Heat and Mass Transfer in Free Convective MHD Flow through a Porous Medium in the Presence of Radiation, Chemical reaction and Hall current with Periodic Suction

Suresh Rana

Dept. of Mathematics

Govt. College of Teacher Education

Dharamshala (H.P) India

Email:sureshrana428@gmail.com.

ABSTRACT:-*In this paper the effect of hall current, chemical reaction, radiation on a free convective MHD flow bounded* by an infinite porous flat plate with variable suction *under the influence of uniform magnetic field, which is applied normal to the surface , is studied* . The flow becomes three-dimensional because of the variation of suction velocity. *The problem is solved analytically and expressions for velocity, temperature, concentration, rate of heat transfer, stress component and Sherwood number have been obtained. The effect of permeability, magnetic number ,hall parameter , radiation parameter ,Grashof number ,modified Grashof number ,chemical reaction on velocity ,temperature ,stress component and heat transfer are obtained and shown respectively with the help of figures and tables and are discussed in detail.*

Keywords*: - Chemical reaction; Radiation; Permeability; hall current; Concentration.*

I. INTRODUCTION

The phenomenon of free convection arises in the fluid when temperature and concentration changes cause density variation leading to buoyancy forces acting on the fluid elements.The mass transfer differences effect the rate of heat transfer. In industries, many transport processes exist in which heat and mass transfer take place simultaneously as a result of combined buoyancy effect of thermal diffusion and diffusion thermo chemical species. The phenomenon of heat and mass transfer frequently exists in chemically processed industries such as food processing and polymer production. Free convection flows are also of great interest in a number of industrial applications such as fiber and granular insulation geothermal system etc. Convection in porous media has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. Magneto-hydrodynamics is attracting the attention of many authors due to its application in geophysics. In engineering in MHD pumps, MHD bearing etc. at high temperature attained in some engineering devices. Since some fluids can emit and absorb thermal radiation, it is of interest to study the effect of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing thermal radiation. This is of interest because heat transfer by thermal radiation is becoming of great importance when we are concerned with space application and higher operating temperatures.
The growing need for chemical reactions in chemical and hydrometallurgical industries require the study of heat and mass transfer with chemical reaction. Chemical reactions occur in air or water due to the presence of foreign mass. It may be present by itself or as mixtures with air or water. In many chemical engineering processes, a chemical reaction occurs between a foreign mass and the fluid in which the plate is moving .These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing.

Soundalgekar and Takhar [1] studied the effects of radiation on the natural convection flow of a gas past a semi-infinite plate using the Cogly-Vincentine-Gillas equilibrium model. Takhar et.al.[2] also investigated the effect of radiation on MHD free convection flow past a semi-infinite vertical plate for same gas. Muthucumarswamy and Kumar[3] studied the thermal radiation effects on moving infinite vertical plate in presence of variable temperature and mass diffusion.Hussain et.al.[4] studied the effect of radiation on free convection on porous vertical plate.Chamkha el.al.[5] studied the effect of hydro-magnetic combined heat and mass transfer by natural convection from a permeable surface embedded in fluid Saturated porous medium**.**

The effect of chemical reaction on heat and mass transfer in a laminar boundary layer flow has been studied under different conditions by several authors. The effect of a chemical reaction on moving isothermal vertical surface with suction has been studied by Muthucumarswamy [6].Manivannan et.al. [7] has investigated radiation and chemical reaction effects on isothermal vertical oscillatory plate with variable mass diffusion.

Sharma et.al. [8] studied the influence of chemical reaction and radiation on unsteady MHD free convective flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in presence of heat source. Mahapatra et.al.[9] studied the effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface.Rajsekhar et.al.[10],Kishan and Srinivas[11] ,Anjalidevi and David[12],Kishan and Deepa[13] and Gaikwad and Rahuldev[14] studied the effects of various parameters on fluid flow. Recently Tavva Sudhakar Reddy et.al.[15] studied the MHD free convection heat and mass transfer flow through a medium bounded by a vertical surface in presence of hall current. Recently Rana [16] studied Heat and Mass Transfer on MHD Free Convective unsteady Fluctuating flow through a Porous medium bounded by a vertical plate in the presence of Hall current and variable permeability. The purpose of this paper is to study Heat and Mass transfer in free convective MHD flow through a porous medium in the presence of radiation, chemical reaction and Hall current with periodic Suction.

II. FORMULATION OF THE PROBLEM

Consider an electrically conducting, radiating, viscous, incompressible fluid through a porous medium bounded by an infinite porous flat plate with variable suction in the presence of hall current .The x'-z' plane lie along the surface of the plate and y'-axis is taken normal to it. A magnetic field of uniform strength, B_0, is applied perpendicular to the free stream and is along y'-axis .The fluid properties are assumed to be constant except that the influence of density in the body term. A chemically reactive species are emitted from the vertical surface in to a hydrodynamic flow field .It diffuses into the fluid when it undergoes a homogenous chemical reaction. The reaction is assumed to take place entirely in the stream. Since the plate is considered infinite in x'-direction, so all physical quantities will be independent of x', however, the flow remains three-dimensional because of the variation of suction velocity distribution of the form

$$v'(z') = -V\left(1+\varepsilon cos\pi\frac{z'}{L}\right). \quad (1)$$

Which consists of basic steady distribution V>0 with a superimposed weak distribution $\varepsilon V cos\pi\frac{z'}{L}$ of wave length L. The negative sign indicates that the suction is towards the plate .The fluid is a grey, absorbing-emitting radiation but non-scattering medium .Under these conditions, the governing equations for the steady, viscous, laminar, three-dimensional boundary layer flow past an infinite flat porous plate with transverse sinusoidal suction velocity under the influence of transverse magnetic field, chemical reaction, radiation and hall current are

$$\frac{\partial v'}{\partial y'}+\frac{\partial v'}{\partial w'}=0 \quad (2)$$

$$\left(v'\frac{\partial u'}{\partial y'}+w'\frac{\partial u'}{\partial y'}\right)=g\beta(T'-T'_\infty)+g\beta'(c'-c'_\infty)+\vartheta\left(\frac{\partial^2 u'}{\partial y'^2}+\frac{\partial^2 u'}{\partial z'^2}\right)-\frac{\sigma B_0^2 u'}{\rho(1+m^2)}-\frac{\vartheta u'}{k'} \quad (3)$$

$$\left(v'\frac{\partial v'}{\partial y'}+w'\frac{\partial v'}{\partial y'}\right)=-\frac{1}{\rho}\frac{\partial p'}{\partial y'}+\vartheta\left(\frac{\partial^2 v'}{\partial y'^2}+\frac{\partial^2 v'}{\partial z'^2}\right)-\frac{\sigma B_0^2 v'}{\rho(1+m^2)}-\frac{\vartheta v'}{K'} \quad (4)$$

$$\left(v'\frac{\partial w'}{\partial y'}+w'\frac{\partial w'}{\partial y'}\right)=-\frac{1}{\rho}\frac{\partial p'}{\partial z'}+\vartheta\left(\frac{\partial^2 w'}{\partial y'^2}+\frac{\partial^2 w'}{\partial z'^2}\right)-\frac{\sigma B_0^2 w'}{\rho(1+m^2)}-\frac{\vartheta w'}{K'} \quad (5)$$

$$v'\frac{\partial T'}{\partial y'}+w'\frac{\partial T'}{\partial z'}=\frac{K}{\rho c_p}\left(\frac{\partial^2 T'}{\partial y'^2}+\frac{\partial^2 T'}{\partial z'^2}\right)-\frac{1}{\rho c_p}\frac{\partial q}{\partial y'} \quad (6)$$

$$v'\frac{\partial c'}{\partial y'}+w'\frac{\partial c'}{\partial z'}=D\left(\frac{\partial^2 c'}{\partial y'^2}+\frac{\partial^2 c'}{\partial z'^2}\right)-k'_r(c'-c'_\infty) \quad (7)$$

All the physical variables have been defined in nomenclature.

The boundary conditions of the problem are

$$\left.\begin{array}{l} y'=0, u'=0, v'(z')=-V\left(1+\varepsilon cos\pi\frac{z'}{L}\right), w'=0, T'=T'_w, c'=c'_w \\ y'\to\infty; \quad u'=U, \quad w'=0, \quad T'=T'_\infty, \quad p'=p'_\infty, \quad c'=c'_\infty \end{array}\right\} \quad (8)$$

Also

$$-\frac{\partial q_r}{\partial y'}=4d\sigma^*(T'^4_w-T'^4)$$

$$=16d\sigma'\, T'^3_w(T'_w-T') \quad (9)$$

Introducing following non-dimensional parameters, we have

$$F=\frac{16d\sigma' {T'_\infty}^3\vartheta}{kU};\ y=\frac{y'}{L};\ z=\frac{z'}{L};\ u=\frac{u'}{U};\ v=\frac{v'}{U};\ w=\frac{w'}{U};\ p=\frac{p'}{\rho U^2};\ R=\frac{UL}{\vartheta}$$

$\theta = \frac{T'-T'_\infty}{T'_w - T'_\infty}$; $c = \frac{C'-C'_\infty}{C'_w - C'_\infty}$; $P = \frac{\mu c_p}{K}$; $S_c = \frac{\vartheta}{D}$; k= $\frac{k' U^2}{\vartheta^2}$; $\alpha = \frac{V}{D}, k_1 = \frac{k'_r \vartheta}{U^2}$

M $= \frac{\sigma B_0^2 \vartheta}{\rho U^2}$; $G_r = \frac{g\beta(T'_w - T'_\infty)L}{U^2}$; $G_m = \frac{g\beta'(c'_w - c'_\infty)L}{U^2}$

We get

$$\frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (10)$$

$$v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = G_r\theta + G_m c + \frac{1}{R}\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) - R\left(\frac{M}{1+m^2} + \frac{1}{k}\right)u \quad (11)$$

$$v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{R}\left(\frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) - R\left(\frac{M}{1+m^2} + \frac{1}{k}\right)v \quad (12)$$

$$v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{R}\left(\frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) - R\left(\frac{M}{1+m^2} + \frac{1}{k}\right)w \quad (13)$$

$$v\frac{\partial \theta}{\partial y} + w\frac{\partial \theta}{\partial z} = \frac{1}{RP}\left(\frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2}\right) - \frac{F\theta}{P} \quad (14)$$

$$v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{1}{Rs_c}\left(\frac{\partial^2 c}{\partial y^2} + \frac{\partial^2 c}{\partial z^2}\right) - Rk_1 c \quad (15)$$

Corresponding boundary conditions are

$$\left.\begin{array}{l} y = 0;\ u = 0, v = -\alpha(1 + \varepsilon\cos\pi z), w = 0, \theta = 1, c = 1 \\ y \to \infty;\ u = 1,\ v = 0, w = 0,\ p = p_\infty,\ \theta = 0,\ c = 0 \end{array}\right\} \quad (16)$$

III. Method of Solution

When the amplitude $\varepsilon \ll 1$, we assume the solution in the neighbourhood of the plate of the form

$$u(y,z) = u_0(y) + \varepsilon u_1(y,z) + \varepsilon^2 u_2(y,z) \quad (17)$$

$$v(y,z) = v_0(y) + \varepsilon v_1(y,z) + \varepsilon^2 v_2(y,z) \quad (18)$$

$$w(y,z) = w_0(y) + \varepsilon w_1(y,z) + \varepsilon^2 w_2(y,z) \quad (19)$$

$$\theta(y,z) = \theta_0(y) + \varepsilon \theta_1(y,z) + \varepsilon^2 \theta_2(y,z) \quad (20)$$

$$c(y,z) = c_0(y) + \varepsilon c_1(y,z) + \varepsilon^2 c_2(y,z) \quad (21)$$

Substituting equations (17)-(21) in equations (10)-(15) and comparing the terms independent of ε we find that the problem reduces to two-dimensional flow with constant suction at the plate. In this case the equations (10)-(15) reduces to

$$v_0' = 0 \quad (22)$$

$$u_0'' + \alpha R u_0' - R^2 M_1 u_0 = -RG_r\theta_0 - RG_m c_0 \quad (23)$$

$$\theta_0'' + \alpha PR\theta_0' - RF\theta_0 = 0 \quad (24)$$

$$c_0'' + \alpha Rs_c c_0' - R^2 s_c k c_0 = 0 \quad (25)$$

Where primes denotes the differentiation with respect to y

With boundary conditions

$$\left.\begin{array}{l} y = 0;\ u_0 = 0, v_0 = -\alpha, \theta_0 = 1, c_0 = 1 \\ y \to \infty;\ u_0 = 1,\ v_0 = 0,\ \theta_0 = 0,\ c_0 = 0 \end{array}\right\} \quad (26)$$

The solutions of equations from (22) - (25) with (26) is given as

$$u_0(y) = A_1(e^{-m_3 y} - e^{-m_1 y}) + A_2(e^{-m_3 y} - e^{-m_2 y}) \quad (27)$$

$$\theta_0(y) = e^{-m_1 y} \quad (28)$$

$c_0(\mathrm{y}) = e^{-m_2 y}$ (29)

With $v_0 = -\alpha$, $w_0 = 0$, $p_0 = p_\infty$

Where $m_1 = \frac{1}{2}\left[\alpha PR + \sqrt{R^2 P^2 \alpha^2 + 4FR}\right]$; $m_2 = \frac{1}{2}\left[\alpha s_c R + \sqrt{R^2 {s_c}^2 \alpha^2 + 4R^2 k_1 s_c}\right]$

$m_3 = \frac{1}{2}\left[\alpha R + \sqrt{R^2 \alpha^2 + 4R^2 M_1}\right]$; $M_1 = \frac{M}{1+m^2} + \frac{1}{k}$

Now comparing the coefficients of ε, and neglecting that of ε^2, we get

$$\frac{\partial v_1}{\partial y} + \frac{\partial w_1}{\partial z} = 0 \qquad (30)$$

$$v_1 \frac{\partial u_0}{\partial y} - \alpha \frac{\partial u_1}{\partial y} = G_r \theta_1 + G_m c_1 + \frac{1}{R}\left(\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial^2 u_1}{\partial z^2}\right) - RM_1 u_1 \qquad (31)$$

$$-\alpha \frac{\partial v_1}{\partial y} = -\frac{\partial p_1}{\partial y} + \frac{1}{R}\left(\frac{\partial^2 v_1}{\partial y^2} + \frac{\partial^2 v_1}{\partial z^2}\right) - RM_1 v_1 \qquad (32)$$

$$-\alpha \frac{\partial w_1}{\partial y} = -\frac{\partial p_1}{\partial z} + \frac{1}{R}\left(\frac{\partial^2 w_1}{\partial y^2} + \frac{\partial^2 w_1}{\partial z^2}\right) - RM_1 w_1 \qquad (33)$$

$$v_1 \frac{\partial \theta_0}{\partial y} - \alpha \frac{\partial \theta_1}{\partial y} = \frac{1}{RP}\left(\frac{\partial^2 \theta_1}{\partial y^2} + \frac{\partial^2 \theta_1}{\partial z^2}\right) + \frac{F}{P}\theta_1 \qquad (34)$$

$$v_1 \frac{\partial c_0}{\partial y} - \alpha \frac{\partial c_1}{\partial y} = \frac{1}{RS_c}\left(\frac{\partial^2 c_1}{\partial y^2} + \frac{\partial^2 c_1}{\partial z^2}\right) - Rk_1 c_1 \qquad (35)$$

With corresponding boundary conditions $p_1(y,z) = p_{11}\,(y)\cos\pi z$

$$\left.\begin{array}{l} y = 0\,;\; u_1 = 0, v_1 = -\alpha cos\pi z, w_1 = 0, \theta_1 = 0\,, c_1 = 0 \\ y \to \infty\,;\; u_1 = 0,\quad p_1 = 0,\; w_1 = 0,\quad \theta_1 = 0\;\;, c_1 = 0 \end{array}\right\} \qquad (36)$$

These are the linear partial differential equations which describe the three dimensional flow.

In order to solve these equations we shall first consider the equations (30), (32), (33) being independent of main flow components u_1 and temperature field θ_1 we assume v_1, w_1 and p_1 of the $form$

$$\left.\begin{array}{r} v_1(y,z) = v_{11}\,(y)\cos\pi z \\ w_1(y,z) = -\dfrac{1}{\pi}v_{11}'(y)\sin\pi z \\ p_1(y,z) = p_{11}\,(y)\cos\pi z \end{array}\right\} \qquad (37)$$

$$v_1(y,z) = \frac{\alpha}{m_4 - \pi}\left(\pi e^{-m_4 y} - m_4\, e^{-\pi y}\right)\cos\pi z \qquad (38)$$

$$w_1(y,z) = \frac{\alpha m_4}{m_4 - \pi}\left(e^{-m_4 y} - e^{-\pi y}\right)\sin\pi z \qquad (39)$$

$$p_1(y,z) = \left\{\frac{\alpha m_4(\pi\alpha + R\,M_1)}{\pi(\pi - m_4)}\; e^{-\pi y}\right\}\cos\pi z \qquad (40)$$

Where $m_4 = \frac{1}{2}\left[\alpha R + \sqrt{R^2 \alpha^2 + 4(\pi^2 + R^2 M_1)}\right]$

In order to solve the differential equations (31), (34) and (35) we assume

$$\left.\begin{array}{l} u_1(y,z) = u_{11}\,(y)\cos\pi z \\ \theta_1(y,z) = \theta_{11}\,(y)\cos\pi z \\ c_1(y,z) = c_{11}\,(y)\cos\pi z \end{array}\right\} \qquad (41)$$

Substituting these equations in (31), (34) and (35) we obtain the following equations

$$u_{11}'' + \alpha R u_{11}' - (\pi^2 + R^2 M_1)u_{11} = -\mathrm{R}G_r\theta_{11} - \mathrm{R}G_m c_{11} + v_{11}u_0' R \qquad (42)$$

$$\theta_{11}'' + \alpha RP\theta_{11}' - (\pi^2 + FR)\theta_{11} = -m_1 v_{11}\, RPe^{-m_1 y} \qquad (43)$$

$c''_{11} + \alpha RPc'_{11} - (\pi^2 + R^2 k_1 s_c) c_{11} = - m_2 v_{11} s_c R\, e^{-m_2 y}$ (44)

With corresponding boundary conditions

$$\left.\begin{array}{l} y = 0 \;\; u_{11} = 0,\; \theta_{11} = 0,\;\; c_{11} = 0 \\ y \to \infty;\; u_{11} = 0,\;\; \theta_{11} = 0\;\;,\; c_{11} = 0 \end{array}\right\} \quad (45)$$

Solving equations (42), (43) and (44) using (45) we get

$$c_{11} = s_c \mathrm{R}\, m_2 \frac{\alpha}{m_4 - \pi} \left[\frac{m_4}{\pi(2m_2 - \alpha s_c R)} \left(e^{-(m_2+\pi)y} - e^{-m_5 y}\right) + \frac{\pi}{m_6^2 - \alpha s_c R m_6 - (\pi^2 + R^2 k_1 s_c)} \left(e^{-m_5 y} - e^{-m_6 y}\right) \right] \quad (46)$$

$$\theta_{11} = \frac{\alpha m_1}{m_4 - \pi} \left[\frac{\pi}{m_8^2 - \alpha P R m_8 - (\pi^2 + FR)} \left(e^{-m_7 y} - e^{-m_8 y}\right) - \frac{m_4}{\pi(2m_1 - RP\alpha)} \left(e^{-m_7 y} - e^{-(m_1+\pi)y}\right) \right] \quad (47)$$

$$u_{11} = \frac{R\alpha m_1 G_r}{m_4 - \pi} \left[B_{12}\{A_{12}(e^{-m_4 y} - e^{-m_7 y}) - A_{13}(e^{-m_4 y} - e^{-m_8 y})\} - B_{11}\{A_{12}(e^{-m_4 y} - e^{-m_7 y}) - A_{11}(e^{-m_4 y} - e^{-(m_1+\pi)y})\} \right] + \frac{R^2 s_c \alpha m_2 G_m}{m_4 - \pi} \left[B_{14}\{A_{15}(e^{-m_4 y} - e^{-m_5 y}) - A_{16}(e^{-m_4 y} - e^{-m_6 y})\} - B_{13}\{A_{15}(e^{-m_4 y} - e^{-m_5 y}) - A_{14}(e^{-m_4 y} - e^{-(m_2+\pi)y})\} \right] + \frac{\alpha R}{m_4 - \pi} \left[A_1 m_1 \{A_{13}(e^{-m_4 y} - e^{-m_8 y}) - A_{11}(e^{-m_4 y} - e^{-(\pi+m_1)y}\} + A_2 m_2 \{A_{16}(e^{-m_4 y} - e^{-m_6 y}) - A_{14}(e^{-m_4 y} - e^{-(\pi+m_2)y}\} - (A_1 + A_2) m_3 \{A_{17}(e^{-m_4 y} - e^{-m_9 y}) - A_{18}(e^{-m_4 y} - e^{-(\pi+m_3)y}\} \right] \quad (48)$$

Hence u(y, z) = $A_1(e^{-m_3 y} - e^{-m_1 y}) + A_2(e^{-m_3 y} - e^{-m_2 y}) + \varepsilon \langle \frac{R\alpha m_1 G_r}{m_4 - \pi} \left[B_{12}\{A_{12}(e^{-m_4 y} - e^{-m_7 y}) - A_{13}(e^{-m_4 y} - e^{-m_8 y})\} - B_{11}\{A_{12}(e^{-m_4 y} - e^{-m_7 y}) - A_{11}(e^{-m_4 y} - e^{-(m_1+\pi)y})\} \right] + \frac{R^2 s_c \alpha m_2 G_m}{m_4 - \pi} \left[B_{14}\{A_{15}(e^{-m_4 y} - e^{-m_5 y}) - A_{16}(e^{-m_4 y} - e^{-m_6 y})\} - B_{13}\{A_{15}(e^{-m_4 y} - e^{-m_5 y}) - A_{14}(e^{-m_4 y} - e^{-(m_2+\pi)y})\} \right] + \frac{\alpha R}{m_4 - \pi} \left[A_1 m_1 \{A_{13}(e^{-m_4 y} - e^{-m_8 y}) - A_{11}(e^{-m_4 y} - e^{-(\pi+m_1)y}\} + A_2 m_2 \{A_{16}(e^{-m_4 y} - e^{-m_6 y}) - A_{14}(e^{-m_4 y} - e^{-(\pi+m_2)y})\} - (A_1 + A_2) m_3 \{A_{17}(e^{-m_4 y} - e^{-m_9 y}) - A_{18}(e^{-m_4 y} - e^{-(\pi+m_3)y})\} \right] \rangle \cos \pi z$.
(49)

v$(y, z) = \frac{\alpha}{m_4 - \pi} \left(\pi e^{-m_4 y} - m_4\, e^{-\pi y}\right) \cos \pi z$ (50)

w$(y, z) = \frac{\alpha m_4}{m_4 - \pi} \left(e^{-m_4 y} - e^{-\pi y}\right) \sin \pi z$ (51)

p$(y, z) = \left\{ \frac{\alpha m_4 (\pi\alpha + R M_1)}{\pi(\pi - m_4)} e^{-\pi y} \right\} \cos \pi z$ (52)

c$(y, z) = e^{-m_2 y} + \varepsilon \langle s_c \mathrm{R} m_2 \frac{\alpha}{m_4 - \pi} \left[\frac{m_4}{\pi(2m_2 - \alpha s_c R)} \left(e^{-(m_2+\pi)y} - e^{-m_5 y}\right) + \frac{\pi}{m_6^2 - \alpha s_c R m_6 - (\pi^2 + R^2 k_1 s_c)} \left(e^{-m_5 y} - e^{-m_6 y}\right) \right] \rangle \cos \pi z$
(53)

$\theta(y, z) = e^{-m_1 y} + \varepsilon \langle \frac{\alpha m_1}{m_4 - \pi} \left[\frac{\pi}{m_8^2 - \alpha P R m_8 - (\pi^2 + FR)} \left(e^{-m_7 y} - e^{-m_8 y}\right) - \frac{m_4}{\pi(2m_1 - RP\alpha)} \left(e^{-m_7 y} - e^{-(m_1+\pi)y}\right) \right] \rangle \cos \pi z$
(54)

Where

$A_1 = \frac{RG_r}{m_1^2 - \alpha R m_1 - R^2 M_1}$; $A_2 = \frac{RG_m}{m_2^2 - \alpha R m_2 - R^2 M_1}$; $B_{11} = \frac{m_4}{\pi(2m_1 - RP\alpha)}$; $B_{12} = \frac{\pi}{m_8^2 - \alpha RP m_8 - (\pi^2 + FR)}$; $B_{13} = \frac{m_4}{\pi(2m_2 - R\alpha s_c)}$

$B_{14} = \frac{\pi}{m_6^2 - \alpha R s_c m_6 - (\pi^2 + s_c R^2 k_1)}$; $A_{11} = \frac{RG_r}{m_1^2 + (2\pi - \alpha R) m_1 - R(\alpha\pi + RM_1)}$; $A_{12} = \frac{1}{R\alpha m_7 (P - 1) - R(F + RM_1)}$

$A_{13} = \frac{1}{m_8^2 - \alpha R m_8 - (\pi^2 + R^2 M_1)}$; $A_{14} = \frac{1}{m_2^2 + (2\pi - \alpha R) m_2 - R(\alpha\pi + RM_1)}$; $A_{15} = \frac{1}{R\alpha m_5 (s_c - 1) + R^2 (s_c k_1 - M_1)}$;

$A_{16} = \frac{1}{m_6^2 - \alpha R m_6 - (\pi^2 + R^2 M_1)}$; $A_{17} = \frac{1}{m_9^2 - \alpha R m_9 - (\pi^2 + R^2 M_1)}$; $A_{18} = \frac{m_4}{\pi(2m_3 - R\alpha)}$;

$m_4 = \frac{1}{2}\left[\alpha R + \sqrt{R^2 \alpha^2 + 4(\pi^2 + R^2 M_1)}\right]$; $m_5 = \frac{1}{2}\left[\alpha s_c R + \sqrt{R^2 {s_c}^2 \alpha^2 + 4(\pi^2 + R^2 k_1 s_c}\right]$;

$m_6 = m_2 + m_4$; $m_7 = \frac{1}{2}\left[\alpha PR + \sqrt{R^2 P^2 \alpha^2 + 4(\pi^2 + FR)}\right]$; $m_8 = m_1 + m_4$;

$m_9 = m_3 + m_4$.

IV. Results and Discussion

In order to point out the effects of radiation, chemical reaction and hall current on transient velocity when the plate is subjected to transverse sinusoidal suction, the following discussion is set out. Numerical calculations are carried out for different values of the Grashof number G_r, the modified Grashof number G_m,the Prandtl number Pr, the Schmidt number s_c,the radiation parameter F,the hall parameter m, the magnetic field constant M,chemical reaction k_1 and permeability constant k.From the practical point of view ,the values of Prandtl number are chosen as 0.71 and 7 which represent air and water at 20^0c.

Figure 1 represents the transient velocity profile for radiation parameter F.It is found that transient velocity decreases for increasing values of F.Transient velocity profile for different values of Grashof number is shown in figure 2 and it is found that transient velocity increases for increasing values of Grashof number. Figure 3 represents the transient velocity for modified Grashof number and it is found that velocity increases for increasing of modified Grashof number. Transient velocity profile for permeability k and chemical reaction k_1 is represented in figure 4 and it is found that velocity increases with increasing of k in the presence k_1 .Figure 5 represents the velocity profile for permeability parameter k in the absence of magnetic field M and radiation parameter F and it is found that velocity increases with increasing value k. Figure 6 represents the transient velocity for hall factor m and it is found that velocity increases with increasing of m.Figure 7 represents the transient velocity for magnetic field parameter M in the presence of radiation and found that velocity decreases with increasing of M. Figure (8) depicts the effect of chemical reaction k_1. It has been observed that for $k_1 < 0$ (generative reaction) the velocity increases but for $k_1 > 0$ (destructive reaction) the velocity decreases in the presence of magnetic field M and radiation parameter F.

Knowing the velocity field we can obtain the expression for stress component in z^*-direction in non-dimensional form as:

$$\tau_z = \frac{\tau_z^*}{\mu V/L} = \frac{U}{V}\left(\frac{\partial w}{\partial y}\right)_{y=0} = -\varepsilon m_4 \sin \pi z = -\varepsilon F_1(\alpha, R, m, M, k) \quad (55)$$

where

$$F_1(\alpha, R, m, M, k) = m_4 \quad . \quad (56)$$

The transverse component τ_z of the plate shear stress results from the secondary flow perpendicular to the main flow direction. The numerical values of the function $F_1(\alpha, R, m, M, k)$ defined in equation (56) has been listed in Table 1 for various values of α, R, m, M and k . A study of this table shows that value of F_1 increases with increasing of suction parameter α for very large values of k and value of F_1 increases considerably for small value k and with increasing of α . Keeping α constant if value of k is increased, the value of F_2 decreases.

The rate of heat transfer coefficient at the surface of the plate in terms of Nusselt number is given by

$$N_u = -\frac{1}{\alpha RP}\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$$

$$= \frac{m_1}{\alpha RP} + \varepsilon\left[\frac{m_1}{RP(m_4-\pi)}\{B_{12}(m_8 - m_7) - B_{11}(m_1 + \pi - m_7)\}\right]\cos \pi z$$

$$= \frac{m_1}{\alpha RP} + \varepsilon\,[1 - F_2(\alpha, P, R, k, M, m, F)]\cos \pi z \quad (57)$$

Where

$$F_2(\alpha, P, R, k, M, m, F) = 1 - \frac{m_1}{RP(m_4-\pi)}\{B_{12}(m_8 - m_7) - B_{11}(m_1 + \pi - m_7)\} \quad (58)$$

The function $F_2(\alpha, P, R, k, M, m, F)$ in equation (58) is numerically evaluated for different values of suction parameter α ,Reynolds number R, permeability parameter k and Prandtl number P in Table 2.. From the table it is clear that value of F_2 increases with increasing of suction parameter α and for large values of k keeping F constant. The value of F_2 increases if F is increased keeping suction parameter α and k constant. For P = 7, F_2 increases if α is increased keeping k and F constant.

The non-dimensional number Sherhood number is given by

$$\text{Sh} = -\left(\frac{\partial c}{\partial y}\right)_{y=0} = m_2 + \varepsilon\left[\frac{s_c m_2 \alpha R}{(m_4-\pi)}\{B_{13}(m_5 - m_2 - \pi) - B_{14}(m_5 - m_6)\}\right]\cos \pi z \quad (59)$$

The numerical values of Sherwood number has been numerically evaluated for z=0 and different values of chemical reaction parameter k_1, s_c and ϵ and it is found that the value of Sherwood number sh decreases with increasing of ϵ and increases with increasing of s_c .The value of Sherwood number decreases for $k_1 < 0$ (generative reaction) and increases for $k_1 > 0$ (destructive reaction) .

IV. FIGURES AND TABLES

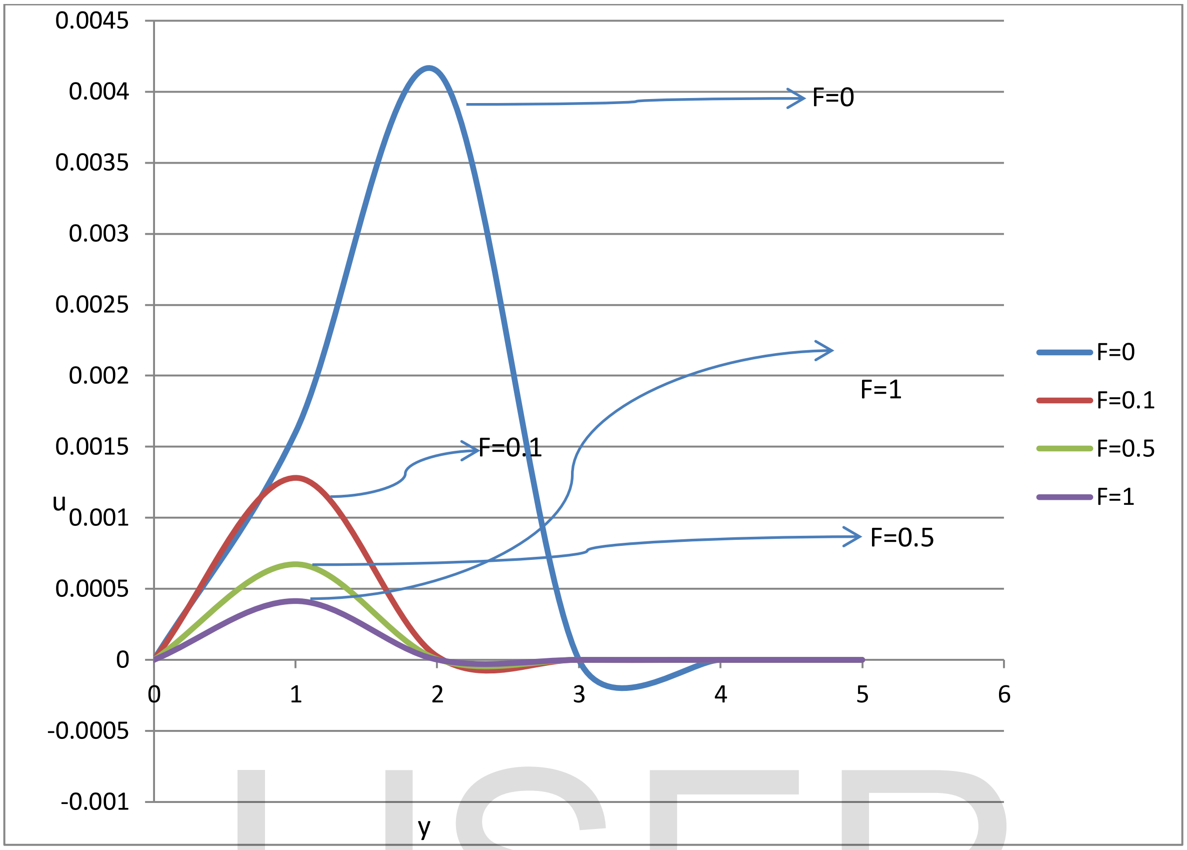


Figure 1: Transient Velocity Profile for M=2, Gr=5, Gm=5, m=5, Pr=0.71, K_1=0.1, α=0.5 at z=0.

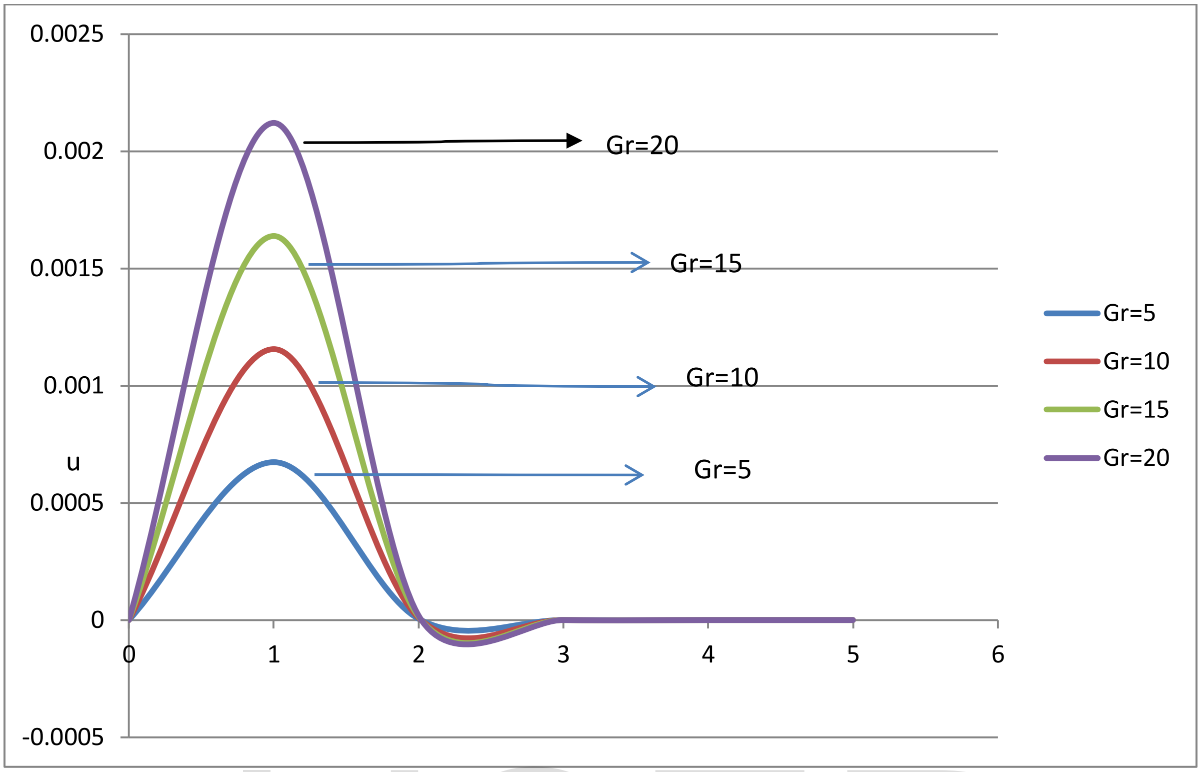
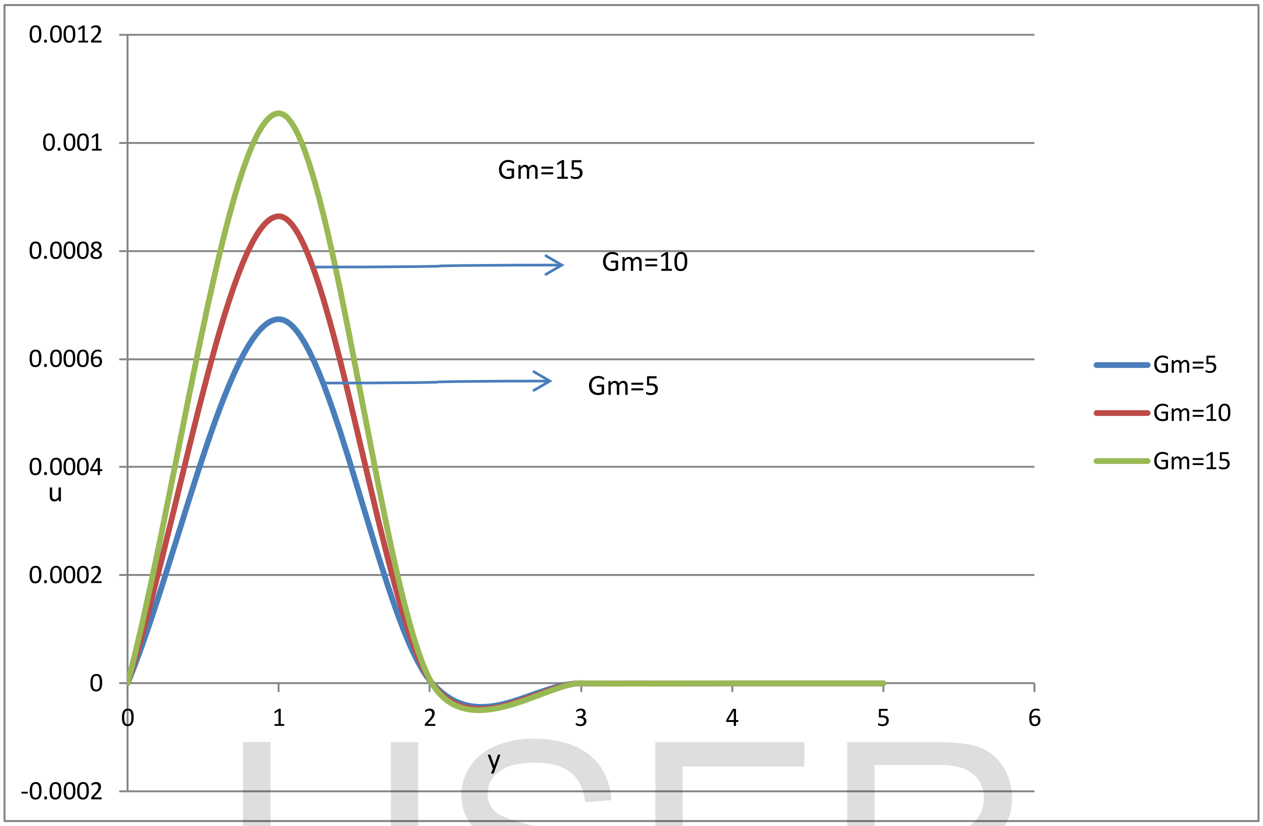
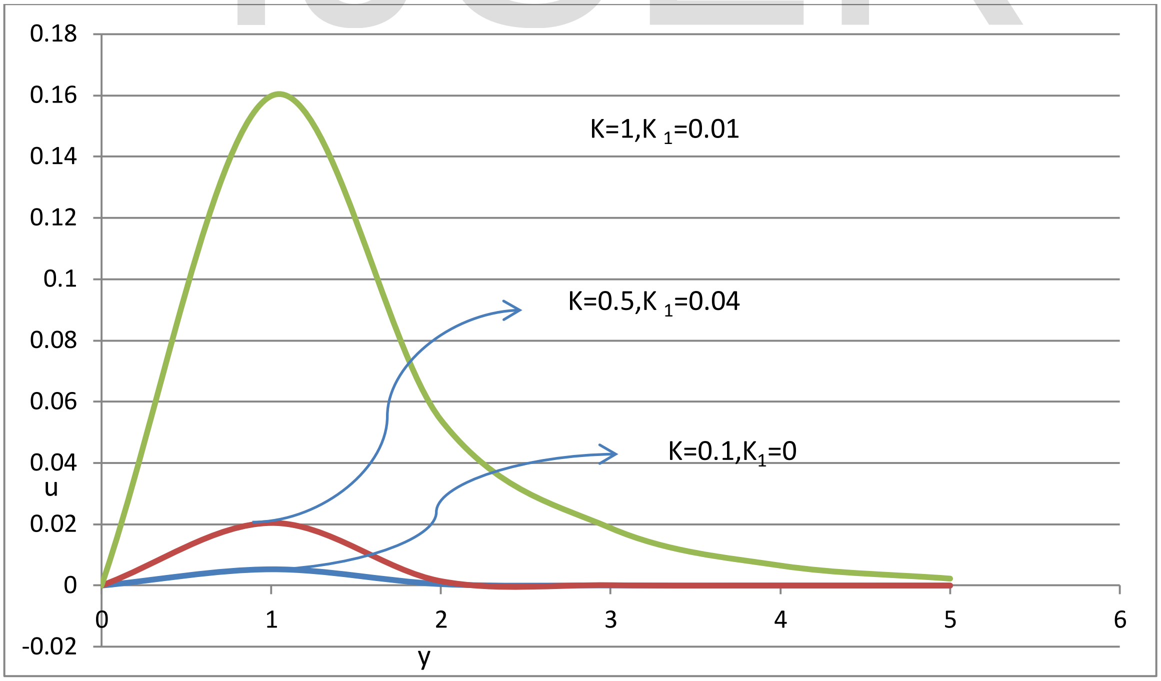
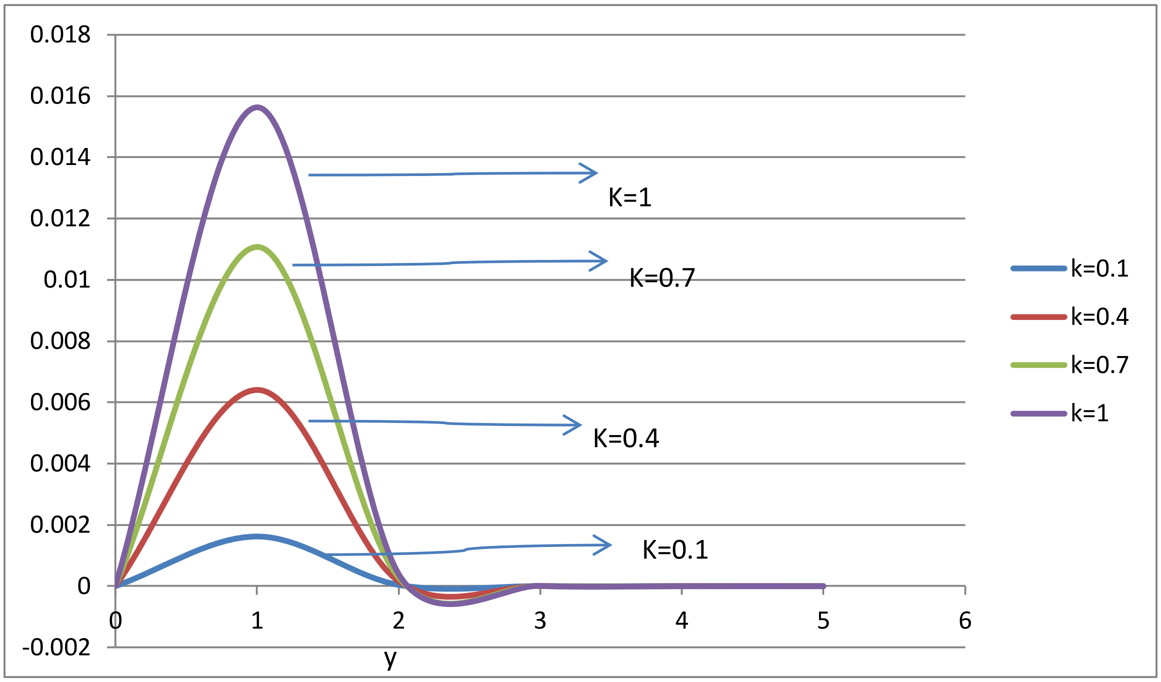


Figure 2: Transient velocity Profile for M=2,Gm=5,Pr=0.71, K=0.1,K_1=1,m=5,Sc=0.22,α=0.5 at z=0.


0.0012
0.001
0.0008
0.0006
0.0004
u
0.0002
0
-0.0002
0
1
2
3
4
5
6
y
Gm=15
Gm=10
Gm=5
Gm=5
Gm=10
Gm=15


0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
u
0.02
0
-0.02
0
1
2
3
4
5
6
y
K=1,K 1=0.01
K=0.5,K 1=0.04
K=0.1,K1=0



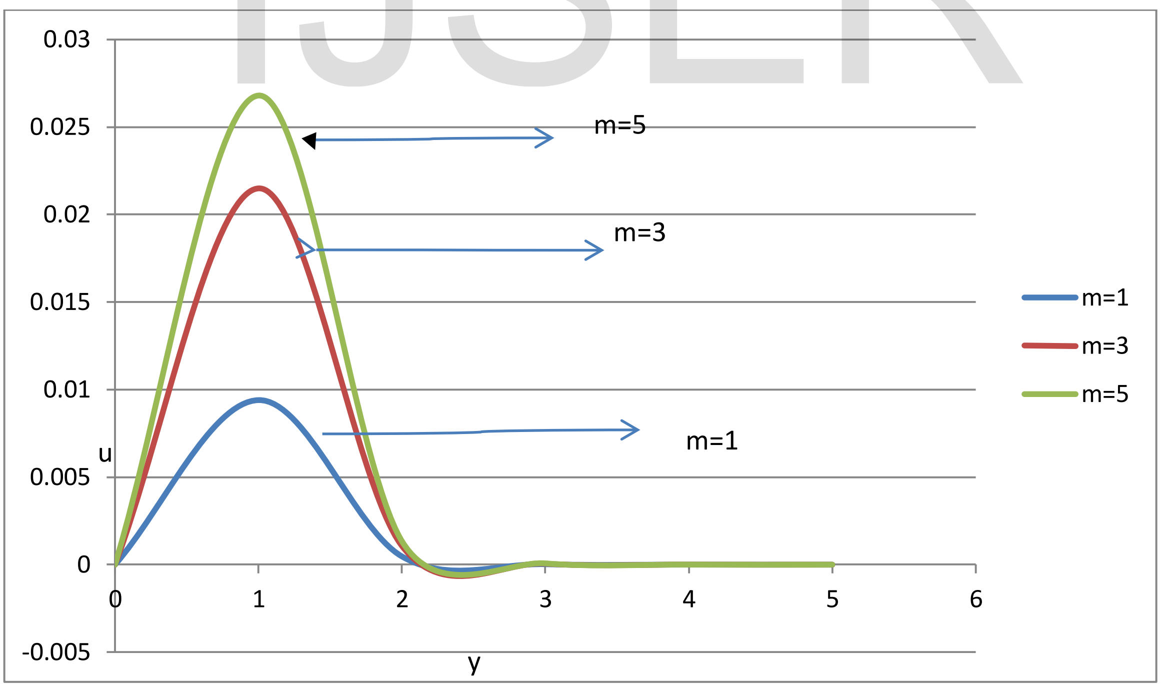
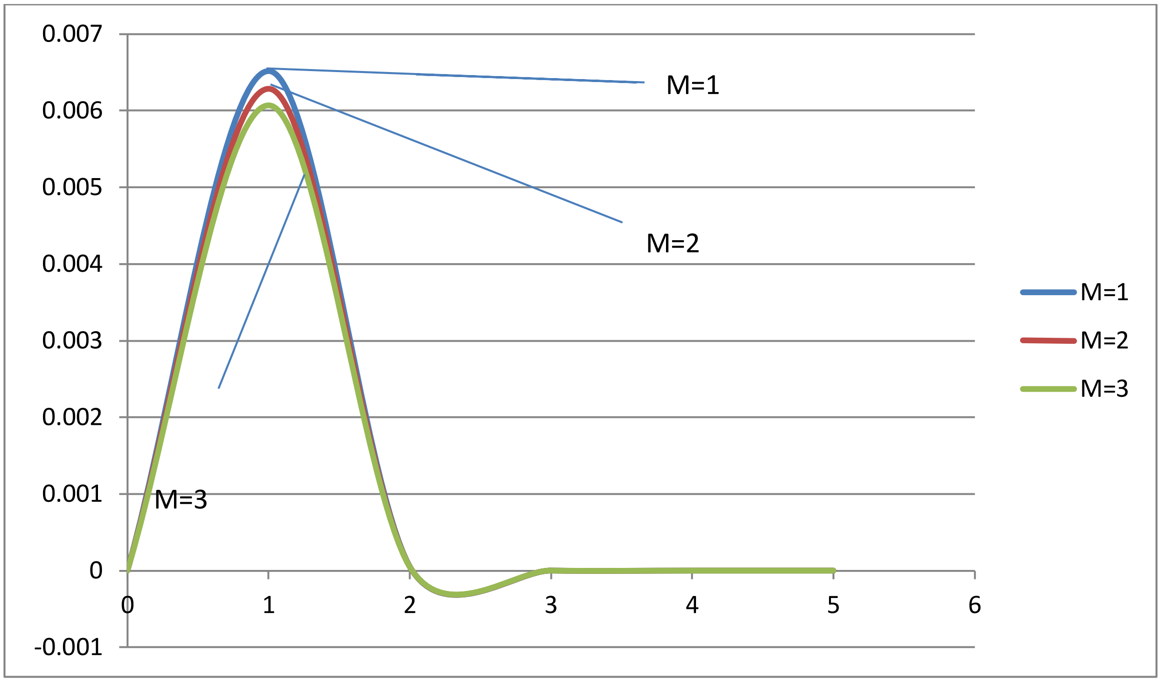
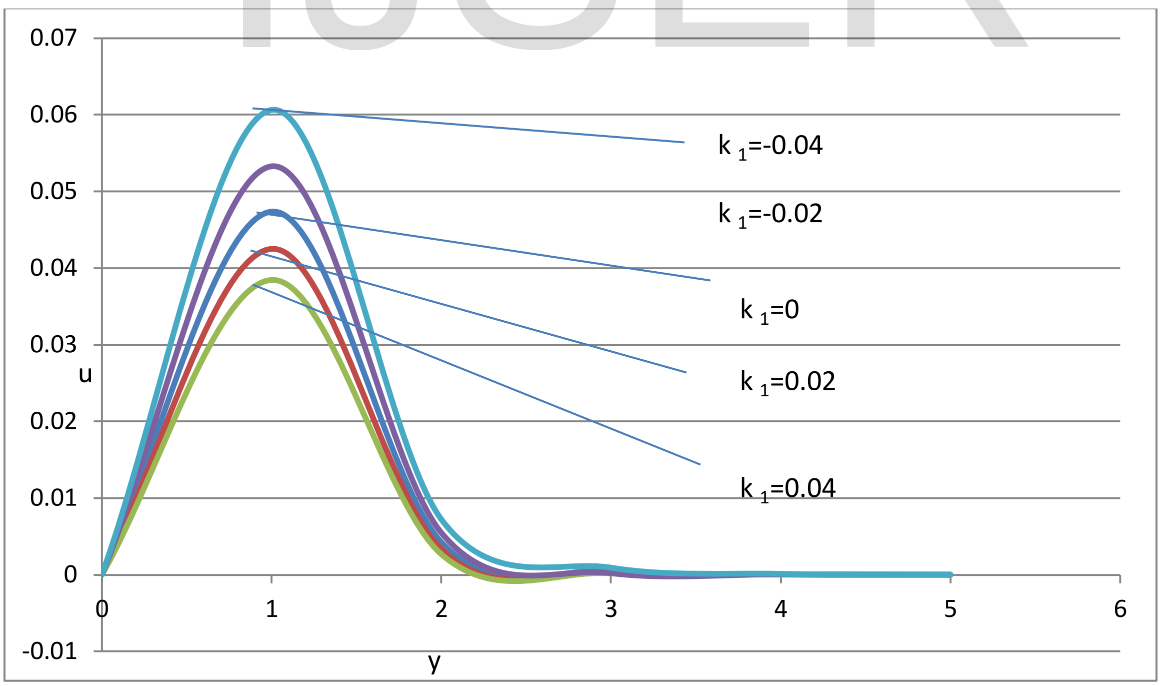


Figure 6: Transient Velocity Profile for M=5,Gr=5, Gm=5,Pr=0.71,,Sc=0.22,α=0.5 ,F=0.5,k $_1$=1,R=10,K=1,z=0.


0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
0
1
2
3
4
5
6
M=1
M=2
M=3
M=1
M=2
M=3


0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
u
0
1
2
3
4
5
6
y
k 1=-0.04
k 1=-0.02
k 1=0
k 1=0.02
k 1=0.04

ISSN 2229-5518

Table 1

A	K/R	10^{-2}	10^{-1}	1	10^{1}	10^{2}
0.5	∞	62.471	7.3797	3.4237	3.1668	3.1441
1.0	∞	107.26	11.524	3.6932	3.1921	3.1466
0.5	5	83.344	9.119	3.4452	3.1671	3.1441
1.0	5	122.66	12.910	3.7244	3.1924	3.1466
1.0	10	115.41	12.250	3.7088	3.1923	3.1466

Table 2

P	F	A	K/R	10^{-2}	10^{-1}	1	10^{1}	10^{2}
0.71	0.5	1	∞	3.5077	1.8374	1.3166	1.0997	1.0136
0.71	0.5	0.5	∞	3.3823	1.7744	1.2566	1.0775	1.0129
0.71	0.5	0.5	10	3.3823	1.7759	1.2565	1.0766	1.0128
0.71	1	0.5	10	4.2744	2.0494	1.3166	1.0781	1.0125
0.71	0.5	0.5	10^{2}	3.3825	1.7785	1.2463	1.0774	1.0129
7	0.5	0.5	10	1.3091	1.1473	1.0807	1.0139	1.0014
7	0.5	1	10	3.5077	1.8372	1.3164	1.0993	1.0132

Table 3

K_1	S_c	ϵ	Sherwood no
0.04	0.22	0.01	2.5543
0.04	0.22	0.05	2.5413
0.04	0.22	0.1	2.525
0.04	0.22	0.2	2.4924
0.04	0.60	0.05	3.6921
0.04	0.78	0.05	4.3617
0.00	0.22	0.05	2.3096
-.04	0.22	0.05	2.0426

VII. Nomenclature

C - dimensionless concentration ; U --- mean stream velocity

c' - Concentration; u, v, w --- dimensionless velocity components of the fluid

c'_w ---Species concentration at the plate; u', v', w' -- velocity components of the fluid

c'_∞ ---Species concentration far away from the plate; T' ---- temperature of the fluid;

C_p --- specific heat at constant pressure; v_0 - suction velocity

D --- Chemical diffusivity; x', y', z' -- co-ordinate axis

$g_{x'}$ --acceleration due to gravity ; T'_w ----------- Temperature of fluid at the plate;

G_r --- Grashof number; α --- suction parameter

G_m --- modified Grashof number; β ---- coefficient of thermal expansion

K --- thermal conductivity; β^* ---- coefficient of concentration expansion

P_r --- Prandtl number; ϑ ----- kinematic viscosity

P' --- pressure; ρ ----- density

q' ---- heat flux at the plate; σ ----- Stefan-Boltzman constant

F ---- radiation parameter; S_c ----schmidt number

T ---- dimensionless fluid temperature ; M ---- magnetic parameter

T'_∞ ---- temperature of fluid away from the plate ; m --- Hall current parameter

k_1 ---- chemical reaction parameter

t --- dimensionless time; k ----- permeability parameter

t' --- time; R ----- Reynolds number.

REFRENCES

[1] Soundalgekar V M, Takhar H S., *Modelling Measure and Cont.*, 51, 1992, 31-40.
[2] Tahkar H S, Gorla S R, Soundalgekar V M., *Int. J. Numerical Methods heat fluid flow*, 6, 1996, 77-83.
[3] Muthucumarswamy R and Kumar G S, *Theoret. Appl. Mach*., 31(1), 2004, 35-46.
[4] Hossain A M, Alim M A and Rees D A S, *Int.J.Heat Mass Transfer*, 42, 1999**,** 181-191.
[5] Chamaka A.J, *Int. J. Num.Methods for heat and fluid flow*, 10(5), 2000, 455-476.
[6] Muthucumarswamy R., *Acta Mech*. 155, 2002, 65-70.
[7] Manivannan K, Muthucumarswamy R, Thangaraj V., Thermal *science*, 13(2),2009, 155-162.
[8] Sharma P R, Kumar N, Sharma P., *Appl. Math. Sciences*, 46(5), 2011, 2249-2260.
[9] Mahaptra N, Dash G C, Panda S, Acharya M., *J.Engg. Phys. and Thermo physics*, 83(1), 2010.
[10] Rajasekhar K, Ramana Reddy G V, Prasad B D C N, *Advances in applied science Research*, 3(5), 2012, 2652-2659.
[11] Kishan N, Srinivas M, *Advances in applied science Research*, 3(1), 2012, 60-74.
[12] Anjalidevi S P, David A M G, *Advances in applied science Research, 3(1), 2012, 319-334*.
[13] Kishan N, Deepa G*, Advances in applied science Research, 3(1), 2012, 430-439.*
[14] Gaikwad S N, Rahuldev B M, *Advances in applied science Research, 3(2), 2012***,** *720-734.*

[15] Tavva. Sudhakar Reddy, O. Siva Prasad Reddy, M. C. Raju and S. V. K. Varma, *Advances in applied science Research, 3(6),* 2012**,** *3482-3490.*

[16] Rana Suresh, Int.Journal of Advance Research,IJOAR.org.1(9),2013,7-28.