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MASS TRANSFER EFFECTS ON UNSTEADY HYDROMAGNETIC CONVECTIVE FLOW PAST AN INFINITE VERTICAL POROUS FLAT PLATE IN A POROUS MEDIUM IN PRESENCE OF JOULEAN DISSIPATION AND SLIP FLOW REGIME

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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 Joulean dissipation and periodic temperature and mass concentration has been studied. Solutions are obtained for velocity, temperature, concentration; Nusselt number, Sherwood number and skin friction for mean and transitive parts .The result of various material parameters are discussed on flow variables and presented by graphs and tables.

Keywords: *Vertical plate, Heat and mass transfer, Porous medium, slip-flow regime, Joulean dissipation, free convection and MHD.*

1. INTRODUCTION

MHD plays an important role in power generation, space propulsions, cure of diseases, control of thermonuclear reactor, boundary layer control in 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 and thermal energy storage. The effect of magnetic field on free convection flow is important in liquid–metals and ionized gases. The flow through porous media has become an important topic because of the recovery of crude oil from pores of reservoir rocks .From the primitive years mass transfer plays an impotent role in vaporization of ocean, burning of pool of oil, spray drying, leaching and abolition of a meteorite. 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.

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 cannot 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. Sharma [7] 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. Senapati *et.al.* [8] have studied the effect of heat and mass transfer on MHD free convection flow past in oscillating vertical plate with variable temperature embedded in porous medium. Das. *et.al.* [9] have studied the effect of heat source on MHD free convection flow past an oscillating porous plate in the slip flow regime.

It is proposed to study the Mass transfer effects on unsteady hydromagnetic convective flow past an infinite vertical porous flat plate in a porous medium in presence of Joulean dissipation and slip flow regime.

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2. 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 constant 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 having 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 of x'. Under these assumptions, the physical variables are function of $y'$and t'only. Temperature and mass concentration changes with time Then neglecting only 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.

$$\frac{\partial v'}{\partial y'} = 0 \ \Rightarrow v' = -v_0 \tag{1}$$

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

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = k\frac{\partial^2 T'}{\partial y'^2} + \frac{\rho}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

The corresponding boundary conditions are

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

where ρ is the density, ν is the kinematic viscosity, g is the acceleration due to gravity, v_0 is the suction / injection parameter, $\beta$is the coefficient of volume expansion for heat transfer, β_c is the coefficient of volume expansion for mass transfer, D is the mass 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, $B_0 = H_0\mu_e$ is and the other symbols have their usual meanings.

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

$$\left.\begin{array}{l} y = \dfrac{y' v_0}{\nu}, t = t'\dfrac{v_0^2}{4\nu}, u = \dfrac{u'}{v_0}\ , \theta = \dfrac{T' - T_\infty'}{T_w' - T_\infty'}\ , \varphi = \dfrac{C' - C_\infty'}{C_w' - C_\infty'}\ , Sc = \dfrac{\nu}{D}, \\ Pr = \frac{\mu C_p}{k}\ , Ec = \frac{v_0^2}{C_p\left(T_w' - T_\infty'\right)}, Gr = \frac{\nu g\beta\,(T_w' - T_\infty')}{v_0^3}\ , Gm = \frac{\nu g\,\beta_c(C_w' - C_\infty')}{v_0^3}, \\ K = \frac{K' v_0^2}{\nu^2}\ , M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, h = \frac{v_0 L'}{\nu}, \omega = \frac{4\nu\omega'}{v_0^2} \end{array}\right\} \tag{6}$$

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, ω the frequency of oscillation , K the permeability parameter porous medium , h rarefaction parameter,Ec Eckert number and *M* the Hartmann number.
Then equation (1) – (4) and the boundary condition (5) reduces to

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = Gr\theta + Gm\varphi + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u \tag{7}$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{8}$$

$$\frac{1}{4}\frac{\partial \varphi}{\partial t} - \frac{\partial \varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} \tag{9}$$

with corresponding boundary conditions

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

3. METHOD OF SOLUTION

To solve equations (7) - (9), we assume ε to be very small and the velocity, temperature and mass concentration distribution of the flow field in the neighbourhood of the plate as

$$\left.\begin{aligned} u(y,t) &= u_0(y) + \in u_1(y)e^{i\omega t} \\ \theta(y,t) &= \theta_0(y) + \in \theta_1(y)e^{i\omega t} \\ \varphi(y,t) &= \varphi_0(y) + \in \varphi_1(y)e^{i\omega t} \end{aligned}\right\} \tag{11}$$

Substituting equations (7) - (10) in equations (7) - (9) respectively, equating the harmonic and non-harmonic terms and neglecting the coefficients of ε2, we get

ZEROTH ORDER:

$$-\frac{\partial u_0}{\partial y} = Gr\theta_0 + Gm\varphi_0 + \frac{\partial^2 u_0}{\partial y^2} - \left(M + \frac{1}{K}\right)u_0 \tag{12}$$

$$-\frac{\partial \theta_0}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_0}{\partial y^2}\right) + Ec\left(\frac{\partial u_0}{\partial y}\right)^2 \tag{13}$$

$$-\frac{\partial \varphi_0}{\partial y} = \frac{1}{Sc}\left(\frac{\partial^2 \varphi_0}{\partial y^2}\right) \tag{14}$$

FIRST ORDER:

$$\frac{\omega i}{4}u_1 - \frac{\partial u_1}{\partial y} = Gr\theta_1 + Gm\varphi_1 + \frac{\partial^2 u_1}{\partial y^2} - \left(M + \frac{1}{K}\right)u_1 \tag{15}$$

$$\frac{\omega i}{4}\theta_1 - \frac{\partial \theta_1}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_1}{\partial y^2}\right) + 2Ec\ \frac{\partial u_0}{\partial y}\frac{\partial u_1}{\partial y} \tag{16}$$

$$\frac{\omega i}{4}\varphi_1 - \frac{\partial \varphi_1}{\partial y} = \frac{1}{Sc}\left(\frac{\partial^2 \varphi_1}{\partial y^2}\right) \tag{17}$$

with the following boundary conditions

$$\left.\begin{aligned} & u_0 = h\frac{\partial u_0}{\partial y}, u_1 = h\frac{\partial u_1}{\partial y}, \theta_0 = 1, \theta_1 = 1, \varphi_0 = 1, \varphi_1 = 1 \quad at\ y = 0 \\ & u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, \varphi_0 \to 0, \varphi_1 \to 0 \quad as\ y \to \infty \end{aligned}\right\} \tag{18}$$

By solving equations (14) and (17) using equation (18) we get

$$\left.\begin{aligned} \varphi_0 &= e^{-Scy} \\ \varphi_1 &= e^{-\frac{\left(Sc+\sqrt{Sc^2+\omega i Sc}\right)y}{2}} \end{aligned}\right\} \tag{19}$$

To solve equation (12), (13), (15) and (16) take multi parameter perturbation technique and Ec<<1, we assume

$$\left.\begin{aligned} u_0 &= u_{00} + Ecu_{01} \\ u_1 &= u_{10} + Ecu_{11} \\ \theta_0 &= \theta_{00} + Ec\theta_{01} \\ \theta_1 &= \theta_{10} + Ec\theta_{11} \end{aligned}\right\} \tag{20}$$

Then the equations reduce to

$$-\frac{\partial u_{00}}{\partial y} = Gr\theta_{00} + Gm\varphi_0 + \frac{\partial^2 u_{00}}{\partial y^2} - \left(M + \frac{1}{K}\right)u_{00} \tag{21}$$

$$-\frac{\partial u_{01}}{\partial y} = Gr\theta_{01} + \frac{\partial^2 u_{01}}{\partial y^2} - \left(M + \frac{1}{K}\right)u_{01} \tag{22}$$

$$-\frac{\partial \theta_{00}}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_{00}}{\partial y^2}\right) \tag{23}$$

$$-\frac{\partial \theta_{01}}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_{01}}{\partial y^2}\right) + \left(\frac{\partial u_{00}}{\partial y}\right)^2 \tag{24}$$

$$\frac{\omega i}{4}u_{10} - \frac{\partial u_{10}}{\partial y} = Gr\theta_{10} + Gm\varphi_1 + \frac{\partial^2 u_{10}}{\partial y^2} - \left(M + \frac{1}{K}\right)u_{10} \tag{25}$$

$$\frac{\omega i}{4}u_{11} - \frac{\partial u_{11}}{\partial y} = Gr\theta_{11} + \frac{\partial^2 u_{11}}{\partial y^2} - \left(M + \frac{1}{K}\right)u_{11} \tag{26}$$

$$\frac{\omega i}{4}\theta_{10} - \frac{\partial \theta_{10}}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_{10}}{\partial y^2}\right) \tag{27}$$

$$\frac{\omega i}{4}\theta_{11} - \frac{\partial \theta_{11}}{\partial y} = \frac{1}{Pr}\left(\frac{\partial^2 \theta_{11}}{\partial y^2}\right) + 2\,\frac{\partial u_{00}}{\partial y}\frac{\partial u_{10}}{\partial y} \tag{28}$$

With the following boundary conditions

$$\left.\begin{array}{l} u_{00} = h\frac{\partial u_{00}}{\partial y}, u_{01} = h\frac{\partial u_{01}}{\partial y}, u_{10} = h\frac{\partial u_{10}}{\partial y}, u_{11} = h\frac{\partial u_{11}}{\partial y}, \theta_{00} = 1\ \theta_{01} = 0, \theta_{10} = 1, \theta_{11} = 0\ \ at\ y = 0 \\ u_{00} \to 0\ , u_{10} \to 0, \theta_{00} \to 0, \theta_{10} \to 0, u_{01} \to 0\ , u_{11} \to 0, \theta_{01} \to 0, \theta_{11} \to 0\ as\ y \to \infty \end{array}\right\} \tag{29}$$

By solving equations from (21) to (28) using equation (19) and boundary conditions (29) we get

$$u_0 = A_3e^{B_2y} + A_1e^{-Pry} + A_2e^{-Scy}$$
$$+Ec\left(A_{18}e^{B_2y} + A_{11}e^{-Pry} + A_{12}e^{2B_2y} + A_{13}e^{-2Pry} + A_{14}e^{-2Scy} + A_{15}e^{(B_2-Pr)y} + A_{16}e^{-(Sc+Pr)y} + A_{17}e^{(B_2-Sc)y}\right) \tag{30}$$

$$u_1 = A_{21}e^{B_4y} + A_{19}e^{B_1y} + A_{18}e^{B_3y} + Ec(A_{34}e^{B_5y} + A_{32}e^{B_1y} + A_{33}e^{B_3y}) \tag{31}$$

$$\theta_0 = e^{-Pry} + Ec\left(A_{10}e^{-Pry} + A_4e^{2B_2y} + A_5e^{-2Pry} + A_6e^{-2Scy} + A_7e^{(B_2-Pr)y} + A_8e^{-(Sc+Pr)y} + A_9e^{(B_2-Sc)y}\right) \tag{32}$$

$$\theta_1 = e^{B_1y}$$
$$+Ec\begin{pmatrix} A_{31}e^{B_1y} + A_{22}e^{(B_2+B_4)y} + A_{23}e^{(B_4-Pr)y} + A_{24}e^{(B_4-Sc)y} + A_{25}e^{(B_2+B_1)y} + A_{26}e^{(B_1-Pr)y} + A_{27}e^{(B_1-Sc)y} \\ +A_{28}e^{(B_2+B_3)y} + A_{29}e^{(B_3-Pr)y} + A_{30}e^{(B_3-Sc)y} \end{pmatrix} \tag{33}$$

where $B_1 = \frac{-\left(Pr+\sqrt{Pr^2+Pri\omega}\right)}{2}$, $B_2 = \frac{-\left(1+\sqrt{1+4\left(M+\frac{1}{K}\right)}\right)}{2}$, $B_3 = \frac{-\left(Sc+\sqrt{Sc^2+Sci\omega}\right)}{2}$,

$B_4 = \frac{-\left(1+\sqrt{1+\omega i+4\left(M+\frac{1}{K}\right)}\right)}{2}$, $B_5 = \frac{-\left(1+\sqrt{1+4\left(M+\frac{1}{K}+\frac{\omega i}{4}\right)}\right)}{2}$

$$A_1 = \frac{-Gr}{Pr^2 - Pr - \left(M + \frac{1}{K}\right)}, A_2 = \frac{-Gm}{Sc^2 - Sc - \left(M + \frac{1}{K}\right)}, A_3 = -(PrA_1 + ScA_2 + A_1 + A_2)/(1 - hB_2)$$

$$A_4 = \frac{{A_3}^2}{4B_2^2 + 2PrB_2}, A_5 = \frac{A_1^2}{2Pr^2}, A_6 = \frac{A_2^2}{2Sc^2}, A_7 = \frac{2A_3A_1}{B_2^2 + PrB_2}, A_8 = \frac{2A_2A_1}{Sc^2 + PrSc},$$

$$A_9 = \frac{2A_2A_3}{(B_3 - Sc)^2 + Pr(B_3 - Sc)}, A_{10} = 1 - (A_4 + A_5 + A_6 + A_7 + A_8 + A_9)$$

$$A_{11} = \frac{-GrA_{10}}{Pr^2 - Pr - \left(M + \frac{1}{K}\right)}, A_{12} = \frac{-GrA_4}{4\,{B_2}^2 + 2\,B_2 - \left(M + \frac{1}{K}\right)},$$

$$A_{13} = \frac{-GrA_5}{4Pr^2 - 2Pr - \left(M + \frac{1}{K}\right)},$$

$$A_{14} = \frac{-GrA_6}{4Sc^2 - Sc - \left(M + \frac{1}{K}\right)},\ A_{15} = \frac{-GrA_7}{(B_2 - \mathrm{Pr})^2 + (B_2 - Pr) - \left(M + \frac{1}{K}\right)},$$

$$A_{16} = \frac{-GrA_8}{(Sc + \mathrm{Pr})^2 - (Sc + Pr) - \left(M + \frac{1}{K}\right)},\ A_{17} = \frac{-GrA_9}{(B_2 - \mathrm{Sc})^2 + (B_2 - Sc) - \left(M + \frac{1}{K}\right)}$$

$$A_{18} = \frac{A_{11} + A_{12} + A_{13} + A_{14} + +A_{15} + A_{16} + A_{17} + h(A_{11}Pr - 2A_{12}B_2 + 2A_{13}Pr + 2ScA_{14} + (B_2 - Pr)A_{15} + (Sc + Pr)A_{16} - (B_2 - Sc)A_{17})}{(hB_2 - 1)}$$

$$A_{19} = \frac{-Gr}{{B_1}^2 + B_1 - \left(\omega i + M + \frac{1}{K}\right)},\ A_{20} = \frac{-Gm}{{B_3}^2 + B_3 - \left(\omega i + M + \frac{1}{K}\right)}$$

$$A_{21} = \frac{h(B_1A_{19} + B_3A_{20}) - A_{19} - A_{20}}{(1 - hB_4)},\ A_{22} = \frac{-2A_{21}B_4A_3B_2}{(B_4 + B_2)^2 - Pr(B_4 + B_2) - \left(\frac{Pri\omega}{4}\right)}$$

$$A_{23} = \frac{2A_{21}B_4A_1Pr}{(B_4 - Sc)^2 - Pr(B_4 - Sc) - \left(\frac{Pri\omega}{4}\right)},\ A_{24} = \frac{2A_{21}B_4A_2Sc}{(B_4 - Pr)^2 - Pr(B_4 - Pr) - \left(\frac{Pri\omega}{4}\right)}$$

$$A_{25} = \frac{-2A_{19}B_1\ A_3B_2}{(B_1 + B_2)^2 - Pr(B_1 + B_2) - \left(\frac{Pri\omega}{4}\right)},\ A_{26} = \frac{2A_{19}B_1A_1Pr}{(B_1 - Pr)^2 - Pr(B_1 - Pr) - \left(\frac{Pri\omega}{4}\right)}$$

$$A_{27} = \frac{2A_{19}B_1\ A_2Sc}{(B_1 + B_2)^2 - Pr(B_1 + B_2) - \left(\frac{Pri\omega}{4}\right)},\ A_{28} = \frac{-2A_{19}B_3A_3B_2}{(B_1 - Pr)^2 - Pr(B_1 - Pr) - \left(\frac{Pri\omega}{4}\right)}$$

$$A_{29} = \frac{2A_{18}B_3\ A_1Pr}{(B_3 - Pr)^2 - Pr(B_3 - Pr) - \left(\frac{Pri\omega}{4}\right)},\ A_{30} = \frac{2A_{18}B_3 2Sc}{(B_3 - Sc)^2 - Pr(B_3 - Sc) - \left(\frac{Pri\omega}{4}\right)}$$

$$A_{31} = -(A_{22} + A_{23} + A_{24} + A_{25} + A_{26} + A_{27} + A_{28} + A_{29} + A_{30})$$

$$A_{32} = \frac{-Gr}{{B_1}^2 + B_1 - \left(M + \frac{1}{K} + \frac{\omega i}{4}\right)},\ A_{33} = \frac{-Gm}{{B_3}^2 + B_3 - \left(M + \frac{1}{K} + \frac{\omega i}{4}\right)}$$

$$A_{34} = \frac{A_{32} + A_{33} - h(B_1A_{32} + B_3A_{33})}{hB_5 - 1}$$

The mean skin friction/shearing stress at the plate in dimensional form is given by

$$\tau_0 = \left(\frac{\partial u_0}{\partial y}\right)_{y=0} = B_2A_3 - PrA_1 - ScA_2 + Ec[A_{18}B_2 - PrA_{11} + 2B_2A_{12} - 2PrA_{13} - 2ScA_{14} + A_{15}(B_2 - Pr) - A_{16}(Sc + Pr) + A_{17}(B_2 - Sc)]$$

Similarly, the mean rate of heat transfer at the plate/Nusselt Number is given by

$$Nu_0 = -\left(\frac{\partial\theta_0}{\partial y}\right)_{y=0} = Pr + Ec[-PrA_{10} + 2B_2A_4 + 2A_5Pr + 2ScA_6 - A_7(B_2 - Pr) + A_8(Sc + Pr) - A_9(B_2 - Sc)]$$

and the mean rate of mass concentration transfer at the plate/Sherwood Number is given by

$$Sh_0 = -\left(\frac{\partial\varphi_0}{\partial y}\right)_{y=0} = Sc$$

4. DISCUSSION OF RESULTS

In this paper we have studied the effect of Mass transfer on unsteady hydromagnetic convective flow past an infinite vertical porous flat plate in a porous medium in presence of Joulean dissipation and slip flow regime. The effect of the parameters Gr, Gm, M, h, Ec, K, Pr 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 Sc=0.22(for hydrogen),Sc=0.3(for helium),Sc=0.66(for oxygen) and Sc=0.96 (for carbon dioxide). To obtain the graphs by taking the real parts of velocity, temperature, mass concentration w.r.t parameter (y).

Velocity profiles: The velocity profiles are depicted in Figs 1-4. Figure-(1)) shows the effect of the parameters Gr and Gm on velocity profile at any point of the fluid, when Ec=0.2, Pr=0.22, Sc=7, M=2, K=2, h=1, t=0.1 and ω=1.It is noticed that the velocity increases with the increase of Grashoff number (Gr) and modified Grashoff number(Gm).

Figure-(2) shows the effect of the parameters M and K on velocity at any point of the fluid, when Ec=0.2, Pr=0.22, Sc=7, Gr=2, Gm=2, h=1, t=0.1 and ω=1. It is noticed that the velocity increases with the increase of magnetic parameter (M) and Porous parameter (K).

Figure-(3) shows the effect of the parameters Sc, Pr and h on velocity at any point of the fluid, when Ec=0.2, Gr=2, Gm=2,M=2, K=2, t=0.1 and ω=0.5. It is noticed that the velocity increases with the increase of Prandtl number (Pr) and rarefaction parameter (h) whereas decreases with the increase of Schmidt number (Sc).

Figure-(4) shows the effect of the parameters Ec, ω and t on velocity at any point of the fluid, when Sc=0.22, Gr=2, Gm=2, M=2, K=2, Pr=7 and h=1. It is noticed that the velocity increases with the increase of Eckert number (Ec), oscillating frequency (ω) and time (t).

Temperature profile: The temperature profiles are depicted in Figs 5-8.Figure-(5) shows the effect of the parameters,Gr and Gm on Temperature profile at any point of the fluid, when Sc=0.22, Ec=0.6, h=1, M=2, K=2, Pr=7, t=0.1 and $\omega = 1$. It is noticed that the temperature falls when Grashoff number(Gr) increases and rises in the increase of modified Grashoff number (Gm)..

Figure-(6) shows the effect of the parameters M and K on Temperature profile at any point of the fluid, when Sc=0.22, Ec=0.6, h=1, Gm=2, Gr=2, Pr=7, t=0.1 and $\omega = 1$. It is noticed that the temperature falls when magnetic parameter (M) increases and rises in the increase of Porous parameter(K).

Figure-(7) shows the effect of the parameters Pr and Sc on Temperature profile at any point of the fluid, when M=2, Ec=0.6, h=1, Gm=2, Gr=2, K=2, t=0.1 and $\omega = 1$. It is noticed that the temperature falls when Schmidt number (Sc) increases and rises in the increase of Prandtl number (Pr).

Figure-(8) shows the effect of the parameters Ec and h on Temperature profile at any point of the fluid, when M=2, Pr=7, Sc=0.22, Gm=2, Gr=2, K=2, t=0.1 and $\omega = 1$. It is noticed that the temperature falls when rarefaction parameter (h) increases and rises in the increase of Eckert number (Ec).

Mass concentration profile: Figure-(9) shows the effect of the parameters Sc and ω on mass concentration profile at any point of the fluid, when M=2, Pr=7, Sc=0.22, Gm=2, Gr=2, K=2, t=0.1 and $\omega = 1$.It is noticed that the mass concentration decreases with the increase in Schmidt number (Sc) whereas increases with the increase of frequency of oscillation (ω).

Shearing stress of velocity: The Shearing stresses of velocity are depicted in Table-1, it shows the effect of the parameters Pr, h, Sc, Gr, Gm, M and K at Ec=0.02 on shearing stress of velocity at the plate of the fluid. It is noticed that shearing stress at plate decreases with the increase in rarefaction parameter (h), magnetic parameter (M) and Porous parameter (K) whereas increases with the increase in Grashoff number (Gr), Prandtl number (Pr), Schmidt number (Sc) and modified Grashoff number (Gm),

Nusselt number of mean Temperature: Table-(2) shows the effect of the parameters Pr, h, Sc, Gr, Gm, Ec, M and K on rate of heat transfer at the plate ,It is observed that the rate of heat transfer increases with the increase in modified Grashoff number (Gm), Grashoff number (Gr), Porous parameter (K), Prandtl number (Pr) and Eckert number (Ec) whereas decreases with the increase in rarefaction parameter (h), Schmidt number (Scand magnetic parameter (M).

Table-1: Effect of different parameter on Shearing stress of velocity

Gr	K	Gm	M	Sc	Pr	h	Shearing stress
2	2	2	2	0.22	0.71	0.2	1.8235
				0.3			2.5349
				0.66			2.9603
				0.96			3.1083
				0.22	1		7.2505
					2		12.4243
6					0.71		3.6087
8							7.8181
2		4					2.0205
		6					2.8180
		2	4				1.6619
			6				1.3955
	4		2				1.7866
	6						1.7678
	2					0.4	1.3772
						0.6	1.0585

Table-2: Effect of different parameter on Nusselt number of Temperature

Gr	K	Gm	M	Sc	Pr	h	Ec	Nusselt Number
2	2	2	2	0.22	0.71	0.2	0.02	13.3295
				0.3				11.7095
				0.66				1.0613
				0.96				0.4046
				0.22	1			26.023
					2			58.653
4					0.71			21.7124
6								30.6520
2		4						37.5390
		6						72.8504
		2	4					4.5456
			6					2.1440
	4		2					16.0.332
	6							171216
	2					0.4		11.0159
						0.6		9.5718
						0.2	0.04	25.9890
							0.06	38.6422

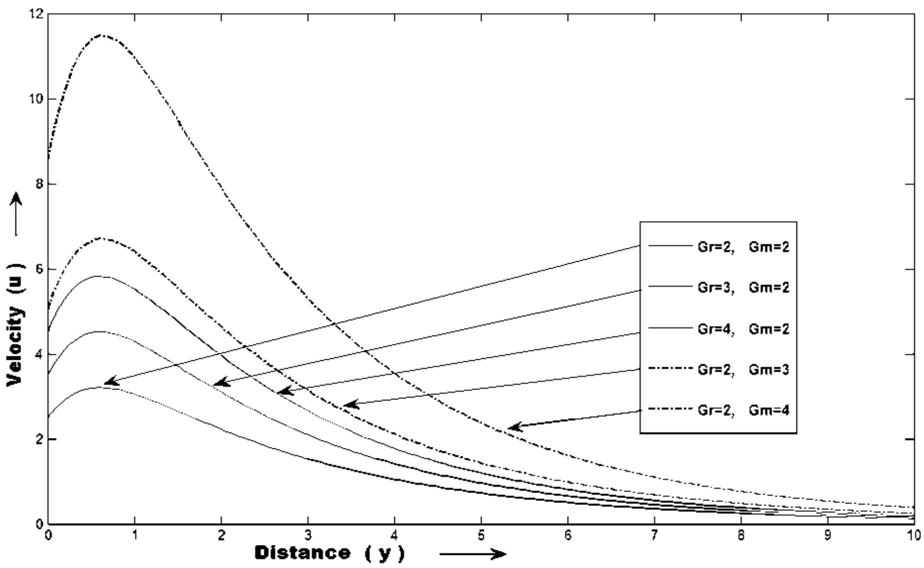

Fig. 1: Effect of Gr and Gm on Velocity profile when Ec=0.2, Pr=0.22, Sc=7, M=2, K=2, h=1, t=0.1 and ω=1.

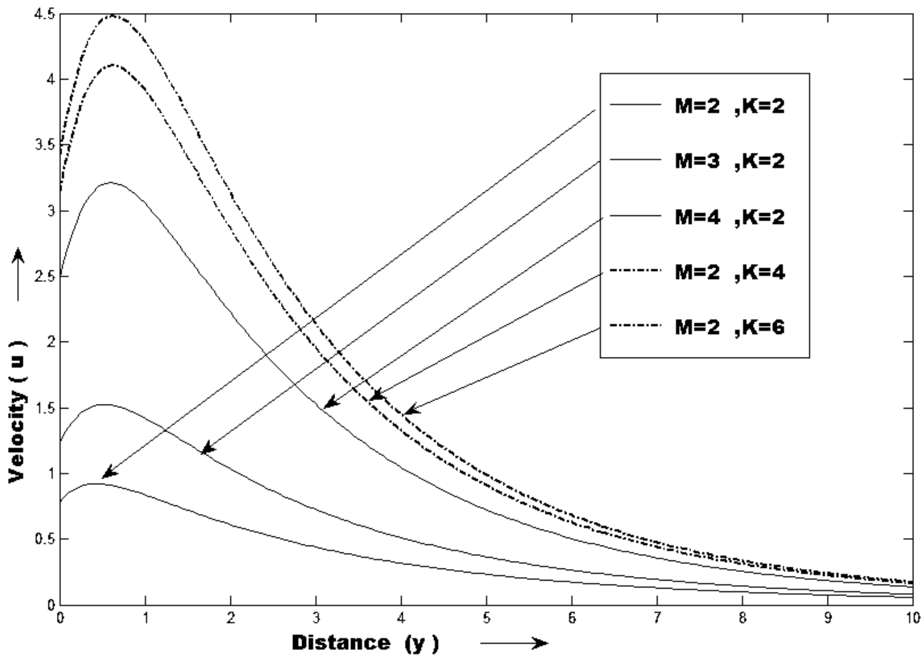

Fig. 2: Effect of K and M on Velocity profile when Ec=0.2, Pr=0.22, Sc=7, Gr=2, Gm=2, h=1, t=0.1 and ω=1.

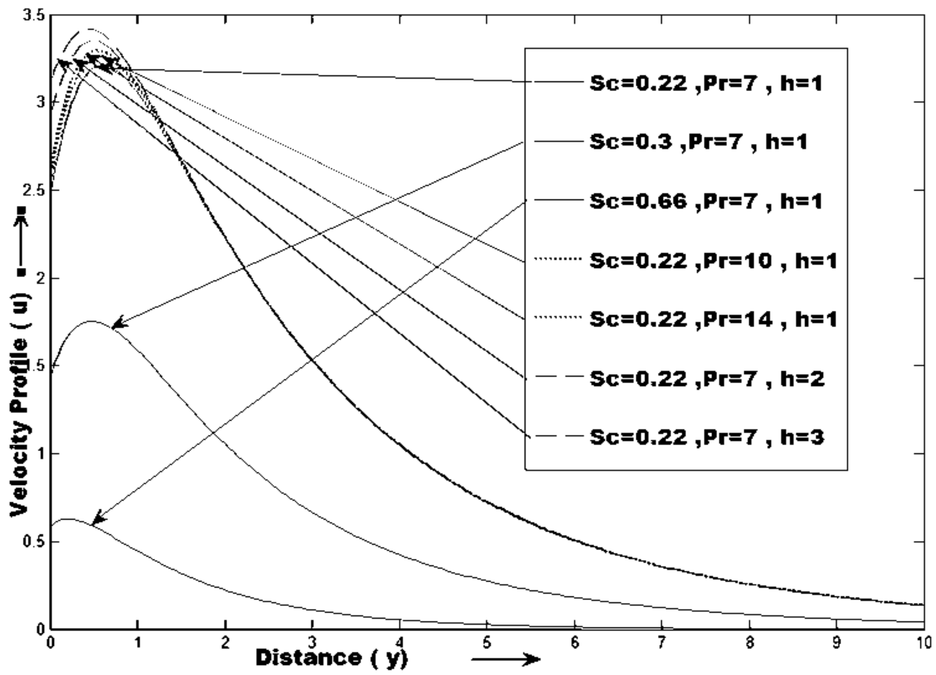

Fig. 3: Effect of Pr, Sc and h on Velocity profile when Ec=0.2, Gr=2, Gm=2, M=2, K=2, t=0.1 and ω=0.5.

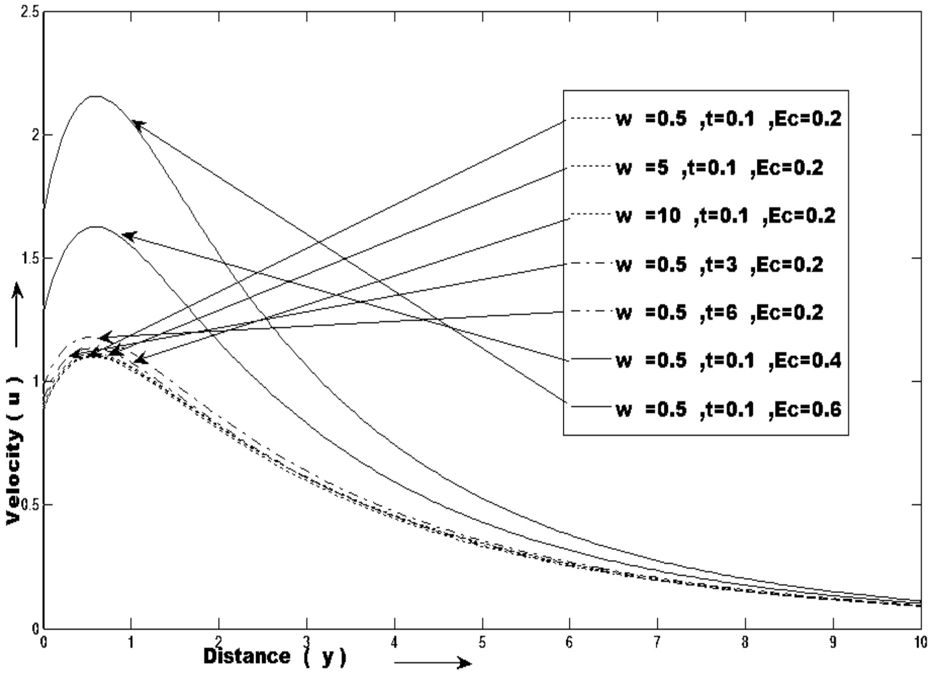

Fig. 4: Effect of t , Ec and ω on Velocity profile when Sc=0.22, Gr=2, Gm=2, M=2, K=2, Pr=7 and h=1.

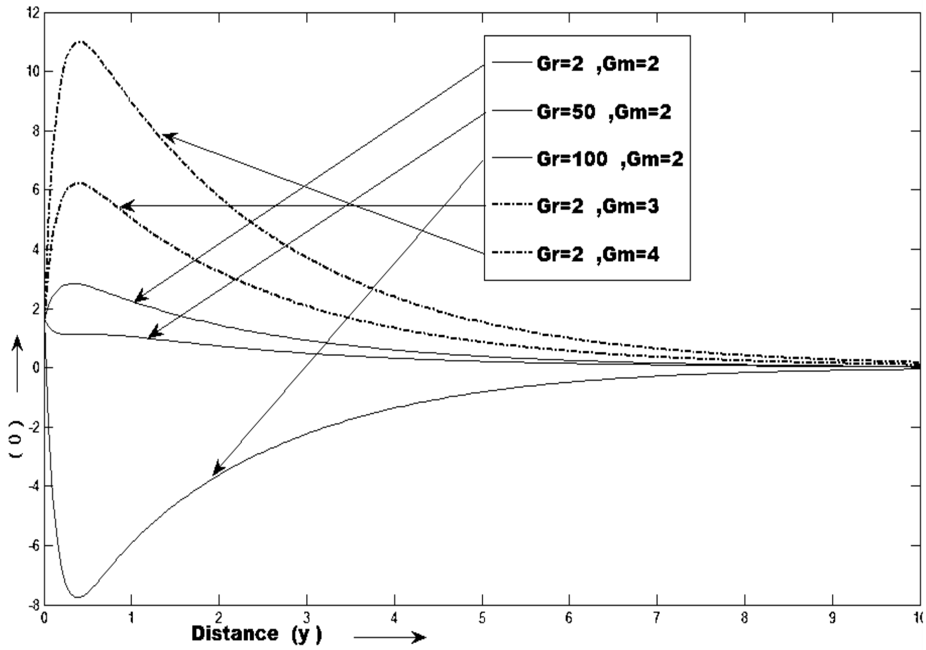

Fig. 5: Effect of Gr and Gm on Heat profile when Sc=0.22, Ec=0.6, h=1, M=2, K=2, Pr=7, t=0.1 and $\omega = 1$

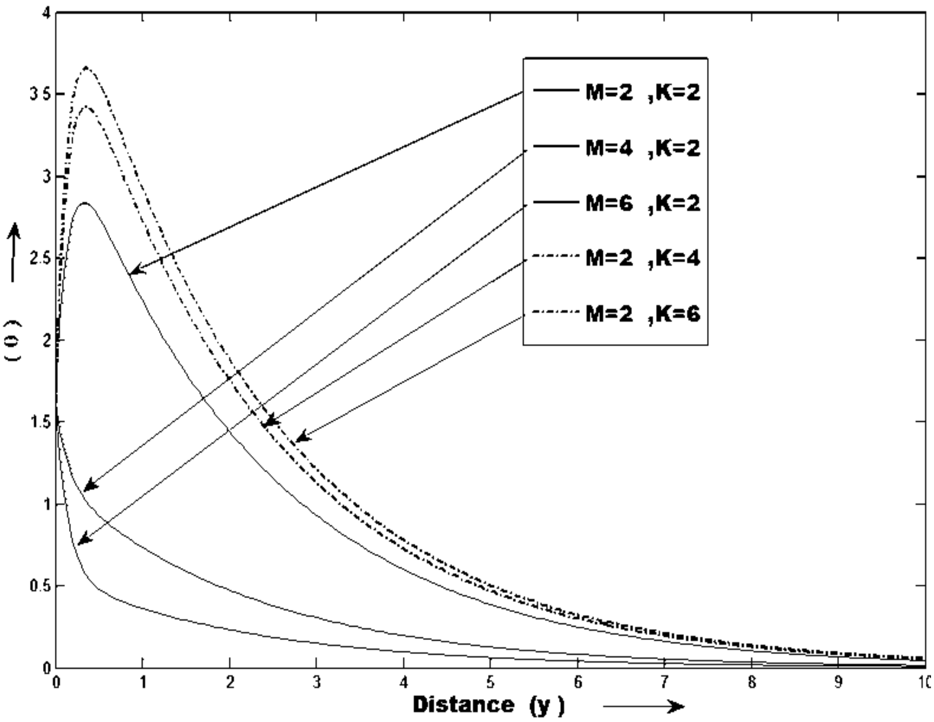

Fig. 6: Effect of M and K on Heat profile when Sc=0.22, Ec=0.6, h=1, Gm=2, Gr=2, Pr=7, t=0.1 and $\omega = 1$

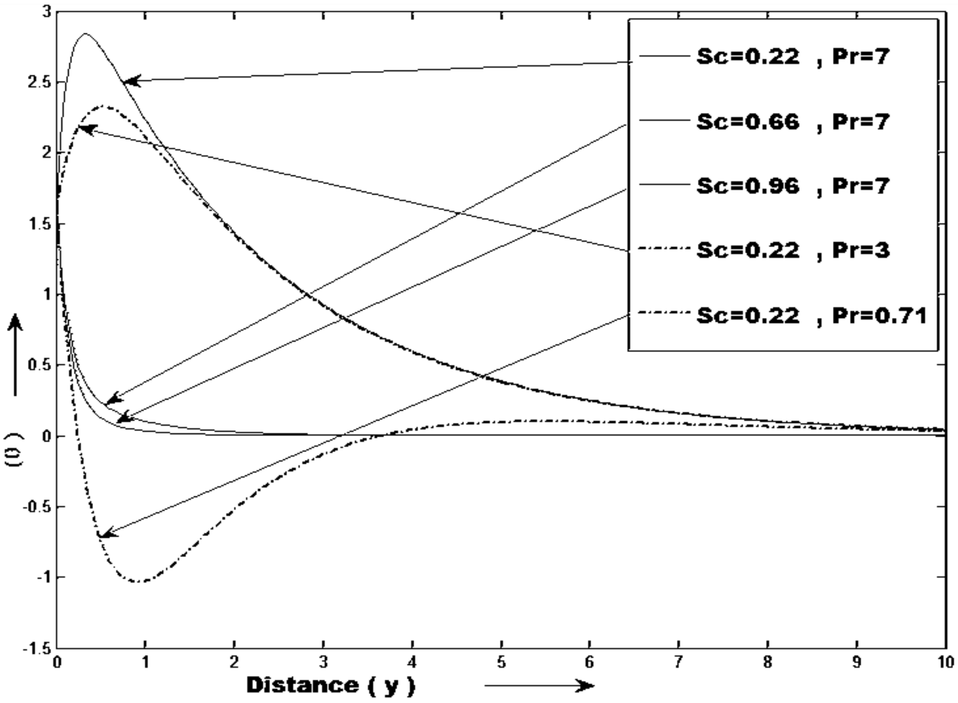

Fig. 7: Effect of Sc and Pr on Heat profile when M=2, Ec=0.6, h=1, Gm=2, Gr=2, K=2, t=0.1 and $\omega = 1$

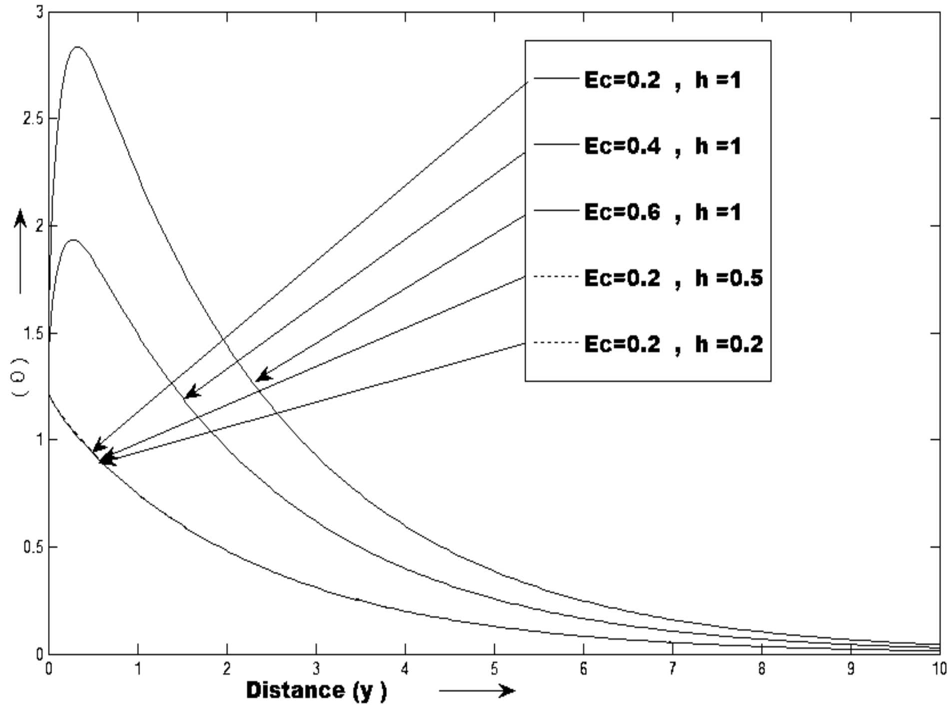

Fig. 8: Effect of Ec and h on Heat profile when M=2, Pr=7, Sc=0.22, Gm=2, Gr=2, K=2, t=0.1 and $\omega = 1$

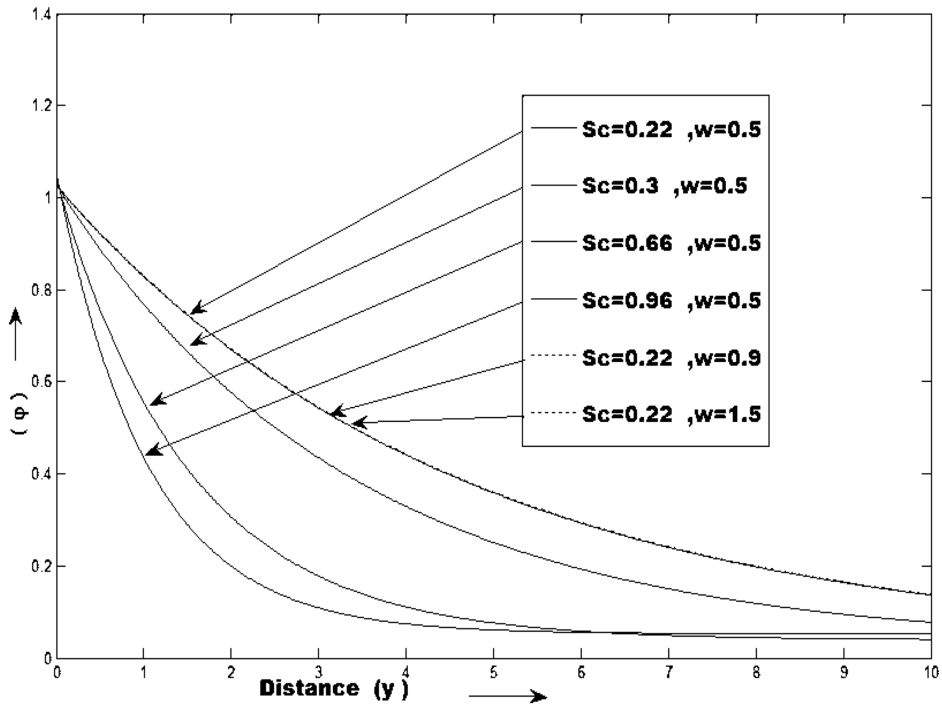

Fig. 9: Effect of Sc and w on mass concentration profile at t=0.1 in the absence of other parameters

5. CONCLUSIONS

i. The velocity increases with the increase when kinetic viscosity dominant over thermal diffusion, magnetic force dominant over viscus force, increase of viod space in porous and increase of convective amount of heat and mass concentration. But it decreases when kinetic viscosity dominant over mass diffusion.

ii. The heat rises when kinetic viscosity dominant over thermal diffusion, increase of viod space in porous and increase of convective amount mass concentration,whereas falls when magnetic force dominant over viscus force , increase in amount of convective heat and kinetic viscosity dominant over mass diffusion.

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