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MHD flow of a uniformly stretched vertical permeable membrane in the presence of zero order reaction and quadratic heat generation

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Abstract

We present a magneto - hydrodynamic flow of a uniformly stretched vertical permeable surface undergoing Arrhenius heat reaction. The analytical solutions are obtained for concentration, temperature and velocity fields using an asymptotic approximation, similar to that of Ayeni et al 2004. It is shown that the temperature field and the velocity field depend heavily on the thermal grashof numbers, heat generation/absorption, magnetic induction, chemical reaction parameters and reaction order. It is also established that maximum velocity occurs in the body of the fluid close to the surface and not the surface.

***Keywords*:** Permeable surface, Buoyancy, source term, thermal expansion, suction, ambient, magnetic induction, asymptotic variable.

Classification: 76W05

1.0 Introduction

The study of flow and heat and mass transfer in the boundary layer induced by a surface moving with a uniform or non uniform velocity in a quiescent ambient fluid is important in several manufacturing process in industry which include the boundary layer along material handling. Also many industrial processes involve fluid flow, heat and mass transfer in the boundary layers induced by a surface moving with a uniform velocity [2]. Chamka [2] examined the boundary layer of an MHD flow when the heat generation is linear in temperature. Ayeni et al. 2004 extended the problem posed by Chamka, to heat generation that is quadratic in temperature.

Nomenclatures

c: concentration
c_p: specific heat
C: fluid concentration
C_w: wall concentration
α_D: mass diffusion-coefficient
D: chemical reaction parameter
Q_0 : heat generation coefficient
Nu : Nuselt number
$\Pr$: Prandtl number
Sc : Shmidt number
E: activation energy
g : gravitational pull
B_0 : magnetic induction
T : fluid temperature
n: reaction order
R: universal gas constant
T_w : wall temperature
v : fluid transverse velocity
v_W : suction velocity
x : axial or vertical coordinate
y : transverse coordinate

Greek Symbols

γ : chemical reaction parameter
ρ : fluid density

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T_w : wall temperature
v : fluid transverse velocity
v_W : suction velocity
x : axial or vertical coordinate
y : transverse coordinate

Greek Symbols
γ : chemical reaction parameter
ρ : fluid density
θ : dimensionless temperature
R_i : Richardson number
σ : electric conductivity
β_τ : coefficient of thermal expansion
β_c : coefficient of mass expansion

Subscripts
w : condition on the wall
∞ : ambient condition

The study of magnetohydrodynamics of vertically conducting fluids in the presence of a magnetic field is encountered in many important problems in geophysical and astrophysics. There has been a renewed interest in studying magnetohydrodynamics (MHD) flow and heat transfer aspects in various geometries due to the effect of magnetic field on the flow control and on the performance of many system using electrically conducting fluids such as liquid metals, water mixed with little acid and others hence a lot of work has been reported in the literature. Chamka. [3] has a good review of some of these works. Recently Okedoye and Ayeni [3], presented a numerical solution of heat and mass transfer in MHD flow in the presence of chemical reaction of order 1 and Arrhenius heat generation of a permeable membrane. In their paper, they obtained the solutions numerically.

In this paper we extend the problem posed by Chamka [2] to quadratic heat generation and with zero order exothermic reaction. We then use the approximation similar to the ones in Ayeni [1] to obtain analytical solutions to the concentration, velocity and temperature fields.

2.0 Mathematical formulations

Consider coupled heat and mass transfer by hydro – magnetic flow of a continuously moving vertical permeable surface in the presence of suction, heat generation/absorption effects, transverse magnetic field effect and Arrhenius reactions. The flow is assumed steady, laminar and two – dimensional and the surface is maintained at a uniform temperature and the concentration species, and is assumed to be infinitely long. It is also assumed that the applied transverse magnetic Reynolds number is small so that the induced magnetic field is neglected. In addition, there is no applied electric field and all of the Hall effect, viscous dissipation and Joule heating are neglected, thermo-physical properties are assumed constant except the density in the buoyancy terms of the momentum equation which is approximated according to the Boussinesq approximation.

With these assumptions, the steady equations that describe the physical situation are given as:

$$\frac{\partial v}{\partial y} = 0 \tag{2.1}$$

$$v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial^2 y} + g\beta_\tau\left(T - T_\infty\right) + g\beta_C\left(c - c_\infty\right) - \frac{\sigma B_0^2 u}{\sigma} \tag{2.2}$$

$$\rho c_p v\frac{\partial T}{\partial y} = k\frac{\partial^2 T}{\partial y^2} + \left(c - c_\infty\right)^n\left\{Q_0\left(T - T_\infty\right) + Q_1\left(T - T_\infty\right)^2\right\} \tag{2.3}$$

$$v\frac{\partial c}{\partial y} = D\frac{\partial^2 c}{\partial y^2} - \left\{\gamma_0\left(T - T_\infty\right) + \gamma_1\left(T - T_\infty\right)^2\right\}, \tag{2.4}$$

where y is the horizontal or transverse coordinate, it is the axial velocity, v is the transverse velocity, T is the fluid temperature, c is the concentration, $T\infty$ is the ambient temperature $c\infty$ is the ambient concentration, and ρ, g, B_T, β_c v σ, B_c, Q, D, γ and n are the density, gravitational acceleration, coefficient of thermal expansion, coefficient of concentration expansion, kinematics viscosity, fluid electrical conductivity, magnetic induction, heat generation/coefficient and the chemical reaction parameter and real number respectively.

With the physical boundary conditions

$$u(0)=u_w, v(0)=-v_w, T(0)=T_w, C(0)=C_w$$
$$as\ y\to\infty, u\to\infty, T\to\infty, C\to\infty, \tag{2.5}$$

where u_w, v_w >0, T_w and c_w are surface velocity, suction velocity, surface temperature and concentration respectively.

3.0 Method of solution

We use the non–dimensional variables

$$y^1 = yv_W/\upsilon,\ u^1=\frac{u}{u_W},\ \theta = (\mathrm{T}-\mathrm{T}_\infty)\frac{E}{RT_\infty^2}, c^1=\frac{c-c_\infty}{c_W-c_\infty} \tag{3.1}$$

From equation (2.1) *i.e* $\frac{dv}{dy}=0$. We have v = constant, but $v(0)=-v_w$ = constant $\Rightarrow$

$$v(y)=-v_w \tag{3.2}$$

Substituting equations (3.1) and (3.2) into equations (2.2) – (2.5) and dropping (‘), we have

$$\frac{d^2u}{dy^2}+\frac{du}{dy}+G_{r\mathrm{T}}\,\theta+G_{rc}\,c-M^2u=0 \tag{3.3}$$

$$\frac{d^2\theta}{dy^2}+p_r\ \frac{d\theta}{dy}+\phi\,\mathrm{Pr}\,\theta+\varepsilon\phi_1\theta^2=0 \tag{3.4}$$

$$\frac{d^2C}{dy^2}+s_c\,\frac{dC}{dy}-K_1Sc\left(\theta+\varepsilon\theta^2\right)=0 \tag{3.5}$$

The dimensionless boundary conditions are

$$u(0)=1,\ \theta(0)=1,\ c(0)=1$$
$$y\to\infty\ \ u\to 0,\ \theta\to 0,\ c\to 0 \tag{3.6}$$

where $G_{r\mathrm{T}}=\frac{B_{\mathrm{T}}\,v_g RT_o^2}{U_W EV_W^2}$, $G_{rc}=g\frac{B_c\,v(C_W-C_\infty)}{U_W V_W^2}$, $P_r=\frac{\mu cp}{k}$, $S_c=\frac{V_W}{D}$, $M^2=\frac{\sigma\beta_o v}{\rho v_W^2}$,

$\frac{vQ}{\mu cpv_W^2} = \frac{\upsilon Q}{\rho c_p v_W{}^2}\cdot\frac{\upsilon\rho c_p}{k} = \phi\,\mathrm{Pr}$, $\frac{vQ}{\mu cpv_w^2}\frac{RT_0^2}{E} = \varepsilon\phi\ \ \mathrm{Pr}$, $b=(C_W-C_\infty)^n\frac{E}{RT_o^2}e^{-\frac{1}{\varepsilon}}$,

We assume the approximation similar to the one in Ayeni et. al (2004), and for a reaction of order zero, n = 0. Then the system (3.3 – 3.5) becomes

$$\frac{d^2u}{dy^2}+\alpha_1\frac{du}{dy}+\varepsilon Grt\,\theta+\varepsilon Grc.c(y)-M^2u=0 \qquad (3.7$$

$$\frac{d^2\theta}{dy^2}+\mathrm{Pr}\,\frac{d\theta}{dy}+\mathrm{Pr}\,\phi_0\left(1+(e-2)\theta+\theta^2\right)=0 \qquad (3.8)\quad (3$$

$$\frac{d^2c}{dy^2}+Sc\frac{dc}{dy}+k_0Sc\left(1+(e-2)\theta+\theta^2\right)=0 \tag{3.9}$$

which has a quadratic temperature field. Now expanding asymptotically using the following asymptotic variables

$$\left.\begin{aligned} u &= u_0 + \varepsilon u_1 + \varepsilon^2 u_2 + \cdots \\ \theta &= \theta_0 + \varepsilon\theta_1 + \varepsilon\theta_2 + \cdots \\ c &= c_0 + \varepsilon c_1 + \varepsilon c_2 + \cdots \\ \phi_1 &= \varepsilon\phi_0 + \varepsilon^2\phi_2 + \ldots \end{aligned}\right\} \tag{3.10}$$

and equate the powers of ε we have

$$\varepsilon^0: \quad \frac{d^2u_0}{dy^2} + \alpha_1\frac{du_0}{dy} - M^2u_0 = 0 \tag{3.7.1}$$

$$\frac{d^2\theta_0}{dy^2} + \Pr\frac{d\theta_0}{dy} + \Pr\phi_0\theta_0 = 0 \tag{3.8.1}$$

$$\frac{d^2C_0}{dy^2} + Sc\frac{dC_0}{dy} + k_0ScC_0 + k_1Sc\theta_0 \tag{3.9.1}$$

$$\left.\begin{aligned} &u_0(0) = \theta_0(0) = C_0(0) = 1 \\ &u_0(y) \to 0, \theta_0(y) \to 0, C_0(y) \to 0 \; as \; y \to \infty \end{aligned}\right\} \tag{3.6.1}$$

$$\varepsilon^1: \quad \frac{d^2u_1}{dy^2} + \alpha_1\frac{du_1}{dy} - M^2u_1 + GrcC_0 + Grt\theta_0 = 0 \tag{3.7.2}$$

$$\frac{d^2\theta_1}{dy^2} + \Pr\frac{d\theta_1}{dy} + \Pr\phi_0\theta_1 + \Pr\phi_0\theta_0{}^2 = 0 \tag{3.8.2}$$

$$\frac{d^2C_1}{dy^2} + Sc\frac{dC_1}{dy} + k_0ScC_1 + k_1Sc\left(\theta_1 + \theta_0{}^2\right) \tag{3.9.2}$$

$$\left.\begin{aligned} &u_1(0) = \theta_1(0) = C_1(0) = 0 \\ &u_1(y) \to 0, \theta_1(y) \to 0, C_1(y) \to 0 \; as \; y \to \infty \end{aligned}\right\} \tag{3.6.2}$$

$$\varepsilon^2: \quad \frac{d^2u_2}{dy^2} + \alpha_1\frac{du_2}{dy} - M^2u_2 + GrcC_1 + Grt\,\theta_1 = 0 \tag{3.7.3}$$

$$\frac{d^2\theta_2}{dy^2} + \Pr\frac{d\theta_2}{dy} + \Pr\phi_0\theta_2 + 2\Pr\phi_0\theta_0\theta_1 = 0 \tag{3.8.3}$$

$$\frac{d^2C_2}{dy^2} + Sc\frac{dC_2}{dy} + k_0ScC_2 + k_1Sc(\theta_2 + \theta_0\theta_1) \tag{3.9.2}$$

$$\left.\begin{aligned} &u_2(0) = \theta_2(0) = C_2(0) = 0 \\ &u_2(y) \to 0, \theta_2(y) \to 0, C_2(y) \to 0 \; as \; y \to \infty \end{aligned}\right\} \tag{3.6.3}$$

Now from equations (2.7.1) and (2.8.1), we have the solution

$$u_0(y) = e^{-ry}, \quad r = \frac{\alpha_1 + \sqrt{\alpha_1^2 + 4M^2}}{2} \tag{3.11}$$

and $\quad \theta_0(y) = e^{-my}, \; m = \dfrac{\Pr + \sqrt{\Pr^2 - 4\Pr\phi_0}}{2}$ (3.12)

respectively!

Using the solution for $\theta_0(y)$ in (3.9.1) we have $\dfrac{d^2C_0}{dy^2} + Sc\dfrac{dC_0}{dy} + k_0ScC_0 = k_1Sce^{-my}$

letting $C_0(y)_c = a_2e^{-n_1 y} + a_5e^{n_1 y}$, and $C_0(y)_p = a_6e^{-my} \Rightarrow a_6(m^2 - ms_c + k_os_c)e^{-my} =$ $-k_1s_ce^{-my}$ from which $a_6 = \dfrac{-k_1s_c}{m^2 - ms_c + k_0s_c}$ so that $C_0(y) = a_2e^{-n_1 y} + a_5e^{n_2 y} +$ a_6e^{-my}, and by imposing the boundary conditions $C_0(0) = a_2 + a_5 + a_6 = 1$, $C_0(\infty) = a_5\varphi = 0$, $\Rightarrow$ $a_5 = 0$. Hence,

$$C_0(y) = a_2e^{-n y} + a_6e^{-my} \tag{3.13}$$

where $a_6 = \dfrac{-k_1s_c}{m^2 - ms_c + k_0s_c}$, $a_2 = 1 - a_6$.

Now from (3.8.2) $\dfrac{d^2\theta_1}{dy^2} + \Pr\dfrac{d\theta_1}{dy} + \Pr\phi_0\theta_1 = -\Pr\phi_1e^{-2my}$, $\theta_1(0) = 0$, $\theta_1(\infty) = 0$, we let $\theta_{1c} = a_5e^{-my} + a_8{}^{+m_2 y}$, $\theta_{1p} = a_7{}^{-2my} \Rightarrow a_7 = (4m - 2m\Pr + \Pr\phi_0)e^{-2my} = -Pr\phi_0 e^{-2my} \Rightarrow$ $a_7 = \dfrac{-\Pr\phi_1}{4m^2 - 2m\Pr + \Pr\phi_0}$, i.e $\theta_1(y) = \theta_{1c} + \theta_{1p} = a_5e^{-my} + a_7e^{-2my} + a_8e^{m_2 y}$

The boundary conditions gives $\theta_1(0) = a_5 + a_7 + a_8 = 0$, $\theta_1(\infty) = a_8\varphi = 0 \Rightarrow a_8 = 0$, $a_5 = -a_7$

hHence $\quad \theta_1(y) = -a_7e^{-my} + a_7e^{-2my}, \; a_7 = \dfrac{-\Pr\phi_1}{4m^2 - 2m\Pr + \Pr\phi_0}$ (3.14)

Also from (3.9.2), using the solutions (3.13) and (3.14), we obtain

$$\frac{d^2c_1}{dy^2} + Sc\frac{dc_1}{dy} + k_0ScC_1 = a_7k_1Sc\left(e^{-2my} - e^{-my}\right)1 - k_1Sce^{-2my}$$

$$= k_1S_8(a_7 - 1)e^{-2my} - a_7k_1Sc\; e^{-my}$$

$$C_{1c} = a_5\, e^{-ny} + a_{10}e^{n_1 y}$$

Let $C_{1p} = a_8e^{-2my} + a_9e^{-my} \Rightarrow a_8(4m^2 - 2mSc + k_0s_c)e^{-2my} + + a_9\left(m^2 - mSc + k_0s_c\right)e^{-my}$

$$= a_7k_1Sc\; e^{-2my} - a_7k_1Sc\; e^{-my}$$

from where we have $\quad a_8 = \dfrac{\left(-(1 - a_7)k_1s_c\right)}{4m^2 - 2ms_c + k_0s_c}$, $a_9\dfrac{a_7k_1s_c}{m^2 - ms_c + k_0s_c}$

$$\Rightarrow C_1 = a_5e^{-ny} + a_{10}e^{ny} + a_8e^{-2my} + a_9e^{-my}$$

$C_1(0) = 0$, $C_1(y) \to 0$ as $y \to \infty \Rightarrow a_{10} = 0$, $a_5 = -(a_8 + a_9)$

$$C_1(y) = a_5e^{-ny} + a_8e^{-2my} + a_9e^{-my} \tag{3.15}$$

Using the (3.12) and (3.13), equation (3.7.2) becomes

$$\frac{d^2u_1}{dy^2}+\alpha_1\frac{du_1}{dy}-M^2u_1=-Grte^{-my}-Grc\left(a_2e^{-ny}+a_6e^{-my}\right)$$

which gives $u_1(y)_c=a_{10}e^{ry}+a_{13}e^{r_1 y}$, we let $u_1(y)_p=a_{11}e^{-my}+a_{12}e^{-ny}$

$$\Rightarrow u_1(y)=a_{10}e^{-ry}+a_{11}e^{-my}+a_{12}e^{-ny} \qquad (3.16)$$

where $a_{11}=\dfrac{-(Grt+a_6Grc)}{m^2-\alpha_1 m-m^2}$, $a_{12}=\dfrac{-Grc\,a_2}{n^2-\alpha_1 n-m^2}$, $a_{10}=-(a_{11}+a_{12})$

By (3.8.3) we have $\dfrac{d^2\theta_2}{dy^2}+p_r\dfrac{d\theta_2}{dy}+p_r\phi_0\theta_2=-2p_r\phi_1 a_1\left(e^{-3my}-e^{-2my}\right)$.

Letting $\theta_{2p}=a_{13}e^{-3my}+a_{14}e^{-2my}$, and the complementary solution is given as $\theta_{2c}=a_{15}e^{-my}+a_{16}e^{m,y}$. Combining the particular and complementary solutions and evaluate at the boundary we have

$$\theta_2(y)=a_{13}e^{-3my}+a_{14}e^{-2my}+a_{15}e^{-my} \qquad (3.17)$$

where $a_{13}=\dfrac{-2p_r\phi_1 a_1}{am^2-3mp_r+p_r\phi_0}$, $a_{14}=\dfrac{-2p_r\phi_1 a_1}{4m^2-2mp_r+p_r\phi_0}$, $a_{15}=(a_{13}+a_{14})$

Now from (3.9.3) we have $\dfrac{d^2C_2}{dy^2}+Sc\dfrac{dC_2}{dy}+k_0ScC_2=k_1Sc(\theta_2+\theta_0\theta_1)$

$$=-k_1Sc\left(\left(a_7e^{-2my}-a_7e^{-my}\right)e^{-my}+a_{13}e^{-3my}+a_{14}e^{-my}+a_{15}e^{-my}\right)$$

$$=-k_1Sc\left((a_{13}+a_7)e^{-3my}+(a_{14}-a_7)e^{-2my}+a_{15}e^{-my}\right)$$

This gives the solution

$$C_2(y)=a_{17}e^{-3my}+a_{18}e^{-2my}+a_{19}e^{-my}+a_{20}e^{-Scy} \qquad (3.18)$$

where $a_{17}=\dfrac{-k_1Sc(a_{13}+a_7)}{3m(3m-Sc)}$, $a_{18}=\dfrac{-k_1Sc(a_{14}-a_7)}{2m(2m-Sc)}$, $a_{19}=\dfrac{-k_1Sca_{15}}{m(m-Sc)}$, $a_{20}=-(a_{17}+a_{18}+a_{19})$.

And from (3.8.3)

$$\frac{d^2u_2}{dy^2}+\alpha_1\frac{du_2}{dy}-M^2u_2=-Grt\theta_1-GrcC_1$$

$$=-a_7Grt\left(e^{-2my}-e^{-my}\right)-Grc\left(a_5e^{-ny}+a_8e^{-2my}+a_9e^{-my}\right)$$

$$=-(a_7Grt+a_8Grc)e^{-2my}+(a_7Grt-a_9Grc)e^{-my}-a_5e^{-ny}$$

which gives the solution $u_2(y)=a_{21}e^{-2my}+a_{22}e^{-my}+a_{23}e^{-ny}+a_{24}e^{-ry}$ (3.19)

$a_{21}=\dfrac{-(a_7Grt+a_8Grc)}{4m^2-2m-M^2}$, $a_{22}=\dfrac{-(a_7Grt-a_9Grc)}{m^2-m-M^2}$, $a_{23}=\dfrac{-a_5Grc}{n^2-n-M^2}$, $a_{24}=-(a_{21}+a_{22}+a_{23})$

4.0 Discussion of results

In this analysis, the parameters $\phi_0, K, Ri, \Pr$ *and* Sc are assigned values –0.1, -0.1, 0.3, 0.71, and 0.6 respectively except where stated. It should be noted that K > 0 indicate a destructive chemical reaction, while K< 0 correspond to a generative chemical reaction. Also, ϕ_0 < 0 indicate heat generation and ϕ_0> 0 imply heat absorption. And K = 0 and ϕ_0 =0 indicate no chemical reaction and no heat generation/absorption effects respectively.

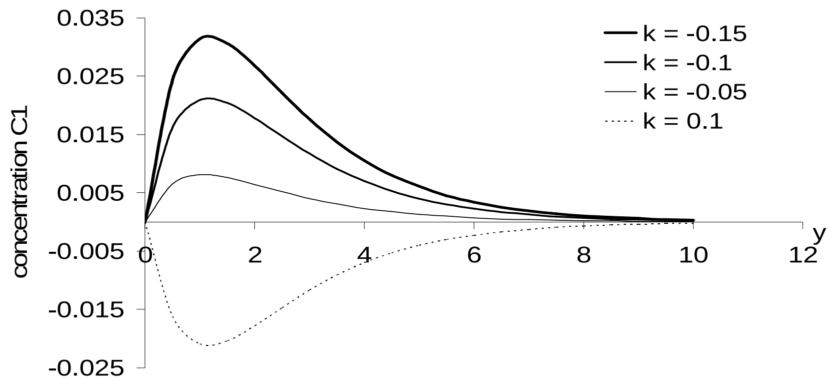


Figure 1: Graph of concentration $C1$ against position y for various values of k, when Grt = 1, Grc = 1, ϕ_0 =- 0.1, ϕ_1 = -0.2, Pr = 0.71, Sc = 0.6, M =0 .5,

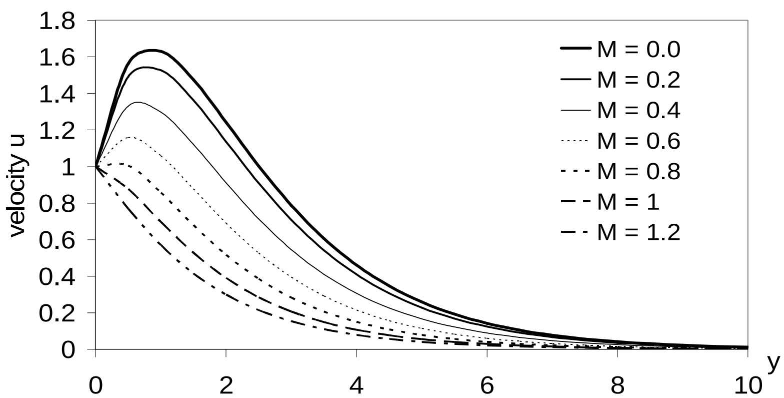


Figure 2: Velocity profile for various M, when Grt = 1, Grc = 1, □ = 0.1, ϕ_1 =- 0.2, Pr = 0.71, Sc = 0.6, k =- 0.1, M = 0.5,

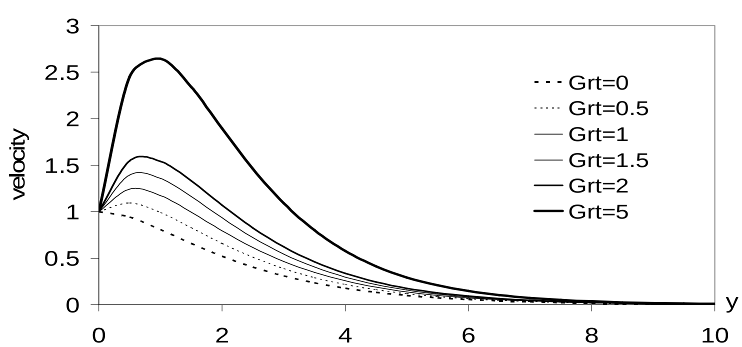


Figure 3: Velocity profile for various Thermal Grashof number, when Grt = 1, Grc = 1, ϕ_1 = -0.1, Pr = 0.71, Sc = 0.6, k =- 0.1, M = 0.5,

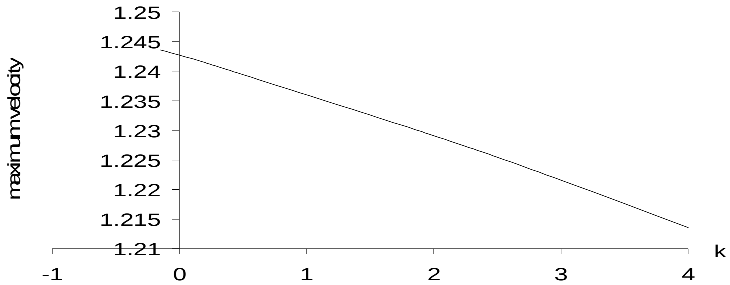


Figure 4.: Graph of maximum velocity against k for various values of when Gr t= 1, Grc=1, ϕ_0 =- 0.1, ϕ_1 =- 0.2, Pr = 0.71, Sc = 0.6, M = 0.5,

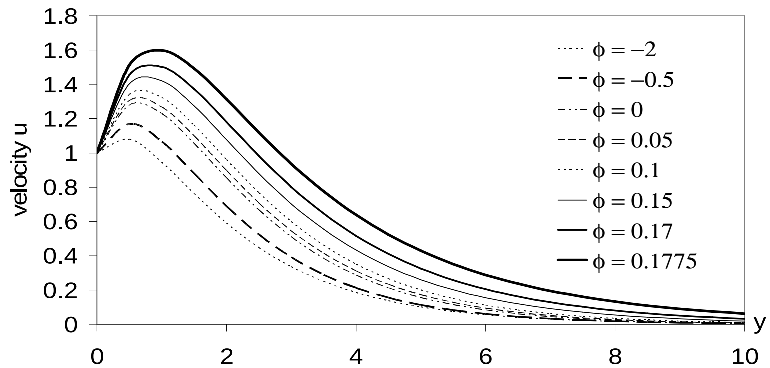


Figure 5: Velocity profile for various values of ϕ_0, when Grt = 1, Grc = 1, ϕ_1 =-0.1, Pr = 0.71, Sc = 0.6, M = 0.5, k = -1,

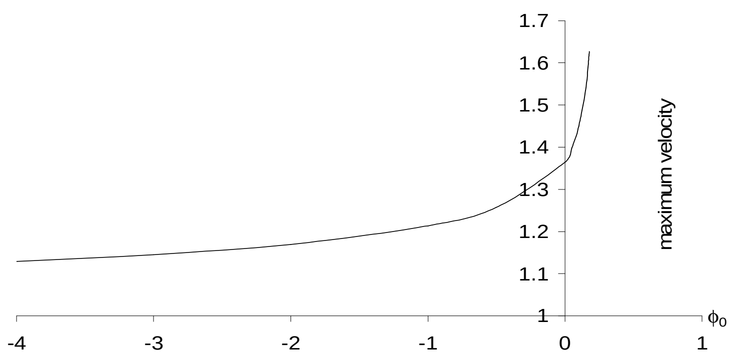


Figure 6: Graph of maximum velocity against *f* when *Grt* = 1, *Grc* = 1, *K* =-0.1, ϕ_1 =-0.1, Pr=0.71, Sc=0.6, M=0.5,

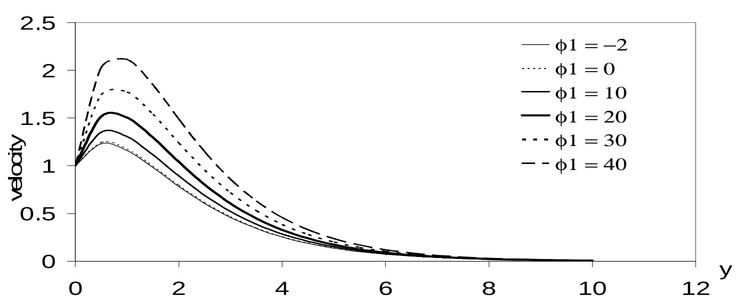


Figure 7: Velocity profile for various values of ϕ, when Grt=1, *Grc*v = 1, ϕ_1 =-0.1 Pr=0.71, Sc=0.6, M=0.5,

The three dimensional graphical presented in figures 8 – 16, show clearly the relationship between the fields and the control parameters along the y – axis. We display in figures 1 – 7, the temperature profile, velocity profile and concentration profile for various values of the parameters. In figure 1 we display the second asymptotic solution to concentration field, it is shown that concentration field increases as chemical reaction parameters (a generative reaction) increases. The effect of magnetic induction is shown in figure 2. It could be seen that increase in magnetic induction brings about reduction in velocity field, this is explained by Lorentz force and conservation theory. In addition, it could also be seen that distinct peaks in velocity field is obtained when the magnetic induction $M < 0.8$. This indicates that maximum velocity occurs in the body of the fluid. Also in figure 3, increase in thermal grashof number increases the velocity field. Figure 4 shows the relationship between the maximum velocity and chemical reaction parameter k. It could be deduced that maximum velocity reduces as destructive chemical reaction increases. In figure 5 and 7 the effect of primary and secondary heat generation was shown. In both cases, we can deduce that increases in heat generation brings about increase in velocity while in figure 6, we display the maximum velocity as a function of heat generation. It could be seen that as the rate of heat absorption increases the maximum velocity increases.

In figures 8 – 16, we display the 3- dimensional graphs of concentration, temperature and velocity fields. Figure 8 shows that increase in chemical reaction parameter k increase the concentration field and reduces along y – direction. While in figures 9 and 10, the symmetry of k_1 about $k_1 = 0$ with the concentration and velocity fields having maximum for $k_1 > 0$ and $k_1 < 0$, reduces along the flow channel. In figures 11, 12 and 13, we show the effect of ϕ_0 on concentration, temperature and velocity fields, As $\phi_0 \rightarrow 0.1776$, a kink is noticed in concentration and velocity fields. These sudden jumps in the values of both fields depend on the direction of approach. While a general reduction in the profile is obtain near zero in temperature in temperature field. The velocity field is analyzed in figures 14 – 16, taking into consideration, the important parameters M, Grc and Grt. We show the effect M on the velocity field in figure 14. It could be seen that maximum velocity occurs at $M = 0$ when there is no opposing force and reduces either way. Also figure 15 and 16 shows the effect of buoyant forces which increases as grashof number increases. We could see that maximum velocity occur when there is heating of the plate ($Grt > 0$)

On the other hand, figure 6 shows that the velocity layer increases as K increases. Figure (7) – (9) show that the reaction order has significant effect on the reac The boundary layers of the three fields get thinner as the reaction or

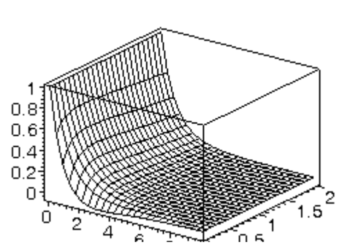


Figure 8: Concentration profile for $0 \le k_0 \le 2$

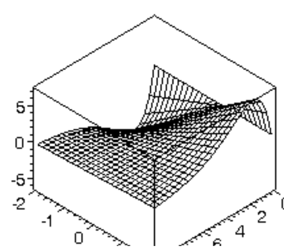


Figure 9: Concentration profile for $0 \le k_1 \le 2$

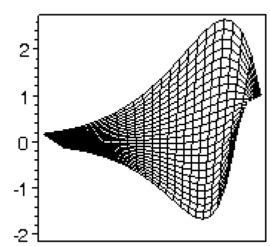
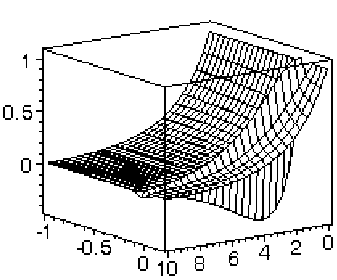


Figure 10: Velocity profile for $0 \le k_0 \le 2$



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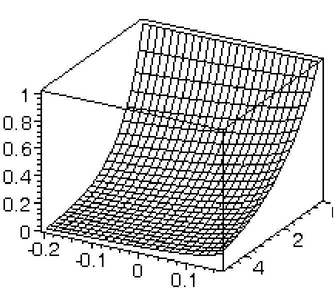

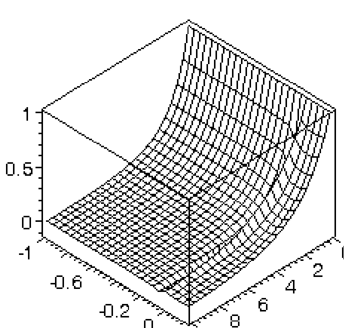

Figure 11: Concentration profile for $0 \le \phi_0 \le 2$

Figure 12: Temperature profile for $-0.2 \le \phi_0 \le 0.17$

Figure 13: Velocity profile for $1 \le \phi_0 \le 0.175$

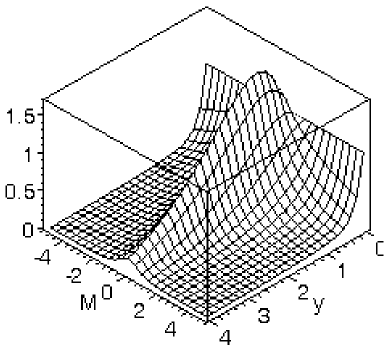

Figure 14: Velocity profile for $-5 \le M \le 5$

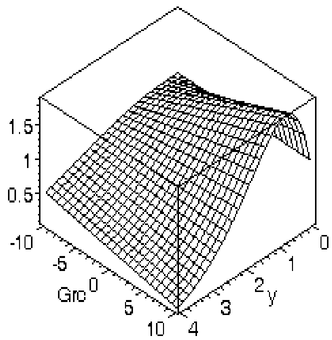

Figure 15: Velocity profile for $-10 \le Grc \le 10$

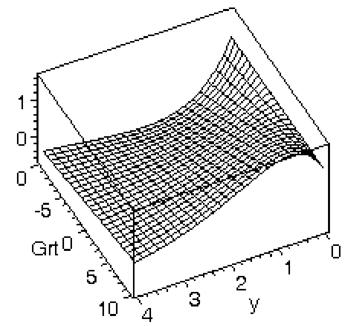

Figure 15: Velocity profile for $-10 \le Grt \le 10$

5.0 Concluding remarks

Analytical solutions of an electrically conducting fluid on a uniformly moving vertical permeable surface in the presence of a magnetic field were reported. Based on the obtained graphical results, the following conclusions were deduced:

(1) The fluid velocity decreases as the strength of the magnetic field was increased and decreased as either of the thermal or concentration buoyancy effect were decreased as expected.

(2) The velocity increases as heat absorption into the system increases.

(3) Maximum velocity occurs when the magnetic induction is zero within the body of the fluid.

(4) Magnetic induction could be used to prevent the transition to turbulent flow.

(5) Maximum velocity decreases as heat generation increases ($\phi_0 < 0$) and decreases as destructive chemical reaction parameter increases.

References

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