Chemical Reaction and Radiation Effects on the Hydro-Magnetic Free Convection Flow of Visco-Elastic Fluid along an Infinite Vertical Porous Plate in a Porous Medium

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Abstract
An unsteady hydro magnetic laminar free convection heat and mass transfer flow of a visco-elastic, dissipative fluid along an infinite vertical Porous plate through porous medium is analyzed in the presence of chemical reaction and thermal radiation. The solution of the problem is obtained in the form of power series of ε which is very small. Analytical expressions for the velocity, temperature and concentration fields are given, as well as for the skin friction, the rate of heat transfer and the rate of mass transfer coefficient at the plate. The influence of the magnetic parameter M, thermal grashof numbers Gr and solutal, grashof numbers Gm, visco-elastic parameter λ_1, permeability parameter Kp, Prandtl number $\Pr$, Eckert number E, Radiation Parameter R, Schmidt number Sc and chemical reaction parameter Kr has been discussed and analyzed through graphs.
Keywords: Chemical reaction, MHD, Porous Medium, Thermal Radiation, Visco elastic parameter

1. Introduction

The Science of magneto hydrodyanmics (MHD) was concerned with geophysical and astrophysical problems for a number of years. In recent years, the possible use of MHD is to affect a flow stream of an electrically conducting fluid for the purpose of thermal protection, braking, propulsion and control. From the point of applications, model studies on the effect of magnetic field on free convection flows have been made by several investigators.

In many engineering applications natural convection flows play an important role and hence these have attracted the attention of many research workers. The phenomenon of mass transfer is very common in the theories of stellar structure and observable effects are easily detectable at least on the solar surface. On the other hand, the results of the effects of magnetic field on the flow of an eclectically-conducting viscous fluid in the presence of mass transfer are also useful in stellar atmosphere. The flow of viscous incompressible fluid past an horizontal plate oscillating on its own plane was investigated by Stokes [1851].The convective heat and mass transfer flows through/past a porous media was studied in [2005,2001]. Cookey et al.[2003]. Investigated the influence of viscous dissipation and radiation on unsteady MHD free-convective flow past an infinite heated vertical plate in a porous medium with time dependent suction. Das et al. [2009] analyzed the effect of mass transfer on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source and recently [2010] investigated the hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source.

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. Many researchers are being carried out across the globe. The study of heat and mass transfer with chemical reaction is given primary importance in chemical and hydrometallurgical industries. Muthucumarswamy and Kulaivel [2003] presented a analytical solution to the problem of flow past an impulsively started infinite vertical plate in the presence of uniform heat flux and variable mass diffusion, taking into account the homogeneous chemical reaction of first order. Seddeck et al [2007] has studied the effects of chemical reaction and variable viscosity hydromagnetic mixed convection heat and mass transfer for Heimenz flow through porous media with radiation. Muthucumaraswamy and Ganesan [2002] studied the diffusion and first-order chemical reaction on impulsively stated infinite vertical plate with variable temperature. Badruddin et al [2005] analyzed the free convection and radiation characteristics for a vertical plate embedded in porous medium.

The influence of chemical reaction on transient MHD free convection over a moving vertical plate was discussed by Al-Odat and Al-Azad [2007]. The heat and mass transfer of unsteady MHD natural convection flow of rotating fluid past a vertical porous plate in the presence of radiative heat transfer was analyzed by Mbeledogu and Ogulu [2007]. Orhan and Ahmet [2008] presented radiation effects on MHD mixed convection flow about a permeable vertical plate.

A number of scholars have developed their extensive research on the study of heat and mass transfer due to day-to-day applications in science and technology. The phenomenon of heat and mass transfer are observed in buoyancy induced motions in the atmosphere, in water bodies, quasi-solid bodies such as earth and so on. In many transport process in nature and in industrial applications in which heat and mass transfer are a consequence of buoyancy effects caused by diffusing of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production, chemical oil recovery, underground energy transformed, manufacturing of ceramic and food processing. Natural or free convection processes in double diffusive convection are also encountered in many natural processes such as condensation and agricultural drying, and in many industrial applications, such as the curing of plastics, cleaning and chemical processing of materials relevant to the manufacture of printed circuit.

The main objective of the present investigation to study the effects of chemical reaction, radiation effects,visco-elastic fluid along an infinite vertical porous plate subjected to the suction velocity varying with time. Inspite of all the above sited papers the effects of chemical reaction and radiation effects has received little action.

2. Mathematical Formulation:

We consider the unsteady, two dimensional, hydro magnetic free convection and mass transfer flow, of a viscous incompressible, electrically conducting, visco elastic fluid through a highly porous medium which is bounded by a vertical infinite porous plane surface in the presence of a first order chemical reaction, thermal radiation and viscous dissipation effects. Taking the x- axis along the plate with direction opposite the direction of the gravity and the y-axis is taken to be normal to it. A uniform magnetic field of strength B_0 is applied transversally to the direction of flow. In the present analysis, the following assumptions are made.

- The flow is unsteady and Laminar
- Visco-elastic fluid is of kuvshinshiki model
- The vertical plate is sufficiently long, so all the flow variables do not depend on vertical coordinate x
- The fluid is assumed to be grey emitting and absorbing radiation but not scattering medium
- The radiative heat flux in the x-direction is negligible
- The plate temperature and concentration is constant
- Applied magnetic field is uniform and the magnetic reynold number is small enough so that the induced magnetic field is neglected
- There is no applied voltage so that the applied electric filed is neglected
- Hall current and joule's dissipation effects are neglected.
- The suction velocity normal to the plate is constant
- Initially it is assumed that the plate and fluid are at the same temperature $\left(T_\infty\right)$ and concentration $\left(C_\infty\right)$ everywhere in the fluid.
- The level of the foreign mass is assumed to low so that soret and dufour effects are negligible
- All the thermo physical properties are constant except the density in the boundary terms of the linear momentum equation.

Under the above stated assumptions, the governing boundary layer equations of the problem are given by.

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

$$\left(1+\lambda\frac{\partial}{\partial t^*}\right)\frac{\partial u^*}{\partial t^*} + v\frac{\partial u^*}{\partial y^*} = g\beta\left(T-T_\infty\right) + g\beta^*\left(C-C_\infty\right) + \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} - \left(1+\lambda\frac{\partial}{\partial t^*}\right)\left(\frac{\vartheta}{K^*} + \frac{\sigma_e B_0^2}{\rho}\right)u^* \tag{2}$$

$$\left(1+\lambda\frac{\partial}{\partial t^*}\right)\frac{\partial T}{\partial t^*} + v\frac{\partial T}{\partial y^*} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^{*2}} + \frac{\vartheta}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{3}$$

$$\left(1+\lambda\frac{\partial}{\partial t^*}\right)\frac{\partial C}{\partial t^*} + v\frac{\partial C}{\partial y^*} = D\frac{\partial^2 C}{\partial y^{*2}} - K_1^*\left(C-C_\infty\right) \tag{4}$$

The equation (1) gives

$$V = V_0 \tag{5}$$

Where V_0 is the constant, the suction velocity normal to the plate.

The boundary conditions are

$$\left.\begin{array}{l}\text{For } t^* \le 0, u^* = 0, T = T_\infty, C = C_\infty, \qquad \forall\ y^* \\ \text{For } t^* > 0, u^* = V_0(1+\varepsilon e^{-n^* t^*}), T = T_w, C = C_w \quad \text{at } y^* = 0 \\ \text{For } t^* > 0, u^* \to 0, T \to T_\infty, C \to C_\infty \quad as\ \ y^* \to \infty \end{array}\right\} \tag{6}$$

By using the Rosseland approximation, the radiative heat flux q_r given by

$$q_r = \frac{-4\sigma^*}{3K^*}\frac{\partial T^4}{\partial y} \tag{7}$$

Where σ^* is the Stefan-Boltzmann constant and K^* is the mean absorption coefficient. It is should be noted that the present analysis is limited to optically thick fluids. Assuming that the differences in temperature with in flow are such that T^4 can be expressed as a linear combination of the temperature, we expand T^4 in a Taylor's series about T_∞ as follows.

$$T^4 = T_\infty^4 + 4T_\infty^3(T - T_\infty) + 6T_\infty^2(T - T_\infty)^2 + ...$$

And neglecting the higher order terms beyond the first degree in $(T - T_\infty)$, we get

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{8}$$

Form (7) and (8), we obtain

$$q_r = \frac{-4\sigma^*}{3K^*}\frac{\partial}{\partial y}\left(4T_\infty^3 T - 3T_\infty^4\right)$$

$$= \frac{-16\sigma^* T_\infty^3}{3K^*}\frac{\partial T}{\partial y}$$

$$\frac{\partial q_r}{\partial y} = \frac{-16\sigma^* T_\infty^3}{3K^*}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

In view of (5) and (9), the equation (2), (3) and (4) reduces to

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} - V_0\frac{\partial u}{\partial y} = g\beta(T - T_\infty) + g\beta^*(C - C_\infty) + \vartheta\frac{\partial^2 u}{\partial y^2} - \left(\frac{\vartheta}{K} + \frac{\sigma_e B_0^2}{\rho}\right)\left(1+\lambda\frac{\partial}{\partial t}\right)u \tag{10}$$

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial T}{\partial t} - V_0\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{\vartheta}{C_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{16\sigma^* T_\infty^3}{3\rho C_p K^*}\frac{\partial^2 T}{\partial y^2} \tag{11}$$

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial C}{\partial t} - V_0\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - K_1(C - C_\infty) \tag{12}$$

Introducing the following non-dimensional quantities

$$u = \frac{u^*}{V_0},\ y = \frac{y^* V_0}{\vartheta},\ t = \frac{t^* V_0^2}{\vartheta}, n = \frac{n^* v}{V_0^2}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty}$$

$$Gr = \frac{g\beta\vartheta(T_w - T_\infty)}{V_0^3}, Gm = \frac{g\beta\vartheta(C_w - C_\infty)}{V_0^3}, Kp = \frac{K^* V_0^2}{\vartheta^2}, \Pr = \frac{\mu C_p}{k}, Kr = \frac{K_1^*\vartheta}{V_0^2}$$

$$R = \frac{4\sigma^* T_\infty^3}{K^* K},\ M = \frac{\sigma\beta_0^2\vartheta}{\rho V_0^2}, Sc = \frac{\vartheta}{D},\ E = \frac{V_0^2}{C_p(T_w - T_\infty)}, \lambda_1 = \frac{V_0^2\lambda}{\vartheta} \tag{13}$$

In view of (13), the equation (10), (11) and (12) reduce to the following

$$\alpha_1\frac{\partial u}{\partial t} + \lambda_1\frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} + Gr\theta + Gm\phi - M_1 u \tag{14}$$

$$\Pr\frac{\partial\theta}{\partial t} + \Pr\lambda_1\frac{\partial^2\theta}{\partial t^2} = N_1\frac{\partial^2\theta}{\partial y^2} + \Pr\frac{\partial\theta}{\partial y} + \Pr E\left(\frac{\partial u}{\partial y}\right)^2 \tag{15}$$

$$Sc\frac{\partial\phi}{\partial t}+Sc\lambda_1\frac{\partial^2\phi}{\partial t^2}=\frac{\partial^2\phi}{\partial y^2}+Sc\frac{\partial\phi}{\partial y}-KrSc\phi \tag{16}$$

Where $M_1=M+\frac{1}{Kp}$, $\alpha_1=1+\lambda_1M_1$, $N_1=1+\frac{4R}{3}$

The corresponding boundary conditions reduce to

$$u=1+\varepsilon e^{-nt},\quad \theta=1,\quad \phi=1 \quad \text{at } y=0 \tag{17}$$

3. Solution Of The Problem:

The equation (14), (15) and (16) are coupled non-liner differential equation. We may represent the velocity (u), temperature (θ) and concentration (ϕ) of the fluid in power of $\varepsilon\,(\varepsilon<<1)$. Hence we can write

$$u=u_0(y)+\varepsilon u_1(y)e^{-nt}+......$$
$$\theta=\theta_0(y)+\varepsilon\theta_1(y)e^{-nt}+......$$
$$\phi=\phi_0(y)+\varepsilon\phi_1(y)e^{-nt}+...... \tag{18}$$

Substituting equations (18) into (14) to (17) and equating the like powers of ε, neglecting ε^2 and higher order terms, we obtain

$$u_0''+u_0'-M_1u_0=-Gr\theta_0-Gm\phi_0 \tag{19}$$
$$N_1\theta_0''+\Pr\theta_0'=-\Pr Eu_0'^2 \tag{20}$$
$$\phi_0''+Sc\phi_0'-KrSc\phi_0=0 \tag{21}$$
$$u_1''+u_1'-M_2u_1=-Gr\theta_1-Gm\phi_1 \tag{22}$$
$$N_1\theta_1''+\Pr\theta_1'+N_2\theta_1=-2\Pr Eu_0'u_1' \tag{23}$$
$$\phi_1''+Sc\phi_1'+L_1\phi_1=0 \tag{24}$$

Where prime denotes the differentiation with respect to y

The corresponding boundary conditions (17) are

$$u_0=1,u_1=1,\theta_0=1,\theta_1=0,\phi_0=1,\phi_1=0 \quad \text{at} \quad y=0$$
$$u_0\to0,u_1\to0,\theta_0\to0,\theta_1\to0,\phi_0\to0,\phi_1\to0 \quad \text{at} \quad y\to\infty \tag{25}$$

Where,

$$N_2=\mathrm{nP_r}(1-n\lambda_1)$$
$$M_2=-\alpha_1n+\lambda_1n^2+M_1$$
$$L_1=nSc-n^2Sc\lambda_1-KrSc$$

Solving the equation (21) and (24) under the corresponding boundary conditions (25), we obtain

$$\phi_0=e^{-a_1y} \tag{26}$$
$$\phi_1=0 \tag{27}$$

The equation (19), (21), (22) and (23) are still coupled non-linear equation, whose exact solutions are not possible. We may represent u_0,θ_0,u_1 and θ_1 in powers of Eckert number E which is very small. Hence we can write

$$u_0=u_{00}+Eu_{01}+....$$
$$\theta_0=\theta_{00}+E\theta_{01}+....$$
$$u_1=u_{10}+Eu_{11}+....$$
$$\theta_1=\theta_{10}+E\theta_{11}+.... \tag{28}$$

Substituting these equations into (19), (21), (22) equating the like power of E, neglecting E^2 and higher order terms, we obtain

$$u_{00}'' + u_{00}' - M_1 u_{00} = -Gr\theta_{00} - Gm\phi_0 \tag{29}$$

$$u_{01}'' + u_{01}' - M_1 u_{01} = -Gr\theta_{01} \tag{30}$$

$$N_1\theta_{00}'' + \Pr\theta_{00}' = 0 \tag{31}$$

$$N_1\theta_{01}'' + \Pr\theta_{01}' = -\Pr u_{00}'^{\,2} \tag{32}$$

$$N_1\theta_{10}'' + \Pr\theta_{10}' + N_2\theta_{10} = 0 \tag{33}$$

$$N_1\theta_{11}'' + \Pr\theta_{11}' + N_2\theta_{11} = -2\Pr u_{00}' u_{10}' \tag{34}$$

$$u_{10}'' + u_{10}' - M_2 u_{10} = -Gr\theta_{10} - Gm\phi_1 \tag{35}$$

$$u_{11}'' + u_{11}' - M_2 u_{11} = -Gr\theta_{11} \tag{36}$$

The corresponding boundary conditions are

$$\begin{aligned} & u_{00} = 1,\ u_{01} = 0,\ u_{10} = 1,\ u_{11} = 0 \\ & \theta_{00} = 1,\ \theta_{01} = 0,\ \theta_{10} = 0,\ \theta_{11} = 0 \quad \text{at} \quad y = 0 \\ & u_{00} \to 0,\ u_{01} \to 0,\ u_{10} \to 0,\ u_{11} \to 0 \\ & \theta_{00} \to 0,\ \theta_{01} \to 0,\ \theta_{10} \to 0,\ \theta_{11} \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{37}$$

In view of (37), solving equation (29) to (36), we obtain

$$\theta_{00} = e^{-b_1 y} \tag{38}$$

$$u_{00} = A_1 e^{-a_1 y} + B_1 e^{-b_1 y} + C_1 e^{-c_1 y} \tag{39}$$

$$\theta_{01} = D_1 e^{-b_1 y} - d_1 e^{-2a_1 y} - d_2 e^{-2b_1 y} - d_3 e^{-2c_1 y} - d_4 e^{-(a_1+b_1)y} - d_5 e^{-(b_1+c_1)y} - d_6 e^{-(c_1+a_1)y} \tag{40}$$

$$u_{01} = -A_2 e^{-c_1 y} + He^{-b_1 y} + H_1 e^{-2a_1 y} + H_2 e^{-2b_1 y} + H_3 e^{-2c_1 y} + H_4 e^{-(a_1+b_1)y} + H_5 e^{-(b_1+c_1)y} + H_6 e^{-(c_1+a_1)y} \tag{41}$$

$$\theta_{10} = 0 \tag{42}$$

$$u_{10} = e^{-a_2 y} \tag{43}$$

$$\theta_{11} = D_2 e^{-b_2 y} - F_1 e^{-(a_2+a_1)y} - F_2 e^{-(a_2+b_1)y} - F_3 e^{-(a_2+c_1)y} \tag{44}$$

$$u_{11} = Ie^{-b_2 y} + I_1 e^{-(a_2+a_1)y} + I_2 e^{-(a_2+b_1)y} + I_3 e^{-(a_2+c_1)y} + B_2 e^{-a_2 y} \tag{45}$$

In view of (38) to (45), (18), (26), (27) and (28), the velocity, temperature and concentration field are

$$u = \left(u_{00} + Eu_{01}\right) + \varepsilon\left(u_{10} + Eu_{11}\right)e^{-nt} \tag{46}$$

$$\theta = \left(\theta_{00} + E\theta_{01}\right) + \varepsilon\left(\theta_{10} + E\theta_{11}\right)e^{-nt} \tag{47}$$

$$\phi = \phi_0 + \varepsilon\phi_1 e^{-nt} \tag{48}$$

From the velocity field we now study the Skin friction it is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} =$$

$$\left[\begin{array}{l} \left(-A_1 a_1 - B_1 b_1 - C_1 c_1\right) + E\left(c_1 A_2 - b_1 H - 2a_1 H_1 - 2b_1 H_2 - 2c_1 H_3 - H_4\left(a_1 + b_1\right) - H_5\left(b_1 + c_1\right) - H_6\left(c_1 + a_1\right)\right) \\ +\varepsilon e^{-nt}\left(-a_2 + E\left(-b_2 I - I_1\left(a_1 + a_2\right) - I_2\left(a_2 + b_1\right) - I_3\left(c_1 + a_2\right) - B_2 a_2\right)\right) \end{array}\right] \tag{49}$$

The rate of heat transfer is given by

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

$$= -\begin{bmatrix} -b_1 + E\left(-D_1 b_1 + 2a_1 d_1 + 2b_1 d_2 + 2c_1 d_3 + d_4\left(a_1 + b_1\right) + d_5\left(b_1 + c_1\right) + d_6\left(c_1 + a_1\right)\right) \\ +\varepsilon e^{-nt}\left(E\left(-D_2 b_2 + F_1\left(a_1 + a_2\right) + F_2\left(a_2 + b_1\right) + F_3\left(c_1 + a_2\right)\right)\right) \end{bmatrix} \tag{50}$$

The rate of Mass transfer is given by

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = a_1 \tag{51}$$

Graphs:

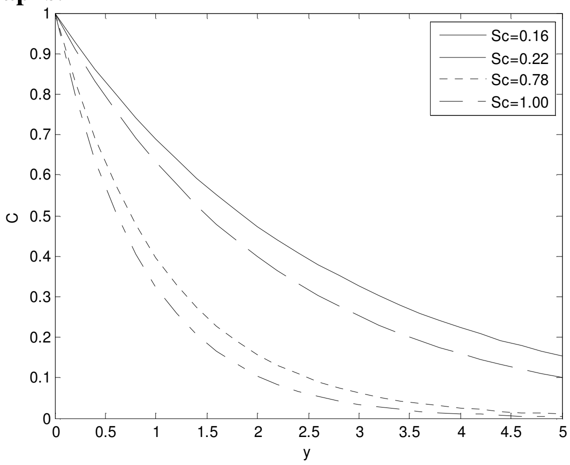

Fig.1. Concentration profiles against spanwise coordinate y for different values of Schmidt number Sc with $Kr = 0.5, \varepsilon = 0.2, t = 1.0, n = 0.2$.

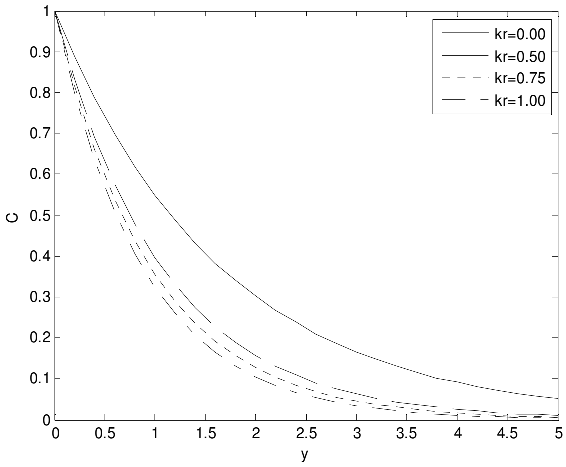

Fig.2 Concentration profiles against spanwise co-ordinate y for different Chemical reaction parameter Kr with $Sc = 0.5, \varepsilon = 0.2, t = 1.0, n = 0.2, Kr = 1.0$

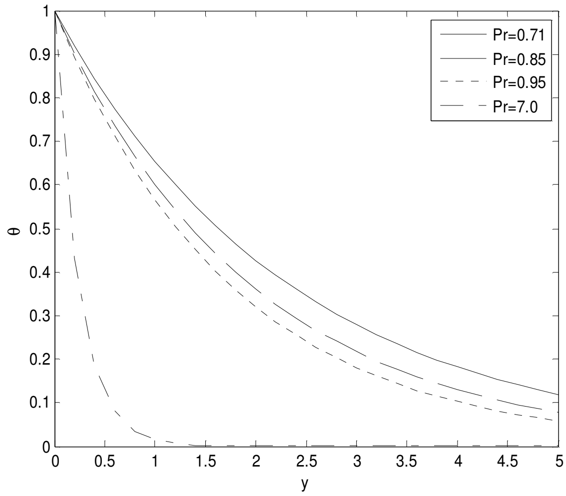

Fig.3 Temperature profiles against span wise co-ordinate y for different Prandtl number $\Pr$ with $Sc = 0.60, Kr = 1.0, Kp = 0.5, n = 0.2, M = 1.0, \Pr = 7, \varepsilon = 0.2, R = 0.5, \lambda_1 = 1,$ $Gr = 4, Gm = 2.0, E = 0.002, t = 1.0$

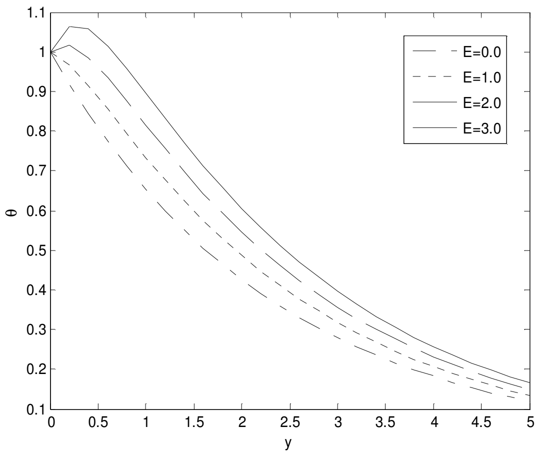

Fig.4 Temperature profiles against span wise co-ordinate y for different values of Eckert number E with $Sc = 0.60, Kr = 1.0, Kp = 0.5, n = 0.2, M = 2.0, \Pr = 0.71, \varepsilon = 0.2, R = 0.5, \lambda_1 = 1, Gr = 1,$ $Gm = 2.0, E = 3, t = 1.0$

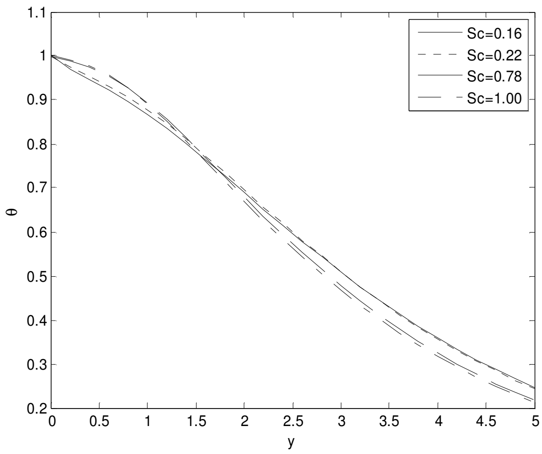

Fig.5 Temperature profiles against span wise co-ordinate y for different values of Schmidt number Sc with $Sc = 1.0, Kr = 0.3, Kp = 0.5, n = 0.2, M = 2.0, \Pr = 0.71, \varepsilon = 0.2, R = 0.5, \lambda_1 = 1,$ $Gr = 4, Gm = 2.0, E = 3, t = 1.0$

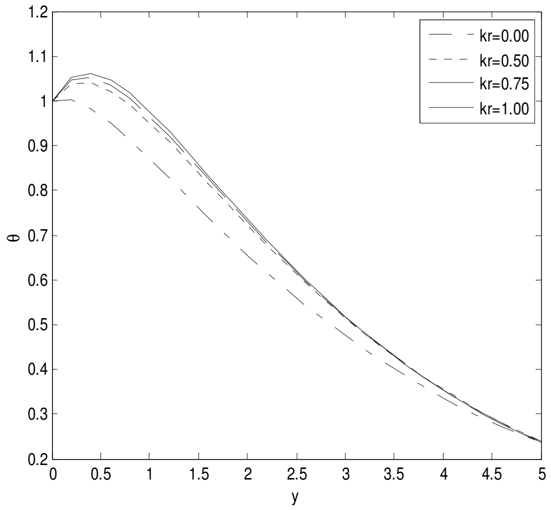

Fig.6 Temperature profiles for different values of Chemical reaction parameter Kr with $Sc=0.16, Kp=0.5, n=0.2, M=2.0, \Pr=0.71, \varepsilon=0.2, R=0.5, \lambda_1=2,$
$Gr=2.0, Gm=2, E=5, t=1.0$

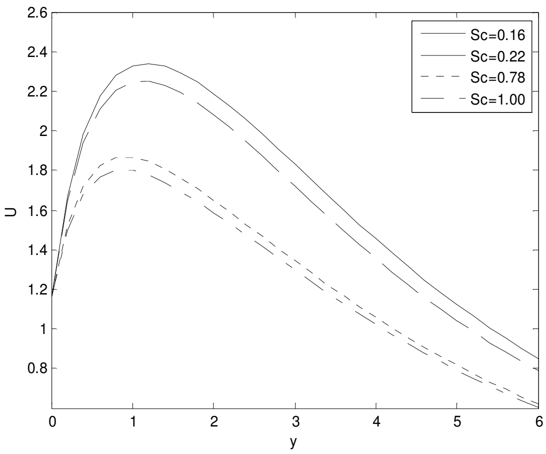

Fig.7 Velocity profiles against spanwise co-ordinate y for different Schmidt number Sc with $Sc=1.0, Kr=1.0, Kp=10, n=0.2, M=2, \Pr=0.71, \varepsilon=0.2, R=1, \lambda_1=2.0,$
$Gr=4, Gm=2, E=3, t=1$

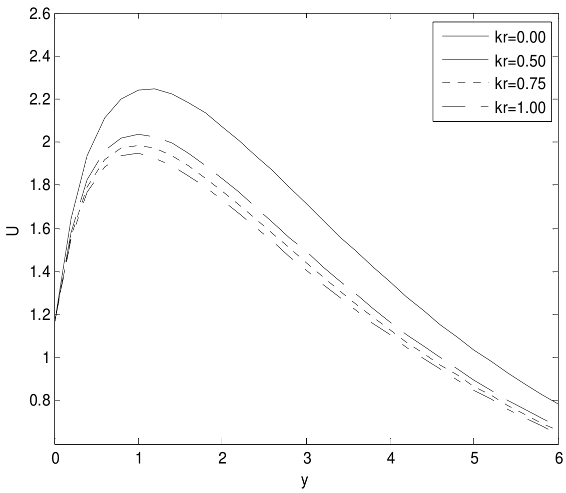

Fig.8 Velocity profiles against spanwise co-ordinate y for different Schmidt number with Kr with

$Sc = 0.60, Kr = 1.0, Kp = 10, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 1, \lambda_1 = 2.0,$
$Gr = 4, Gm = 2, E = 3, t = 1$

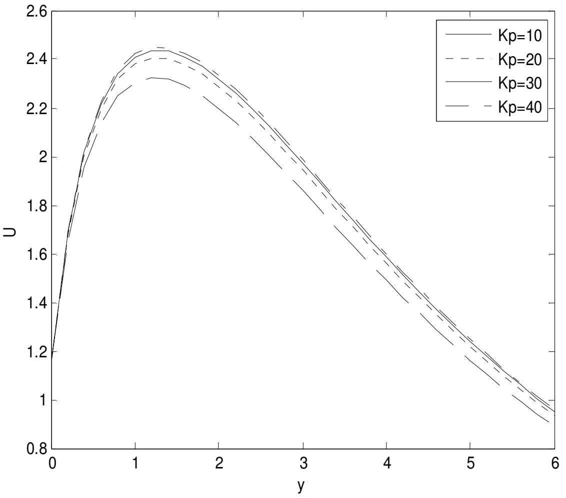

Fig.9 Velocity profiles against spanwise co-ordinate y for different Permeability parameter Kp with
$Sc = 0.60, Kr = 1.0, Kp = 40, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 1, \lambda_1 = 2.0,$
$Gr = 4, Gm = 2, E = 5, t = 1$

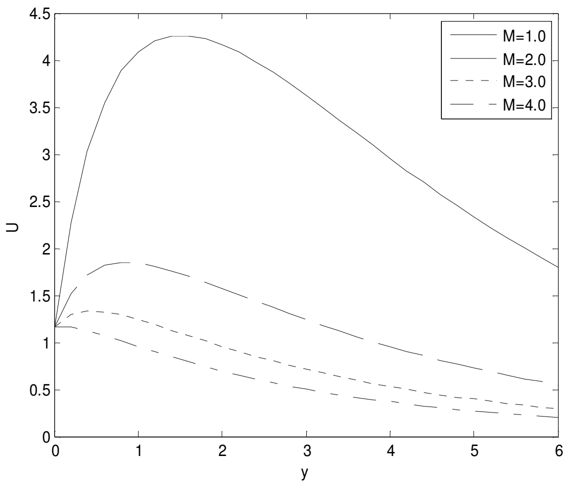

Fig.10 Velocity profiles against spanwise co-ordinate y for different Values of Magnetic parameter M with
$Sc = 0.60, Kr = 0.5, Kp = 10, n = 0.2, M = 4, \Pr = 0.71, \varepsilon = 0.2, R = 1, \lambda_1 = 2.0,$
$Gr = 4, Gm = 2, E = 2, t = 1$

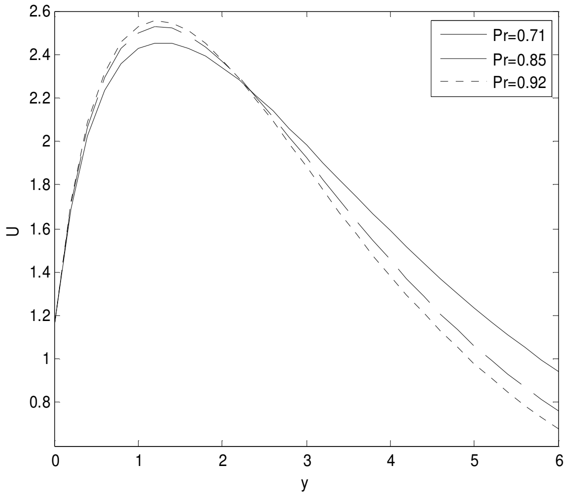

Fig.11 Velocity profiles against spanwise co-ordinate y for different Values of Prandtl number $\Pr$ with $Sc = 0.60, Kr = 0.5, Kp = 10, n = 0.2, M = 2, \Pr = 0.92, \varepsilon = 0.2, R = 1, \lambda_1 = 2.0,$
$Gr = 4, Gm = 2, E = 2, t = 1$

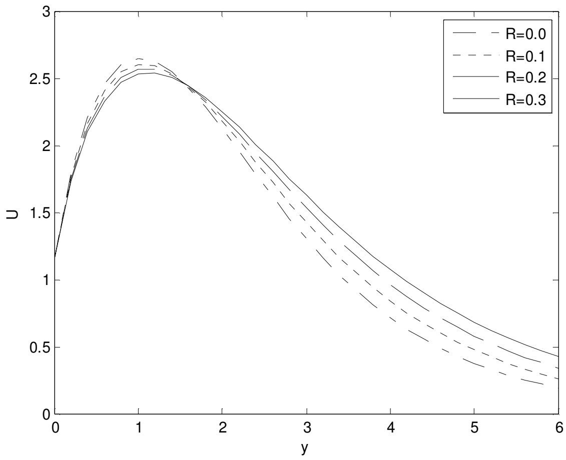

Fig.12 Velocity profiles against spanwise co-ordinate y for different Values of Radiation parameter $\Pr$ with $Sc = 0.60, Kr = 1.0, Kp = 10, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 0.3, \lambda_1 = 2.0,$
$Gr = 4, Gm = 2, E = 5, t = 1$

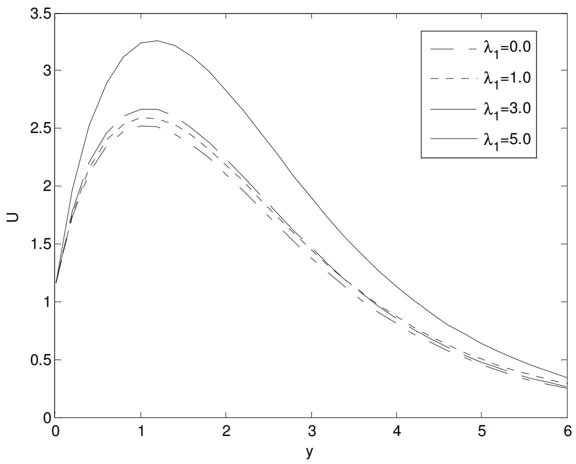

Fig.13 Velocity profiles against spanwise co-ordinate y for different Values of λ_1

$Sc = 0.60, Kr = 1.0, Kp = 10, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 0.1, \lambda_1 = 5.0,$
$Gr = 4, Gm = 2, E = 5, t = 1$

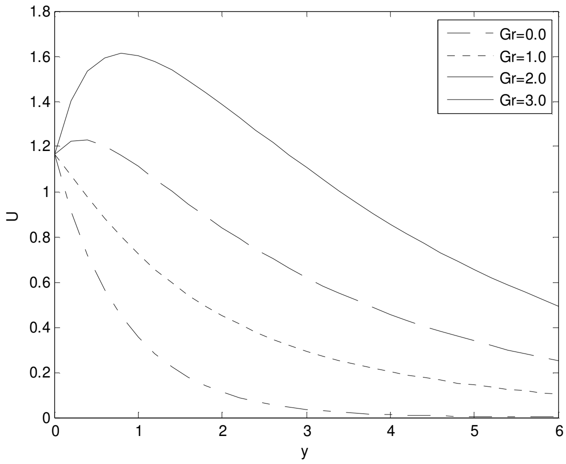

Fig.14 Velocity profiles against spanwise co-ordinate y for different Values of Thermal Grashof number Gr with
$Sc = 0.60, Kr = 1.0, Kp = 10, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 1, \lambda_1 = 1.0,$
$Gr = 3, Gm = 2, E = 5, t = 1$

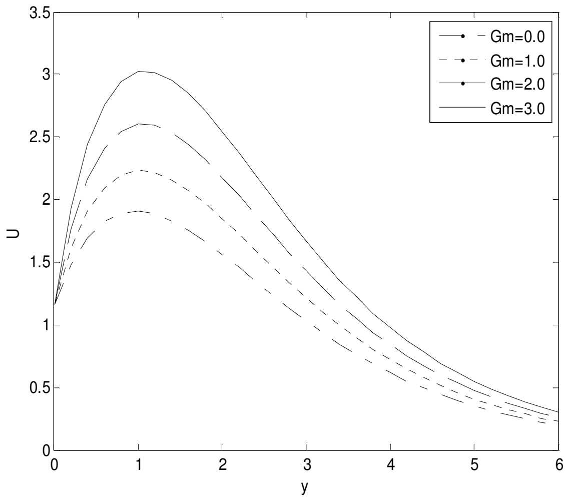

Fig.15 Velocity profiles against spanwise co-ordinate y for different Values of Solutal Grashof number Gm with
$Sc = 0.60, Kr = 1.0, Kp = 10, n = 0.2, M = 2, \Pr = 0.71, \varepsilon = 0.2, R = 0.1, \lambda_1 = 2.0,$
$Gr = 4, Gm = 3, E = 5, t = 1$

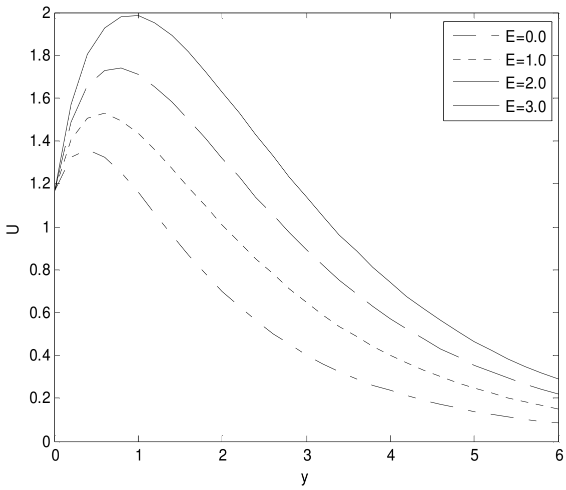

Fig.16 Velocity profiles against spanwise co-ordinate y for different Values of Eckert number E .
$Sc=0.60, Kr=1.0, Kp=10, n=0.2, M=2, \Pr=0.71, \varepsilon=0.2, R=0.1, \lambda_1=2.0,$
$Gr=4, Gm=3, E=5, t=1$

4. Results and Discussion:

The concentration profiles for different dimension less fluid flow parameters like Sc or Kr are depicted in fig.1-2. From fig.1 it is clear that at first the concentration decreases fastly with the high values of Sc , the effects of chemical reaction parameter on concentration are depicted in fig.2 from this figure it is noticed that the concentration decreases with Kr and reaches the stream condition.

The dimension less temperature profiles for various fluid flow parameters like Pr , E , Sc , Kr , t or K_p are shown in fig.3-6. Fig.3 depicts the temperature profiles for various values of Pr , it is observed that at first the temperature decreases slowly then after that it decreases rapidly for higher values of Pr .The influence of the fluid flow parameter E and Kr , on the temperature are also investigated and presented in fig.4 and fig.6 from this figures it is clear that the temperature increases with E and Kr .Fig.5 illustrate the effect of Sc on the distributions of temperature, it is seen that the temperature increases near the plate it decreases far away from the plate.

The dimensionless velocity profiles different fluid flow parameters are plotted in fig.7-16.The velocity profiles for different values of Sc for different fluids like 0.22 (Hydrogen) and 1.00 (Methanol) shown in fig.7 from this figure it is clear that the velocity decreases slowly it decreases fastly with Sc .The effects of Kr on the dimensionless velocity profiles are shown in fig.8, we see that the velocity increases uniformly with the increase of Kr upto a value about 0.75,but when Kr gets large exceeding 0.75, velocity is increase rapidly.

The effect of Kp on the velocity are depicted in fig.9, from this figure we observe that as we increase the, the velocity is increases. Fig.10 displays the effect of magnetic field on the velocity, it is clear that the velocity decreases very rapidly with increasing M while it decreases slowly with M , also it is noticed the velocity decreases near the wall and reaches the free stream condition.In fig.11 we have plotted the dimensionless velocity profiles showing effect of Pr . It can be seen that near the plate the velocity is increases while it decreases far away the plate, that is opposite phenomena is observed nearly at $y \geq 2.3$, also maximum velocity is obtained. Fig.12 shows transient velocity field due to variation in R , it is observed that the velocity decreases near the plate and increases far away from the plate and reaches the free stream condition.

In fig.13 the velocity profiles are viewed for different values of λ_1, in this case the velocity increases uniformly upto $\lambda_1=3.0$ then it increases suddenly with maximum value.In fig.14 illustrate the behavior of the profiles for different values of Gr , it is apparent from the figure that the increasing values of Gr enhance the velocity. The dimension less velocity profiles for different values of Gm are shown in fig.15 from this figure it is clear that the velocity increases with Gm and reaches the free stream condition. Fig.16 represents the variation in the velocity field for various of E, it is observed that an increase in E increase the velocity field . It is also observed that the velocity field increases rapidly in the presence of E.

Appendix:

$$a_1=\frac{\left[Sc+\sqrt{Sc^2+4KrSc}\right]}{2},b_1=\frac{\Pr}{N_1},C_1=\frac{\left[1+\sqrt{1+4M_1}\right]}{2},A_1=\frac{-Gm}{a_1^2-a_1-M_1}$$

$$B_1=\frac{-Gr}{b_1^2-b_1-M_1},C_1=1-A_1-B_1,d_1=\frac{\Pr a_1^2A_1^2}{4N_1a_1^2-2a_1\Pr},d_2=\frac{\Pr b_1^2B_1^2}{4N_1b_1^2-2b_1\Pr}$$

$$d_3=\frac{\Pr c_1^2C_1^2}{4N_1c_1^2-2c_1\Pr},d_4=\frac{2\Pr a_1b_1A_1B_1}{(a_1+b_1)^2_{N_1}-\Pr(a_1+b_1)},d_5=\frac{2\Pr b_1c_1B_1C_1}{(b_1+c_1)^2N_1-\Pr(b_1+c_1)}$$

$$d_6=\frac{2\Pr c_1a_1C_1A_1}{(c_1+a_1)^2N_1-\Pr(c_1+a_1)},D_1=d_1+d_2+d_3+d_4+d_5+d_6$$

$$H=\frac{-GrD_1}{b_1^2-b_1-M_1},H_1=\frac{Grd_1}{4a_1^2-2a_1-M_1},H_2=\frac{Grd_2}{4b_1^2-2b_1-M_1},H_3=\frac{Grd_3}{4c_1^2-2c_1-M_1}$$

$$H_4=\frac{Grd_4}{(a_1+b_1)^2-(a_1+b_1)-M_1},H_5=\frac{Grd_5}{(b_1+c_1)^2-(b_1+c_1)-M_1},$$

$$H_6=\frac{Grd_6}{(c_1+a_1)^2-(c_1+a_1)-M_1}$$

$$A_2=(H+H_1+H_2+H_3+H_4+H_5+H_6),a_2=\frac{\left[1+\sqrt{1+4M_2}\right]}{2},$$

$$b_2=\frac{\left[\Pr+\sqrt{\Pr^2-4N_1N_2}\right]}{2}$$

$$F_1=\frac{2\Pr a_1a_2A_1}{(a_1+a_2)^2N_1-\Pr(a_1+a_2)+N_2},F_2=\frac{2\Pr b_1a_2B_1}{(b_1+a_2)^2N_1-\Pr(b_1+a_2)+N_2},$$

$$F_3=\frac{2\Pr c_1a_2C_1}{(c_1+a_2)^2N_1-\Pr(c_1+a_2)+N_2}$$

$$D_2=(F_1+F_2+F_3),I=\frac{-GrD_2}{b_2^2-b_2-M_2},I_1=\frac{GrF_1}{(a_1+a_2)^2-(a_1+a_2)-M_2},$$

$$I_2=\frac{GrF_2}{(a_2+b_1)^2-(a_2+b_1)-M_2}$$

$$I_3=\frac{GrF_3}{(a_2+c_1)^2-(a_2+c_1)-M_2},B_2=-(I+I_1+I_2+I_3)$$

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