with Prandtl number (Pr)

Heat Profile: Figure-(5) shows the effect of the parameters fw, Pr and So on Heat profile at any point of the fluid ,when Sc=0.22,Gr=10,M=2,K=2,R=2 and Gm=15 . It is noticed that the temperature falls in the increase of Prandtl number (Pr) and suction parameter (fw) , whereas temperature rises with Soret number (So).

Mass concentration profile: Figure-(6) shows the effect of the parameters Scand R on mass concentration profile at any point of the fluid, when Gr=10,M=2,K=2,S=2 ,So=2 ,Gm=15 and fw=0.5.It is noticed that the mass concentration increases with the increase of Schmidt number (Sc) and chemical reaction parameter(R) .

Figure-(7) shows the effect of the parameters So , S and fw on mass concentration profile at any point of the fluid ,when Pr=0.71, Sc=0.22,Gr=10,M=2,K=2,R=2 , Gm=15 .It is noticed that the mass concentration increases with the increase of suction parameter (fw) and Soret number (So),whereas decreases with the increase of source parameter (S).

Figure-(8) shows the effect of the parameters Pr and M on mass concentration profile at any point of the fluid when Gr=10,K=2,S=2 ,So=2 ,Gm=15 ,Sc=0.22 and fw=0.5 .It is noticed that the mass concentration decreases with the increase of Prandtl number (Pr) and magnetic parameter (M).

Skin friction: The numerical values of skin-friction (τ) at the plate due to variation in Grashof number (Gr), modified Grashof number (Gm), heat source parameter (S), Soret number (So), magnetic parameter (M), Schmit number (Sc), suction parameter (fw), and Prandtl number (Pr) for externally cooled plate is given in Table-1. It is observed that both the presence of So in the fluid flow decrease the skin-friction .The increase of M, Gr and Gm decreases the skin-friction while an increase in Pr, Sc,fw and R increase the skin-friction.

Table-2 represents the skin-friction for heating of the plate and in this table it is clear that Gm,Sc,So,M and K play the reverses phenomena of the Table-(1) are happened.

Nusselt Number: Table-(3) illustrates the effect of the parameters Pr ,S and fw on Nusselt number at plate, It is observed that Nusselt number increases at the plate with the increase of prandtl number (Pr) ,whereas increases with the increase of source parameter (S) and suction parameter (fw).

Sherwood Number: Table-(4), illustrates the effect of the parameters of Sc, S, So, fw, Pr and R on Sherwood Number at plate. It is noticed that Sherwood Number at plate increases with the increase of Schmidt number (Sc) , reaction parameter (R) and Soret number (So), whereas decreases with the increase of source parameter (S), Prandtl number (Pr) and suction parameter (fw).

Table-1: Numerical values of Skin-Friction (τ) due to cooling of the plate.

Sl.No	Gm	Gr	Pr	Sc	S	So	R	fw	M	K	Skin Friction(τ)
1	10	10	0.71	0.22	2	2	2	0.5	2	2	-164220
2	12	10	0.71	0.22	2	2	2	0.5	2	2	-167189
3	15	10	0.71	0.22	2	2	2	0.5	2	2	-171643
4	10	12	0.71	0.22	2	2	2	0.5	2	2	-211390
5	10	15	0.71	0.22	2	2	2	0.5	2	2	-291833
6	10	10	0.71	0.3	2	2	2	0.5	2	2	-137359
7	10	10	0.8	0.22	2	2	2	0.5	2	2	-150937
8	10	10	0.71	0.22	2	2	2	0.5	4	2	-275392
9	10	10	0.71	0.22	2	2	2	0.5	5	2	-330965
10	10	10	0.71	0.22	2	2	2	0.5	2	4	-150321

11	10	10	0.71	0.22	2	2	2	0.5	2	5	-147541
12	10	10	0.71	0.22	2	2	3	0.5	2	2	-141856
13	10	10	0.71	0.22	2	2	4	0.5	2	2	-101270
14	10	10	0.71	0.22	2	3	2	0.5	2	2	-195444
15	10	10	0.71	0.22	2	4	2	0.5	2	2	-223418
16	10	10	0.71	0.22	2	2	2	0.7	2	2	-42991
17	10	10	0.71	0.22	2	2	2	0.8	2	2	-25290

Table-2: Numerical values of Skin-Friction (τ) due to heating of the plate.

Sl.No	Gm	Gr	Sc	Pr	S	So	R	fw	M	K	Skin Friction(τ)
01	-10	-10	0.22	0.71	2	2	2	0.5	2	2	17342
02	-10	-15	0.22	0.71	2	2	2	0.5	2	2	15876
03	-10	-20	0.22	0.71	2	2	2	0.5	2	2	14410
04	-15	-10	0.22	0.71	2	2	2	0.5	2	2	-25545
05	-20	-10	0.22	0.71	2	2	2	0.5	2	2	-10055
06	-10	-10	0.22	0.71	2	2	2	0.5	3	2	73030
07	-10	-10	0.22	0.71	2	2	2	0.5	4	2	128727
08	-10	-10	0.22	0.71	2	2	2	0.5	2	3	8062
09	-10	-10	0.22	0.71	2	2	2	0.5	2	4	4322
10	-10	-10	0.22	0.71	2	2	3	0.5	2	2	-62253
11	-10	-10	0.22	0.71	2	2	4	0.5	2	2	-16007
12	-10	-10	0.22	0.71	2	3	2	0.5	2	2	23021
13	-10	-10	0.22	0.71	2	4	2	0.5	2	2	31947
14	-10	-10	0.22	0.71	3	2	2	0.5	2	2	17342
15	-10	-10	0.22	0.8	2	2	2	0.5	2	2	23868
16	-10	-10	0.3	0.71	2	2	2	0.5	2	2	8085

Table-3: Numerical values of the Rate of Heat Transfer (Nu)

Sl.No	S	Pr	fw	Nu
01	2	0.71	0.5	7304
02	2	0.8	0.5	8333
03	2	0.9	0.5	9534
04	3	0.71	0.5	7173
05	4	0.71	0.5	6996
06	2	0.71	0.8	741
07	2	0.71	0.9	361

Table-4: Numerical values of the Rate of Mass Transfer (Sh)

Sl.No	S	So	Sc	Pr	fw	R	Sh
01	2	2	0.22	0.71	0.5	2	-8388
02	3	2	0.22	0.71	0.5	2	-8423
03	4	2	0.22	0.71	0.5	2	-8463
04	2	3	0.22	0.71	0.5	2	-6891
05	2	4	0.22	0.71	0.5	2	1296
06	2	2	0.22	0.8	0.5	2	-8639
07	2	2	0.22	0.9	0.5	2	-10683
08	2	2	0.3	0.71	0.5	2	-6358
09	2	2	0.4	0.71	0.5	2	11542
10	2	2	0.22	0.71	0.5	3	-382
11	2	2	0.22	0.71	0.5	4	16398
12	2	2	0.22	0.71	0.6	2	-4059
13	2	2	0.22	0.71	0.7	2	-2200

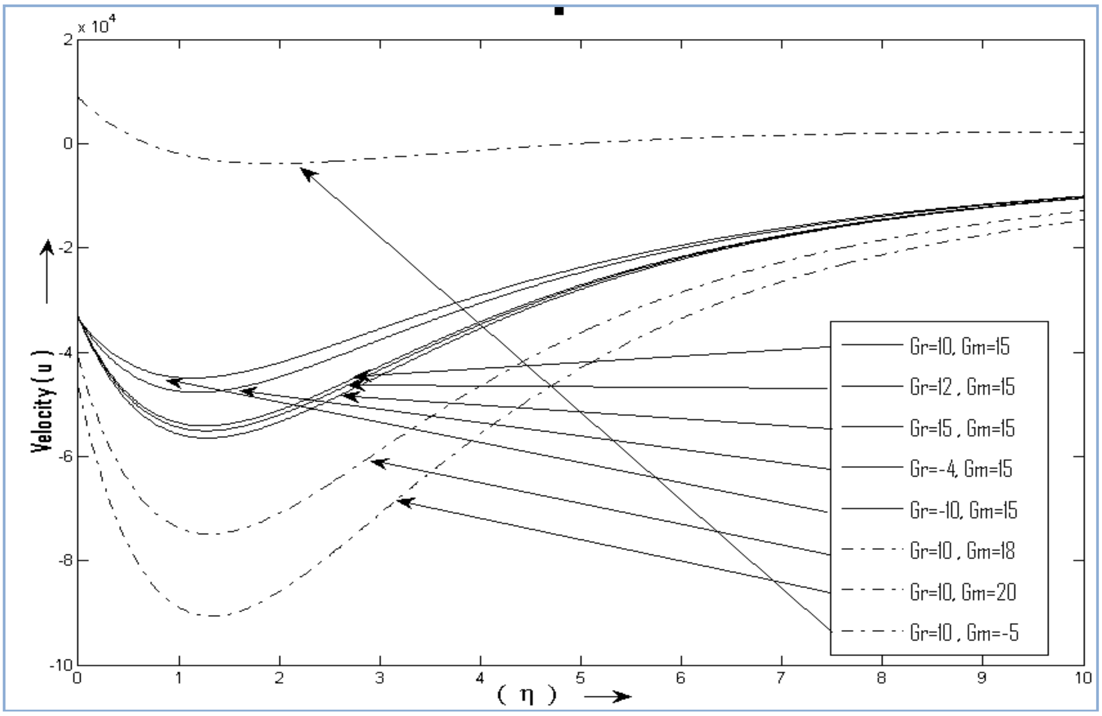

Fig-(1) Effect of Gr and Gm on velocity profile when Sc=0.22,Pr=0.71,M=2,K=2,R=2 ,So=0.5 ,S=0.5 and fw=0.5.

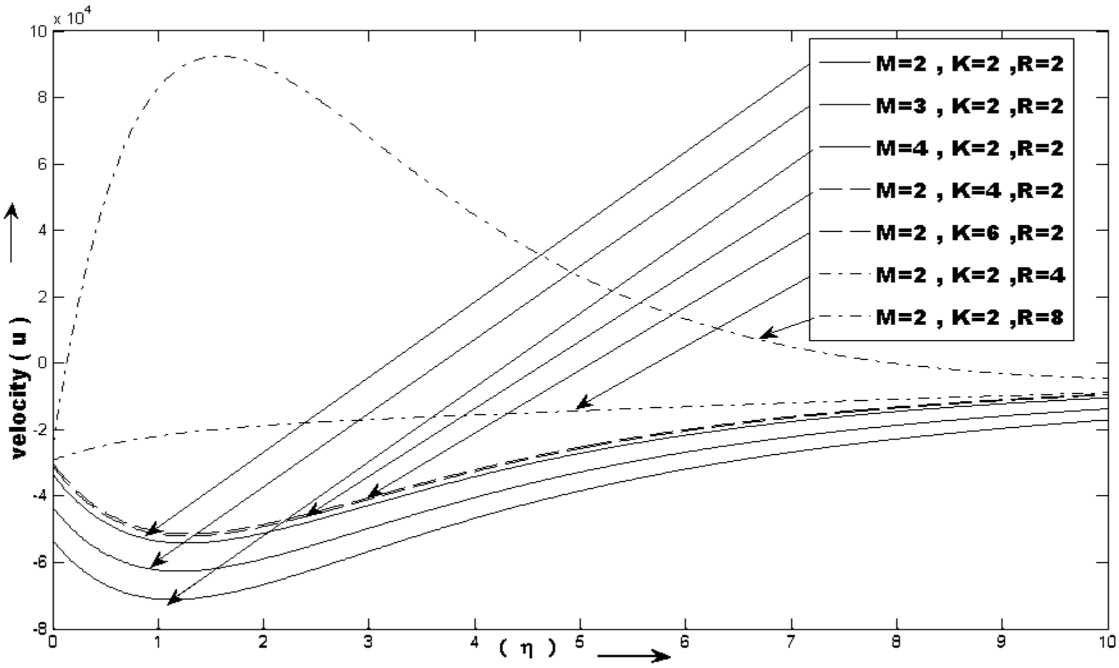

Fig-(2) Effect of M,K and R on velocity profile when Sc=0.22,Pr=0.71, Gm=15,Gr=10 ,So=0.5 ,S=0.5 and fw=0.5.

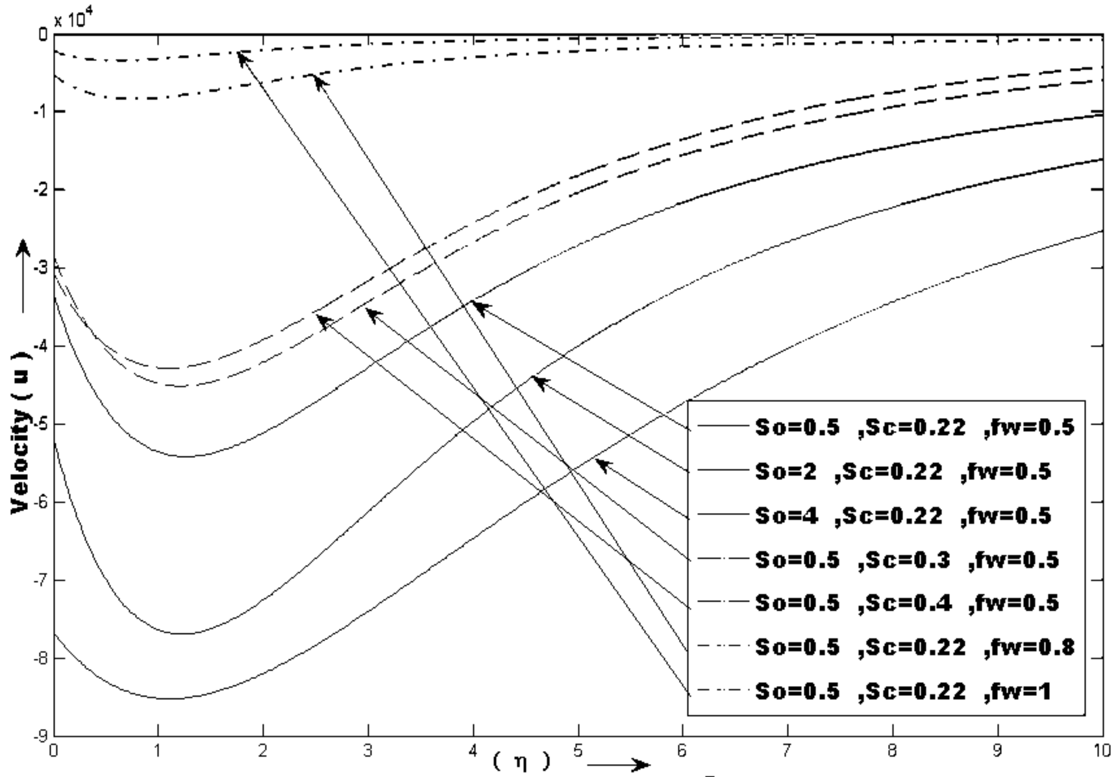

Fig-(3) Effect of So ,Sc and fw on velocity profile when Pr=0.71,M=2,K=2,R=2 ,Gr=10 and Gm=15 .

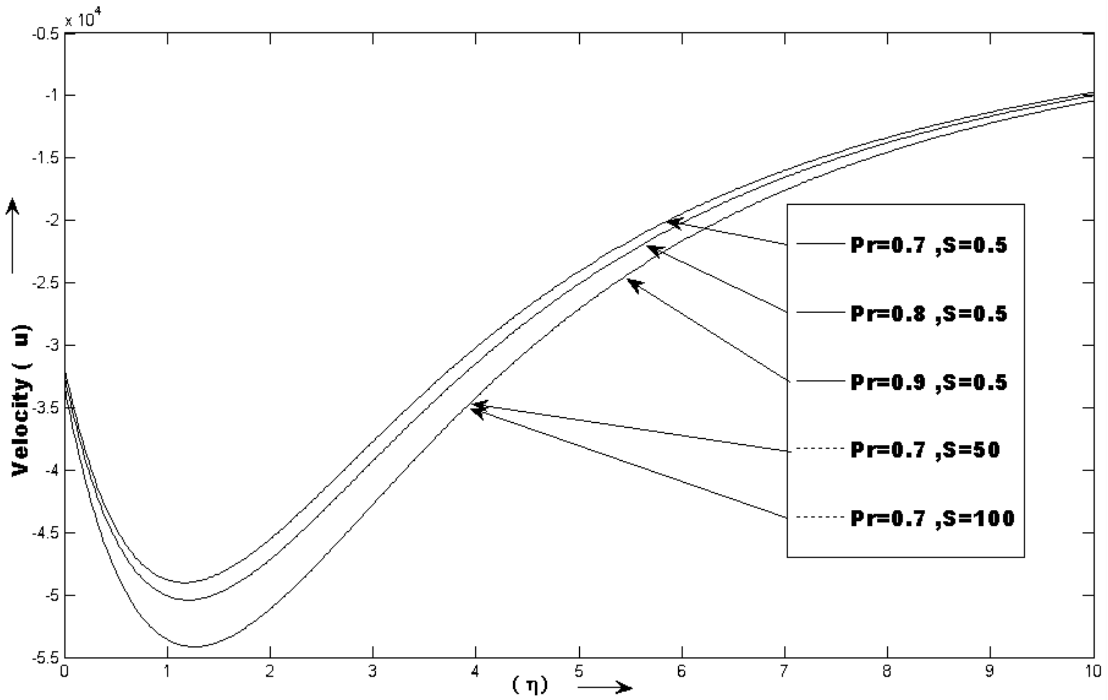

Fig-(4) Effect of Pr and S on velocity profile when Sc=0.22,Gr=10,M=2,K=2,R=2 ,So=0.5 ,Gm=15 and fw=0.5.

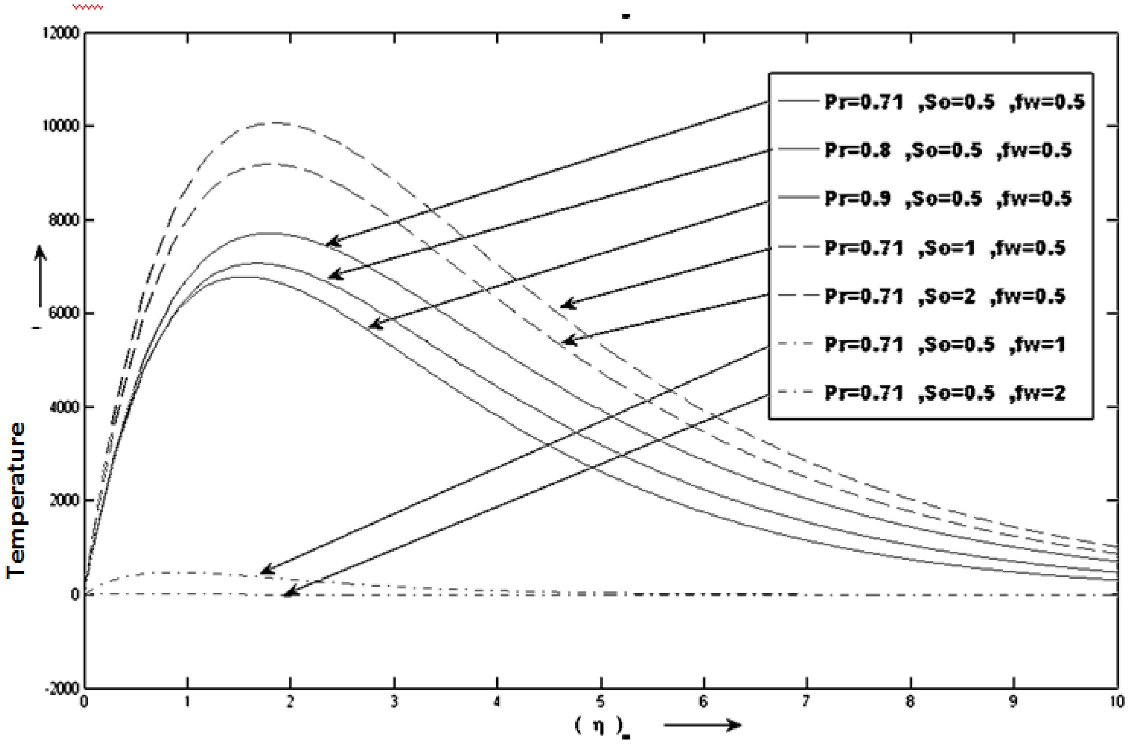

Fig-(5) Effect of fw,Pr and So on Temperature profile when Sc=0.22,Gr=10,M=2,K=2,R=2 and Gm=15

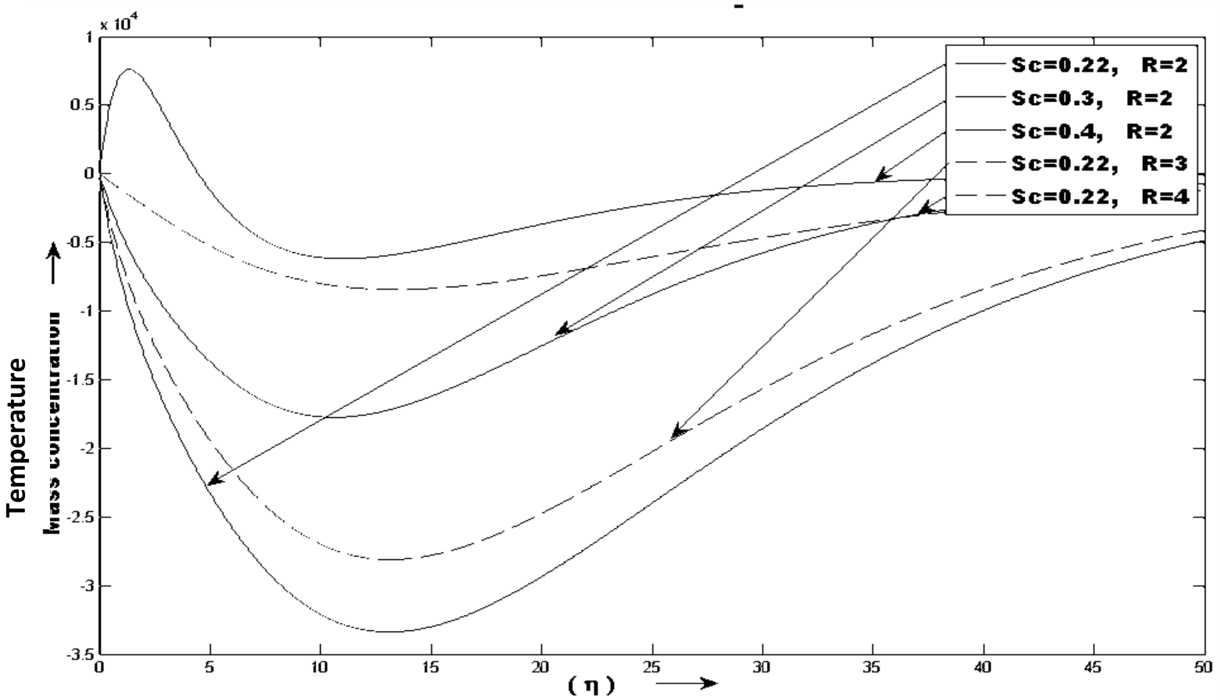

Fig-(6) Effect of R and Sc on mass concentration profile when Gr=10,M=2,K=2,S=2 ,So=2 ,Gm=15 and fw=0.5.

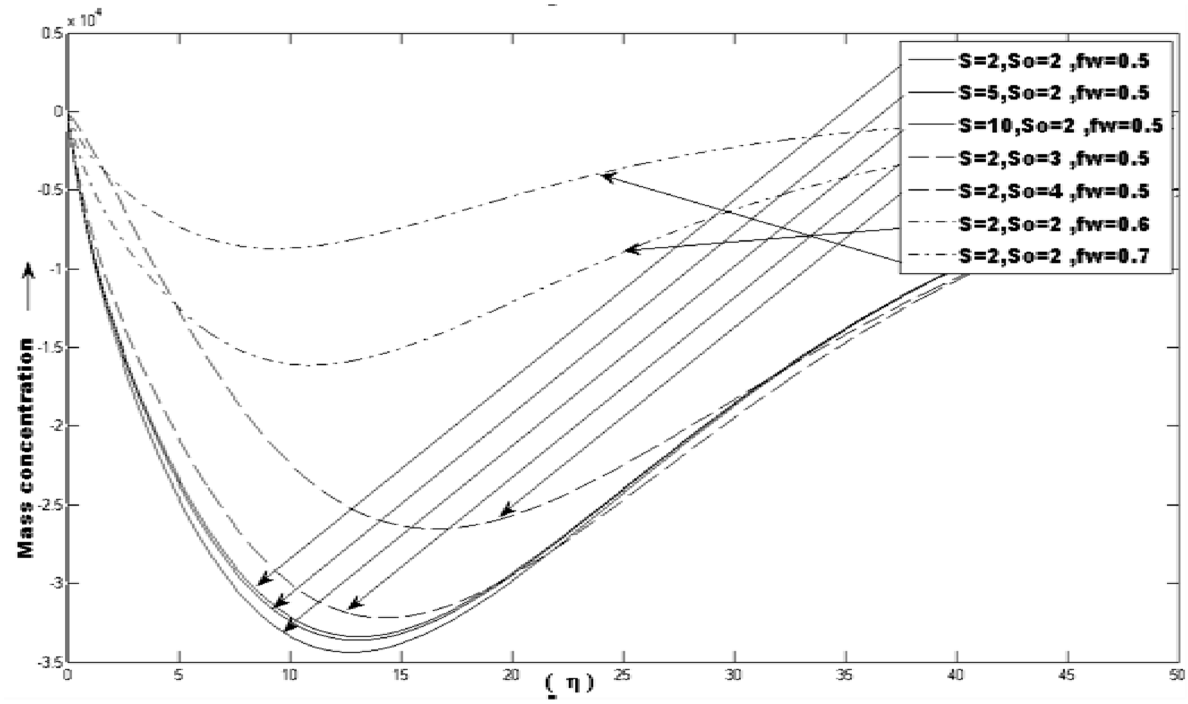

Fig-(7) Effect of S.So and fw on mass concentration profile when Pr=0.71, Sc=0.22,Gr=10,M=2, K=2,R=2 , Gm=15 .

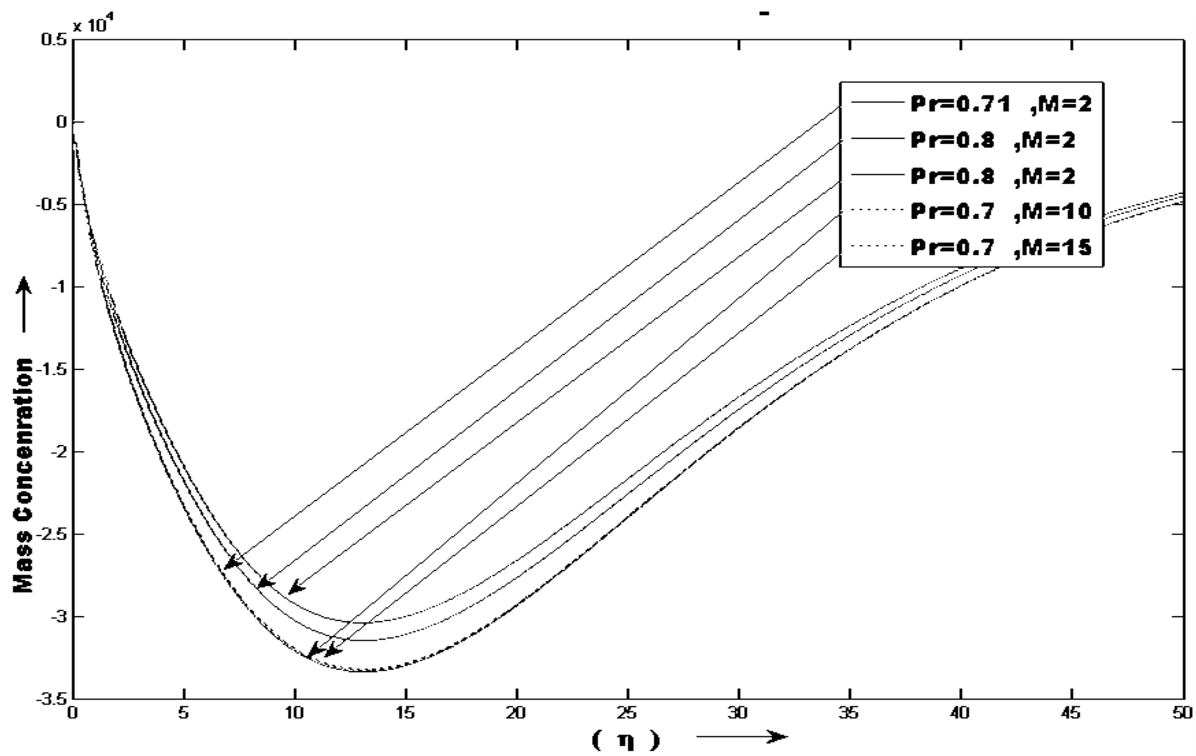

Fig-(8) Effect of Pr and M on mass concentration profile when Gr=10,K=2,S=2 ,So=2 ,Gm=15 ,Sc=0.22 and fw=0.5.

V. CONCLUSION

In this study, the following conclusions Chemical reaction effect on MHD Free Convection and Mass Transfer Flow past a Vertical Flat Plate with porous medium are set out:

i. The velocity increases with the increase in K, R,Sc,fw, and Pr, whereas decreases with the increase in of M,Gr, Gm ,So and S .

ii. The mass concentration of fluid increases with the increase of R,So,Sc and fw ,whereas decreases with increase of M,S,and Pr.

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