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EFFECT OF CHEMICAL REACTION ON MHD FLOW PAST AN OSCILLATING INFINITE VERTICAL PLATE EMBEDDED IN POROUS MEDIUM IN THE PRESENCE OF HEAT SINK

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Abstract: An analytical investigation is presented to examine the influence of heat sink and chemical reaction on heat and mass transfer flow past an oscillating vertical plate embedded in porous medium in the presence magnetic field. A uniform magnetic field of uniform strength B_o is applied normal to the main flow direction. The resulting non linear coupled partial differential equations for the velocity, temperature and concentration fields with the boundary conditions are reduced to non dimensional form. The governing equations are solved in closed form by adopting the Laplace transform technique and obtained the solutions of velocity, temperature and concentration fields. The effects of the physical parameters such as magnetic parameter, thermal Grashof number, solutal Grashof number, permeability parameter, Prandtl number, Schmidt number, heat sink and chemical reaction involved in the flow problem and the transport characteristics are examined with the help different graphs.

Key Words: MHD, Oscillating plate, Prandtl number, Schmidt number.

Mathematical subject classification (2010): 76W05, 76D

1. Introduction

MHD is the science of motion of electrically conducting fluid in presence of magnetic field. MHD is currently undergoing a period of great enlargement and differentiation of subject matter. Engineers apply MHD principle in fusion reactors, dispersion of metals, metallurgy, design of MHD pumps, MHD generator and MHD flow meters etc. Geophysics encounters MHD characteristics in the interaction of conducting fluid and magnetic field. In the field of power generation, MHD is receiving considerable attention due to the possibilities it offers for much higher thermal efficiencies in power plants. The various applications of MHD flows in technological fields have been compiled by Moreau [9]. On the other hand, to study the underground water resources, seepage of water in river beds, the filtration and water purification processes in chemical engineering, one need the knowledge of the fluid flow through porous medium. The porous medium is in fact a non homogeneous medium but for the sake of analysis, it may be possible to replace it with a homogeneous fluid saturated medium which was dynamical properties equal to those of non homogeneous continuum. Ahmadi and Manvi [1] have derived the general equation of motion and applied the results to some basic flow problems. Ram and Mishra [11] applied these equations to study MHD flow of conducting fluid through porous medium. Sahoo and Sahoo [12] have discussed MHD free convection flow past a vertical plate through porous medium in presence of foreign mass. Combined heat and mass transfer effects on MHD free convective flow through porous medium is discussed by Chaudhary and Jain [4].

Mass diffusion rates can be changed extremely with chemical reactions. The chemical reaction effects depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an edge or as a solo phase volume reaction. In well mixed system, if the reaction takes place in solution it will be homogeneous and if the reaction takes place at an interface it will be heterogeneous. In most of the cases, chemical reaction rate depends on the concentration of the species itself. A reaction is of order n, if the reaction rate is proportional to the n^{th} power of concentration. In particular, a reaction is said to be first order, if the rate of reaction is directly proportional to concentration itself [6]. Chamber and Young [5] have worked on thermal diffusion of a chemically reactive species in laminar boundary layer flow. Muthucumaraswamy and Meenakshisundaram [10] have investigated theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Senapati and Dhal [14] have studied magnetic effect on heat and mass transfer of hydrodynamic flow past a vertical oscillating plate in occurrence of chemical reaction.

Heat generation/absorption plays a significant role in various physical phenomena such as convection in earth's mantle [8], application in the field of nuclear energy and fire combustion modelling [7]. In electronic system, a heat sink is a passive component that cools a device by dissipating heat into the surrounding air. Due to its grand applicability to ceramic tiles production problems, the study of heat transfer in the presence of a source/sink has acquired newer scope. Vajravelu [15] have concluded that the heat source/sink play an important character in delaying the velocity and the temperature to attain the steady state condition. Ahmed *et al.* [3] have deliberated the natural convection in MHD transient flow with heat sink. Ahmed *et al.* [2] have investigated the influence of heat sink and chemical reaction on an oscillatory MHD unsteady flow past an infinite vertical porous plate with variable suction.

The aim of this present study is to extend the work of Saraswat and Srivastava [13]. In the present work MHD, chemical reaction and heat source/sink are taken into accounts which were not considered on the study of Saraswat and Srivastava [13]. The prime objective of this present work is to deliberate the simultaneous effects of first order chemical reaction and heat sink on oscillating vertical plate embedded in porous medium in presence of magnetic field.

Nomenclature

B_o	strength of the applied magnetic field
C'	species concentration in the fluid
C'_w	concentration of the plate
C'_∞	concentration in the fluid far away from the plate
C	dimensionless concentration
C_p	specific heat at constant pressure
D	mass diffusion coefficient
g	acceleration due to gravity
Gr	thermal Grashof number
Gm	mass Grashof number
k	thermal conductivity of the fluid
k'	permeability of porous medium
K'	first order homogeneous chemical reaction rate
K	dimensionless chemical reaction parameter
M	magnetic parameter
Nu	Nusselt number
Pr	Prandtl number
Q'	dimensional heat absorption term
Q	dimensionless heat sink parameter
Sc	Schmidt number
Sh	Sherwwod number
T'	temperature of the fluid
T'_w	temperature of the plate
T'_∞	temperature of the fluid far away from the plate
t'	time
t	dimensionless time
u'	velocity of the fluid in x' direction
u_o	amplitude of the plate velocity
u	dimensionless velocity
y'	coordinate axis normal to the plate
y	dimensionless coordinate axis normal to the plate
α	permeability parameter of porous medium
β	volumetric coefficient of thermal expansion
β^*	volumetric coefficient of solutal expansion
μ	coefficient of viscosity
ρ	density

ρ_∞	reference density
υ	kinematic viscosity
τ	dimensionless skin friction
ω'	dimensional frequency of oscillation
ω	dimensionless frequency of oscillation
θ	dimensionless temperature

2. Mathematical Analysis

Consider an unsteady flow of an electrically conducting viscous in compressible fluid, along an oscillating infinite vertical plate embedded in porous medium in the presence of heat source and first order chemical reaction. Let the x' axis be taken along the plate in vertically upward direction and y' axis is normal to it. A uniform magnetic field of strength B_o is applied transversely to the direction of the flow. Initially, at time $t' \le 0$, the plate and fluid were at rest at uniform temperature T'_∞ in a stationary condition with concentration level C'_∞ at all points. When $t' > 0$, the plate starts oscillating with a velocity $u' = u_0 \cos \omega' t'$ in its own plane, the plate temperature and the level of the species concentration are raised linearly with time t near the plate. It is assumed that all the fluid have constant properties except that of the influence of the density variations with temperature and concentration which are considered only in body force term. Since the plate is infinite extent in x' direction, therefore all the physical quantities are functions of t' and y' only. Under these assumptions with Boussinesq and boundary layer approximations, the dimensional governing equations describing the flow problem are:

$$\frac{\partial u'}{\partial t'} = g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) + \upsilon \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_o^2}{\rho} u' - \frac{\upsilon}{k'} u' \tag{1}$$

$$\rho C p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - Q'\left(T' - T'_\infty\right) \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'^2}{\partial y'^2} - K'\left(C' - C'_\infty\right) \tag{3}$$

with the following initial and boundary conditions:

$$t' \le 0 : u' = 0 \;,\; T' = T'_\infty \;, C' = C'_\infty \quad \text{for all } y'$$

$$t' > 0 : \begin{bmatrix} u' = u_o \cos\omega' t' \;,\; T' = T'_\infty + \left(T'_w - T'_\infty\right) A t' \;,\; C' = C'_\infty + \left(C'_w - C'_\infty\right) A t' \quad \text{at } y' = 0 \\ u' \to 0 \;,\; T' \to T'_\infty \;,\; C' \to C'_\infty \;,\; y' \to \infty \end{bmatrix} \tag{4}$$

Where $A = \frac{u_o^2}{\upsilon}$

On introducing the following dimensionless quantities and parameters

$$u = \frac{u'}{u_o}, \quad t = \frac{t' u_o^2}{\upsilon}, \quad y = \frac{y' u_o}{\upsilon}, \quad \theta = \left(\frac{T' - T'_\infty}{T'_W - T'_\infty}\right), \quad C = \frac{C' - C'_\infty}{C'_W - C'_\infty}, \quad Q = \frac{Q' \upsilon}{\rho C p u_o^2},$$

$$K = \frac{K' \upsilon}{u_o^2}, \qquad Gr = \frac{g\beta\upsilon\left(T'_w - T'_\infty\right)}{u_o^3}, \quad Gm = \frac{g\beta^* \upsilon\left(C'_w - C'_\infty\right)}{u_o^3},$$

$$\omega = \frac{\upsilon \omega'}{u_o^2}, \quad \alpha = \frac{k' u_o^2}{\upsilon^2}, \quad Pr = \frac{\mu C p}{\kappa}, \quad Sc = \frac{\upsilon}{D} \qquad (5)$$

The non dimensional forms of the equations (1), (2) and (3) are

$$\frac{\partial u}{\partial t} = Gr\theta + GmC + \frac{\partial^2 u}{\partial y^2} - Mu - \frac{1}{\alpha} u \qquad (6)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr} \frac{\partial^2 \theta}{\partial y^2} - Q\theta \qquad (7)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc} \frac{\partial^2 C}{\partial y^2} - KC \qquad (8)$$

Initial and boundary conditions in non dimensional form are

$$\begin{aligned} &u = 0, \quad \theta = 0, \quad C = 0 \qquad \text{for all} \quad y \le 0, \quad t \le 0 \\ &u = \cos\omega t, \quad \theta = t, \quad C = t, \qquad \text{at} \quad y = 0, \quad t > 0 \\ &u = 0, \quad \theta \to 0, \quad C \to 0 \qquad \text{as} \quad y \to \infty \end{aligned} \qquad (9)$$

All the physical quantities are defined in the nomenclature

3. Method of Solution

Taking Laplace transform on the equations (6), (7) and (8), we derive the following ordinary differential equations:

$$\frac{d^2\bar{\theta}}{dy^2} - Pr\left(s + Q\right)\bar{\theta} = 0 \qquad (10)$$

$$\frac{d^2\bar{C}}{dy^2} - Sc\left(s + K\right)\bar{C} = 0 \qquad (11)$$

$$\frac{d^2\bar{u}}{dy^2}-(s+a)\bar{u}=-Gr\bar{\theta}-Gm\bar{C} \tag{12}$$

With the boundary conditions

$$\bar{u}=0,\ \ \bar{\theta}=0,\ \ \bar{C}=0 \quad \text{for all} \quad y\le 0, \quad t\le 0$$

$$\bar{u}=\frac{s}{s^2+\omega^2}\ ,\ \ \bar{\theta}=\frac{1}{s^2}\ ,\ \ \bar{C}=\frac{1}{s^2}\ , \quad \text{at} \ \ y=0, \quad t>0 \tag{13}$$

$$\bar{u}=0,\ \ \bar{\theta}\to 0,\ \ \bar{C}\to 0 \quad \text{as} \ \ y\to\infty$$

Solving equations (10), (11) and (12) with the help of the equation (13), we get the following solutions:

$$\bar{u}=\left[\frac{s}{s^2+w^2}+\frac{a_1}{s^2(s-a_3)}+\frac{a_2}{s^2(s-a_4)}\right]e^{-y\sqrt{s+a}}-\frac{a_1}{s^2(s-a_3)}e^{-y\sqrt{s+Q}\sqrt{Pr}}$$
$$-\frac{a_2}{s^2(s-a_4)}e^{-y\sqrt{s+K}\sqrt{Sc}} \tag{14}$$

$$\bar{\theta}=\frac{1}{s^2}e^{-y\sqrt{s+Q}\sqrt{Pr}} \tag{15}$$

$$\bar{C}=\frac{1}{s^2}e^{-y\sqrt{s+K}\sqrt{Sc}} \tag{16}$$

Inverting equations (14), (15) and (16) in the usual way we obtain the general solution of the problem for the velocity, temperature and concentration fields as:

$$u=\frac{1}{2}\left[e^{-i\omega t}\phi_1+e^{i\omega t}\phi_2\right]-\left(\frac{a_1}{a_3^2}+\frac{a_2}{a_4^2}\right)\phi_3-\left(\frac{a_1}{a_3}+\frac{a_2}{a_4}\right)\psi_1+\frac{a_1}{a_3^2}\left[e^{a_3 t}\phi_4+\phi_6-e^{a_3 t}\phi_8\right]$$
$$+\frac{a_2}{a_4^2}\left[e^{a_4 t}\phi_5+\phi_7-e^{a_4 t}\phi_9\right]+\frac{a_1}{a_3}\psi_2+\frac{a_2}{a_4}\psi_3 \tag{17}$$

$$\theta=\psi_2 \tag{18}$$

$$C=\psi_3 \tag{19}$$

Where,

$$a=M+\frac{1}{\alpha}\ ,\quad a_1=\frac{Gr}{Pr-1}\ ,\quad a_2=\frac{Gm}{Sc-1}\ ,\quad a_3=\frac{a-Q\,Pr}{Pr-1}\ ,\quad a_4=\frac{a-KSc}{Sc-1}\ ,$$

$$\phi_1 = \phi(a - i\omega, y, 1, t)\ ,\quad \phi_2 = \phi(a + i\omega, y, 1, t)\ ,\quad \phi_3 = \phi(a, y, 1, t)\ ,$$

$$\phi_4 = \phi(a + a_3, y, 1, t)\ ,$$

$$\phi_5 = \phi(a + a_4, y, 1, t)\ ,\quad \phi_6 = \phi(Q, y, Pr, t)\ ,\quad \phi_7 = \phi(K, y, Sc, t)\ ,$$

$$\phi_8 = \phi(Q + a_3, y, Pr, t)\ ,$$

$$\phi_9 = \phi(K + a_4, y, Sc, t)\ ,\quad \psi_1 = \psi(a, y, 1, t)\ ,\quad \psi_2 = \psi(Q, y, Pr, t)\ ,$$

$$\psi_3 = \psi(K, y, Sc, t)$$

$$\phi(x, y, z, t) = \frac{1}{2}\left[e^{y\sqrt{z}\sqrt{x}} \operatorname{erfc}\left(\frac{y\sqrt{z}}{2\sqrt{t}} + \sqrt{xt} \right) + e^{-y\sqrt{z}\sqrt{x}} \operatorname{erfc}\left(\frac{y\sqrt{z}}{2\sqrt{t}} - \sqrt{xt} \right) \right]$$

$$\psi(x, y, z, t) = \left(\frac{t}{2} + \frac{y\sqrt{z}}{4\sqrt{x}} \right) e^{y\sqrt{z}\sqrt{x}} \operatorname{erfc}\left(\frac{y\sqrt{z}}{2\sqrt{t}} + \sqrt{xt} \right) + \left(\frac{t}{2} - \frac{y\sqrt{z}}{4\sqrt{x}} \right) e^{-y\sqrt{z}\sqrt{x}} \operatorname{erfc}\left(\frac{y\sqrt{z}}{2\sqrt{t}} - \sqrt{xt} \right)$$

Skin friction: The coefficient of skin friction at the plate in non dimensional form is given by

$$\tau = -\left.\frac{\partial u}{\partial y}\right|_{y=0}$$

$$= \frac{1}{2}\left[e^{-i\omega t}\varphi_1 + e^{i\omega t}\varphi_2 \right] - \left(\frac{a_1}{a_3^2} + \frac{a_2}{a_4^2} \right)\varphi_3 - \left(\frac{a_1}{a_3} + \frac{a_2}{a_4} \right)\xi_1 + \frac{a_1}{a_3^2}\left[e^{a_3 t}\varphi_4 + \varphi_6 - e^{a_3 t}\varphi_8 \right] \quad (20)$$

$$+ \frac{a_2}{a_4^2}\left[e^{a_4 t}\varphi_5 + \varphi_7 - e^{a_4 t}\varphi_9 \right] + \frac{a_1}{a_3}\xi_2 + \frac{a_2}{a_4}\xi_3$$

Nusselt number: The rate of heat transfer coefficient at the plate in terms of Nusselt number in non dimensional form is given by

$$Nu = -\left.\frac{\partial \theta}{\partial y}\right|_{y=0} = \xi_2 \quad (21)$$

Sherwood number: The rate of mass transfer coefficient at the plate in terms of Sherwood number in non dimensional form is given by

$$Sh = -\left.\frac{\partial C}{\partial y}\right|_{y=0} = \xi_3 \quad (22)$$

Where,

$$\varphi_1 = \varphi(a - i\omega, 1, t)\ ,\quad \varphi_2 = \varphi(a + i\omega, 1, t)\ ,\quad \varphi_3 = \varphi(a, y, t)\ ,\quad \varphi_4 = \varphi(a + a_3, 1, t),$$

$$\varphi_5 = \varphi(a + a_4, 1, t)\ ,\quad \varphi_6 = \varphi(Q, Pr, t)\ ,\quad \varphi_7 = \varphi(K, Sc, t)\ ,\quad \varphi_8 = \varphi(Q + a_3, Pr, t),$$

$$\varphi_9 = \varphi(K + a_4, Sc, t)\ ,\quad \xi_1 = \xi(a, 1, t)\ ,\quad \xi_2 = \xi(Q, Pr, t)\ ,\quad \xi_3 = \xi(K, Sc, t)$$

$$\varphi(x, z, t) = \sqrt{x}\sqrt{z}\ \mathrm{erfc}\left(\sqrt{xt}\right) + \frac{\sqrt{z}}{\sqrt{\pi t}} e^{-xt}$$

$$\xi(x, z, t) = \left(\frac{\sqrt{z}}{2\sqrt{x}} + t\sqrt{x}\sqrt{z}\right)\mathrm{erf}\left(\sqrt{xt}\right) + \frac{\sqrt{zt}}{\sqrt{\pi}} e^{-xt}$$

4. Results and Discussions

In order to investigate the effects of chemical reaction, heat sink, magnetic field, permeability, frequency of oscillation, thermal Grashof number, mass Grashof number, Prandtl number and Schmidt number on the velocity, temperature and concentration fields, and skin friction, Nusselt number and Sherwood number at the plate. Numerical computations for the above fields have been carried out for different values of the said parameters and the results are illustrated through different graphs. In most of the cases values of Prandtl number Pr and Schmidt number Sc are respectively fixed at 0.71 and 0.3. We recall that Pr = 0.71 corresponds to air at 25℃ at one atmospheric pressure and Sc= 0.3 represents Helium diffused in dry air.

Figures 1 to 7 demonstrate the variations of the velocity field u versus y under the effects of chemical reaction parameter K, heat sink parameter Q, magnetic parameter M, frequency parameter ω, permeability parameter α, thermal Grashof number Gr and mass Grashof number Gm. It is inferred from the Figures 1 to 4 that an increase in chemical reaction parameter K or heat sink parameter Q or magnetic parameter M or frequency parameter ω causes the fluid flow to retard slowly and steadily. The Figures 5 to 7 show that there is a comprehensive growth in the fluid velocity when permeability parameter α, thermal Grashof number Gr and mass Grashof number Gm are increased. These observations say that when the resistivity of the medium decreases or buoyancy forces increases the fluid velocity in vertically upward direction increases. These phenomena are in good agreement with the physical reality. Further, the consumption of species, heat absorption and the imposition of the transverse magnetic field decelerate the flow. All the Figures excluding the Figure 4 indicate that fluid velocity first increases in a thin layer adjacent to the plate and after attaining maximum value it falls asymptotically as we move away from the plate. This suggests that the effect of the buoyancy force is more pronounced near the plate and its effect gets nullified as moved away from the pate.

Figures 8 and 9 illustrate the change of behaviour of temperature field versus normal coordinate y under the heat sink parameter Q and Prandtl number Pr. These two Figures uniquely establish the fact that there is a considerable fall in the fluid temperature under the effect of the above parameters. It is recalled that Pr is the ratio of momentum and thermal diffusivity. For constant viscosity, Pr increases means thermal diffusivity α decreases. That is to say that as thermal diffusivity increases the fluid temperature raises. This phenomenon is consistent with the physical reality. Again heat sink increases means thermal absorption increases and as thermal absorption increases, temperature falls.

The influence of Schmidt number Sc and chemical reaction parameter K on the concentration field across the boundary layer are exhibited in Figures 10 and 11. It is observed in these Figures that concentration level of the fluid decreases due to the increasing values of Sc and K. Physically, molecular mass diffusivity rises as Sc decreases which enhances the concentration boundary layer. Further, the concentration of the fluid attains maximum value at $y = 0$ and approaches to its minimum value zero as y tends to infinity.

Figures 12 to 16 highlight the effects of Q, K, M, Gm and α against time t on the skin friction. It is inferred from these figures that with increasing values of Q, K and M, the frictional shear stress rises while reverse phenomenon happens for raising Gm and α. Figures 12, 13 and 14 illustrate that viscous drag at the plate increases under the effect of heat absorption, first order chemical reaction and magnetic parameter. Again from the Figure 15 we conclude that ascending the buoyancy force causes to diminish the coefficient skin friction. In other words, buoyancy forces reduce the drag force on the plate. Further Figure 16 depicts that an increase in the values of permeability reduces the viscous drag.

Figures 17 and 18 present the variation of the Nusselt number versus time t for different values of Q and Pr. It is seen from Figure 17 that the Nusselt number on the plate increases with heat sink parameter Q. Also Figure 18 reveals that rate of heat transfer is augmented for higher values of Pr. This is due to fact that for higher values of Pr, frictional forces become dominant and generate greater heat transfer coefficient. Further, it is noticed that the heat flux at the plate gets accelerated as time advances.

The behaviour of Sherwood number against time t is depicted in Figures 19 and 20. Figure 19 elucidates that an increase in Sc augments the rate of mass transfer at the plate. Hence chemical molecular diffusion leads to a drop in the mass flux at the plate. From the Figure 20, it is noted that the effect of chemical reaction reduces the mass flux at the plate. As in Figures 17 and 18, the mass flux at the plate also increases as time progresses.

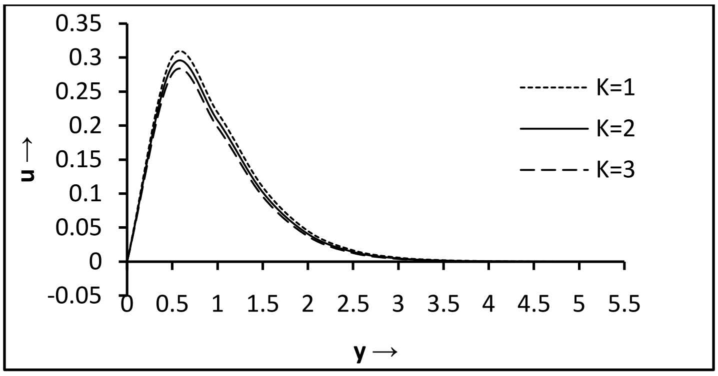

Figure 1: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, M=1, α=1, $\omega = \pi$, t=0.5

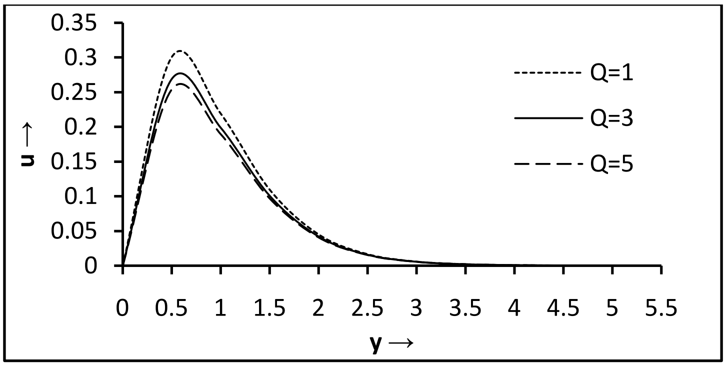

Figure 2: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, K=1, M=1, α=1, $\omega = \pi$, t=0.5

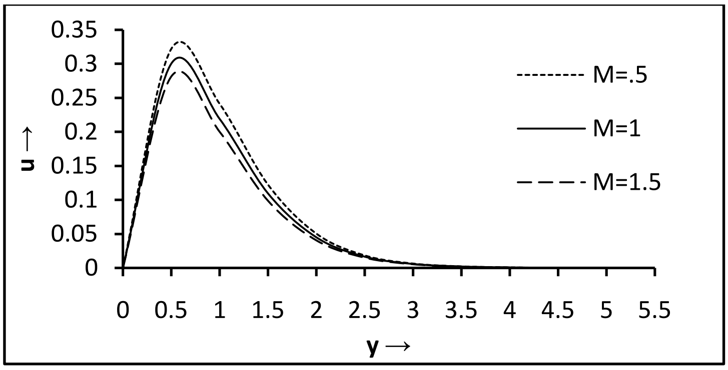

Figure 3: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, K=1, α=1, $\omega = \pi$, t=0.5

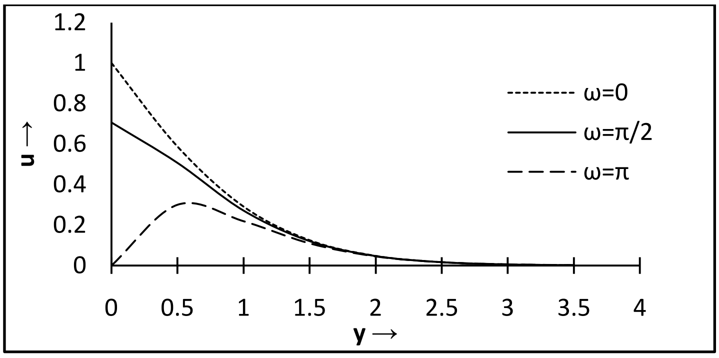

Figure 4: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, K=1, M=1, α=1, t=0.5

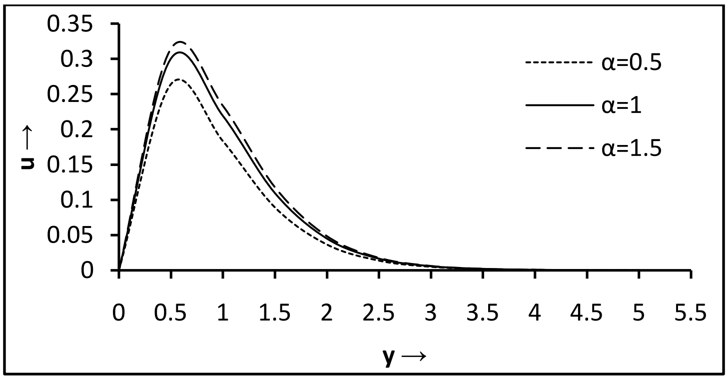

Figure 5: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, M=1, K=1, $\omega = \pi$, t=0.5

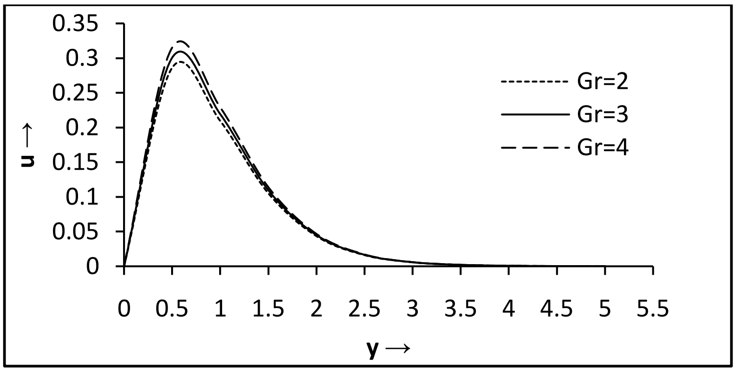

Figure 6: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gm=3, Q=1, K=1, M=1, α=1, $\omega = \pi$, t=0.5

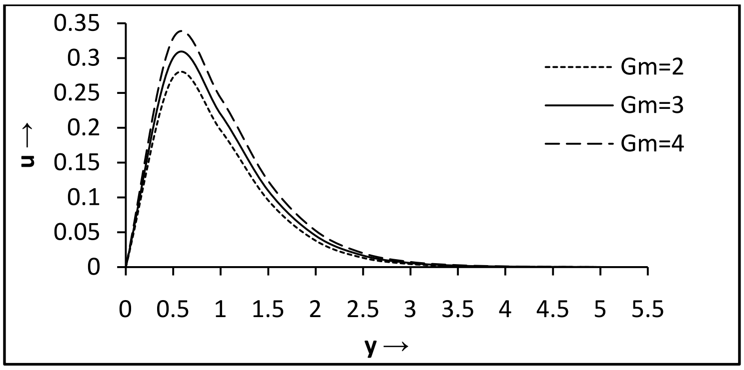

Figure 7: Velocity distribution versus y for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, M=1, α=1, $\omega = \pi$, t=0.5

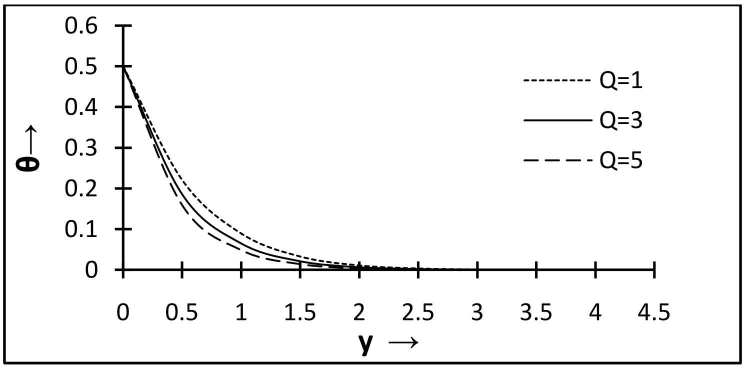

Figure 8: Temperature distribution versus y for Pr=0.71, t=0.5

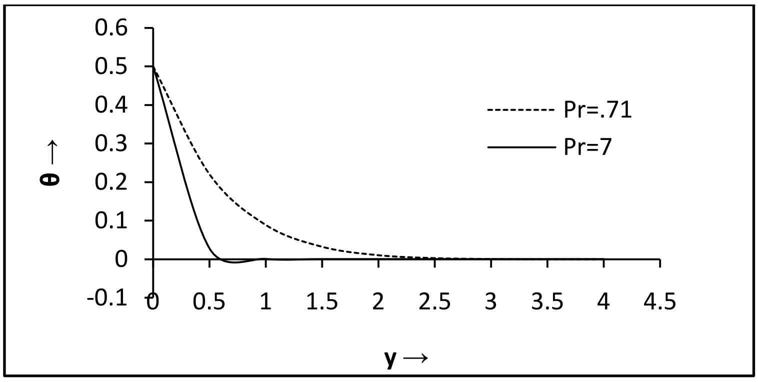

Figure 9: Temperature distribution versus y for Q=1, t=0.5

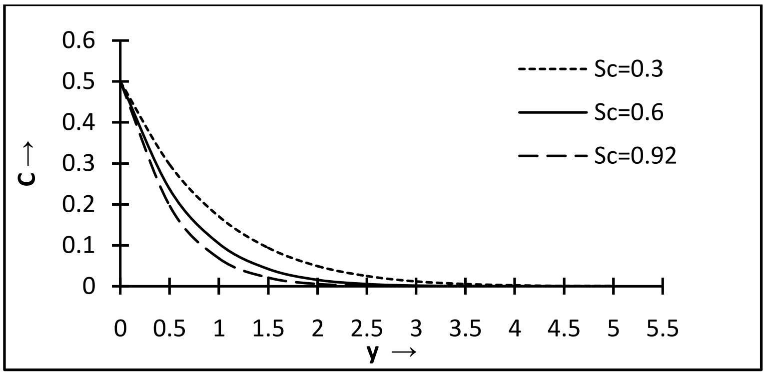

Figure 10: Concentration distribution versus y for K=1, t=0.5

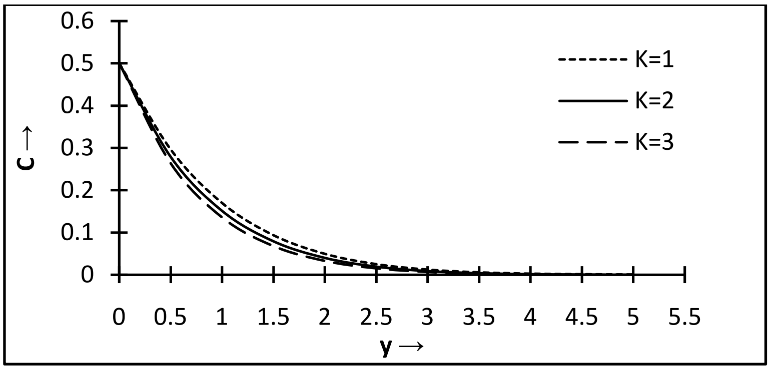

Figure 11: Concentration distribution versus y for Sc=0.3, t=0.5

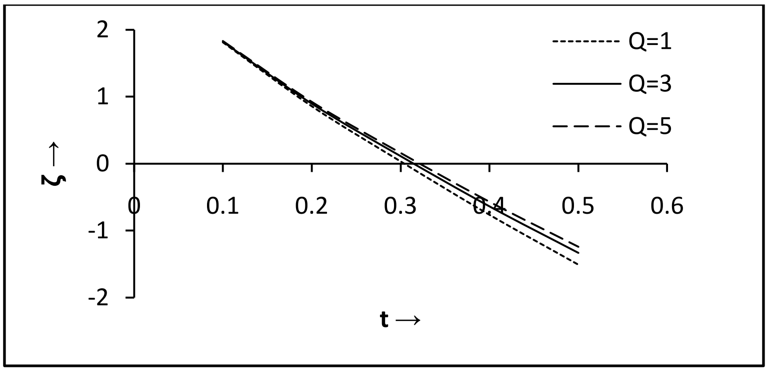

Figure 12: skin friction versus t for Pr=0.71, Sc=0.3,
Gr=3, Gm=3, M=1, K=1, α=1, $\omega = \pi$

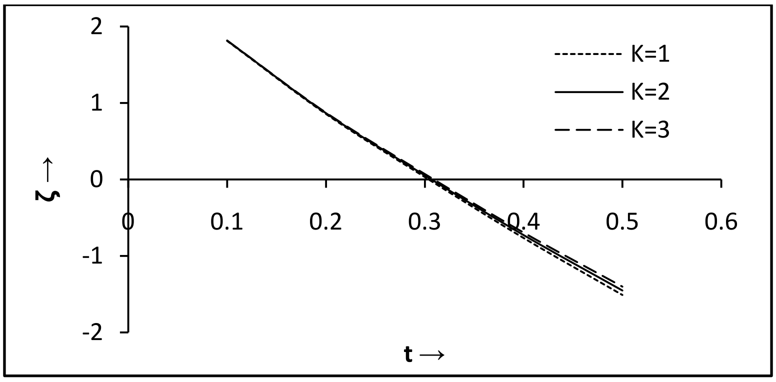

Figure 13: skin friction versus t for Pr=0.71, Sc=0.3, Gr=3, Gm=3, M=1, Q=1, α=1, $\omega = \pi$

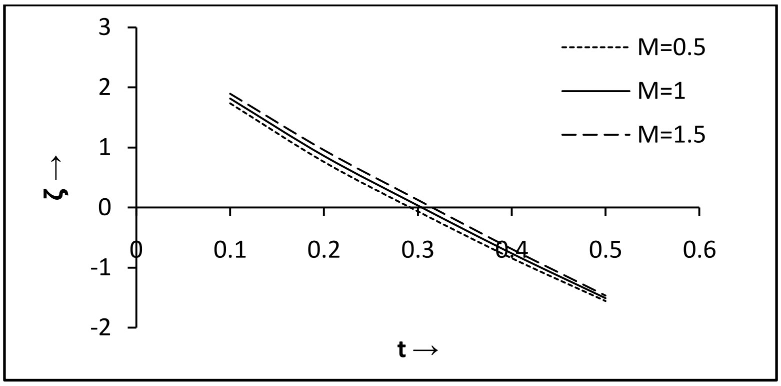

Figure 14: skin friction versus t for Pr=0.71, Sc=0.3, Gr=3, Gm=3, Q=1, K=1, α=1, $\omega = \pi$

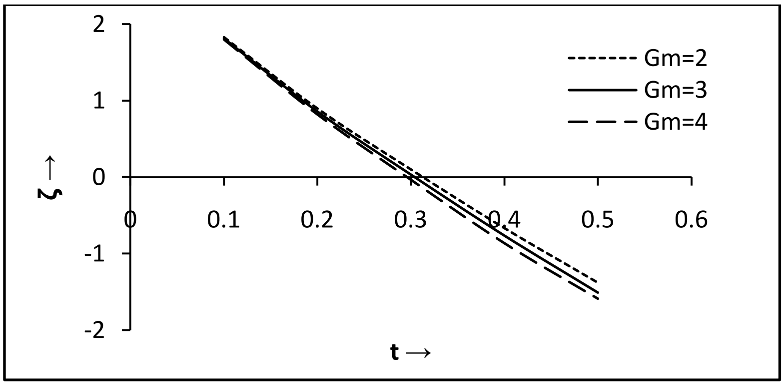

Figure 15: skin friction versus t for Pr=0.71, Sc=0.3, Gr=3, Q=1, M=1, K=1, α=1, $\omega = \pi$

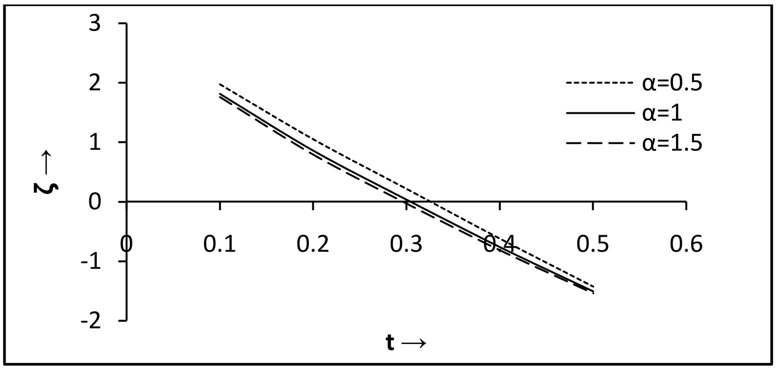

Figure 16: skin friction versus t for Pr=0.71, Sc=0.3, Gr=3, Gm=3, M=1, K=1, Q=1, $\omega = \pi$

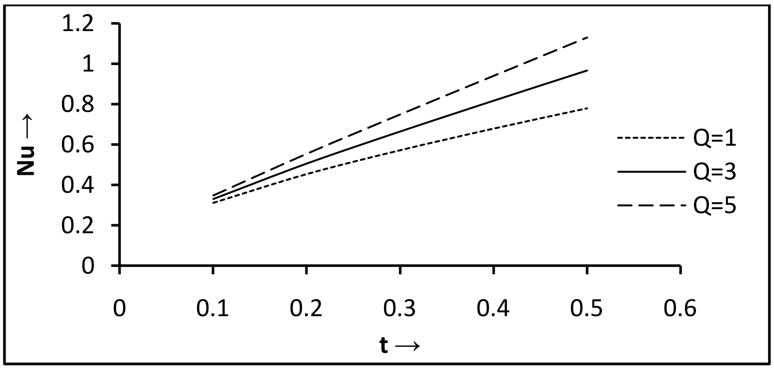

Figure 17: Nusselt number versus t for Pr=0.71

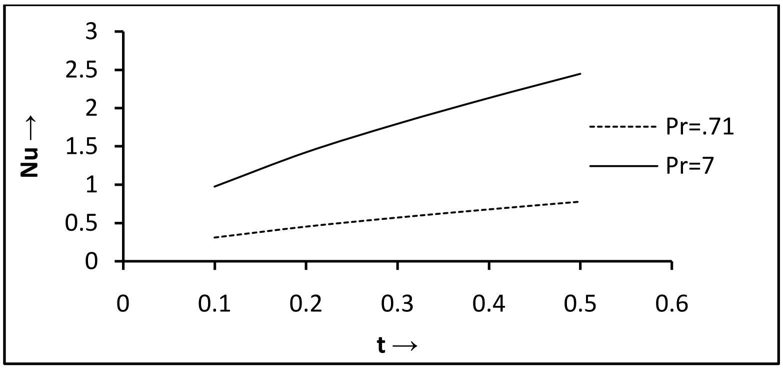

Figure 18: Nusselt number versus t for Q=1

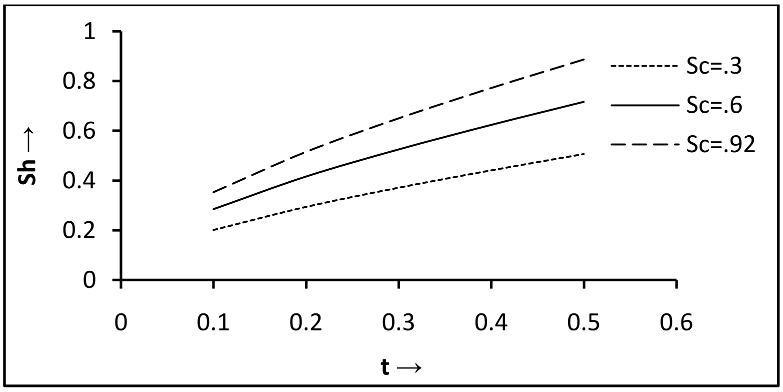

Figure 19: Sherwood number versus t for K=1

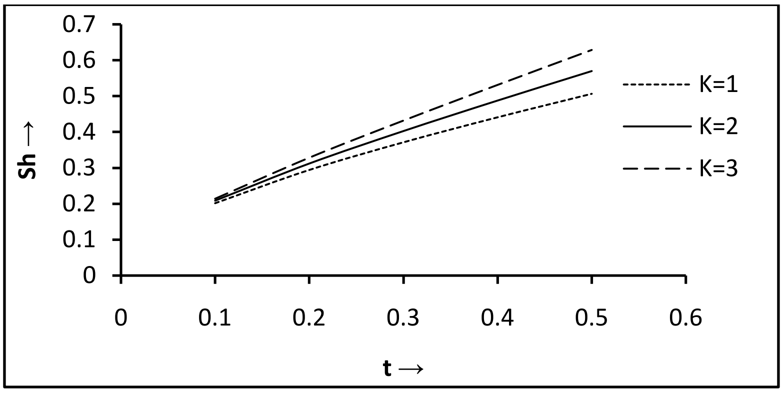

Figure 20: Sherwood number versus t for Sc=0.3

5. Conclusions

1. The consumption of species, heat absorption and the imposition of the transverse magnetic field decelerate the flow.
2. As thermal diffusivity increases the fluid temperature raises.
3. The concentration boundary layer enhances due to molecular mass diffusivity.
4. Viscous drag at the plate decreases under the effect of heat absorption and first order chemical reaction.
5. The heat flux and the mass flux at the plate increase as time advances.

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