RADIATION AND CHEMICAL REACTION EFFECTS ON CONVECTIVE RIVLIN-ERICKSEN FLOW PAST A POROUS VERTICAL PLATE.

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(Received: 7th April, 2016; Accepted: 1st Oct., 2016)

ABSTRACT

In this study, the influences of radiation and chemical reaction on unsteady, two-dimensional, laminar, boundary-layer free convective Rivlin-Ericksen flow of incompressible and electrically conducting fluids past a porous vertical plate with a periodic suction are discussed. The dimensionless governing equations of the flow field comprising of continuity, momentum, energy and species equations are solved analytically using two-term harmonic and non-harmonic functions. The effects of various parameters on velocity, temperature and concentration fields are presented graphically and discussed. It is detected that velocity and temperature decreases with increase in radiation parameter.

Keywords: Rivlin-Ericksen Fluid, Unsteady, Porous Medium, Chemical Reaction, Free Convective

INTRODUCTION

An elastic material strains when stretched and quickly returns to its original state when load is removed. While a viscous fluid, for example custard, resists shear flow and strain linearly with time when a load is applied. However, viscoelastic materials under deformation exhibit both viscous and elastic features and, as such, display time-depentent strain.

However, Rivlin-Ericksen fluid is a type of viscoelastic fluid, non-newtonian models, a theoretical model proposed by Rivlin-Ericksen (1955). In a non-Newtonian fluid the relation between the shear stress and the shear rate is non-linear and can even be time-dependent. Many salt solutions and molten polymers, as well as, some commonly found substance such as custard, toothpaste, starch suspensions, paint, honey, blood and shampoo are non-Newtonian fluids (Rao, 2007).

Convective heat transfer is the transfer of heat from one place to another as a result of the fluid motion. It can simply be referred to as convection. In liquids and gases, major form of heat transfer is convection. It can also be produced by movement of a fluid by means other than buoyancy forces. Natural buoyancy forces alone are entirely responsible for fluid motion when the fluid is heated. The study of convective fluid flow with mass transfer past a porous vertical plate has received attention due to its importance.

The study of Rivlin-Ericksen fluid has become increasingly important due to its useful applications in several branches of science, petroleum industry, food and paper industry and similar activities. The importance of this type of fluid arose the interest of some researchers. Ravikumar *et al.* (2014) considered combined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi infinite vertical porous plate with variable temperature and suction, and reported that as the dimensionless viscoelasticity parameter and heat absorption coefficient increase, the velocity decreases. However, radiation and chemical reaction influences were not considered. Das *et al.* (2005) discussed the laminar flow of a viscoelastic Rivlin-Ericksen fluid through porous parallel plates with suction and injection, the lower plate being stretched. Uwanta and Hussaini (2012) considered effects of mass transfer on Hydromagnetic free convective Rivlin-Ericksen flow through a porous medium with time dependent suction. They considered optically thin gray gas approximation in their study. Gbadeyan and Dada (2013) discussed on the influence of radiation and heat transfer on an unsteady MHD non-Newtonian fluid flow with slip in a porous medium. Stratified Rivlin-Ericksen fluid effects on MHD free convective flow with heat and mass transfer past a vertical porous plate was studied by Dharmendra and Varshney (2012) and it was observed that velocity increased with an increase in visco-elastic parameter up to y=2, then decreased. Varshney et al. (2013) investigated the effects of Rotatory Rivlin-Ericksen fluid on MHD free convection and mass transfer flow through porous medium with constant heat and mass flux across moving plate. They concluded that primary velocity decreases with the increase in rotation velocity parameter, while secondary velocity decreases.Lakshmi and Gomathi (2012) considered a study on flow of Rivlin-Ericksen fluid past a porous vertical wall with constant suction. It was observed that velocity decreases as suction parameter increases. The above investigations did not take into consideration the effects of some useful parameters onfluid flow like radiation, heat absorption, chemical reaction and pressure gradient. Sreekanth *et al*. (2011) studied the hydromagnetic unsteady Hele-shaw flow of a viscoelastic Rivlin-Ericken fluid through porous media and discovered from their findings that velocity decreases with the increase in visco-elastic parameter. Reddy *et al.*(2013) considered MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction. It is found that skin friction coefficient decreases with chemical reaction parameter. Nayak and Dash (2014) studied the effect of chemical reaction on MHD flow of a visco-elastic fluid through porous medium, but did not consider effects of heat absorption and radiation. Chemical reaction and dissipation effects on MHD unsteady free convective walter's memory flow with constant suction and heat sink were investigated by Vijaya and Viswanadh (2012).

In all the studies discussed above, the combined effects of radiation and chemical reaction with pressure gradient on heat and mass transfer of convective Rivlin-Ericksen fluid flow were neglected. These combined effects as far as industrial applications are concerned, cannot be over emphasized. Also, radiation effect could not be ignored in glass production and furnace design and in space technology applications such as plasma physics and spacecraft which operate at higher temperatures. In view of its importance, therefore, this research is concerned with the effects of radiation, heat and mass transfer on free convective Rivlin-Ericksen flow past a vertical plate.

NOMENCLATURE:

x^*-dimensional distance along the plate
y^*- dimensional distance perpendicular to the plate
t^*-dimensional time
u^*-component of dimensional velocity along x^* direction
υ^*-component of dimensional velocity along y^* direction
ρ^*- fluid density
ν^*-kinematic viscosity
C_p-specific heat at constant pressure
σ-fluid electrical conductivity (Stefan-Boltzman constant)
B_0-magnetic induction
k^*-permeability of the porous medium
T^*-dimensional temperature
C^*-dimensional concentration
D-chemical molecular diffusivity
Q_0-dimensional heat absorption coefficient
α-thermal diffusivity
g-gravitational acceleration
β_T, β_C-thermal, concentration expansion coefficient
β_1-kinematic viscoelasticity
u_p^* -wall dimensional velocity
T_w^* -wall dimensional temperature
C_w^* -wall dimensional concentration
U_∞^* -free stream dimensional velocity
T_∞^* -free stream dimensional temperature
C_∞^*-free stream dimensional concentration
U_0, $n^*$are constants.
N-radiation parameter
k-permeability of the porous medium
k_r-chemical reaction parameter
M-magnetic parameter
Pr-Prandtl number
Sc-Schmidt number
Gr, Gc-Grashof number for heat transfer and Grashof number for mass transfer
Q-dimensionless heat absorption coefficient
Rm-dimensionless viscoelasticity parameter of the Rivlin-Ericksen fluid
$\in$-scalar constant
A-suction velocity parameter.
k^1-mean absorption coefficient
V_0-scale of suction velocity contain non-zero positive constant

PROBLEM FORMULATION

An unsteady two-dimensional free convective Rivlin-Ericksen flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical plate in the presence of periodicsuction and transverse magnetic field is considered. Let u and v be the velocity components along x-direction and y-direction respectively. All the physical variables are function of y and t only. The uniform magnetic field is applied y-direction perpendicular to the plate (See Fig.1a). The magnetic Reynolds number and transversely applied magnetic field are assumed to be very small. Therefore, the induced magnetic field and the Hall effects are neglected. The concentration of the diffusing species is assumed to be very low in comparison with other chemical species present; hence Soret and Dufour effects are negligible. The pressure in the flow field is assumed to be constant. With these assumptions, the equations governing the flow are given as:

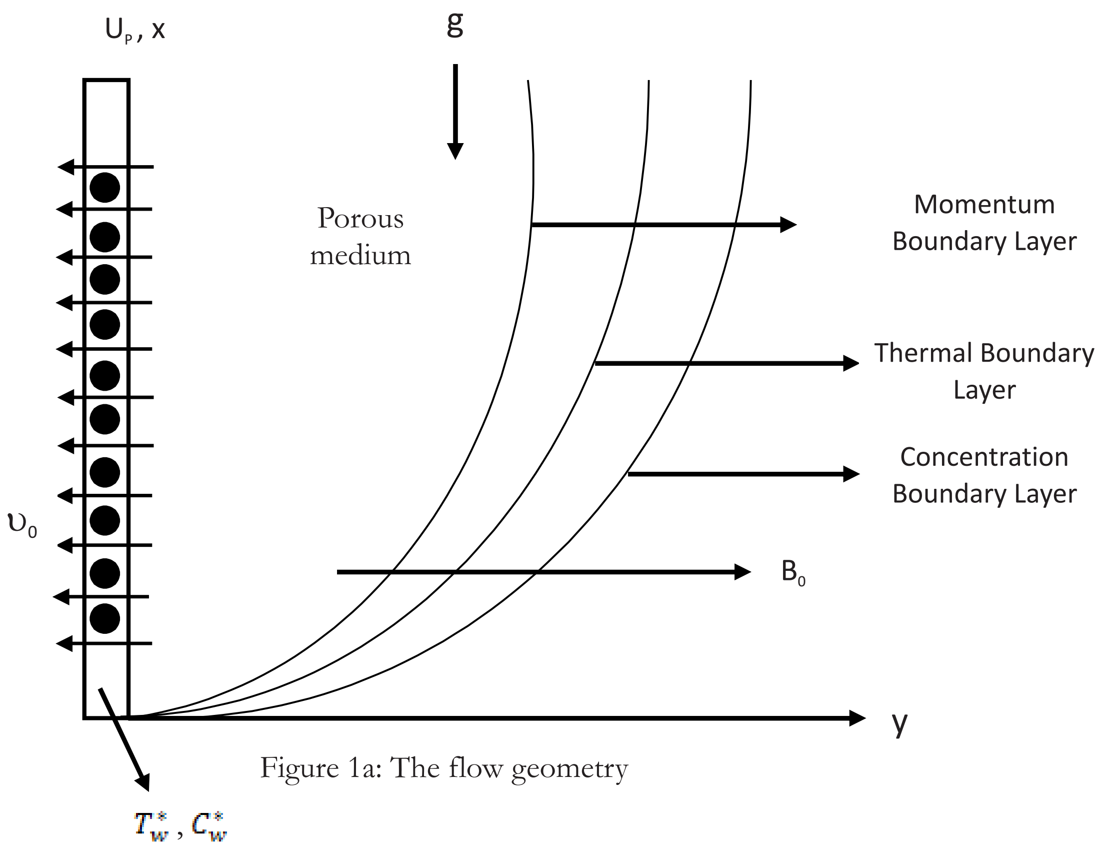


Figure 1a: The flow geometry

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \nu\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T(T^* - T_\infty^*) + g\beta_C(C^* - C_\infty^*) - \nu\frac{u^*}{k^*} - \frac{\sigma B_0^2 u^*}{\rho} - \beta_1\left(\frac{\partial^3 u^*}{\partial t^*\partial y^{*2}} + v^*\frac{\partial^3 u^*}{\partial y^{*3}}\right) \qquad (2)$$

Energy equation:

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \propto \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T^* - T_\infty^*) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} \qquad (3)$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*} + v^*\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - k_r^*(C^* - C_\infty^*) \qquad (4)$$

The boundary condition of the problem are:

$$u^* = u_p^*, T^* = T_w^* + \epsilon\,(T_w^* - T_\infty^*)e^{n^* t^*},$$

$$C^* = C_w^* + \epsilon\,(C_w^* - C_\infty^*)e^{n^* t^*} \text{ at } y^* = 0$$

$u^* \to u^*_\infty = U_0\left(1 + \epsilon A\, e^{n^* t^*}\right). \ T^* \to T^*_\infty,$

$C^* \to C^*_\infty$ as $y^* \to \infty$ (5)

The suction velocity at the plate is obtained (Das *et al.* (2011)) in exponential form as: $v^* = -V_0^*\left(1 + \epsilon A\, e^{n^* t^*}\right)$, where ∈ and ∈A are small numbers less than unity. Following Rosseland approximation (Brewstar (1972)) the radiative heat flux q_r is modeled as:

$$q_r = \frac{4\sigma}{3k^1}\frac{\partial T^{*4}}{\partial y^*}.$$

It should be noted that by using the Rosseland approximation the present analysis is limited to optically thick fluid. The quartic temperature function T^{*4} can be expanded in Taylor series and neglecting higher order terms if the temperature differences within the flow are sufficiently small. Then

$$T^{*4} \approx 4T^{*3}_\infty T^* - 3T^{*4}_\infty,$$

Which is substituted into energy equation {3}. Outside the boundary layer, equation {2} becomes:

$$-\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} = \frac{dU^*_\infty}{dt^*} + \frac{\nu}{k^*}U_\infty + \frac{\sigma}{\rho}B_0^2 U^*_\infty$$

(Ravikumar (2014))

The following non-dimensional variables are used to reduce the governing equations to non-dimensional form.

$$u = \frac{u^*}{U_o},\ \ v = \frac{v^*}{V_0},\ y = \frac{V_o y^*}{\nu},U_\infty = \frac{U^*_\infty}{U_0}, u_p = \frac{u^*_p}{U_0},$$

$$t = \frac{t^* V_0^2}{\nu}, \theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty}, n = \frac{n^* \nu}{V_0^2}, k = \frac{k^* V_0^*}{\nu^2},$$

$$Pr = \frac{\nu\rho C_p}{k} = \frac{\nu}{\alpha}, M = \frac{\sigma B_0^2 \nu}{\rho V_0^2}, Gr = \frac{\nu g\beta_T (T^*_w - T^*_\infty)}{U_0 V_0^2},$$

$$Q = \frac{\nu Q_0}{\rho C_p V_0^2}, Rm = \frac{\beta_0 V_0^2}{\nu^2}, w^* = \frac{4\nu w}{V_0^2},$$

$$Gc = \frac{\nu g\beta_C (C^*_w - C^*_\infty)}{U_0 V_0^2}, C = \frac{C^* - C^*_\infty}{C^*_w - C^*_\infty}, Sc = \frac{\nu}{D},$$

$$N = \frac{k^1 k}{4\sigma T^{*3}_\infty}$$

Substituting the non-dimensional variables into equations (2)-(5) and the suction velocity, we have the following non-dimensional governing equations:

Momentum Equation:

$$\frac{\partial u}{\partial t} - \left(1 + \epsilon A\, e^{nt}\right)\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} +$$

$$Gr\theta + GcC + F(U_\infty - u) -$$

$$Rm\left(\frac{\partial^3 u}{\partial t \partial y^2} - \left(1 + \epsilon A\, e^{nt}\right)\frac{\partial^3 u}{\partial y^3}\right) \quad (6)$$

Energy equation:

$$\frac{\partial \theta}{\partial t} - \left(1 + \epsilon A\, e^{nt}\right)\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - Q\theta + \frac{4}{3NPr}\frac{\partial^2 \theta}{\partial y^2} \quad (7)$$

Concentration equation:

$$\frac{\partial C}{\partial t} - \left(1 + \epsilon A\, e^{nt}\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - k_r C \quad (8)$$

where $F = M + \frac{1}{k}$

The dimensionless form of the boundary conditions become

$u = U_p \ \ \theta = 1 + \epsilon e^{nt}, U = 1 + \epsilon e^{nt},$

$C = 1 + \epsilon e^{nt}$ at $y = 0$

$u \to U_\infty, \ \theta \to 0, \to 0$ as $y \to \infty$

3. Solution of the problem

Perturbation technique is used to solve equations (6)-(8). This is to reduce the partial differential equations to ordinary differential equations. Using two-term harmonic and non-harmonic functions, the resulting equations are solved analytically.

However, to reduce the governing equations to a set of ordinary differential equations, we introduce

$$u(y,t) = u_0(y) + \epsilon e^{nt}u_1(y) + 0(\epsilon^2) + \cdots \quad (9)$$

$$\theta(y,t) = \theta_0(y) + \epsilon e^{nt}\theta_1(y) + 0(\epsilon^2) + \cdots \quad (10)$$

$$C(y,t) = C_0(y) + \epsilon e^{nt}C_1(y) + 0(\epsilon^2) + \cdots \quad (11)$$

Substituting equations (9)-(11) into equation (6)-(8), we have the following set of equations:

$$Rmu_0''' + u_0'' + u_0' - Fu_0 = -Gr\theta_0 - GcC_0 - F \quad (12)$$

$$Rmu_1''' + (1 - nRm)u_1'' + u_1' - (n+F)u_1$$
$$= -n - Gr\theta_1 - GcC_1 - F - RmAu_0''' - Au_0' \quad (13)$$

$$B\theta_0'' + \theta_0' - Q\theta_0 = 0 \quad (14)$$

$$B\theta_1'' + \theta_1' - (n+Q)\theta_1 = -A\theta_0' \quad (15)$$

$$C_0'' + ScC_0' - SckrC_0 = 0 \quad (16)$$

$$C_1'' + ScC_1' - Sc(n+kr)C_1 = -ScAC_0', \quad (17)$$

where $B = \dfrac{1}{Pr} + \dfrac{4}{3NPr} = \dfrac{1}{Pr} + h,$

with the corresponding boundary conditions:

$$u_0 = u_p,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1,\ C_0 = 1,$$
$$C_1 = 1, \text{ at } y = 0 \quad (18)$$

$$u_0 = 1,\ u_1 = 1,\ \theta_0 \to 0,\ C_0 \to 0,\ C_1 \to 0,$$
$$\text{as } y = \infty \quad (19)$$

Equations (14)-(17) are solved analytically; the following are the results:

$$\theta_0 = e^{-m_1 y} \quad (20)$$

$$\theta_1 = h_3 e^{-m_3 y} + g_1 e^{-m_1 y} \quad (21)$$

$$C_0 = e^{-m_5 y} \quad (22)$$

$$C_1 = h_7 e^{-m_7 y} + g_2 e^{-m_5 y} \quad (23)$$

Equation (12) and (13) are third order differential equations with two boundary conditions. In order to make up for sufficient boundary conditions; we introduce, (Beard and walters (1964))

$$u_0 = u_{01} + Rmu_{02} + 0(Rm^2) \quad (24)$$

$$u_1 = u_{11} + Rmu_{12} + 0(Rm^2) \quad (25)$$

Substituting equations (24) and (25) into equations (12) and (13), equating different powers of *Rm* and neglecting O (Rm^2). We have the following set of equations:

$$u_{01}'' + u_{01}' - Fu_{01} = -Gre^{-m_1 y} - Gce^{-m_5 y} - F \quad (26)$$

$$u_{02}'' + u_{02}' - Fu_{02} = -u_{01}''' \quad (27)$$

$$u_{11}'' + u_{11}' - (n+F)u_{11} = -n - (h_3 e^{-m_3 y} + g_1 e^{-m_1 y})$$
$$-Gc(h_7 e^{-m_7 y} + g_2 e^{-m_5 y}) - F - Au_{01}' \quad (28)$$

$$u_{12}'' + u_{12}' - (n+F)u_{12} = nu_{11}'' - u_{11}''' - Au_{02}' - Au_{01}''' \quad (29)$$

The corresponding boundary conditions are:

$$u_{01} = u_p,\ u_{02} = 0,\ u_{11} = 0\ ,\ u_{12} = 0, \text{ at } y = 0 \quad (30)$$

$$u_{01} = 1,\ u_{02} = 0,\ u_{11} = 1,\ u_{12} = 0, \text{ as } y = \infty \quad (31)$$

Solutions to equation (26)-(29) are as follow;

$$u_{01} = h_9 e^{-m_9 y} + g_3 e^{-m_1 y} + g_4 e^{-m_5 y} + 1 \quad (32)$$

$$u_{02} = h_{11} e^{-m_{11} y} + g_5 e^{-m_9 y} + g_6 e^{-m_1 y} + g_7 e^{-m_5 y} \quad (33)$$

$$u_{11} = h_{13} e^{-m_{13} y} + g_8 e^{-m_3 y} + g_{10} e^{-m_7 y} +$$
$$g_{13} e^{-m_9 y} + g_{16} e^{-m_1 y} + g_{17} e^{-m_5 y} + g_{18} \quad (34)$$

$$u_{12} = h_{15} e^{-m_{15} y} + g_{19} e^{-m_{13} y} + g_{20} e^{-m_3 y} +$$
$$g_{21} e^{-m_7 y} + g_{22} e^{-m_9 y} + g_{23} e^{-m_1 y} +$$
$$g_{24} e^{-m_5 y} + g_{25} e^{-m_{11} y} \quad (35)$$

However, velocity, temperature and concentration distributions in the boundary layer become:

$$u(y,t) = h_9 e^{-m_9 y} + g_3 e^{-m_1 y} + g_4 e^{-m_5 y} + 1$$
$$+ Rm(h_{11} e^{-m_{11} y} + g_5 e^{-m_9 y} + g_6 e^{-m_1 y} + g_7 e^{-m_5 y})$$
$$+ \epsilon e^{nt}[h_{13} e^{-m_{13} y} + g_8 e^{-m_3 y} + g_{10} e^{-m_7 y} + g_{13} e^{-m_9 y}$$
$$+ g_{16} e^{-m_1 y} + g_{17} e^{-m_5 y} + g_{18}$$
$$+ Rm(h_{15} e^{-m_{15} y} + g_{19} e^{-m_{13} y} + g_{20} e^{-m_3 y} + g_{21} e^{-m_7 y}$$
$$+ g_{22} e^{-m_9 y} + g_{23} e^{-m_1 y} + g_{24} e^{-m_5 y} + g_{25} e^{-m_{11} y})]$$

$$\theta(y,t) = e^{-m_1 y} + \epsilon e^{nt}(h_3 e^{-m_3 y} + g_1 e^{-m_1 y})$$

$$C(y,t) = e^{-m_5 y} + \epsilon e^{nt}(h_7 e^{-m_7 y} + g_2 e^{-m_5 y})$$

The Skin-friction is given as;

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = -m_9 h_9 - m_1 g_3 - m_5 g_4 + Rm(-m_{11} h_{11}$$
$$- m_9 g_5 - m_1 g_6 - m_5 g_7)$$
$$\epsilon e^{nt}[-m_{13} h_{13} - m_3 g_8 - m_7 g_{10} - m_9 g_{13} - m_1 g_{16}$$
$$m_5 g_{17} \quad Rm(-m_{15} h_{15} - m_{13} g_{19} - m_3 g_{20} - m_7 g_{21}$$
$$m_9 g_{22} - m_1 g_{23} - m_5 g_{24} - m_{11} g_{25})] \quad (36)$$

Nusselt number (Heat transfer coefficient) is defined as;

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -m_1 - \epsilon e^{nt}(m_3 h_3 + m_1 g_1) \quad (37)$$

Sherwood Number (Mass transfer coefficient) is expressed as:

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -m_5 - \epsilon e^{nt}(m_7 h_7 + m_5 g_2) \qquad (38)$$

where

$$m_1 = \frac{1+\sqrt{1+4BQ}}{2B},\ m_3 = \frac{1+\sqrt{1+4B(n+Q)}}{2B},$$

$$m_5 = \frac{Sc+\sqrt{Sc^2+4Sckr}}{2},\ m_7 = \frac{Sc+\sqrt{Sc^2+4Sc(n+kr)}}{2},$$

$$m_9 = \frac{1+\sqrt{1+4F}}{2},\ m_{11} = \frac{1+\sqrt{1+4F}}{2},$$

$$m_{13} = \frac{1+\sqrt{1+4(n+F)}}{2},\ m_{15} = \frac{1+\sqrt{1+4(n+F)}}{2},$$

$$h_1 = 1,\ h_2 = 0,\ h_3 = 1 - g_1,\ h_4 = 0,\ h_5 = 1,$$

$$h_6 = 0,\ h_7 = 1 - g_2,\ h_8 = 0,$$

$$h_9 = u_p - (g_3 + g_4 + 1),\ h_{10} = 0,$$

$$h_{11} = -(g_7 + g_6 + g_5),\ h_{12} = 0,$$

$$h_{13} = -(g_8 + g_{10} + g_{13} + g_{16} + g_{17} + g_{18}),\ h_{14} = 0,$$

$$h_{13} = -(g_{19} + g_{20} + g_{21} + g_{22} + g_{23} + g_{24} + g_{25}),$$

$$g_1 = \frac{Am_1}{Bm_1^2 - m_1 - (n+Q)},$$

$$g_2 = \frac{ScAm_5}{m_5^2 - Scm_5 - Sc(n+kr)},$$

$$g_3 = \frac{-Gr}{m_1^2 - m_1 - F},\ g_4 = \frac{-Gr}{m_5^2 - m_5 - F},\ f_1 = 1,$$

$$g_5 = \frac{h_9 m_9^3}{m_9^2 - m_9 - F},\ g_6 = \frac{g_3 m_1^3}{m_1^2 - m_1 - F},$$

$$g_7 = \frac{g_4 m_5^3}{m_5^2 - m_5 - F},\ g_8 = \frac{-Grh_3}{m_3^2 - m_3 - (n+F)},$$

$$g_9 = \frac{-Grg_1}{m_1^2 - m_1 - (n+F)},\ f_2 = \frac{n}{n+F},$$

$$g_{10} = \frac{Gch_7}{m_7^2 - m_7 - (n+F)},\ g_{11} = \frac{Gcg_2}{m_5^2 - m_5 - (n+F)},$$

$$g_{12} = \frac{F}{n+F},\quad g_{13} = \frac{Ah_4 m_9}{m_9^2 - m_9 - (n+F)},$$

$$g_{14} = \frac{Ag_2 m_1}{m_1^2 - m_1 - (n+F)},\ g_{15} = \frac{Ag_4 m_5}{m_5^2 - m_5 - (n+F)},$$

$$g_{16} = g_9 + g_{14},\ g_{17} = g_{11} + g_{15},\ g_{18} = f_2 + g_{12},$$

$$g_{19} = \frac{nm_{13}^2 h_{13} + m_{13}^3 h_{13}}{m_{13}^2 - m_{13} - (n+F)},\ g_{20} = \frac{nm_3^2 g_8 + m_3^3 g_8}{m_3^2 - m_3 - (n+F)},$$

$$g_{21} = \frac{nm_7^2 g_{10} + m_7^3 g_{10}}{m_7^2 - m_7 - (n+F)},$$

$$g_{22} = \frac{nm_9^2 g_{13} + m_9^3 g_{13} + Am_9 g_5 + Am_9^3 h_9}{m_9^2 - m_9 - (n+F)},$$

$$g_{23} = \frac{nm_1^2 g_{16} + m_1^3 g_{16} + Am_1 g_6 + Am_1^3 g_3}{m_1^2 - m_1 - (n+F)},$$

$$g_{24} = \frac{nm_5^2 g_{17} + m_5^3 g_{17} + Am_5 g_7 + Am_5^3 g_4}{m_5^2 - m_5 - (n+F)},$$

$$g_{25} = \frac{Am_{11} h_{11}}{m_{11}^2 - m_{11} - (n+F)}$$

DISCUSSION OF RESULTS

The equations (6)-(8) are solved analytically using perturbation method along with the boundary conditions. The effects of various parameters in the governing equations on velocity, temperature and concentration profiles are presented in graphical forms. Throughout the computations, we employ $t = 1$, $Gr = Gc = M = 5$, $Rm = 0.05$, $Q = 0.005$, $Pr = 0.71$, $N = 3$, $\in = 0.2$, $A = k = u_p = 0.5$, $n = 0.9$, $kr = 2$, and $Sc = 0.002$ unless otherwise stated.

Figures 1 and 2 show the effects of chemical reaction parameter kr on velocity and concentration distributions. It is obvious that as chemical reaction parameter increases, velocity decreases and it also results in decreasing concentration of species in the boundary layer. This is due to the fact that destructive chemical reduces the boundary thickness and increases the mass transfer. Figures 3 and 4 depict the variation of different values of Schmidt number Sc, from these figures, it is noticed that velocity and concentration decrease as Sc number increases. Effect of magnetic parameter on velocity distribution is shown in Figure 5. From this figure, it is observed that as the magnetic parameter M increases the velocity decreases. This is as a result of the application of transverse magnetic field that acts as a drag force, which is commonly known as Lorentz force. This particular force naturally has the ability of decreasing the velocity.

Furthermore, Figures 6 and 7 show the velocity and temperature profiles for different values of dimensionless heat absorption coefficient Q. Obviously, as parameter Q increases, the velocity distribution decreases. Physically, the pressence of heat absorption coefficient is capable of reducing the fluid temperature. However, as a result, the thermal buoyancy effect decreases leading to a net reduction in the fluid velocity. Hence, an increase in Q leads to a decrease in the temperature profiles as shown in Figure 7. In Figures 8 and 9, it is detected that velocity and temperature decreases with increase in radiation parameter N. The effect of permeability of the porous medium parameter k is shown in Figure 10. This figure witnesses that an increase in permeability parameter increases the velocity.

The velocity profiles for different values of thermal and mass Grashof number Gr and Gc respectively are described in Figures 11 and 12. It is observed from these figures, that an increase in both Gr and Gc enhanced the velocity profiles. Here, the positive values of Gr correspond to cooling of the plate. It can also be noted that the velocity increases rapidly near wall of the plate as Gr increases. Figure 13 depicts the behaviour of the fluid as value of Rm increases; it leads to a decrease in the velocity profiles across the boundary layer. Also, Figures 14 and 15 illustrate velocity and temperature profiles for different values of Prandtl number. Prandtl number is the ratio of momentum diffusivity to thermal diffusivity, hence, it is worthwhile noting that lower thermal conductivity material results in high velocity with high thermal conductivity material resulting in lower velocity. From Figure 14, it is evident that an increase in Prandtl number decreases the velocity distribution. Moreover, Figure 15 reveals that an increase in Pr leads to a decrease of the thermal boundary layer thickness and consequencely lower average temperature within the boundary layer. This is as a result of the fact that an increase in Pr result in an increase in the thermal conductivity of the fluid, hence, heat is able to diffuse away from the heated surface more rapidly for higher values of Pr.

Figures 16, 17 and 18 show the velocity, temperature and concentration profiles for different values of the scalar constant $\in$. It is observed that an increase in the value of $\in$ results in a rise in both velocity and concentration distribution across the boundary layer. As a result, Li increasing $\in$ tends to increase the thermal boundary layer thickness and uniform temperature distribution across the boundary layer. Finally, from Figures 19 and 20, it is clear that an increase in the suction parameter A decreases both the temperature and concentration distributions.

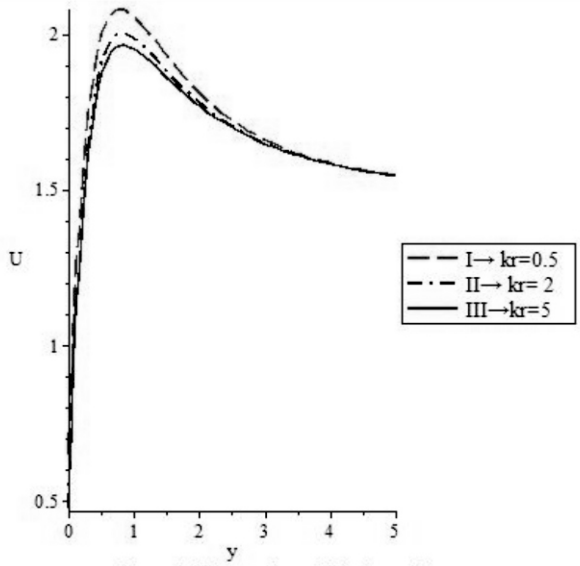


Figure 1: Effects of kr on Velocity profiles

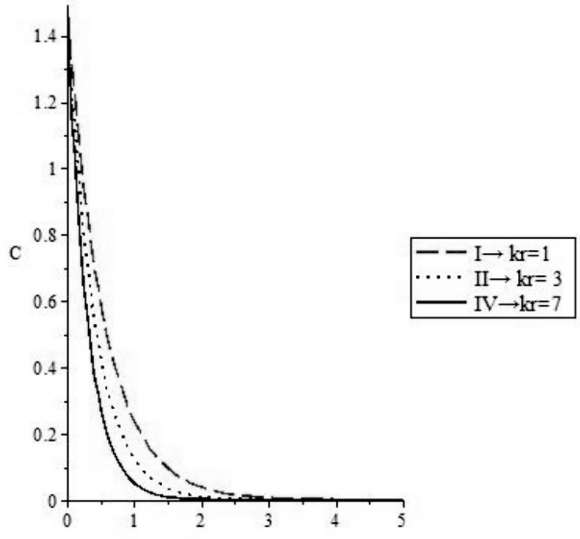


Figure 2: Effects of kr on Concentration profiles

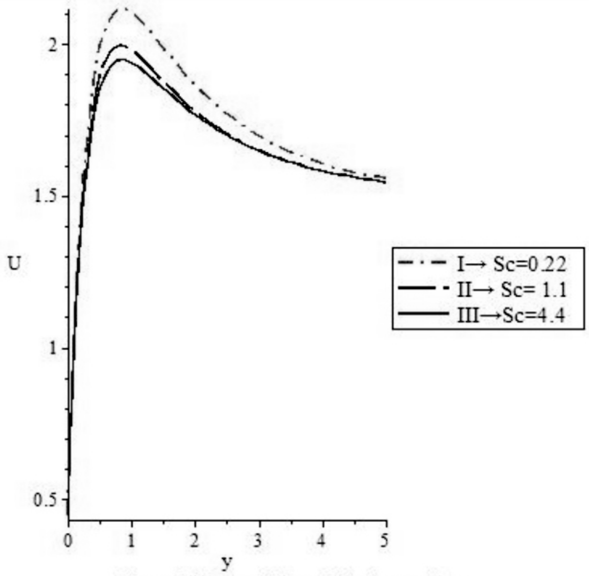


Figure 3: Effects of Sc on Velocity profiles

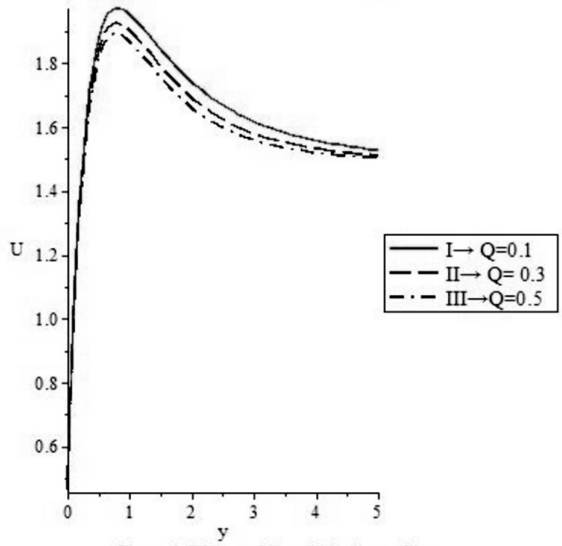


Figure 6: Effects of Q on Velocity profiles

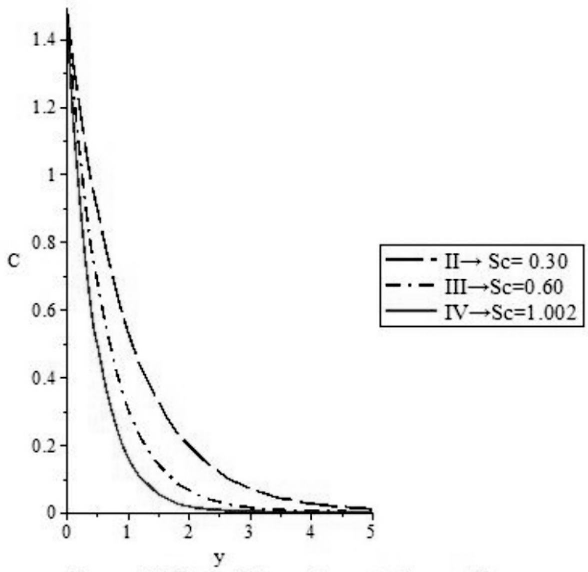


Figure 4: Effects of Sc on Concentration profiles

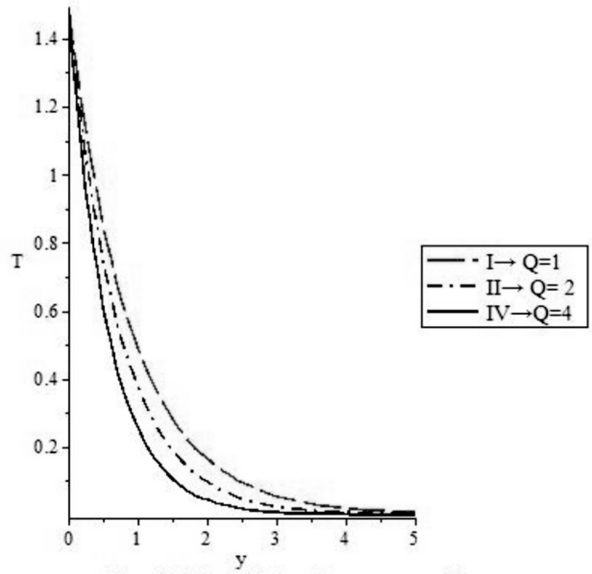


Figure 7 : Effects of Q on Temperature profiles

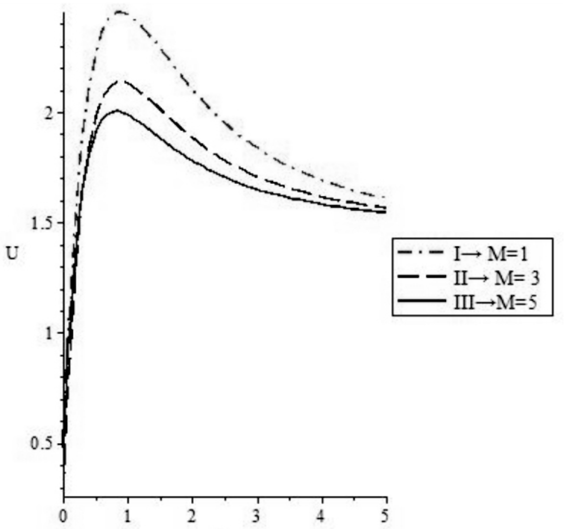


Figure 5: Effects of M on Velocity profiles

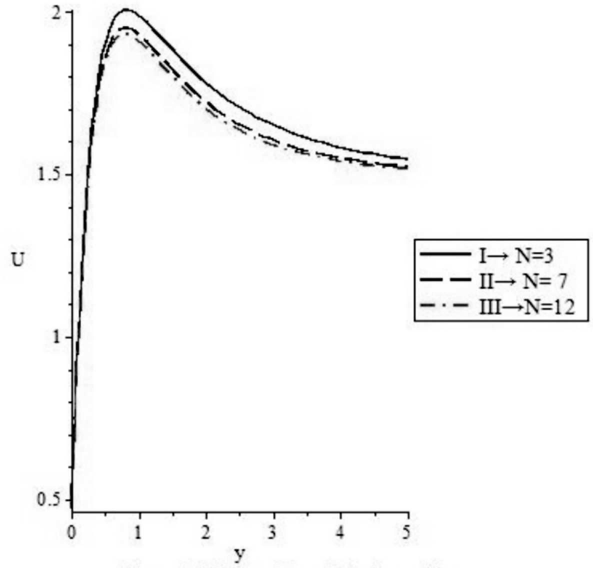


Figure 8: Effects of N on Velocity profiles

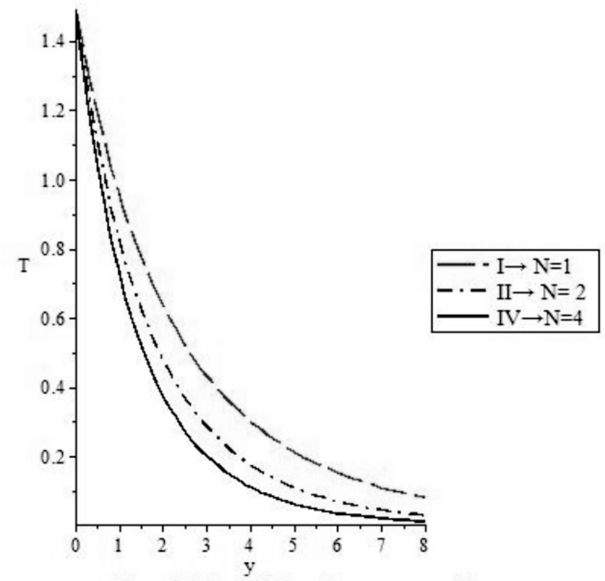


Figure 9 : Effects of N on Temperature profiles

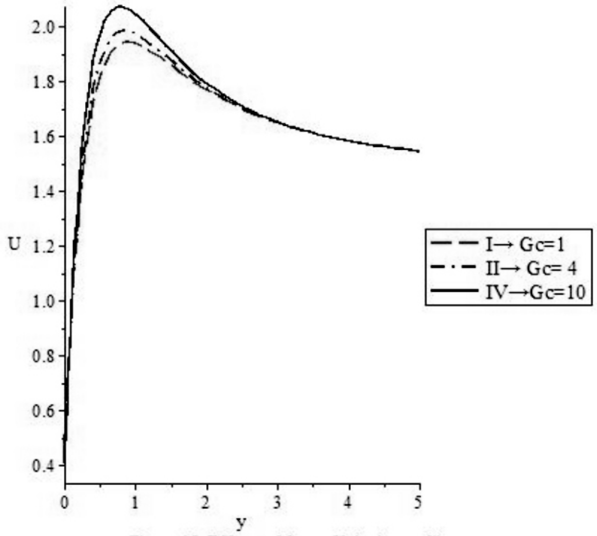
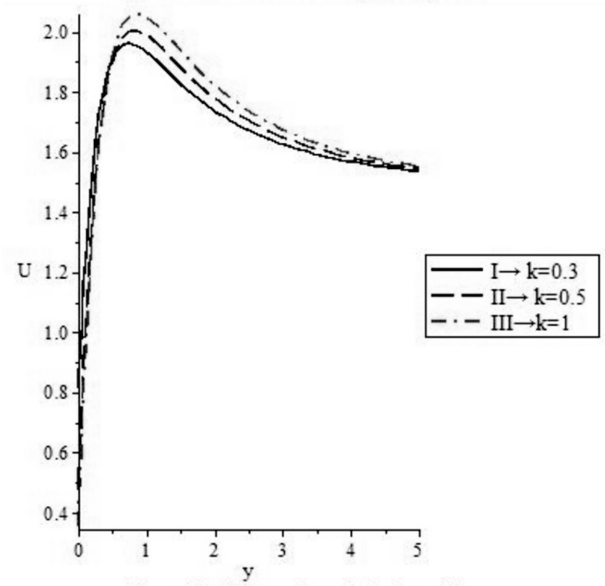


Figure 12: Effects of Gc on Velocity profiles



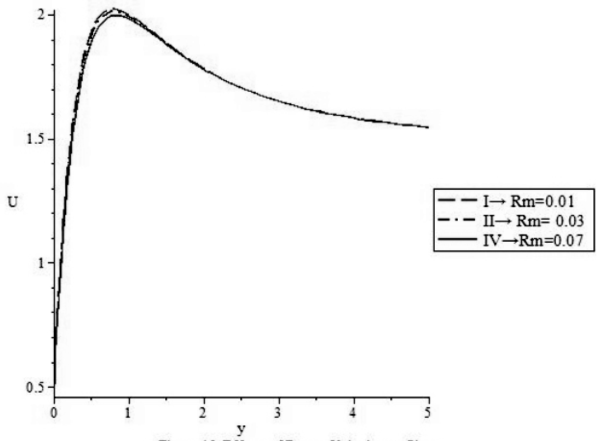


Figure 13: Effects of Rm on Velocity profiles

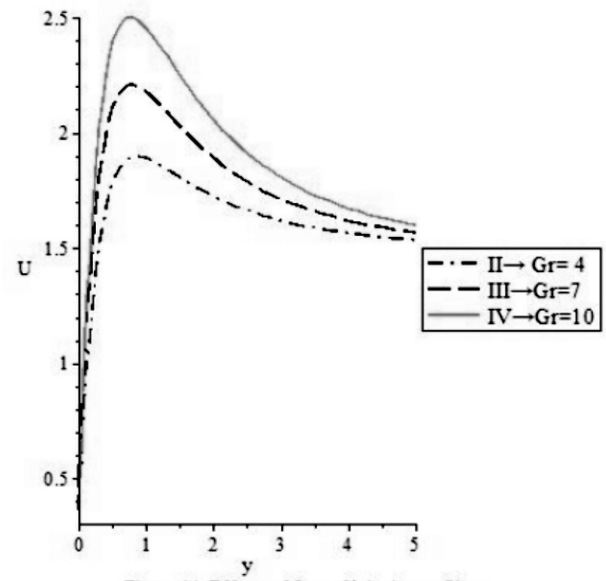


Figure 11: Effects of Gr on Velocity profiles

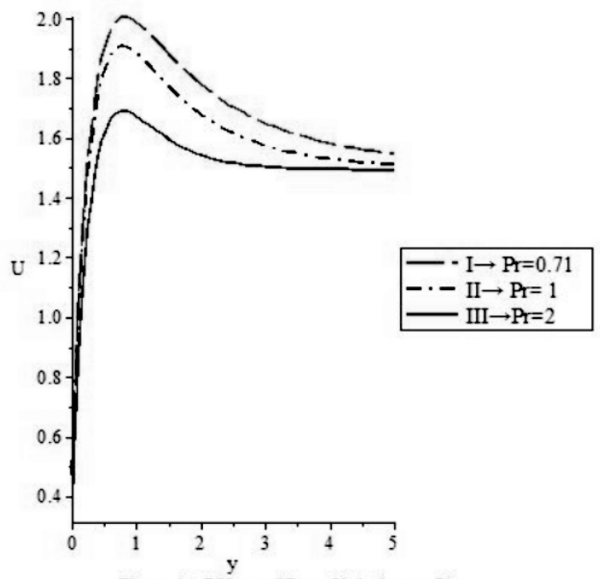


Figure 14: Effects of Pr on Velocity profiles

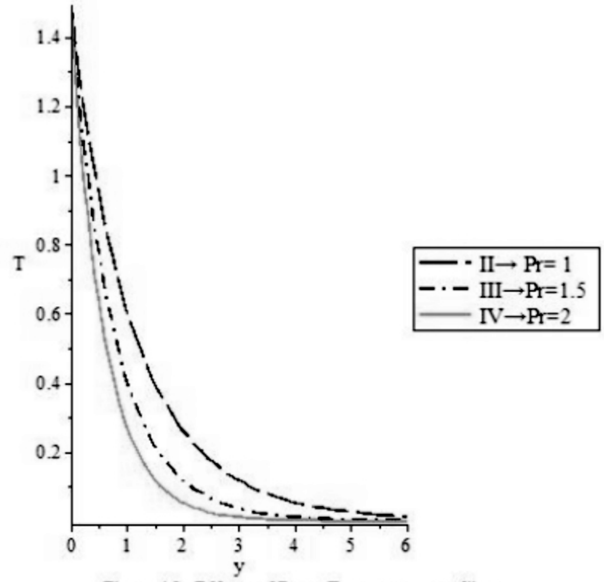


Figure 15 : Effects of Pr on Temperature profiles

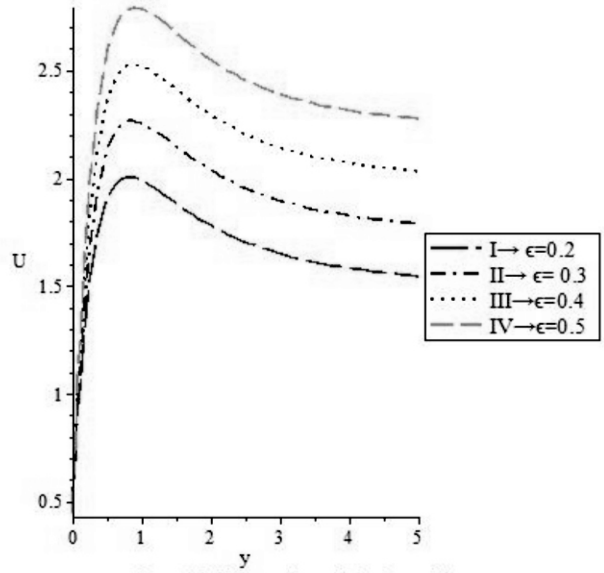


Figure 16: Effects of ϵ on Velocity profiles

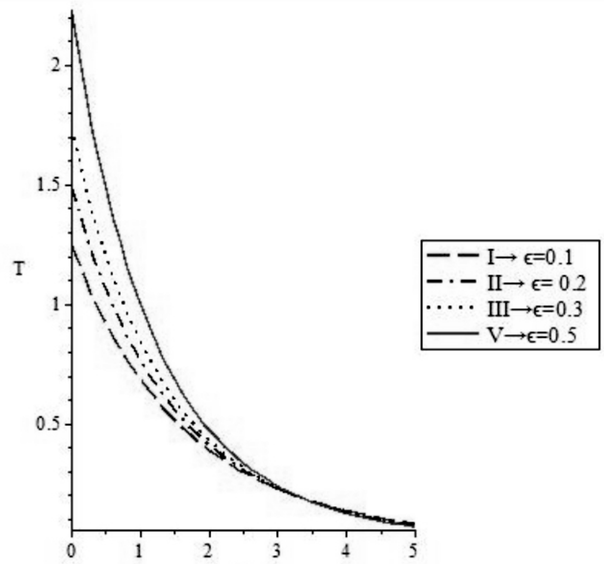


Figure 17 : Effects of ϵ on Temperature profiles

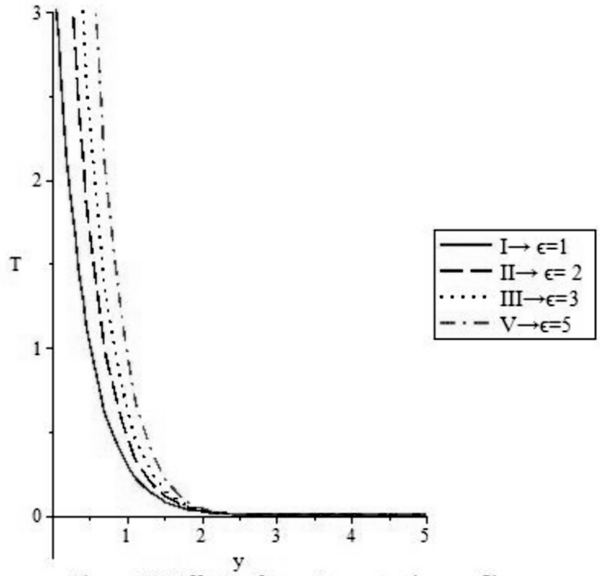


Figure 18: Effects of ϵ on Concentration profiles

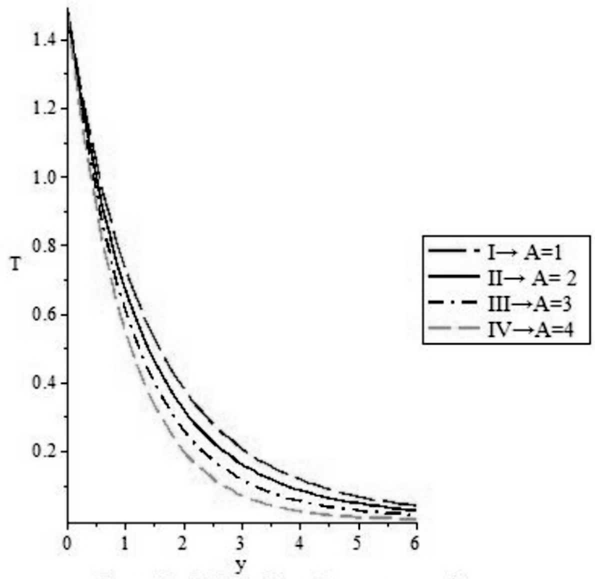


Figure 19 : Effects of A on Temperature profiles

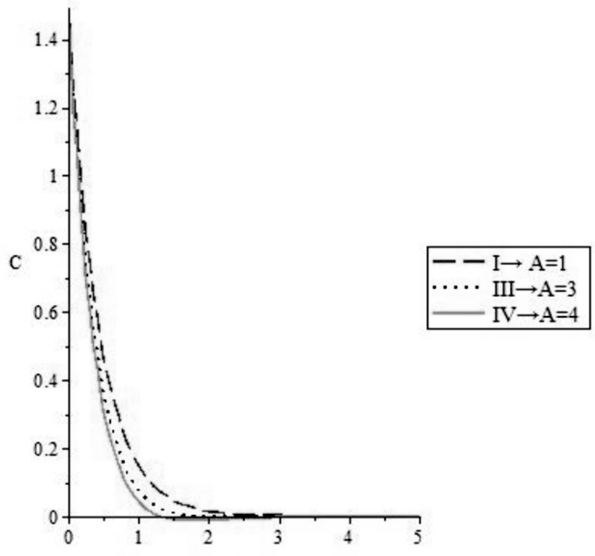


Figure 20: Effects of A on Concentration profiles

It is observed from Table 1 and Table 2 that an increase in the radiation parameter, permeability of the porous medium k, chemical reaction parameter , magnetic parameter, Prandtl number, Grashof number for mass transfer , dimensionless heat absorption coefficient, dimensionless viscoelasticity parameter of the Rivlin-Ericksen fluid Rm makes Skin-friction to reduce. While Schmidt number, Grashof number for heat transfer, scalar constant and suction velocity parameter; enhance the value of the Skin-frition. Nusselt number decreases with an increase in Q, N, Pr, $\in$ and A. Likewise, Sherwood Number decreases as chemical reaction parameter, Schmidt number, $\in$ and suction velocity parameter increase.

Table 1: Values of Skin-friction, Nusselt number and Sherwood Number for different parameters

kr	Sc	M	Q	N	K	T	Nu	Sh
2	1.002	5	0.005	3	0.5	8.131585338	-1.029474389	-3.273682080
3	1.002	5	0.005	3	0.5	6.086926750	-1.029474389	-3.703175439
2	0.30	5	0.005	3	0.5	7.668669502	-1.029474389	-1.761364184
2	0.60	5	0.005	3	0.5	7.884269228	-1.029474389	-2.673426988
2	1.002	1	0.005	3	0.5	130.5022220	-1.029474389	-3.703175439
2	1.002	3	0.005	3	0.5	6.101310932	-1.029474389	-3.703175439
2	1.002	5	0.1	3	0.5	6.024425176	-1.128052720	-3.703175439
2	1.002	5	0.3	3	0.5	5.939969349	-1.286469769	-3.703175439
2	1.002	5	0.005	1	0.5	8.779176503	-.6857195830	-3.703175439
2	1.002	5	0.005	2	0.5	8.620793273	-.9102741015	-3.703175439
2	1.002	5	0.005	3	0.3	7.080049038	-1.029474389	-3.703175439
2	1.002	5	0.005	3	1	5.237823213	-1.029474389	-3.703175439

Table 2: Values of Skin-friction, Nusselt number and Sherwood Number for different parameters

Gr	Gc	Rm	Pr		A	T	Nu	Sh
4	5	0.05	0.71	0.2	0.5	5.145327257	-1.029474389	-3.703175439
7	5	0.05	0.71	0.2	0.5	7.970125713	-1.029474389	-3.703175439
5	1	0.05	0.71	0.2	0.5	5.392996723	-1.029474389	-3.703175439
5	4	0.05	0.71	0.2	0.5	5.298543465	-1.029474389	-3.703175439
5	5	0.01	0.71	0.2	0.5	6.514120874	-1.029474389	-3.703175439
5	5	0.03	0.71	0.2	0.5	6.300523812	-1.029474389	-3.703175439
5	5	0.05	1	0.2	0.5	5.902254044	-1.390251570	-3.703175439
5	5	0.05	2	0.2	0.5	5.776803710	-2.612657259	-3.703175439
5	5	0.05	0.71	0.3	0.5	6.932957763	-1.295967278	-4.401904997
5	5	0.05	0.71	0.4	0.5	7.778988775	-1.562460168	-5.100634556
5	5	0.05	0.71	0.2	1	3.861892378	-1.091901206	-3.851001784
5	5	0.05	0.71	0.2	2	4.331029843	-1.216754838	-4.146654478

CONCLUSION

A theoretical analysis is presented for a problem of radiation and chemical reaction effects on unsteady, two-dimensional free convective Rivlin-Ericksen fluid through a porous vertical plate with variable suction. Analytical and numerical solutions are obtained for velocity, temperature, concentration, Skin friction, Nusselt number and Sherwood number. The effects of various physical parameters on flow quantities are shown graphically and discussed briefly. The following are some of the findings:

1. velocity increases with an increase in k, Gr, Gc, $\in$ and decreases with an increase in N, kr, M, Pr, Sc, Q and Rm.
2. temperature decreases with an increase in N, Pr, Q, A, while it has a reverse tendency in the case of $\in$.
3. Concentration decreases with an increase in chemical reaction parameter, Schmidt number, suction velocity parameter and increases with an increase in scalar constant.
4. Skin friction increases with increase in the value of Sc, Gr, A or $\in$ while an increase in kr, M, Q, N, Rm, Pr and Gc results in a decrease in the skin friction.
5. the Nusselt number decreases with an increase in the value of Q, N, A, $\in$ and Pr.
6. Sherwood number also decreases with an increase in the value of kr, $\in$ and Sc.

REFERENCES

Beard, D. M. and Walters, K. (1964) Proc. *Cambr. Phil. Soc.* (60):667-674.

Brewster, M. Q. (1972) *Termal Radiation Transfer Properties, John Wiley and sons* (12): 6-9.

Das, S. S. , Sahoo S. K. , Dash G. C. and Panda J. P. (2005) Laminar flow of elastico-viscous Rivlin-Ericksen fluid through porous parallel plates with suction and injection, the lower plate being stretched, *AMSE J. Mod. Meas. Cont. B*, 74 (8):1-22.

Das, S. S. ,Maity, M. and Das, J. K. (2011) Effect of heat source and variable suction on unsteady viscous stratified flow past a vertical porous flat moving plate in the slip flow regime. *International Journal of Energy and Environment* 2(2):375-382.

Dharmendra, K and Varshney, N. K. (2012) Stratified Rivlin-Ericksen fluid effect on MHD free convection flow with heat and mass transfer past a vertical porous plate, *Ultra Scientist* 24 (3): 527-534.

Gbadeyan, J. A. and Dada, M. S. (2013) On the influence of radiation and heat transfer on an unsteady MHD non-Newtonian fluid flow with slip in a porous medium. *Journal of Mathematics Research,* 5(3):40-50.

Lakshmi, R. and Gomathi, S. (2012) Study on flow of Rivlin-Ericksen fluid past a porous vertical wall with constant suction. *International Journal of Scientific and Research Publications.* 2(9).

Nayak, M. K. and Dash, G. C. (2014) Effect of chemical reaction on MHD flow of a visco-elastic fluid through porous medium. *Journal of Applied Analysis and computation.* 4 (4):367-381.

Rao, M. A. (2007) *Rheology of fluid and semisolid foods*; Principles and Applications (2nd ed) Springer. ISBN 978-0-387-70929-1, 8.

Ravikumar, V., Raju, M. C. and Raju, G. S. S. (2014) Combined effects of heat absorption and MHD on convective Rivlin- Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction. *Aim Shams Engineering Journal,* 5, 867-875.

Reddy, S. K., Kesavaiah, D. C. and Shekar, M. N. R. (2013) MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction. *International Journal of Innovative Research in Science Engineering and Technolgy.* 2(4): 973-981.

Rivlin, R. S. and Ericksen, J. I. (1955), Stress deformation relations for isotrophic materials, *J. Rational Mech. Anal.* 4:323-329.

Sreekanth, S., Saravana , R., Venkataramana, S. and Heemadri, R. R. (2011) Hydromagnetic Unsteady Hele-shaw flow of a Rivlin-Ericksen fluid Through porous media. *Advances in Applied Science Research* 2 (3): 246-264.

Uwanta, I. J. and Hussaini, A. (2012) Effect of Mass Transfer on Hydromagnetic free convective Rivlin-Ericksen flow through a porous medium with time Dependent suction. *International Journal of Engineering and Science.* ISSN:2278-4721, 1 (4):21-30.

Varshney, N. K., Satyabhan, S. and Singh, J. (2013) Effect of Rotatory Rivlin-Ericksen fluid on MHD free convection and mass transfer flow through porous medium with constant heat and mass flux across moving plate. *10SR Journal of Engineering* (10SRJEN) 1(1) : 010-017.

Vijaya Sekhar, D. and Viswanadh Reddy, G. (2012) Chemical reaction effects on MHD unsteady free convective walter's memory flow with constant suction and heat sink. *Advances in Applied Research*, 3 (4) : 2141-2150.

The authors wish to appreciate the reviewers for their constructive comments which have added values to the manuscript.