IMPACT: International Journal of Research in Humanities, Arts and Literature (IMPACT: IJRHAL)
ISSN(E): 2321-8878; ISSN(P): 2347-4564
Vol. 2, Issue 1, Jan 2014, 19-28

MAGNETIC EFFECTS OF MASS AND HEAT TRANSFER ON FREE CONVECTION FLOW THROUGH POROUS MEDIUM PAST AN INFINITE VERTICAL PLATE IN SLIP – FLOW REGIME IN THE PRESENCE OF CHEMICAL REACTION, VARIABLE SUCTION AND PERIODIC TEMPERATURE AND MASS CONCENTRATION

N. SENAPATI[1] & R. K. DHAL[2]

[1]Department of Mathematics, Ravenshaw University, Cuttack, Orissa, India

[2]J.N.V. Paralakhemundi, Gajapati, Orissa, India

ABSTRACT

Free convection MHD flow of a viscous incompressible fluid flow through porous medium with mass and heat transfer past an infinite vertical plate in slip –flow regime in the presence of variable suction and periodic temperature and mass concentration has been studied. Assuming variable suction at the plate, approximate solutions are obtained for velocity, temperature, concentration, Nusselt number, Sherwood number and skin friction. The result of various material parameters are discussed on flow variable and presented by graphs and tables.

KEYWORDS: Vertical Plate, Heat and Mass Transfer, Porous Medium, Slip-Flow Regime, Chemical Reaction, Free Convection, Variable Suction and MHD

INTRODUCTION

The study of an electrically conducting fluid, which influences many natural and manmade flows, have many applications in engineering problems such as magneto hydrodynamics (MHD) generators, plasma studies, nuclear reactors, geothermal energy extraction, and the boundary layer control in the field of aerodynamics.

The process of heat and mass transfer in free convection flow have attracted the attention of a number of scholars due to their application in many branches of science and engineering, viz. in the early stages of melting adjacent to a heated surface, in chemical engineering processes which are classified as a mass transfer process, in a cooling device aeronautics, fluid fuel nuclear reactor. The phenomenon of free convection arises in the fluid when temperature and mass concentration change cause density variation leading to buoyancy forces acting on the fluid elements.

The study of fluid flows is of paramount importance in engineering. For example, the unsteady free convection flow along a vertical plate has been given considerable interest, because of its application in devices which are cooled by natural convection, as in the case of electrical heaters and transformers. Joule heating in electronics and in physics refers to the increase in temperature of a conductor as a result of moving electrons colliding with atoms, whereupon momentum is transferred to the atom, increasing its kinetic energy.

Revankar, [1] considered Natural convection effects on MHD flow past an impulsively started permeable plate. Mohapatra et.al [2] have been analyzed hydrodynamic free convection flow with mass transfer past a vertical plate. Das et al. [3] studied the transient free convection flow past an infinite vertical plate with periodic temperature variation, because the free convection is enhanced by superimposing oscillating temperature on the mean plate temperature.

Hossain et al. [4] studied the influence of fluctuating surface temperature and concentration on natural convection flow from a vertical flat plate. Free convective flow through a porous medium between two vertical parallel plates has been studied by Singh [5]. The flow regime is called the slip flow regime and this effect can not be neglected. Using this effect Sharma and Chaudhary [6] studied the effect of variable suction on transient free convective viscous incompressible flow past a vertical plate with periodic temperature variations in slip-flow regime. Recently, Sharma and Sharma [7] studied influence of variable suction on unsteady free convective flow from a vertical flat plate and heat transfer in slip-flow regime. Sharma [8]have studied Influence of periodic temperature and concentration on unsteady free convective viscous incompressible flow and heat transfer past a vertical plate in slip-flow regime.

It is proposed to study the Magnetic effects of mass and heat transfer on free convection flow through porous medium past an infinite vertical plate in slip –flow regime in the presence of chemical reaction, variable suction and periodic temperature and mass concentration

FORMULATION OF THE PROBLEM

An unsteady free convection two dimensional flow of an incompressible and electrically conducting viscous fluid through porous medium past an infinite vertical plate in slip-flow regime in the presence of chemical reaction and variable suction is considered. The X'-axis is taken along the plate in vertical upward direction and Y'-axis is taken normal to it. A magnetic field of uniform strength H_0 is applied normal to the plate. Initially surrounding fluid are at rest and are the temperature T'_∞ and mass concentration C'_∞ at all points. Also the plate temperature and mass concentration are respectively T'_w and C'_w. Since the plate is considered infinite along X'direction, all physical quantities will be independent ofx'. Under these assumptions, the physical variables are function of $y'$and t'only. Then neglecting viscous dissipation and assuming variation of density in the body force term. Then by usual boussinesq's approximation the unsteady flow governed by following equations

Equation of continuity

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

which is satisfied with $v' = -v_0\left(1 + \epsilon A e^{i\omega' t'}\right)$= variable suction / injection

The momentum equation

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

The energy equation

$$\frac{\partial T'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} \tag{3}$$

The mass concentration equation

$$\frac{\partial C'}{\partial t'} - v_0\left(1 + \epsilon A e^{i\omega' t'}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - R'(C' - C'_\infty) \tag{4}$$

Where ρ is the density, $\nu$is the kinematic viscosity, g is the acceleration due to gravity, $A$is the suction / injection parameter, $\beta$is the coefficient of volume expansion for heat transfer, $\beta_c$is the coefficient of volume expansion for mass transfer, D is the chemical molecular diffusivity, k is the thermal conductivity, $K'$is the permeability of porous medium, σ is the electrical conductivity, $C_p$is the specific heat at constant pressure,R' is chemical reaction parameter,$B_0 = H_0\mu_e$ is and the other symbols have their usual meanings.

With corresponding boundary conditions

$$\left.\begin{array}{l} y' = 0;\ u' = L'\frac{\partial u'}{\partial y'}, T' = T_w' + \epsilon(T_w' - T_\infty')e^{i\omega' t'}, C' = C_w' + \epsilon(C_w' - C_\infty')e^{i\omega' t'} \\ \text{As } y' \to 0 : u' \to 0, T' \to T_\infty', C' \to C_\infty' \end{array}\right\} \quad (5)$$

We now introduce the following non-dimensional quantities into equations (2) to (5)

$$\left.\begin{array}{l} y = \frac{y' v_0}{\nu}, t = t'\frac{v_0^2}{4\nu}, u = \frac{u'}{v_0}, \theta = \frac{T' - T_\infty'}{T_w' - T_\infty'}, \varphi = \frac{C' - C_\infty'}{C_w' - C_\infty'}, Sc = \frac{\nu}{D}, Pr = \frac{\mu C_p}{k}, R = \frac{R'\nu}{v_0^2} \\ Gr = \frac{hg\beta(T_w' - T_\infty')}{v_0^2}, Gm = \frac{hg\beta_c(C_w' - C_\infty')}{v_0^2}, K = \frac{K' v_0^2}{\nu^2}, M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, h = \frac{v_0 L'}{\nu}, \omega = \frac{4\nu\omega'}{v_0^2} \end{array}\right\} \quad (6)$$

where Pr is the Prandtl number, *S*c the Schmidt number, *G*r the Grashof number for heat transfer, *G*m the modified Grashof number for mass transfer, *R* the chemical reaction parameter, *K* the permeability parameter porous medium, h rarefaction parameter and *M* the Hartmann number.

With the help of equation (6) the equations (2) to (5) reduce to

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1 + \epsilon A e^{i\omega t})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + gm\varphi - \frac{u}{K} - Mu \quad (7)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - (1 + \epsilon A e^{i\omega t})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} \quad (8)$$

$$\frac{1}{4}\frac{\partial \varphi}{\partial t} - (1 + \epsilon A e^{i\omega t})\frac{\partial \varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} - R\varphi \quad (9)$$

and boundary conditions to the problem in the dimensionless form are

$$\left.\begin{array}{l} y = 0 : u = h\frac{\partial u}{\partial y}, \theta = 1 + \epsilon e^{i\omega t}, \varphi = 1 + \epsilon e^{i\omega t} \\ y \to \infty : u \to 0, \theta \to 0, \varphi \to 0 \end{array}\right\} \quad (10)$$

SOLUTION OF THE PROBLEM

Assuming small amplitude oscillations (ϵ<< 1), we can represent the velocity u, temperature $\theta$and concentration φ near the plate as follows

$$\left.\begin{array}{l} u = u_0(y) + \epsilon u_1(y)e^{i\omega t} \\ \theta = \theta_0(y) + \epsilon\theta_1(y)e^{i\omega t} \\ \varphi = \varphi_0(y) + \epsilon\varphi_1(y)e^{i\omega t} \end{array}\right\} \quad (11)$$

Substituting (11) in (7) to (10), equating the coefficients of harmonic and non harmonic terms, neglecting the coefficients of ϵ^2, we get

$$\left.\begin{array}{l} u_0'' + u_0' - \left(\frac{1}{K} + M\right)u_0 = -Gr\theta_0 - Gm\varphi_0 \\ u_1'' + u_1' - \left(\frac{\omega i}{4} + \frac{1}{K} + M\right)u_1 = -Au_0' - Gr\theta_1 - Gm\varphi_1 \\ \theta_0'' + Pr\theta_0' = 0 \\ \theta_1'' + Pr\theta_1' - \frac{Pri\omega\theta_1}{4} = -APr\theta_0' \\ \varphi_0'' + Sc\varphi_0' - ScR\varphi_0 = 0 \\ \varphi_1'' + Sc\varphi_1' - \left(\frac{i\omega Sc}{4} + RSc\right)\varphi_1 = -ASc\varphi_0{}' \end{array}\right\} \quad (12)$$

With the following boundary conditions

$$\left.\begin{aligned} &u_0 = h\frac{\partial u_0}{\partial y}, u_1 = h\frac{\partial u_1}{\partial y}, \theta_0 = 1, \theta_1 = 1, \varphi_0 = 1, \varphi_1 = 1 \text{ at } y = 0 \\ &u_0 = 0, u_1 = 0, \theta_0 = 0, \theta_1 = 0, \varphi_0 = 0, \varphi_1 = 0 \text{ as } y \to \infty \end{aligned}\right\} \tag{13}$$

Solving the set of equation (12) under the boundary conditions (13) we get

$$\theta_0 = e^{-Pry} \tag{14}$$

$$\theta_1 = \left(1 + \frac{4PrA}{i\omega}\right)e^{-a_1 y} - \frac{4PrA}{i\omega}e^{-Pry} \tag{15}$$

$$\varphi_0 = e^{-a_2 y} \tag{16}$$

$$\varphi_1 = A_1 e^{-a_3 y} + A_2 e^{-a_2 y} \tag{17}$$

$$u_0 = A_5 e^{-a_4 y} + A_3 e^{-Pry} + A_4 e^{-a_2 y} \tag{18}$$

$$u_1 = A_{11} e^{-a_5 y} + A_6 e^{-Pry} + A_7 e^{-a_1 y} + A_8 e^{-a_2 y} + A_9 e^{-a_3 y} + A_{10} e^{-a_4 y} \tag{19}$$

where $a_1 = \frac{Pr+\sqrt{Pr^2+Pri\omega}}{2}, a_2 = \frac{Sc+\sqrt{Sc^2+4ScR}}{2}, a_3 = \frac{Sc+\sqrt{Sc^2+\omega iSc+4ScR}}{2}$,

$$a_4 = \frac{1+\sqrt{1+4\left(\frac{1}{K}+M\right)}}{2},\ a_5 = \frac{1+\sqrt{1+4\left(\frac{\omega i}{4}+\frac{1}{K}+M\right)}}{2}$$

$$A_2 = \frac{AScа_2}{a_2^2 - Sca_2 - \frac{\omega iSc}{4} - RSc}, A_1 = 1 - A_2, A_3 = \frac{-Gr}{Pr^2 - Pr - \left(\frac{1}{K}+M\right)}$$

$$A_4 = \frac{-Gm}{a_2{}^2 - a_2 - \left(\frac{1}{K}+M\right)}, A_5 = \frac{-(hA_3Pr + hA_4a_2 + A_3 + A_4)}{1+ha_4}$$

$$A_6 = \frac{AA_3Pr - \frac{4PrGrA}{i\omega}}{Pr^2 - Pr - \left(\frac{\omega i}{4}+\frac{1}{K}+M\right)}, A_7 = \frac{-Gr\left(1+\frac{4PrA}{\omega i}\right)}{a_1^2 - a_1 - \left(\frac{\omega i}{4}+\frac{1}{K}+M\right)},$$

$$A_8 = \frac{AA_4a_2 - GmA_2}{a_2^2 - a_2 - \left(\frac{\omega i}{4}+\frac{1}{K}+M\right)}, A_9 = \frac{-GmA}{\left(a_3^2 - a_3 - \left(\frac{\omega i}{4}+\frac{1}{K}+M\right)\right)}$$

$$A_{10} = \frac{AA_5a_4}{a_4^2 - a_4 - \left(\frac{\omega i}{4}+\frac{1}{K}+M\right)}$$

$$A_{11} = \frac{-(hA_6Pr + ha_1A_7 + ha_2A_8 + ha_3A_9 + ha_4A_{10} + A_6 + A_7 + A_8 + A_9 + A_{10})}{1+ha_5}$$

Let $M_r\ and\ M_i, \theta_r\ and\ \theta_i\ and\ \varphi_r\ and\ \varphi_i$ are the real and imaginary parts of $u_1, \theta_1\ and\ \varphi_1$ respectively.

Now equation (19) can be written as $u_1(y,t) = M_r + iM_i$

Also $u(y,t) = u_0(y,t) + \epsilon u_1(y,t)e^{i\omega t}$

$$= [u_0 + \epsilon(M_r cos\omega t - M_i sin\omega t)] + i\epsilon[M_r sin\omega t + M_i cos\omega t] \tag{20}$$

The real part of $u(y,t)$

$$u_r = u_0 + \epsilon(M_r cos\omega t - M_i sin\omega t) \tag{21}$$

This expression takes simplest form for $\omega t = \frac{\pi}{2}$ and given by $u_r = u_0 - \epsilon M_i$ (22)

Again equations (15) and (17) can be written as $\theta_1(y,t) = \theta_r + i\theta_i$ and $C_1(y,t) = \varphi_r + i\varphi_i$

The real part of $\theta(y,t)$

$$\theta_r = \theta_0 + \epsilon[\theta_r sin\omega t + \theta_i cos\omega t] \quad (23)$$

This expression takes simplest form for $\omega t = \frac{\pi}{2}$ and given by $\theta_r = \theta_0 - \epsilon\theta_i$ (24)

The real part of $\varphi(y,t)$

$$\varphi_r = \varphi_0 + \epsilon[\varphi_r sin\omega t + \varphi_i cos\omega t] \quad (25)$$

This expression takes simplest form for $\omega t = \frac{\pi}{2}$ and given by $\varphi_r = \varphi_0 - \epsilon\varphi_i$ (26)

In view of equations (11), (18) and (19), non-dimensional the skin friction

$$\tau_0 = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \epsilon e^{i\omega t}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$= -(a_4 A_5 + PrA_3 + a_2A_4) + \epsilon e^{i\omega t}(F_r + iF_i)$$

$$= (\tau_m) + \epsilon F e^{i(\omega t+\alpha)}$$

$$= \tau_m + \epsilon|F|e^{i(\omega t+\alpha)} \quad (27)$$

Where $|F| = \sqrt{F_r^2 + F_i^2}$, $tan\alpha = \frac{F_i}{F_r}$, $\tau_m == -(a_4 A_5 + PrA_3 + a_2A_4)$ is skin friction of mean velocity and $F = F_r + iF_i = -(a_5A_{11} + PrA_6 + a_1A_7 + a_2A_8 + a_3A_9 + a_4A_{10})$

In view of equations (11), (14) and (15), the Nusselt number

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0}$$

$$= -\left(\frac{\partial\theta_0}{\partial y} + \epsilon e^{i\omega t}\frac{\partial\theta_1}{\partial y}\right)_{y=0}$$

$$= (Pr) - \epsilon e^{i\omega t}(S_1 + iS_2) \quad (28)$$

where $|Q| = \sqrt{S_1^2 + S_2^2}$, $tan\beta = \frac{S_2}{S_1}$ and $Q = S_1 + iS_2 = -a_1\left(1 + \frac{4PrA}{\omega i}\right) + \frac{4Pr^2A}{\omega i}$

In view of equations (11), (16) and (17), the Sherwood number

$$Sh = -\left(\frac{\partial\varphi}{\partial y}\right)_{y=0}$$

$$= -\left(\frac{\partial\varphi_0}{\partial y} + \epsilon e^{i\omega t}\frac{\partial\varphi_1}{\partial y}\right)_{y=0}$$

$$= (a_2) - \epsilon e^{i\omega t}(S_3 + iS_4) \quad (29)$$

where $|T| = \sqrt{S_3^2 + S_4^2}$, $tan\gamma = \frac{S_4}{S_3}$ and $T = -(a_3A_1 + a_2A_2)$

RESULTS AND DISCUSSIONS

In this paper we have studied the Magnetic effects of mass and heat transfer on free convection flow through porous medium past an infinite vertical plate in slip –flow regime in the presence of chemical reaction, variable suction and periodic temperature and mass concentration. The effect of Gr, Gm, M, K, R, Pr, Sc, A, h, $\boldsymbol{\omega}$ and t on flow characteristics have been studied and shown by means of graphs and tables.

Velocity Profiles

The velocity profiles are depicted in Figures 1-4. Figure 1 illustrates the effect of the parameters R, K and h on velocity at any point of the fluid, when Gr=1, Gm=1, K=1, Sc=1, Pr=1, t=1, A=1 and ω=1.

It is noticed that the velocity increases with the increase of rarefaction parameter (h) and porous parameter (K), where as decreases with the increase of chemical reaction parameter (R).

Figure 2 illustrates the effect of the parameters Gr, Gm and M on velocity at any point of the fluid, when Sc=1, Pr=1, R=3, K=1, t=1, h=1, A=1 and ω=1. It is noticed that the velocity decreases with the increase of magnetic parameter (M) and modified Grashof number (Gm) where as the velocity increases with the increase of Grashof number (Gr).

Figure 3 illustrates the effect of the parameters Sc, t, ω and Pr on velocity at any point of the fluid, when Gr=1, Gm=1, R=3, K=1, M=1, h=1 and ϵ=0.2. It is noticed that the velocity decreases with the increasing of Schmidt number (Sc), prandtl number (Pr) and oscillating frequency (ω), where as decreases with the increase of time (t).

Figure 4 illustrates the effect of the parameter A on velocity at any point of the fluid, when Gr =1, Gm=1, R=3, K=1, M=1, h=1, Sc=0.3, Pr=0.71, t=1, $\omega = 1$ and ϵ=0.2. It is noticed that the velocity increases with the increase of suction parameter(A).

Temperature Profile

The temperature profiles are depicted in Figure 5 only. Figure 5 illustrates the effect of the parameter Pr, A, t and ω on temperature at any point of the fluid at $\epsilon = 0.2$, in the absence of other parameters. It is noticed that the temperature falls with of increasing of prandtl number (Pr) and suction parameter (A), where as it falls initially then rises with the increase of time (t) and oscillating frequency (ω).

Mass Concentration Profile

The mass concentration profiles are depicted in Figure 6 only. Figure 6 illustrates the effect of the parameters Sc, A and R on mass concentration at any point of the fluid at $\omega = 1$, t=1 and $\epsilon = 0.2$, in the absence of other parameters.

It is noticed that the mass concentration decreases with the increasing of Schmidt number (Sc), reaction parameter (R) and suction parameter (A).

Shearing Stress/Skin Friction

Table 1 illustrates the effect of the parameters A, Pr, Sc, Gr, Gm, R, M, K, h, t and ω on Absolute value of skin friction(τ), skin friction of mean velocity (τ_0), Amplitude of skin friction(F) and Phase angle tan(α). It is noticed that

- The phase tan $(\boldsymbol{\varphi})$ of skin friction at plate increases with the increase of magnetic parameter (M), modified grash of number (Gm), oscillating frequency (ω) and chemical reaction parameter (R), and decreases with the increase of rarefaction parameter (h).
- The Absolute value of skin friction(τ) at plate increases with the increase of suction parameter (A), porous parameter (K), grashof number (Gr), modified grashof number (Gm), prandtl number (Pr) and Schmidt number (Sc), and decreases with the increase of chemical reaction parameter (R), magnetic parameter (M), rarefaction parameter (h) and oscillating frequency (ω).
- The skin friction of mean velocity (τ_0) at plate increases with the increase of porous parameter (K), grash of

number (Gr) and modified grashof number (Gm), and decreases with the increase of rarefaction parameter (h), chemical reaction parameter (R), prandtl number (Pr), Schmidt number (Sc) and magnetic parameter (M).

- The Amplitude of skin friction(F) at plate increases with the increase of suction parameter (A), porous parameter (K), grashof number (Gr), modified grashof number (Gm), prandtl number (Pr) and Schmidt number (Sc), and decreases with the increase of magnetic parameter (M), oscillating frequency (ω) and rarefaction parameter (h).

Nusselt Number

Table 2 illustrates the effects of the parameters A, Pr, ω and t on Absolute value of Nusselt Number(Nu_a), Amplitude of Nusselt Number(Q) and Phase angle tan(β). It is noticed that

- The Absolute value of Nusselt Number(Nu_a) at plate increases with the increase of suction parameter (A) and prandtl number (Pr), and decreases with the increase of oscillating frequency (ω) and time (t).
- The Amplitude of Nusselt Number(Q) at plate increases with the increase of suction parameter (A) and prandtl number (Pr), and decreases with the increase of oscillating frequency (ω).
- The Phase angle tan(ψ) at plate increases with the increase of oscillating frequency (ω) and prandtl number (Pr), and decreases with the increase of suction parameter (A).

Shreewood Number

Table 3 illustrates the effects of the parameters A, R Sc, ω and t on Absolute value of Sherwood Number (Sh_a), Amplitude of Sherwood Number (T) and Phase angle tan(γ). It is noticed that

- The Absolute value of Sherwood Number (Sh_a) at plate increases with the increase of suction parameter (A), Schmidt number (Sc), chemical reaction parameter (R), and decreases with the increase of oscillating frequency (ω) and time(t).
- The Amplitude of Sherwood Number (T) at plate increases with the increase of suction parameter (A), Schmidt number (Sc) and chemical reaction parameter (R), and decreases with the increase of oscillating frequency (ω).
- The Phase angle tan(γ) at plate increases with the increase of, chemical reaction parameter (R) and oscillating frequency (ω), and decreases with the increase of suction parameter (A) and Schmidt number (Sc).

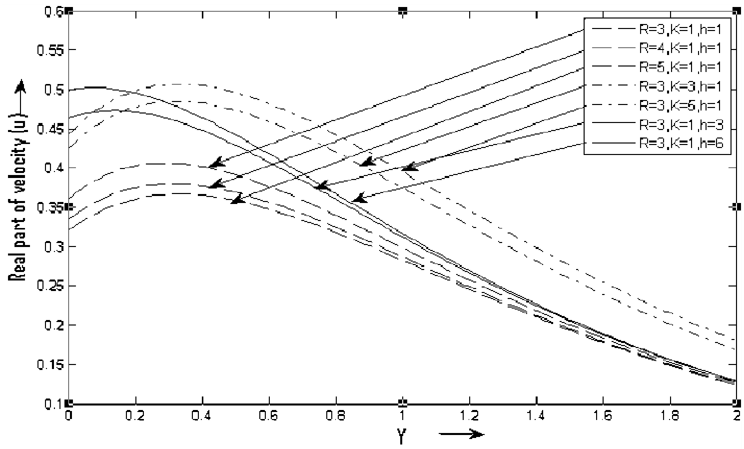

Figure 1: Effect of R, K and h on Velocity Profile When Sc=1, Pr=1, Gr=1, Gm=1, t=1, M=1 and ω=1

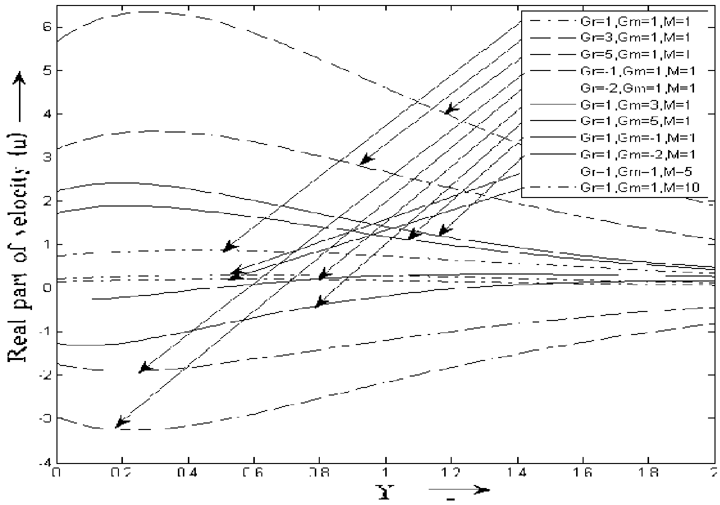

Figure 2: Effect of Gr, Gm and M on Velocity Profile When Sc=1, Pr=1, R=3, K=1, t=1, h=1 and ω=1

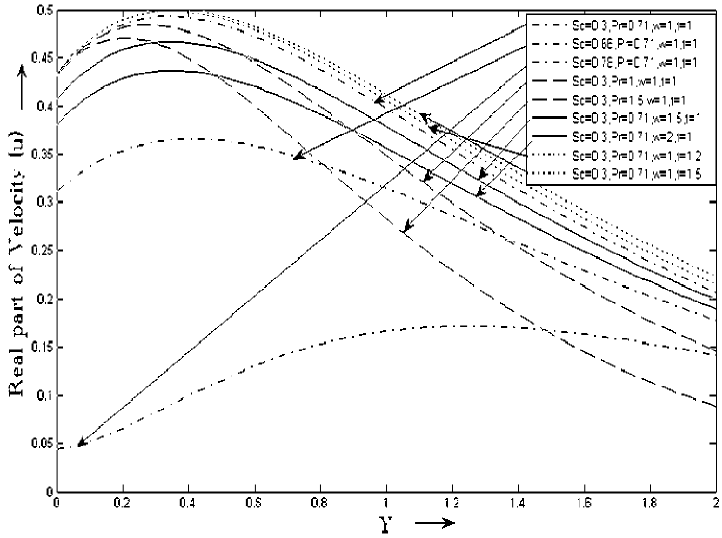

Figure 3: Effect of Sc, Pr ω and t on Velocity Profile When Gr=1, Gm=1, R=3, K=1, M=1, h=1 and ϵ=0.2

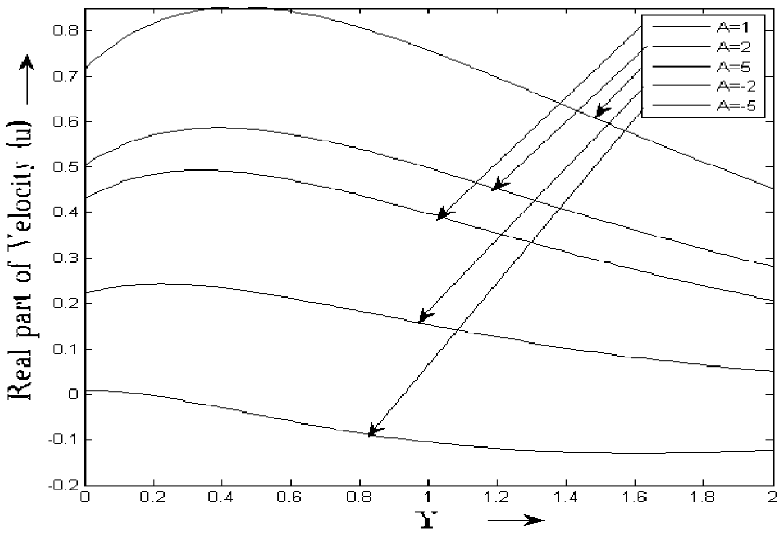

Figure 4: Effect of A on Velocity Profile When Gr=1, Gm=1, R=3, K=1, M=1, h=1, Sc=0.3, Pr=0.71, t=1, $\omega = 1$ and ϵ=0.2

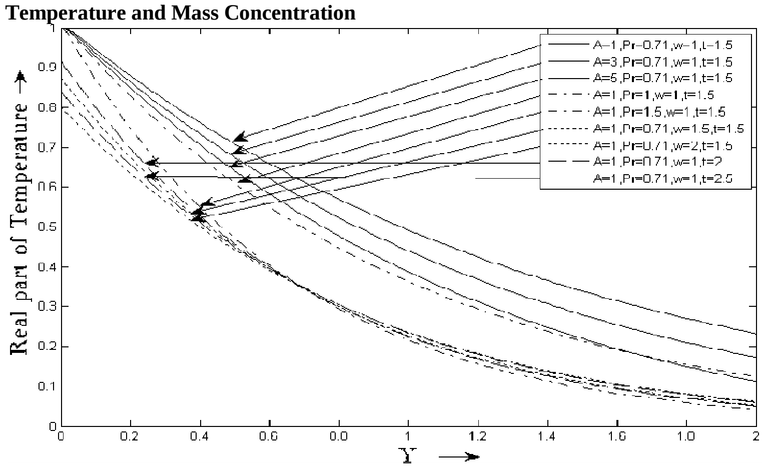

Figure 5: Effect of A, Pr, t and ω on Temperature Profile When ϵ=0.2

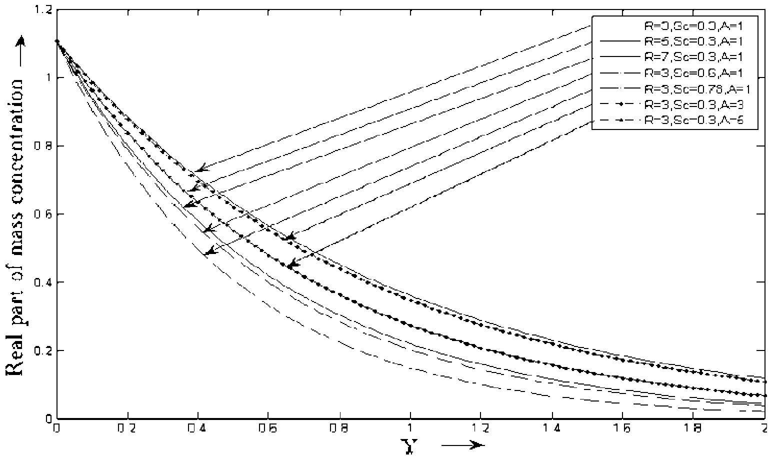

Figure 6: Effect of A, Sc and R on Mass Concentration Profile When ϵ=0.2, t=1 and $\omega = 1$

Table 1: Effect of A, Pr, Sc, Gr, Gm, R, M, K, h, t and ω on Absolute Value of Skin Friction (τ), Skin Friction of Mean Velocity (τ_0), Amplitude of Skin Friction(F) and Phase Angle Tan(α)

Initially Value of the Parameters A=2, R=3, M=1, K=1, Gr=1, Gm=1, Pr=0.71, Sc=0.3, $\omega = 1$, Ec=0.2		Skin Friction of Mean Velocity (τ_0)	Absolute Value of Skin Friction(τ_a)	Amplitude of Skin Friction(F)	Phase Angle Tan(α)
A	2	0.3529	0.4885	0.7569	-44.7983
	5	0.3529	0.6801	1.8525	7.9732
	7	0.3529	0.8164	2.5895	6.4706
R	5	0.3348	0.4598	0.6498	-3.9838
	7	0.3228	0.3916	1.1616	0.5938
M	3	0.2285	0.3232	0.4837	-3.0772
	5	0.1726	0.2774	0.3631	-2.1768
K	3	0.4409	0.5927	0.9704	4.2797
	5	0.4653	0.6185	1.0368	3.1425
h	2	0.2117	0.2929	0.4540	-59.5677
	4	0.1176	0.1626	0.2522	-76.3329
Gr	3	0.7427	1.6695	5.0940	11.4665
	5	1.1326	2.8643	9.4359	10.4130
Gm	3	0.6688	0.4880	2.1105	4.0146
	5	0.9846	0.7463	4.9553	4.8363
Pr	1	0.3246	0.5380	1.2066	14.9599
	7	0.1996	0.8268	3.2495	-61.2345
Sc	0.6	0.3196	0.3524	0.9213	0.5078
	0.78	0.372	0.8392	4.8722	-0.0329
ω	1.5	0.3529	0.4485	0.4780	-14.6083
	2	0.3529	0.4120	0.3392	-7.6540

Table 2: Effect of A, Pr, t and ω on Absolute Value of Nusselt Number (Nu_a), Amplitude of Nusselt Number(Q) and Phase Angle Tan(β)

A	Pr	ω	t	Absolute Value of Nusselt Number (Nu_a)	Amplitude of Nusselt Number (Q)	Phase Angle Tan(β)
2	0.71	1	1	0.9984	1.9894	-0.0625
5	0.71	1	1	1.3550	3.3616	-0.1658
7	0.71	1	1	1.5984	5.1138	-0.1930
2	1	1	1	1.4167	2.8746	-0.0583
2	7	1	1	9.4457	20.9749	-0.0118
2	0.71	1.5	1	0.8475	1.9156	-0.0533
2	0.71	2	1	0.6624	1.8625	-0.0331
2	0.71	1	1.5	0.8588	1.9894	-0.0625
2	0.71	1	2	0.6781	1.9894	-0.0625

Table 3: Effect of ω, Sc, and t on Absolute Value of Sherwood Number(Sh_a), Amplitude of Shreewood Number (T) and Phase Angle Tan(α)

A	R	Sc	ω	t	Absolute Value of Shreewood Number (Sh_a)	Amplitude of Shreewood Number(T)	Phase Angle Tan(γ)
2	3	0.3	1	1	1.2869	1.4582	0.0219
5	3	0.3	1	1	1.3624	1.9778	0.0108
7	3	0.3	1	1	1.4148	2.3242	0.0062
2	5	0.3	1	1	1.5925	1.7208	0.0153
2	7	0.3	1	1	1.8420	1.9381	0.0118
2	3	0.6	1	1	1.9710	2.4065	0.0166
2	3	0.78	1	1	2.3375	2.9421	0.0145
2	3	0.3	1.5	1	1.1588	1.4592	0.0329
2	3	0.3	2	1	1.0114	1.4607	0.0438
2	3	0.3	1	1.5	1.1618	1.4582	0.0219
2	3	0.3	1	2	1.0177	1.4582	0.0219

REFERENCES

1. S. T. Revankar, Natural convection effects on MHD flow past an impulsively started permeable plate, Indian J. pure Appl. Math., 14, 530–539, 1983.

2. P. Mohapatra and N. Senapati hydrodynamic free convection flow with mass transfer past a vertical plate AMSE, 37(1), 1-23, 1990

3. Das, U. N., Deka, R. K., Soundalgekar, V. M. J. Heat Transfer, (ASME), 121, 1091-1094, (1999).

4. Hossain, M. A., Hussain, S., Rees, D. A. S. ZAMM, 81, 699-709, (2001).

5. A. K. Singh, MHD free convective flow through a porous medium between two vertical parallel plates, Ind. J. Pure and Appl. Phys. 40(2002), 709–713.

6. Sharma P. K., Chaudhary, R. C. Emirates Journal for Engineering Research, 8(2), 33-38, (2003).

7. Sharma P.K. Matemáticas Vol. XIII No 151_62 June (2005).