MHD Free Convective Heat and Mass Transfer Flow Past an Inclined Surface with Heat Generation and Chemical reaction

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ABSTRACT: A steady two-dimensional MHD free convection and mass transfer flow past an inclined semi-infinite Surface in the presence of heat generation, large suction and chemical reaction 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 mathematical expressions for velocity field, temperature field, concentration field, skin friction, rate of heat and mass transfer have been constituted. The results are discussed in detail with the help of graphs and tables to observe the effect of different parameters.

KEY WORDS: MHD, Free convection, inclined surface, Heat generation, Mass transfer and large suction, Chemical reaction.

INTRODUCTION:

Magneto-hydrodynamics (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, it also attracts 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.

The phenomena of mass transfer are also very common in theory of stellar structure, and observable effects of mass transfer are also 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 has a vital role in power engineering and metallurgy. A large amount of research work has been taken place in the field of chemical reaction as well as 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 branches of science and engineering. The problem of free convection and mass transfer flow of an electrically conducting fluid past an inclined heated surface under the influence of a magnetic field has attracted interest in the minds of scientists in view of its application to geophysics, astrophysics and many engineering problems, such as cooling of nuclear reactors, the boundary layer control in aerodynamics and cooling towers.

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 [7] have paid attention to the study of MHD free convection and mass transfer flows. Senapati and Dhal [12] have studied magnetic effect on mass and heat transfer of a hydrodynamic flow past a vertical oscillating plate in the presence of chemical reaction. Umemura and Law [6] developed a generalized formulation for the natural convection boundary layer flow over a flat plate with arbitrary inclination. They found that the flow characteristics depend only on the extent of inclination but also on the distance from the leading edge. Hossain et al. [8] studied the free convection flow from an isothermal plate inclined at a small angle to the horizontal. Recently, Anghel et al.[9] presented a numerical solution of free convection flow past an inclined surface. Very recently, Chen [10] performed an analysis to study the natural convection flow over a permeable inclined surface with variable wall temperature and concentration. Rahman et al [13] have studied the MHD Free Convective Heat and Mass Transfer Flow Past an Inclined Surface with Heat Generation.

It is proposed to study the MHD Free Convective Heat and Mass Transfer Flow Past an Inclined Surface with Heat Generation and Chemical reaction.

FORMULATION OF PROBLEM:

Consider a two dimensional steady free convection flow of an incompressible electrically conducting viscous fluid past along an electrically non-conducting continuously moving semi-infinite inclined plate with an acute angle α to the vertical in the presence of chemical reaction species along with heat and mass transfer. Introducing a Cartesian co-ordinate system, x-axis is chosen along the plate in the direction of flow and y-axis normal to it. The flow is assumed to be in the x-direction, which is taken along the semi-infinite inclined plate and y-axis normal to it. A magnetic field of uniform strength Bo is introduced normal to the direction of the flow. 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 be negligible and that of the magnetic field is not enough to cause Joule heating, so the term electrical dissipation (Ohmic 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 (see Sivasankaran et al. [11]) is governed by the following equations:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)\cos\alpha+g\beta_c(C-C_\infty)\cos\alpha-\frac{\sigma B_0^2 u}{\rho} \tag{2}$$

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

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

with boundary conditions

$$\left.\begin{array}{l} u=U_0,\ v=V_0(x),\ T=T_w,\ C=C_w\ \text{at } y=0 \\ u=0,\quad v=0,\quad T=T_\infty,\ C=C_\infty\ \text{as } y\to\infty \end{array}\right\} \tag{5}$$

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 the 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), R' is the chemical reaction parameter, 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 meanings. 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

$$\left.\begin{array}{l} \psi=\sqrt{2\nu x U_0}\,f(\eta),\quad \eta=y\sqrt{\frac{U_0}{2\nu x}},\quad \theta=\frac{T-T_\infty}{T_w-T_\infty},\quad \phi=\frac{C-C_\infty}{C_w-C_\infty}, \\ Pr=\frac{\mu C_p}{k},\quad Gr=\frac{2xg\beta(T_w-T_\infty)}{U_0^2},\quad Gm=\frac{2xg\beta_c(C_w-C_\infty)}{U_0^2}, \\ Sc=\frac{\nu}{D_M y},\ M=\frac{2x\sigma B_0^2}{U_0\rho},\ S=\frac{2xQ}{U_0},\ R=\frac{2x\nu R'}{U_0},\ f_w=V_0(x)\sqrt{\frac{2x}{\nu U_0}} \end{array}\right\} \tag{6}$$

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

$$f'''+ff''-Mf'+Gr\theta\cos\alpha+Gm\phi\cos\alpha=0 \tag{7}$$

$$\theta''+Prf\theta'-SPr\theta=0 \tag{8}$$

$$\phi''+Scf\phi'-(2Scf'-R)\phi=0 \tag{9}$$

with boundary conditions

$$\left.\begin{array}{l} f=f_w,\ f'=1,\ \theta=1,\ \phi=1\quad at\ \eta=0 \\ f'=0,\quad \theta=0,\quad \phi=0\quad as\ \eta\to\infty \end{array}\right\} \tag{10}$$

where Gr is Grashof number, Gm is modified Grashof number, M is magnetic number, Pr is Prandtl number, Sc is Schmidt number, S is heat source parameter, R is non-dimensional chemical reaction parameter and f_w is the suction parameter.

METHOD OF SOLUTION:

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

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

In equations (7) – (9) with boundary conditions (10), we get

$$X'''(\xi) + X''(\xi)X(\xi) = \epsilon(M(\xi) - GrY(\xi)cos\alpha - GmZ(\xi)cos\alpha) \quad (12)$$

$$Y''(\xi) + PrX(\xi)Y'(\xi) = \epsilon SPrY \quad (13)$$

$$Z''(\xi) + ScX(\xi)Z'(\xi) - 2ScX'(\xi)Z(\xi) = -\epsilon RZ(\xi) \quad (14)$$

with boundary conditions

$$\left.\begin{array}{l} X = 1,\ X' = \epsilon,\ \ Y = \epsilon,\ \ Z = \epsilon \ at \ \ \xi = 0 \\ X' = 0\,,\ \ Y = 0,\ \ Z = 0 \ \ \ as \ \ \xi \to \infty \end{array}\right\} \quad (15)$$

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

Let us express X, Y, Z in the series form as follows:

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

Let us substitute the above series in equations (12) to (14) with boundary condition (15).
Comparing the co-efficient of ϵ , ϵ^2 and ϵ^3 after substitution, we get the First order, second order and third order equations.

The First order equations of X_1'', Y_1' and Z_1' are as follows:

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

with boundary conditions

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

The Second order equations of X_2', Y_2 and Z_2 are as follows:

$$\left.\begin{array}{l} X_2''' + X_2'' + X_1X_1'' = MX_1' - Grcos\alpha Y_1 - Gmcos\alpha Z_1 \\ Y_2'' + Pr(Y_2' + X_1Y_1') = SPrY_1 \\ Z_2'' + Sc(Z_2' + X_1Z_1') - 2ScX_1'\,Z_1 = -RZ_1 \end{array}\right\} \quad (19)$$

with boundary conditions

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

Third order equation of $X_3 with\ other\ equations$ are as follows:

$$\left.\begin{array}{l} X_3''' + X_3'' + X_1X_2'' + X_1''X_2 = MX_2' - Grcos\alpha Y_2 - Gmcos\alpha Z_2 \\ Y_3'' + +Pr(X_2Y_1' + Y_2'X_1 + Y_3') = SPrY_2 \\ Z_3'' + Sc(Z_3' + Z_2'X_1 + Z_1'X_2) - 2Sc(Z_2X_1' + Z_1X_2') = -RZ_2 \end{array}\right\} \quad (21)$$

with boundry conditions

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

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

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

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

$$\left.\begin{array}{l} X_2 = A_4 + (A_3 + \xi A_5)e^{-\xi} + \frac{e^{-2\xi}}{4} + A_1 e^{-Sc\xi} + A_2 e^{-Pr\xi} \\ Y_2 = (A_5 + \xi A_6)e^{-Pr\xi} + A_7 e^{-(1+Pr)\xi} \\ Z_2 = A_{10} e^{-Sc\xi} + A_8 \xi e^{-Sc\xi} + A_9 e^{-(Sc+1)\xi} \end{array}\right\} \quad (24)$$

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

$$\left.\begin{array}{l} X_3 = A_{19} + A_{18}e^{-\xi} + A_{11}e^{-(Pr+1)\xi} + A_{12}e^{-(Sc+1)\xi} + A_{13}e^{-Pr\xi} + A_{14}e^{-Sc\xi} \\ \qquad + \frac{2}{45}e^{-3\xi} + A_{15}e^{-2\xi} + A_{16}\xi e^{-\xi} + A_{17}\xi^2 e^{-\xi} \\ Y_3 = A_{20}e^{-Pr\xi} + A_{21}e^{-(Sr+Pr)\xi} + A_{22}e^{-(2+Pr)\xi} + \frac{A_2}{2}e^{-2Pr\xi} \\ \qquad + A_{23}e^{-(1+Pr)\xi} + A_{24}\xi e^{-Pr\xi} + A_{25}\xi^2 e^{-Pr\xi} + A_{26}\xi e^{-(1+Pr)\xi} \\ Z_3 = A_{27}\xi e^{-Sc\xi} + A_{28}e^{-(1+Sc)\xi} + A_{29}e^{-(1+Pr)\xi} + A_{30}e^{-(Pr+Sc)\xi} + A_{31}e^{-(2+Sc)\xi} \\ \qquad + A_{32}\xi^2 e^{-Sc\xi} + A_{33}\xi e^{-(1+Sc)\xi} + A_{34}\xi e^{-(1+Sc)\xi} + A_{35}e^{-Sc\xi} \end{array}\right\} \quad (25)$$

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

Velocity Distribution:

$$u = U_0 f'(\eta) = U_0 f_w^2 X'(\xi) = U_0\left[X_1'(\xi) + \epsilon X_2'(\xi) + \epsilon^2 X_3'(\xi)\right] \quad (26)$$

Temperature Distribution:

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

and

mass concentration Distribution:

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

The main quantities of physical interest are local skin-friction, local Nusselt number and local Sherwood number.

The equation defining the wall skin-friction, $\tau = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$

So the dimensionless skin friction is

$$\tau = 1 + \epsilon\left(A_5 - A_3 - \frac{1}{2} - ScA_1 - PrA_2\right) + \epsilon^2\left(\begin{array}{c} -A_{18} - (Pr+1)A_{11} - (Sc+1)A_{12} - PrA_{13} \\ -ScA_{14} - \frac{2}{15} + A_{15} + A_{16} \end{array}\right) \quad (29)$$

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

So the dimensionless Nusselt Number is

$$Nu = -Pr + \epsilon(A_6 - PrA_5 - (1+Pr)A_7)$$
$$+\epsilon^2(-PrA_{20} - (Sr+Pr)A_{21} + A_{22} - A_2pr - (1+Pr)A_{23} + A_{24} + A_{26}) \quad (30)$$

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

So the dimensionless Sherwood number is

$$Sh = -Sc + \epsilon(-ScA_{10} + ScA_8 - (Sc+1)A_9)$$
$$+\epsilon^2 \left(\begin{matrix} A_{27} - (1+Sc)A_{28} - (1+Pr)A_{29} - (Pr+Sc)A_{30} \\ -(2+Sc)A_{31} + A_{33} + A_{34} - ScA_{35} \end{matrix}\right) \quad (31)$$

where

$A_1 = \frac{Gmcos\alpha}{Sc^3 - Sc^2}$, $A_2 = \frac{Grcos\alpha}{Pr^3 - Pr^2}$, $A_3 = \frac{1}{2} + M - PrA_1$,

$A_4 = -\left(A_3 + A_1 + A_2 + \frac{1}{4}\right)$, $A_5 = \frac{Pr^2}{(1+Pr)}$, $A_6 = Pr + S$, $A_7 = -\frac{Pr^2}{(1+Pr)}$,

$A_8 = \left(A_1Sc^2 + \frac{R - Sc^2}{Sc}\right)$, $A_9 = \frac{2 - Sc}{(Sc+1)}$, $A_{10} = -A_9$,

$A_{11} = \frac{A_2 + A_7Grcos\alpha + Gmcos\alpha A_{10} - A_2Pr^2}{(Pr+1)^3 - (Pr+1)^2}$, $A_{12} = \frac{A_1 + Gmcos\alpha A_9 - A_1Sc^2}{(Sc+1)^3 - (Sc+1)^2}$, $A_{14} = \frac{A_1Sc^2 + ScMA_1 + Gmcos\alpha A_7}{Sc^3 - Sc^2}$, $A_{15} = \frac{-2A_5 + 1 + M/2}{4}$, $A_{13} = \frac{A_2Pr^2 + Gr\,cos\alpha A_5 + MPrA_2}{Pr^3 - Pr^2}$,

$A_{16} = -(A_4 + A_3 + 2A_5 - MA_5A_3) - 2(A_5 + Gmcos\alpha A_8 + A_5M)$,

$A_{17} = \frac{(A_5 + Gmcos\alpha A_8 + A_5M)}{-2}$,

$A_{18} = -A_{11}(Pr+1) - PrA_{13} - ScA_{14} - 2A_{15} + A_{16} + 2A_{17} - \frac{2}{15}$,

$A_{19} = -\left(A_{18} + A_{11} + A_{12} + A_{13} + A_{14} + A_{15} + \frac{2}{45}\right)$,

$A_{21} = \frac{Pr^2A_1}{(Sc+Pr)^2 - Pr(Sc+Pr)}$, $A_{22} = \frac{Pr^2 - 4PrA_7(Pr+1)}{4((2+Pr)^2 - Pr(2+Pr))}$,

$A_{23} = \frac{SPrA_7 + Pr^2A_{11} + PrA_7(1+Pr) - Pr^2A_5 + PrA_6}{(1+Pr)^2 - Pr(1+Pr)} + \frac{Pr^2A_5 - Pr^2A_6}{(1+Pr)}$,

$A_{24} = \frac{SPrA_5 + Pr^2A_4 + Pr^2A_5 - PrA_6}{-Pr} + \frac{SPrA_6 + Pr^2A_6}{-Pr^2}$, $A_{27} = \frac{-RA_{10} + Sc^2A_{10} + Sc^2A_4}{-Sc} + \frac{-RA_8 + Sc^2A_8}{-Sc^2}$,

$A_{25} = \frac{SPrA_6 + Pr^2A_6}{2}$, $A_{26} = \frac{Pr^2(A_5 - A_6)}{1+Pr}$, $A_{20} = -\left(A_{21} + A_{22} + A_{23} + \frac{A_2}{2}\right)$

$A_{28} = \frac{(2+3Sc)(2ScA_8 - Sc^2A_8 + Sc^2A_5 - 2ScA_5)}{(1+Sc)^2(1+2Sc)^2} + \frac{-RA_9 + 2Sc\,A_{10} + 2Sc(A_5 - A_3) - A_3Sc^2(-1 - A_{10}) + Sc(Sc+1)A_9}{(Sc+1)^2 - Sc(Sc+1)}$,

$A_{29} = \frac{2Sc(A_5 - A_3)}{(Pr+1)^2 - Sc(Pr+1)}$, $A_{30} = \frac{(Sc - 2Pr)ScA_2}{(Pr+Sc)^2 - Sc(Pr+Sc)}$, $A_{31} = \frac{\left(\frac{Sc^2}{4} - Sc\right)}{(Sc+2)^2 - Sc(Sc+2)}$,

$A_{32} = -\frac{A_1}{2}$, , $A_{33} = \frac{A_8(Sc^2 - R)}{-2Sc}$, $A_{34} = \frac{(2Sc - Sc^2)(A_8 - A_5)}{(1+Sc)(1+2Sc)}$, $A_{35} = -(A_{28} + A_{29} + A_{30} + A_{31})$

RESULTS AND DISCUSSIONS:

In this paper, we have studied MHD Free Convective Heat and Mass Transfer Flow Past an Inclined Surface with Heat Generation and Chemical reaction. The effect of the parameters Gr, Gm, M, R, Pr, S, fw, α 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 Pr and R on velocity at any point of the fluid, when Sc=0.22, Gr =10, M=2, Gm=10, S=2, $\alpha = \pi/6$ and fw = 0.7. It is noticed that the velocity decreases with the increase of Prandtl number (Pr), where as increases with the increase of chemical reaction parameter(R).

Figure-(2) shows the effect of the parameters M and Gr on velocity at any point of the fluid, when Sc=0.22, Pr=0.71, R=2, Gm=10, S=2, $\alpha = \pi/6$ and fw=0.7. It is noticed that the velocity increases with the increase of Grashof number (Gr), where as decreases with the increase of magnetic parameter (M).

Figure-(3) shows the effect of the parameters Sc and fw on velocity at any point of the fluid, when R=2, Gr=10, M=2, Gm=10, S=2, $\alpha = \pi/6$ and Pr =0.71. It is noticed that the velocity decreases with the increase of Schmidt number (Sc) and suction parameter (fw).

Figure-(4) shows the effect of the parameters α and Gm on velocity at any point of the fluid, when Sc=0.22, R=2, M=2, Gr =10, S=2, Pr = 0.71 and fw =0.7. It is noticed that the velocity decreases with the increase of angle of inclination (α), where as increases with modified Grashof number (Gm) for $\eta < 1$ and reverse else where.

Heat Profile: The Heat profiles are depicted in Figs 5-7. Figure-(5) shows the effect of the parameters Pr and S on Heat profile at any point of the fluid, when Sc=0.22, Gr=10, M=2, R=2, fw=0.7, $\alpha = \frac{\pi}{6}$ and Gm=10 . It is noticed that the temperature falls with the increase of source parameter (S), whereas temperature rises with increase of Prandtl number (Pr).

Figure-(6) shows the effect of the parameters M and Sc on Heat profile at any point of the fluid, when Pr=0.71, Gr=10, S=2, R=2, fw=0.7, $\alpha = \frac{\pi}{6}$ and Gm=10 . It is noticed that the temperature falls in the increase of Schmidt number (Sc), whereas temperature rises with increase of magnetic parameter (M).

Figure-(7) shows the effect of the parameters α and fw on Heat profile at any point of the fluid, when Pr=0.71, Gr=10, S=2, R=2, Sc=0.22, M=2 and Gm=10. It is noticed that the temperature falls with the increase of angle of inclination (α) and suction parameter (fw).

Mass concentration profile: The Mass concentration profiles are depicted in Figures 8-10. Figure-(8) shows the effect of the parameters M and R on mass concentration profile at any point of the fluid, when Gr=10, Pr=0.71, Sc=0.22, $\alpha = \pi/6$, S=2, Gm=10 and fw=0.7. It is noticed that the mass concentration increases with the increase of magnetic parameter (M) and chemical reaction parameter(R).

Figure-(9) shows the effect of the parameters Sc and Pr on mass concentration profile at any point of the fluid, when Gr=10, M=2, R=2, $\alpha = \pi/6$, S=2, Gm=10 and fw=0.7. It is noticed that the mass concentration increases with the increase of Prandtl number (Pr), whereas decreases with the increase of Schmidt number (Sc).

Figure-(10) shows the effect of the parameters fw and α on mass concentration profile at any point of the fluid when Gr=10, M=2, R=2, Sc = 0.22 , S=2, Gm=10 and Pr =0.71. It is noticed that the mass concentration decreases with the increase of angle of inclination (α) and suction parameter (fw).

Skin friction: Table-(1) illustrates the effect of the parameters of Sc, S, M, fw, Pr, α and R on Skin friction at plate. It is observed that Prandtl number (Pr), Schmidt number (Sc), magnetic parameter (M) in the fluid flow decreases the skin-friction, whereas Grashof number (Gr), chemical reaction parameter(R), suction parameter (fw) and angle of inclination (α) increases the skin-friction.

Nusselt Number: Table-(2) illustrates the effect of the parameters Pr, M, α and fw on Nusselt number at the plate. It is observed that Nusselt number decreases at the plate with the increase of Prandtl number (Pr), whereas increases with the increase of suction parameter (fw), angle of inclination (α) and suction parameter (fw).

Sherwood Number: Table-(3) illustrates the effect of the parameters Sc, M, fw, Pr, α and R on Sherwood Number at the plate. It is noticed that Sherwood Number at the plate increases with the increase of Schmidt number (Sc), reaction parameter (R), angle of inclination (α), Prandtl number (Pr), magnetic parameter (M) and suction parameter (fw).

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

Sl.No	Gm	Gr	Pr	Sc	S	α	R	fw	M	Skin Friction(τ)
1	10	10	0.71	0.22	2	$\pi/6$	2	0.7	2	3347
2	10	10	0.8	0.22	2	$\pi/6$	2	0.7	2	3247
3	10	10	0.9	0.22	2	$\pi/6$	2	0.7	2	3115
4	10	10	0.71	0.3	2	$\pi/6$	2	0.7	2	1106
5	10	10	0.71	0.4	2	$\pi/6$	2	0.7	2	181
6	10	10	0.71	0.22	2	$\pi/6$	2	0.7	5	3345
7	10	10	0.71	0.22	2	$\pi/6$	2	0.7	10	3419
8	15	10	0.71	0.22	2	$\pi/6$	2	0.7	2	3347
9	20	10	0.71	0.22	2	$\pi/6$	2	0.7	2	3347
10	10	15	0.71	0.22	2	$\pi/6$	2	0.7	2	4720
11	10	20	0.71	0.22	2	$\pi/6$	2	0.7	2	5894
12	10	10	0.71	0.22	2	$\pi/6$	3	0.7	2	3511
13	10	10	0.71	0.22	2	$\pi/6$	4	0.7	2	3675
14	10	10	0.71	0.22	2	$\pi/6$	2	0.8	2	1877
15	10	10	0.71	0.22	2	$\pi/6$	2	0.9	2	1112
16	10	10	0.71	0.22	2	$\pi/4$	2	0.7	2	2793
17	10	10	0.71	0.22	2	$\pi/3$	2	0.7	2	2030

Table-2: Numerical values of the Rate of Heat Transfer (Nu)

Sl.No	α	Pr	fw	M	Nu
01	$\pi/6$	0.71	0.7	2	-1935
02	$\pi/4$	0.71	0.7	2	2793
03	$\pi/3$	0.71	0.7	2	2030
04	$\pi/6$	0.8	0.7	2	-2423
05	$\pi/6$	0.9	0.7	2	-3024
06	$\pi/6$	0.71	0.8	2	-1133
07	$\pi/6$	0.71	0.9	2	-707
08	$\pi/6$	0.71	0.7	5	-1926
09	$\pi/6$	0.71	0.7	10	-1911

Table-3: Numerical values of the Rate of Mass Transfer (Sh)

Sl.No	α	M	Sc	Pr	fw	R	Sh
01	$\pi/6$	2	0.22	0.71	0.7	2	-24.06
02	$\pi/4$	2	0.22	0.71	0.7	2	276.9
03	$\pi/3$	2	0.22	0.71	0.7	2	669.12
04	$\pi/6$	5	0.22	0.71	0.7	2	-13.36
05	$\pi/6$	10	0.22	0.71	0.7	2	4.465
06	$\pi/6$	2	0.3	0.71	0.7	2	-254.03
07	$\pi/6$	2	0.4	0.71	0.7	2	-194.5
08	$\pi/6$	2	0.22	0.8	0.7	2	21.03
09	$\pi/6$	2	0.22	0.9	0.7	2	78.12
10	$\pi/6$	2	0.22	0.71	0.8	2	-14.91
11	$\pi/6$	2	0.22	0.71	0.9	2	-9.89
12	$\pi/6$	2	0.22	0.71	0.7	3	1021
13	$\pi/6$	2	0.22	0.71	0.7	4	2935

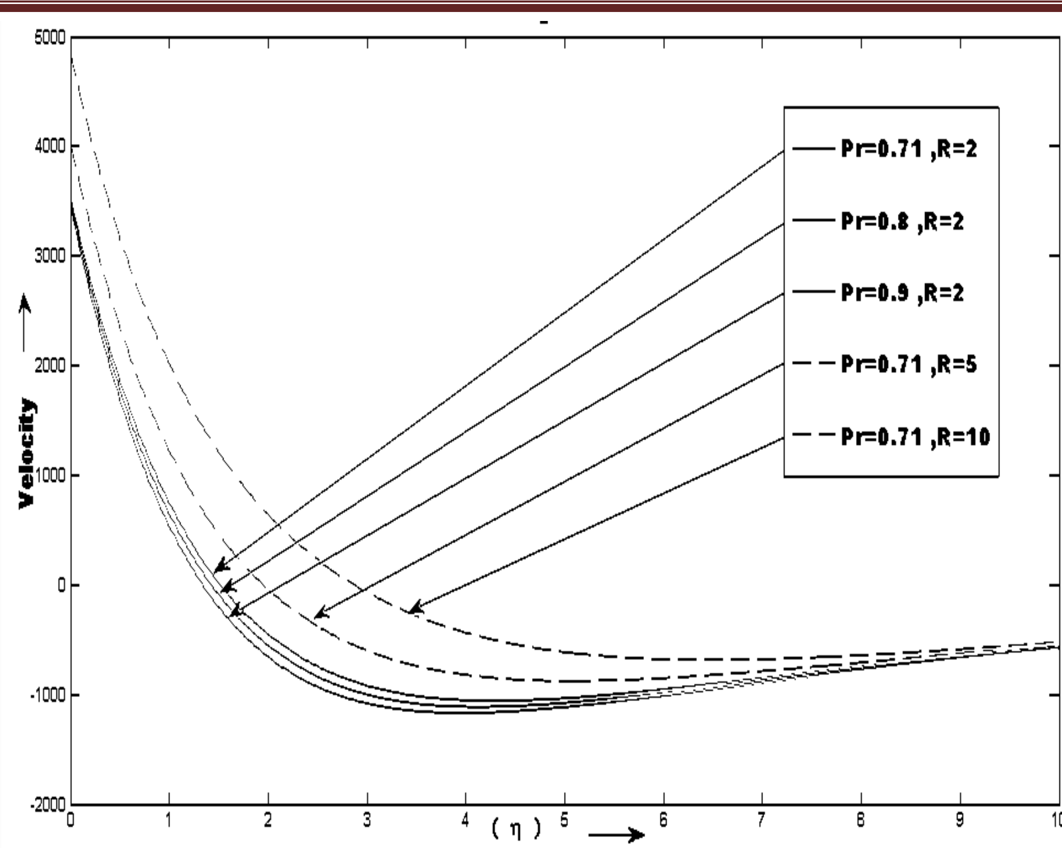

Fig-(1): Effect of Pr and R on velocity profile when Sc=0.22, Gr=10, M=2, Gm=10, S=2, $\alpha = \pi/6$ and fw=0.7.

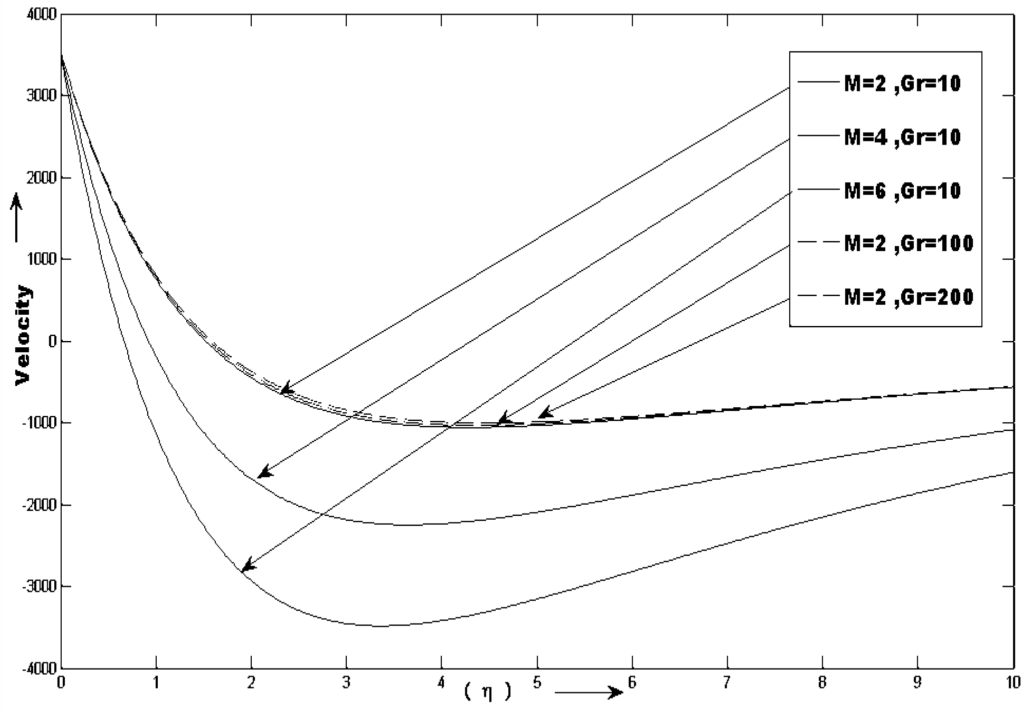

Fig-(2): Effect of M and Gr on velocity profile when Sc=0.22, Pr=0.71, R=2, Gm=10, S=2, $\alpha = \pi/6$ and fw=0.7.

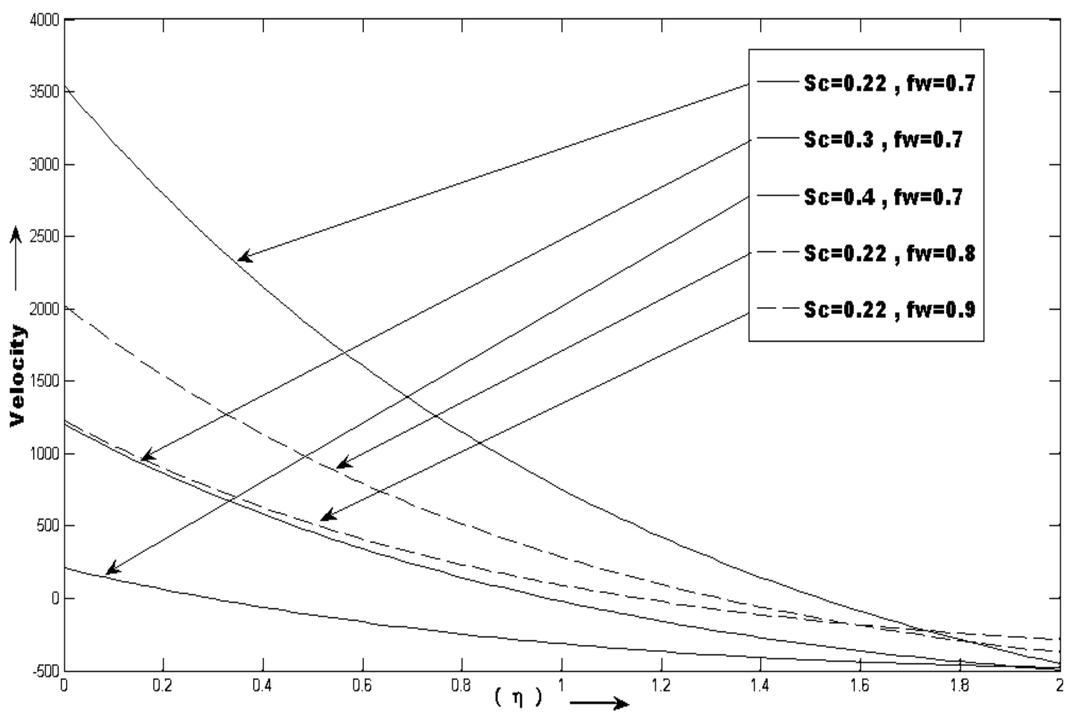

Fig-(3): Effect of Sc and fw on velocity profile when R=2, Gr=10, M=2, Gm=10, S=2, $\alpha = \pi/6$ and Pr=0.71.

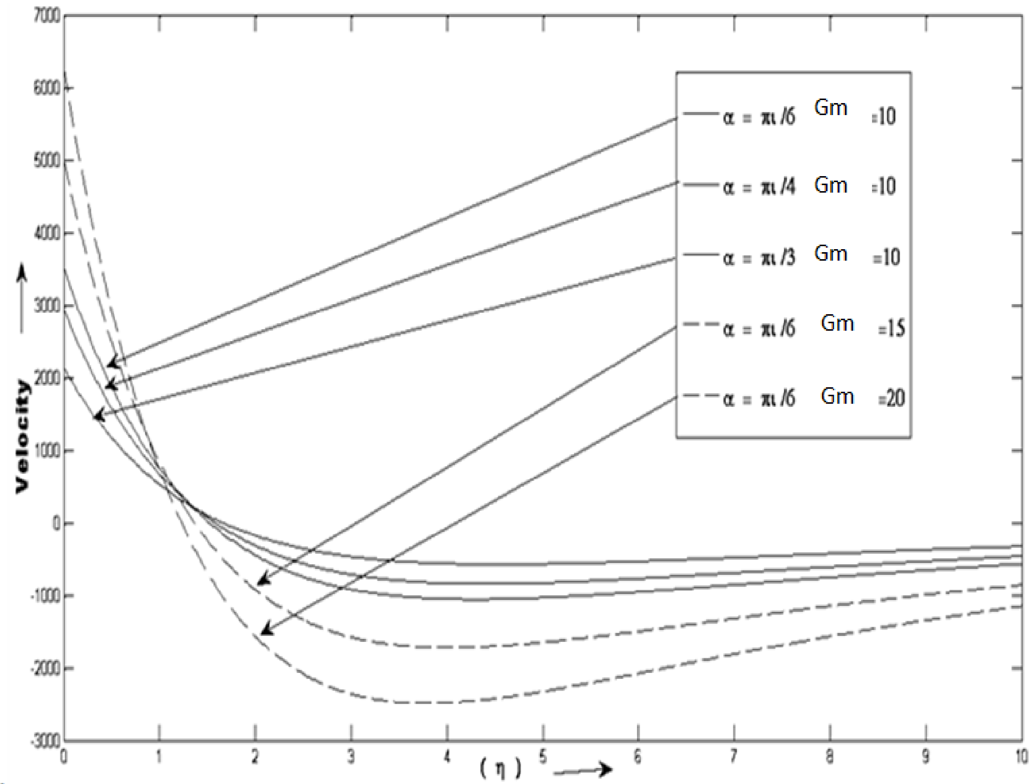

Fig-(4): Effect of α and Gr on velocity profile when Sc=0.22, R=2, M=2, Gm=10 , S=2, $Pr = 0.71$ and fw=0.7.

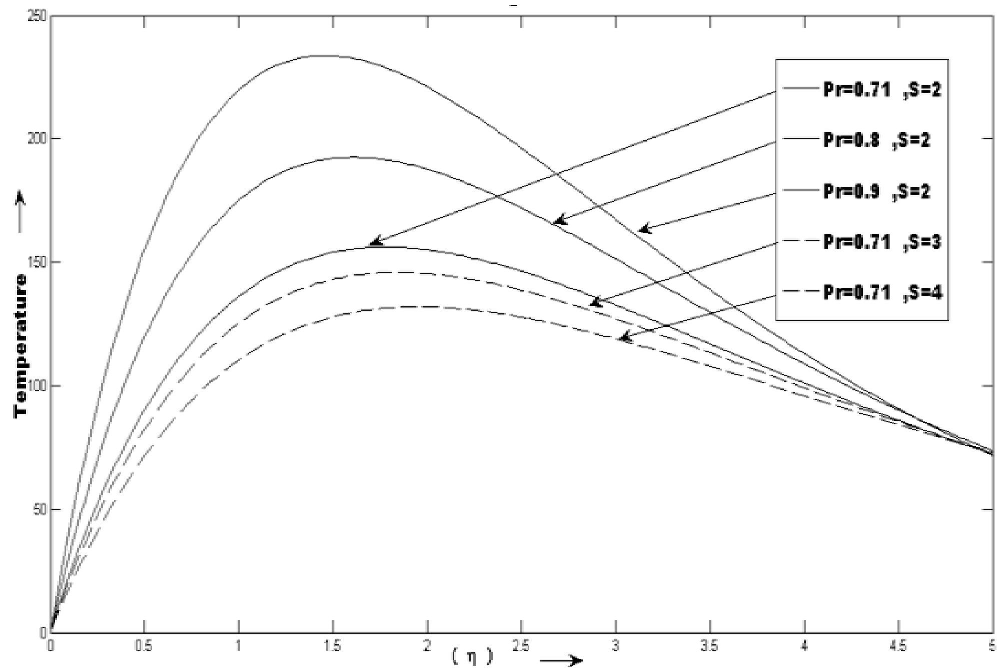

Fig-(5): Effect of Pr and S on Temperature profile when Sc=0.22, Gr=10, M=2, R=2, fw=0.7, $\alpha = \frac{\pi}{6}$ and Gm=10.

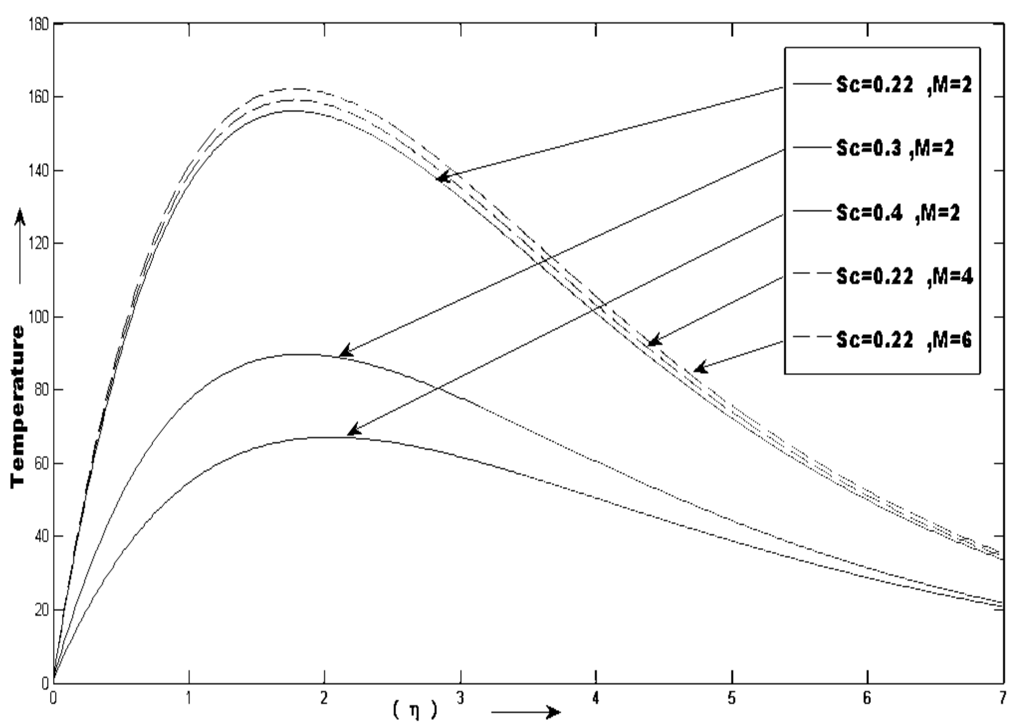

Fig-(6): Effect of M and Sc on Temperature profile when Pr=0.71, Gr=10, S=2, R=2, fw=0.7, $\alpha = \frac{\pi}{6}$ and Gm=10.

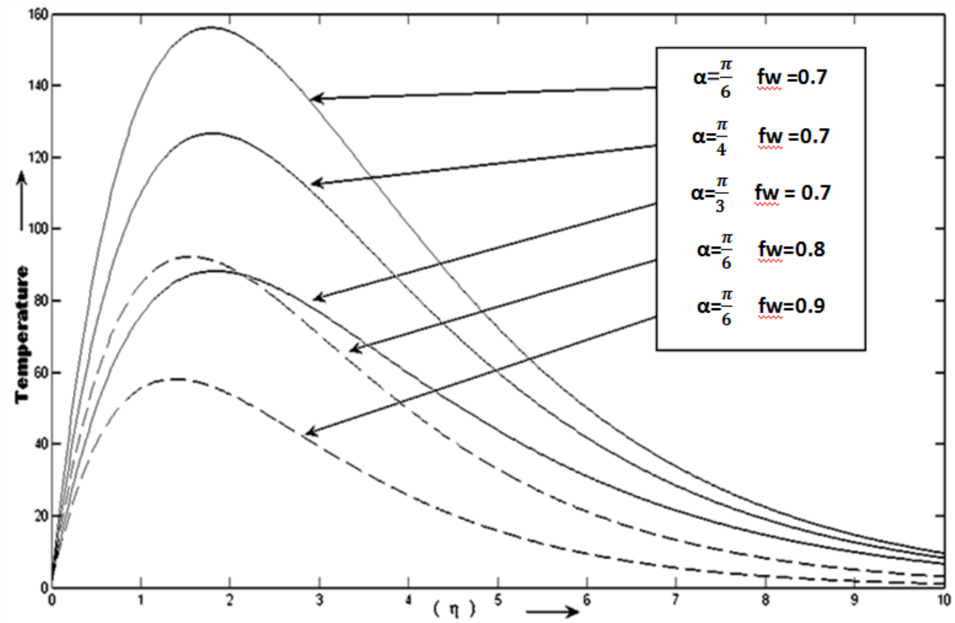

Fig-(7): Effect of α and fw on Temperature profile when Pr=0.71, Gr=10, S=2, R=2, Sc=0.22, M=2 and Gm=10.

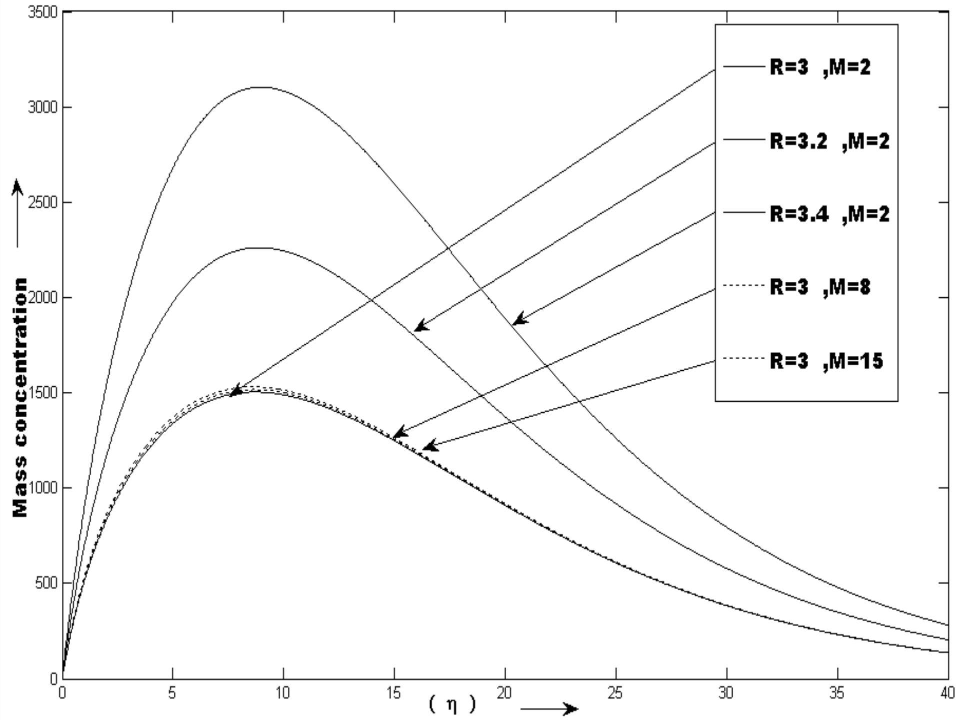

Fig-(8): Effect of R and M on mass concentration profile when Gr=10, Pr=0.71, Sc=0.22, $\alpha = \pi/6$, S=2, Gm=10 and fw=0.7.

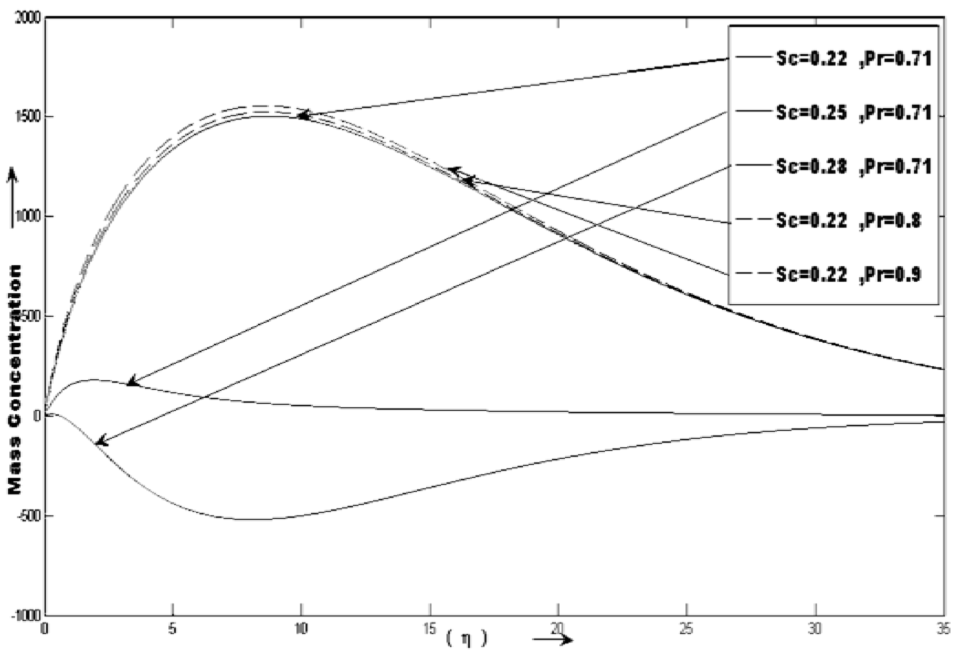

Fig-(9): Effect of Sc and Pr on mass concentration profile when Gr=10, M=2, R=2, $\alpha = \pi/6$, S=2, Gm=10 and fw=0.7.

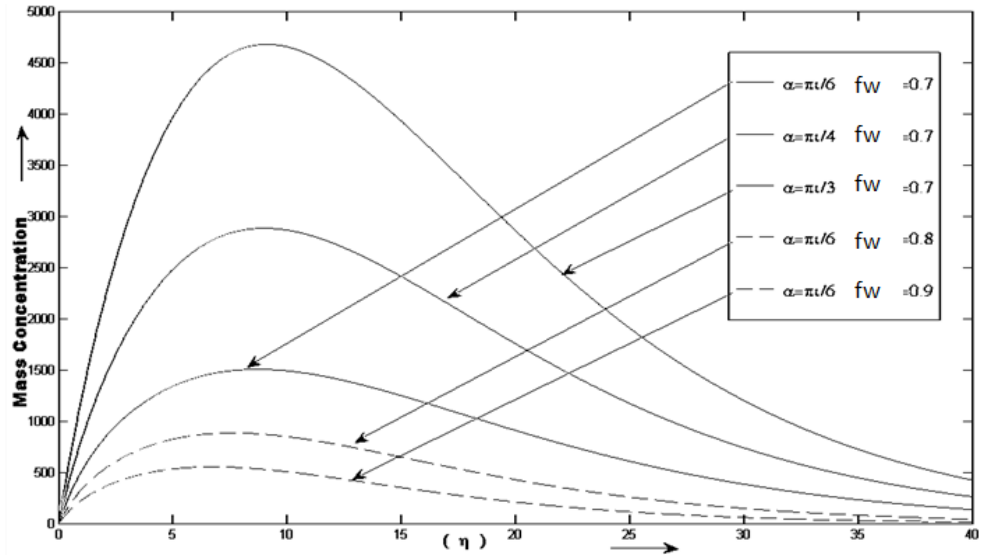

Fig-(10): Effect of α and fw on mass concentration profile when Gr=10, M=2, R=2, Sc = 0.22 , S=2, Gm=10 and Pr =0.71.

CONCLUSION:

The following conclusions are drawn on the study of MHD Free Convective Heat and Mass Transfer Flow Past an Inclined Surface with Heat Generation and Chemical reaction:

i. Velocity increases with the increase in Gr and R whereas decreases with M, Pr, Sc and fw. Also velocity decreases for the increase of α and Gm at the point having less than unit distance from the plate.

ii. Temperature of fluid falls with the increase of S, Sc, fw and α and rises with Pr and M.

iii. Mass concentration of the fluid increases with the increase of M, R and Pr, whereas decreases with Sc, fw and α.

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