Heat and Mass Transfer Characteristics of Mhd Free Convective Rivlin-Ericksen Fluid Flow Past a Porous Plate

T. Suneetha[#1], A. Sailakumari[*2]

[#1]Research Scholar, Department of Mathematics, JNTUA Ananathapuramu, A.P., India.

[*2]Department of Mathematics, JNTUA Ananthapuramu, A.P., India.

Abstract — *A numerical solution is presented for a fully developed free convective flow of a chemically reactive, Rivlin-Ericksen fluid past a vertical porous plate bounded by a porous medium in the presence of radiation absorption. A magnetic field of uniform strength B0 is applied perpendicular to the plate. The novelty of the study is to investigate the effect of radiation absorption, chemical reaction on a double diffusive Rivlin-Ericksen fluid in the presence of time dependent variable suction and permeability. The coupled dimensionless non-linear partial differential equations are solved numerically by using a finite difference method. The expressions for skin friction, Nusselt number and Sherwood number are also derived. The numerical computations have been studied through figures and tables.*

Keywords — *MHD, Rivilin-Ericksen fluid, thermal diffusion, variable suction, variable permeability, vertical porous plate, heat and mass transfer and Finite difference method.*

.

I. INTRODUCTION

MHD free convection flows frequently occurs in petro-chemical industry, chemical vapor deposition on surface, cooling of nuclear reactors, heat exchanger design, forest fire dynamics and geophysics as well as magneto-hydrodynamic power generation systems. The unsteady magneto-hydrodynamic free convection flows past an infinite plate have received much attention because of non-linearity of the governing equations. The Rivlin–Ericksen elastic-viscous fluid has relevance and importance in geophysical fluid dynamics, industries and chemical technology. Sajid and Hayat [1, 2] examined the effects of thermal radiation on the flow due to an exponentially stretching surface. MHD boundary layer flow due to an exponentially stretching sheet having the effect of radiation was addressed by Bidin and Nazar [3]. Similarity solutions of the boundary layer equations for a nonlinearly stretching sheet were presented by Akyildiz et al. [4]. Pal [5] considered a mixed convection heat transfer in the boundary layer on an exponentially stretching surface with magnetic field. Thermal diffusion effect on MHD mixed convection unsteady flow of a micro polar fluid past a semi-infinite vertical porous plate with radiation and mass transfer was presented by Mamatha et al. [6]. Ishak [7] discussed the combined effects of magnetic field and ther- mal radiation on flow and heat transfer over an exponentially stretching sheet. Sahoo and Poncet [8] addressed the flow of third grade fluid past an exponentially stretching sheet with slip condition. Mukhopadhyay and Gorla [9] examined the effects of partial slip on boundary layer flow past a permeable exponential stretching sheet in presence of thermal radiation. MHD three dimensional Couette flow past a porous plate with heat transfer was initiated by Ravikumar et al. [10]. Effects of thermal radiation and magnetic field on unsteady stretching permeable sheet in presence of free stream velocity were checked by Singh et al. [11]. Unsteady MHD free convection and chemically reactive flow past an infinite vertical porous plate was addressed by Raju et al. [12]. Umamaheswar et al. [13 – 19] in their studies, addressed several aspects related to the characteristics of heat and mass transfer. Magneto-convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration was investigated by Reddy et al. [20]. Unsteady free convection flow past a periodically accelerated vertical plate with Newtonian heating was considered by Raju et al. [21]. Heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source was presented by Ravikumar et al. [22]. Ghosh and Shit [23, 24] considered mixed convection MHD flow of viscoelastic fluid in a porous medium past a hot vertical plate. An analytical study of MHD natural convective flow of incompressible fluid flow from a vertical flat plate in porous medium was presented by Kapoor et al. [25]. Combined effects of Joule heating and viscous dissipation on MHD flow past a permeable, stretching surface with free convection and radiative heat transfer was investigated by Chen [26]. Singh and Gorla [27] studied free convective heat and mass transfer with Hall current, Joule heating and thermal diffusion. Thermal and solutal buoyancy effect on MHD boundary layer flow of a visco-elastic fluid past a porous plate with varying suction and heat source in the presence of thermal diffusion is investigated by Reddy et al. [28]. Recently Ravikumar et al. [29] and Reddy et al. [30, 31] considered various aspects of Rivlin-Ericksen fluid past a porous plate.

Motivated by the above studies, in this manuscript, an attempt is made to investigate heat and mass transfer characteristics of MHD free convective Rivlin-Ericksen fluid flow past a porous plate. This is an extension to the work of Reddy et al. [28] in which thermal diffusion and radiation absorption effects were not addressed. In this manuscript, a detailed study is presented for various parameters on the flow quantities including thermal diffusion and radiation absorption. The novelty of this study is the consideration of thermal diffusion and radiation absorption effects of a non-Newtonian fluid namely Rivlin-Ericksen fluid (in base paper Newtonian fluid is considered.

II. Formulation of the Problem

The unsteady free convection heat and mass transfer flow of a well-known non-Newtonian fluid, namely Rivlin Ericksen fluid past an infinite vertical porous plate, embedded in a porous medium in the presence of thermal diffusion, oscillatory suction as well as variable permeability is considered. A uniform magnetic field of strength B_0 is applied perpendicular to the plate. Let x^1 axis be taken along with the plate in the direction of the flow and y^1 axis is normal to it. Let us consider the magnetic Reynolds number is much less than unity so that the induced magnetic field is neglected in comparison with the applied transverse magnetic field. The basic flow in the medium is, therefore, entirely due to the buoyancy force caused by the temperature difference between the wall and the medium. It is assumed that initially, at tl ≤ 0, the plate as well as fluid is at the same temperature and concentration. When tl >0, the temperature of the plate is instantaneously raised to and the concentration of the species is set to .

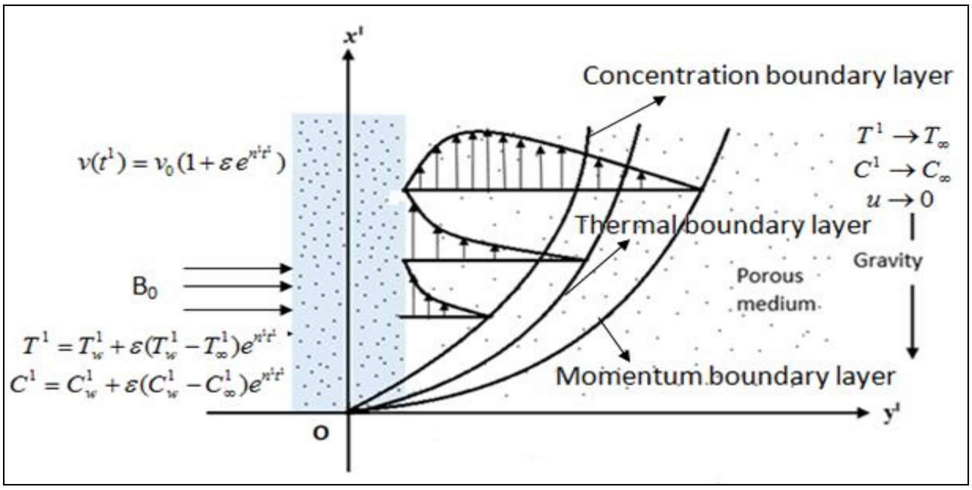

Figure 1: Flow geometry and coordinate system

Under the above assumptions with usual Boussinesq's approximation, and as stated by Reddy et al. [43] the governing equations and boundary conditions are given by

$$\frac{\partial u^1}{\partial t^1} + v\frac{\partial u^1}{\partial y^1} = \upsilon\frac{\partial^2 u^1}{\partial y^{12}} + g\beta(T^1 - T_\infty) + g\beta^1(C^1 - C_\infty) - \frac{\sigma B_0^2 u^1}{\rho} - \frac{\upsilon u^1}{K^1(t^1)} - \frac{k_0}{\rho}\left[\frac{\partial^3 u^1}{\partial t^1 \partial y^{12}}\right] \tag{1}$$

$$\frac{\partial T^1}{\partial t^1} + v\frac{\partial T^1}{\partial y^1} = \frac{K}{\rho C_p}\frac{\partial^2 T^1}{\partial y^{12}} + \frac{q_0}{\rho C_p}(T^1 - T_\infty^1) + Q_l^1\frac{(C^1 - C_\infty^1)}{\rho C_p} \tag{2}$$

$$\frac{\partial C^1}{\partial t^1} + v\frac{\partial C^1}{\partial y^1} = D\frac{\partial^2 C^1}{\partial y^{12}} + D_1\frac{\partial^2 T^1}{\partial y^{12}} - K_C(C^1 - C_\infty^1) \tag{3}$$

With the boundary conditions

$$u = 0, T^1 = T_W^1 + \varepsilon(T_W^1 - T_\infty^1)e^{n^1t^1},\ C^1 = C_W^1 + \varepsilon(C_W^1 - C_\infty^1)e^{n^1t^1} \quad at\ y = 0$$

$$u \to 0, T^1 \to T_\infty, C^1 \to C_\infty \quad as \quad y \to \infty \tag{4}$$

Let the permeability of the porous medium and the suction velocity be of the form

$$K(t^1) = K_p^1(1+\varepsilon e^{n^1 t^1}) \tag{5}$$

$$v(t^1) = -v_0(1+\varepsilon e^{n^1 t^1}) \tag{6}$$

Where $v_0 > 0$ and ε« 1 are positive constants. Introducing the non-dimensional quantities.

$$y = \frac{v_0 y^1}{\upsilon}, \quad t = \frac{v_0^2 t^1}{4\upsilon}, \quad w = \frac{4\upsilon w^1}{v_0^2}, \quad u = \frac{u^1}{v_0}, \quad \theta = \frac{T^1 - T_\infty}{T_w - T_\infty},$$

$$C = \frac{C^1 - C_\infty}{C_w - C_\infty}, \; Q = \frac{q_0 v}{\rho C_p v_0^2}, \; K = \frac{v_0^2 K_p^1}{\upsilon^2}, \; \Pr = \frac{\upsilon}{\mathrm{K}}, \; Km = \frac{Q_l U_r^2 v}{\rho C_p v_0^2}, \; Sc = \frac{\upsilon}{D}, \tag{7}$$

$$M = \frac{\sigma B_0^2 \upsilon}{\rho v_0^2}, \quad Rc = \frac{k_0 v_0^2}{\sigma \upsilon^2}, \quad n = \frac{4\upsilon n^1}{v_0^2}, \quad Gc = \frac{\upsilon g \beta^1 (C_w - C_\infty)}{v_0^3},$$

$$Gr = \frac{\upsilon g \beta (T_w - T_\infty)}{v_0^3}, \quad S_0 = \frac{D_1 (T_w - T_\infty)}{\upsilon (C_w - C_\infty)}, \quad Kr = \frac{K_C v}{v_0^2}$$

The equations (3), (4), (5) reduce to the following non-dimensional form:

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GcC - M^2 u - \frac{u}{K(1+\varepsilon e^{nt})} - \frac{Rc}{4}\frac{\partial^3 u}{\partial t \partial y^2} \tag{8}$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} + Q\theta + K_m C \tag{9}$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + S0\frac{\partial^2 T}{\partial y^2} - K_r C \tag{10}$$

With the boundary conditions

$$u = 0, T = 1+\varepsilon e^{nt}, C = 1+\varepsilon e^{nt} \quad at \quad y = 0$$
$$u \to 0, T = 0, C = 0 \quad as \quad y \to \infty \tag{11}$$

$G_r = \dfrac{\upsilon g \beta (T_W^* - T_W^\infty)}{v_0^3}$ (Grashof number); $G_C = \dfrac{\upsilon g \beta (C_W^* - C_W^\infty)}{v_0^3}$ (Modified Grashof number);

$M = \dfrac{\sigma B_0^2 \upsilon}{\rho v_0^2}$ (Magnetic parameter); $K = \dfrac{v_0^2 K_p^*}{v^2}$ (Porosity parameter);

$R_C = \dfrac{K_0 v_0^2}{\rho v^2}$ (Elastic parameter); $P_r = \dfrac{K}{\rho c_p v_0^2}$, (Prandtl number) ;

$Q = \dfrac{q_0 v}{\rho C_p v_0^2}$, (Heat source parameter); $Km = \dfrac{Q_l U_r^2 v}{\rho C_p v_0^2}$, (Radiation absorption parameter) ;

$K_r = \dfrac{K_C v}{v_0^2}$ (Chemical reaction parameter); $Sc = \dfrac{v}{D}$, (Schmidt number);

$S0 = \dfrac{D_1 (T_w^* - T_\infty^*) U_0}{(C_w^* - C_\infty^*)}$, $(Soret \; number)$

III. SOLUTION OF THE PROBLEM

Equations (1)-(3) are linear partial differential equations and are to be solved with the initial and boundary conditions (11). In fact the exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (1)-(3) are as follows:

$$\frac{1}{4}\frac{u_{i,j+1}-u_{i/j}}{\Delta t}-(1+\varepsilon e^{nt})\frac{u_{i+1,j}-u_{i/j}}{\Delta y}=\frac{u_{i-1,j}-2u_{i/j}+u_{i+1,j}}{(\Delta y)^2}+Gr\theta_{i,j}+GcC_{i,j}-M^2u_{i/j}$$

$$-\frac{u_{i/j}}{K(1+\varepsilon e^{nt})}-\frac{Rc}{4}\left(\frac{u_{i-1,j+1}-2u_{i/j+1}+u_{i+1,j+1}-u_{i-1,j}+2u_{i/j}+u_{i+1,j}}{(\Delta y)^2\Delta t}\right) \quad (12)$$

$$\frac{1}{4}\frac{\theta_{i,j+1}-\theta_{i/j}}{\Delta t}-(1+\varepsilon e^{nt})\frac{\theta_{i+1,j}-\theta_{i/j}}{\Delta y}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i/j}+\theta_{i+1,j}}{(\Delta y)^2}+Q\theta_{i/j}+KmC_{i/j} \quad (13)$$

$$\frac{1}{4}\frac{C_{i,j+1}-C_{i/j}}{\Delta t}-(1+\varepsilon e^{nt})\frac{C_{i+1,j}-C_{i/j}}{\Delta y}=\frac{1}{Sc}\frac{C_{i-1,j}-2C_{i/j}+C_{i+1,j}}{(\Delta y)^2}$$

$$+S0\frac{\theta_{i-1,j}-2\theta_{i/j}+\theta_{i+1,j}}{(\Delta y)^2}-KrC_{i/j} \quad (14)$$

The expressions of velocity, temperature and concentration in finite difference scheme are as follows:

$$u_{i/j+1}=u_{i/j}+4\Delta t(1+\varepsilon e^{nt})\frac{u_{i+1,j}-u_{i/j}}{\Delta y}+v\frac{u_{i-1,j}-2u_{i/j}+u_{i+1,j}}{(\Delta y)^2}+4\Delta tGr\theta_{i,j}+4\Delta tGcC_{i,j}$$

$$-4\Delta tM^2u_{i/j}-4\Delta t\frac{u_{i/j}}{K(1+\varepsilon e^{nt})}-Rc\left(\frac{u_{i-1,j+1}-2u_{i/j+1}+u_{i+1,j+1}-u_{i-1,j}+2u_{i/j}+u_{i+1,j}}{(\Delta y)^2}\right) \quad (15)$$

$$\theta_{i/j+1}=\theta_{i/j}-4\Delta t(1+\varepsilon e^{nt})\frac{\theta_{i+1,j}-\theta_{i/j}}{\Delta y}+4\Delta t\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i/j}+\theta_{i+1,j}}{(\Delta y)^2}+4\Delta tQ\theta_{i/j}+4\Delta tKmC_{i/j} \quad (16)$$

$$C_{i/j+1}=C_{i/j}+4\Delta t(1+\varepsilon e^{nt})\frac{C_{i+1,j}-C_{i/j}}{\Delta y}+\frac{4\Delta t}{Sc}\frac{C_{i-1,j}-2C_{i/j}+C_{i+1,j}}{(\Delta y)^2}+$$

$$4\Delta tS0\frac{\theta_{i-1,j}-2\theta_{i/j}+\theta_{i+1,j}}{(\Delta y)^2}-4\Delta tKrC_{i/j} \quad (17)$$

Here, the suffix i corresponds to y and j to time. The mesh system is divided by taking Δy = 0.1. From the initial condition in (11), we have the following equivalent:

$$u(i,0)=0,\ \theta(i,0)=0, C(i,0)=0\quad \textit{for all } i \quad (18)$$

The boundary conditions from (11) are expressed in finite-difference form as follows

$$u(0,j)=at, \theta(0,j)=\frac{1}{1+t}, C(0,j)=\frac{1}{1+t}\quad \textit{for all } j \quad (19)$$

$$u(i_{\max},j)=0, \theta(i_{\max},j)=0, C(i_{\max},j)=0\quad \textit{for all } j$$

(Here i_{max} was taken as 200)

The velocity at the end of time step viz, u(i, j+1)(i=1,200) is computed from (12) in terms of velocity, temperature and concentration at points on the earlier time-step. After that θ (i, j +1) is computed from (13) and thenC (i, j +1) is computed from (14). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

Skin-friction:

The skin-friction in non-dimensional form is given by the relation

$$\tau = -\left(\frac{du}{dy}\right)_{y=0} \quad where\ \tau = \frac{\tau^1}{\rho U_0^2}$$

Rate of heat transfer:

The dimensionless rate of heat transfer in terms of Nusselt number is given by

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

Rate of mass transfer:

The dimensionless rate of mass transfer in terms of Sherwood number is given by

$$Sh = -\left(\frac{dC}{dy}\right)_{y=0}$$

IV. RESULTS AND DISCUSSION

To gain a perspective of the physics of the flow regime, we have studied numerically the effects of magnetic parameter(M), Grashoff number (Gr), Modified Grashoff number (Gc), Elastic parameter (Rc), Porosity parameter (K), Prandtl number (Pr), Heat source parameter (Q), Radiation absorption parameter (Km), Schmidt number (Sc), Soret number (So), Chemical reaction parameter (Kr) on the velocity, temperature, concentration, skin ftiction, Nusselt number and Sherwood number. (In order to validate of our study we have compared with the result of previous literature by Rout and Pattanayak [17]. The results of this comparison are found to be in very good agreement. It is shown in figure 10.)

Figures 2-6 demonstrate the variations of the fluid velocity under the efects of different parameters. Figures2& 6 shows the effect of Elastic parameter and magnetic parameter on velocity distribution. It is noticed that the velocity decreases with increasing values of Magnetic parameter and Elastic parameter. It is known fact that the application of transverse magnetic field which is applied normal to the flow, results in a flow-resistive force called the Lorentz force which acts in the opposite direction of the flow. This force has the effect of slowing the motion of the fluid.This result is in good agreement with the results of Raju et al. [12].Figures 3 & 4 depict the influence of Modified Grashof number and Grashof number on velocity. It can be seen that the velocity increases for rising values of both the numbers. This is due to the fact that the buoyancy which is acting on the fluid particles due to gravitational forces that enhances the fluid velocity. Figure 5 displays the effect of porous permeability parameter on velocity. It is observed that as the porosity parameter values increases the velocity also increases. Physically, an increase in the permeability of porous medium leads the rise in the flow of fluid through it. When the holes of the porous medium become large, the resistance of the medium may be neglected.In their study Raju et al [21] concluded that velocity increases with an increase in the values of porosity parameter.Figures 7&9 displays the effect of Heat source parameter and Radiation absorption on Temperature. It is observed that the Temperature increases with increasing values of Heat source parameter and Radiation absorption .Figure 8 displays effect of prandtl number on Temperature. Temperature decreases with increasing values of Prandtl number.This is because the fluid of low Prandtl number has high thermal diffusivity hence attains higher temperature in steady state, which in turn means more buoyancy force i.e. more fluid velocity with respect to comparatively high Prandtl fluid. Figures 10 &12 shows the effect of Chemical reaction parameter and Schmidth parameter on Concentration. Concentration decreases with the increasing the values of Chemical reaction parameter and Schmidth parameter. Figure11 shows the variation of the Concentration with the Soret number. Concentration increase with increasing the values of Soret number. It is clear that the velocity boundary layer thickness increases with an increase in Soret number. Figure 8 exhibits the variation of the velocity boundary-layer with the influence of Dufour number. It is noticed that the velocity boundary layer thickness increases with an increase in the Dufour number.

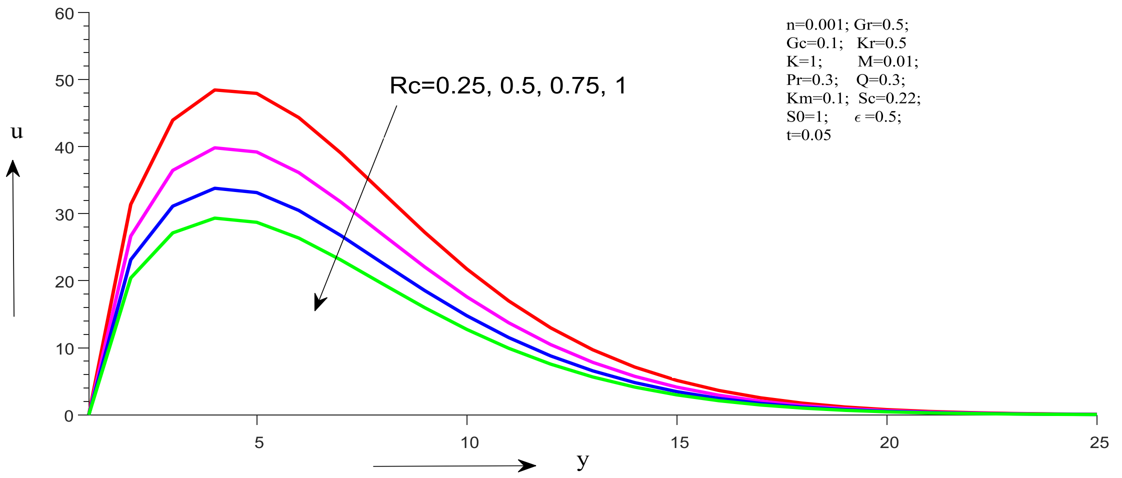

Fig 2 :Effect of Elastic parameter on u.

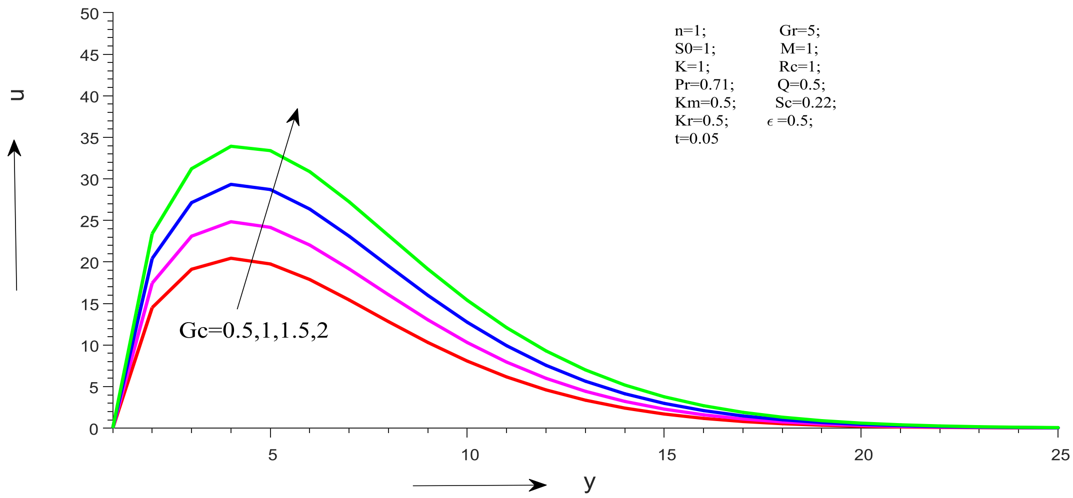

Fig 3: Effect of modified Grashof number on velocity u.

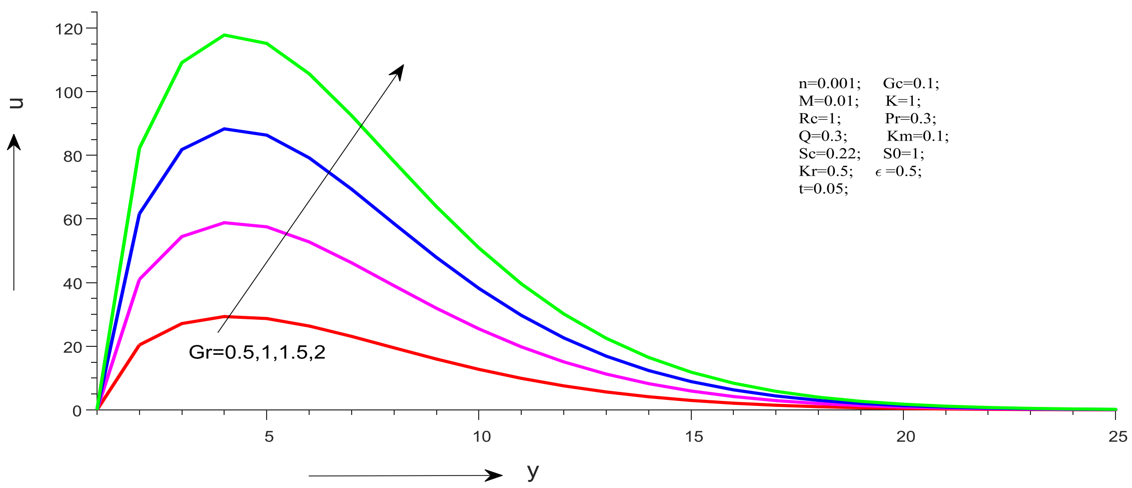

Fig 4:Effect of Grashof number on u.

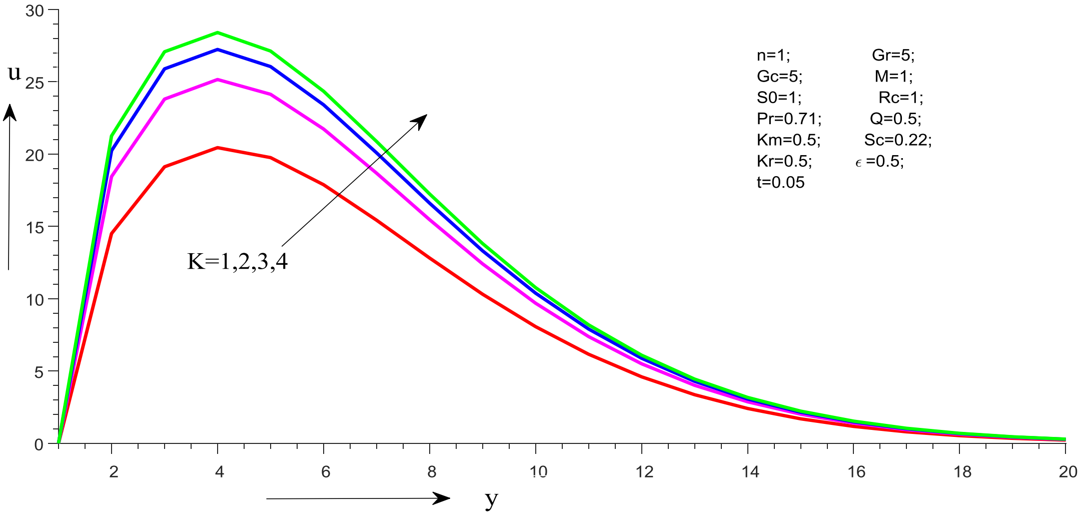

Fig 5 :Effect of porosity parameter on u.

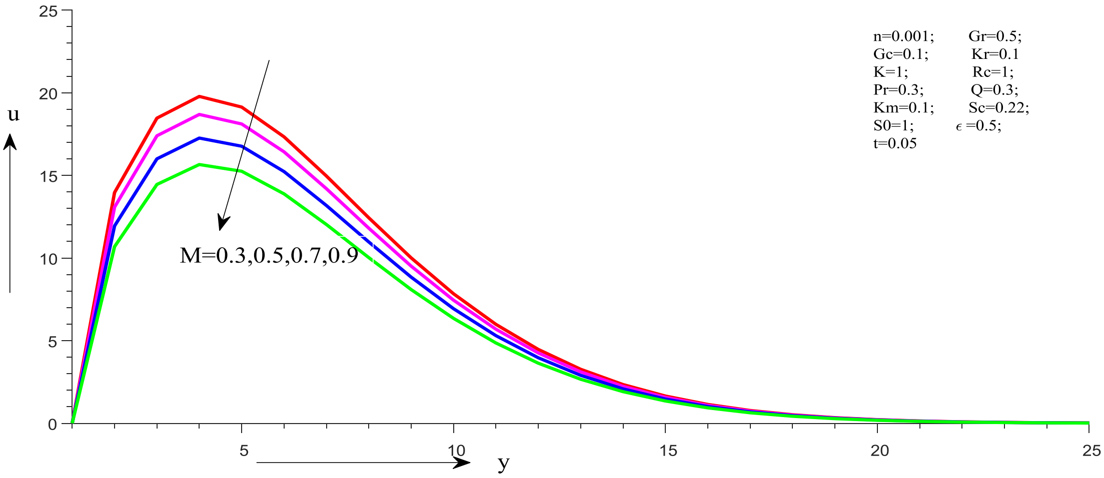

Fig 6:Effect of Magnetic parameter on u.

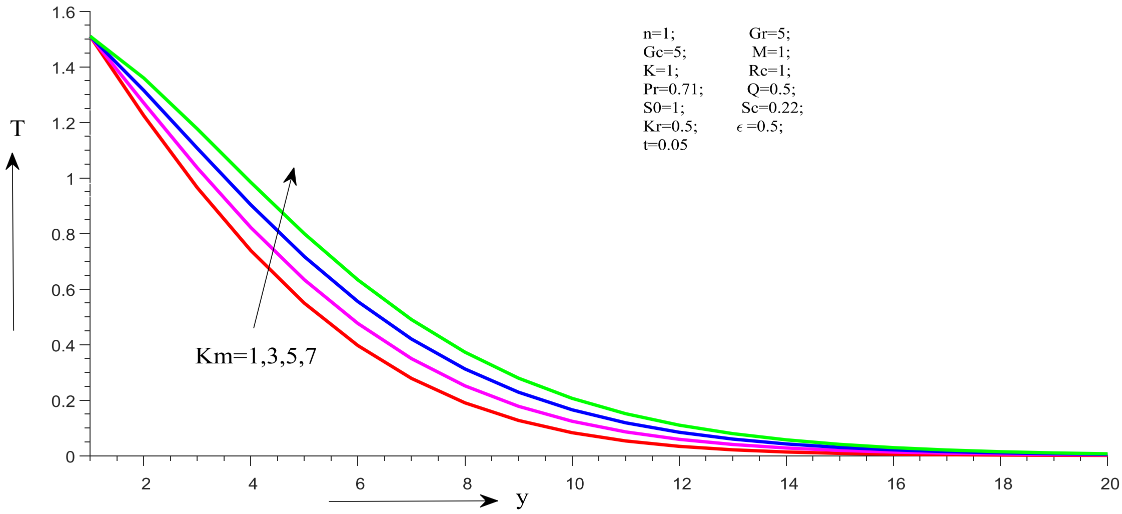

Fig 7:Effect of Radiation absorption parameter on T.

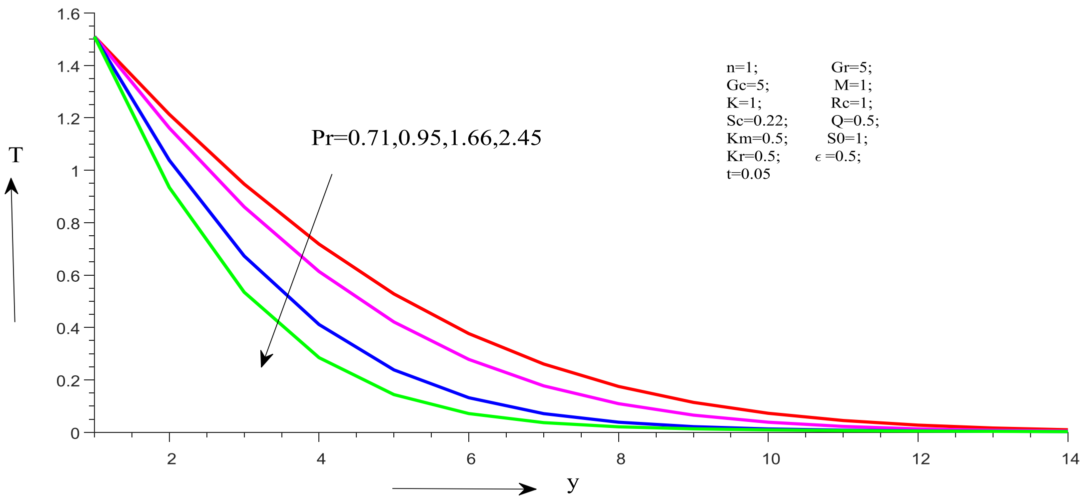

Fig 8:Effect of Prandtl number on T.

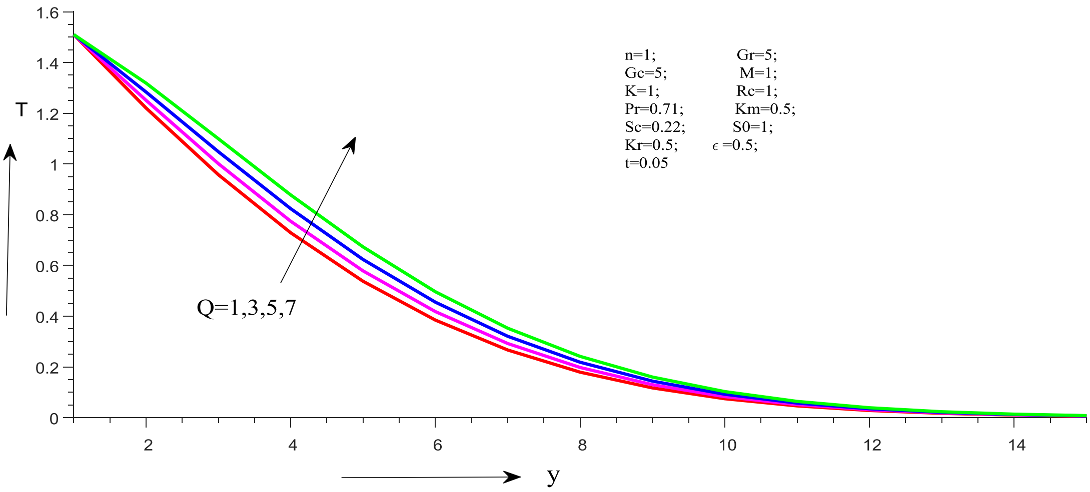

Fig 9:Effect of Heat source parameter on T.

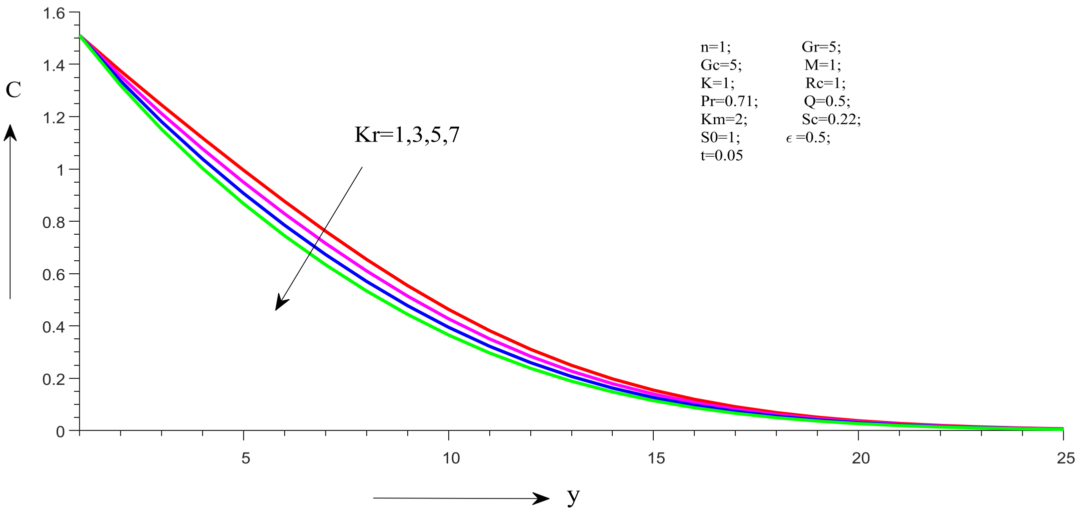

Fig 10:Effect of Chemical Reaction parameter on C

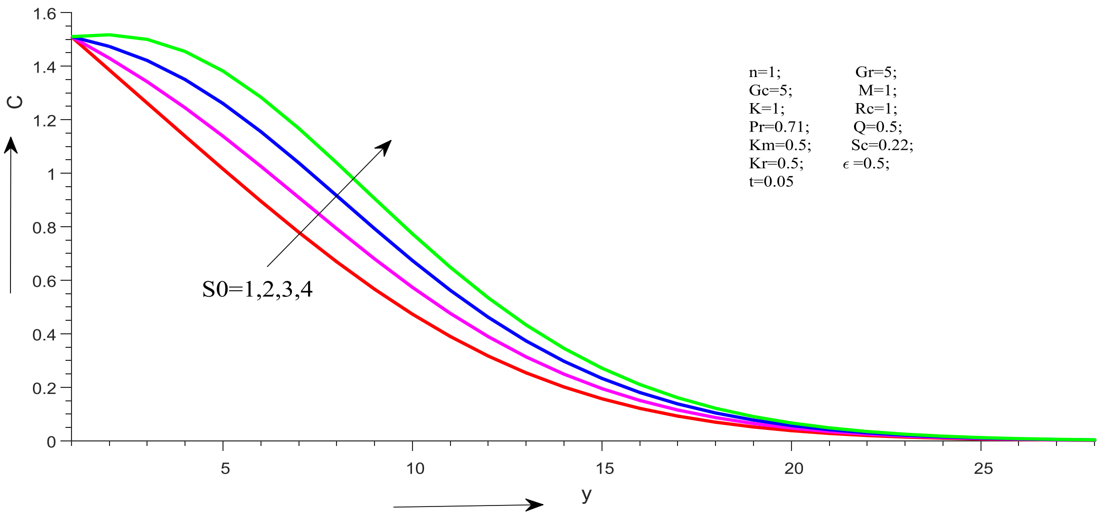

Fig 11:Effect of Soret number on C.

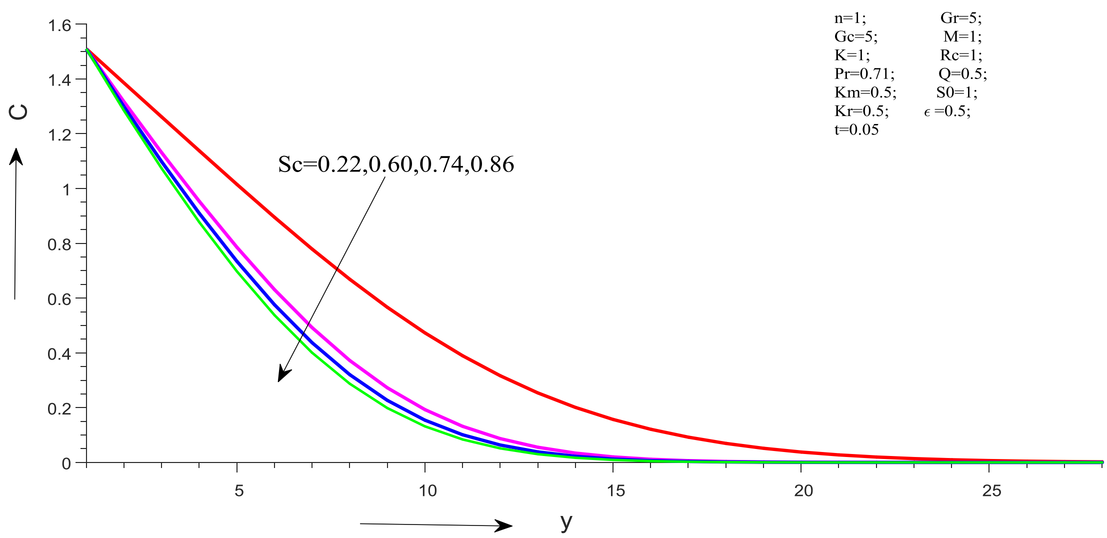

Fig 12:Effect of Schmidt number on C.

Table 1.Effect of various physical parameters on Skin friction

Gc	Gr	M	K	Rc	Km	Pr	Q	Kr	Sc	S0	**Skin Friction**
0.1	0.5	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1031**
0.2	0.5	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1195**
0.2	0.5	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1360**
0.1	1	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1890**
0.1	1.5	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.2762**
0.1	2	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.3628**
0.1	0.5	0.02	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1030**
0.1	0.5	0.50	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.0984**
0.1	0.5	0.94	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.0893**
0.1	0.5	0.01	2	1	0.1	0.3	0.3	0.5	0.22	1	**0.1142**
0.1	0.5	0.01	3	1	0.1	0.3	0.3	0.5	0.22	1	**0.1184**
0.1	0.5	0.01	4	1	0.1	0.3	0.3	0.5	0.22	1	**0.1207**

0.1	0.5	0.01	1	0.5	0.1	0.3	0.3	0.5	0.22	1	**0.1318**
0.1	0.5	0.01	1	0.75	0.1	0.3	0.3	0.5	0.22	1	**0.1154**
0.1	0.5	0.01	1	1	0.1	0.3	0.3	0.5	0.22	1	**0.1031**

Table 2. Effect of various physical parameters on Nusselt number and Sherwood number

Pr	Q	Km	Sc	SO	Kr	Nusselt Number	**Sherwood Number**
0.79	0.5	0.5	0.22	1	0.5	18.3717	**5.2710**
0.85	0.5	0.5	0.22	1	0.5	19.0066	**5.2710**
0.92	0.5	0.5	0.22	1	0.5	19.6765	**5.2710**
0.71	1	0.5	0.22	1	0.5	17.4179	**5.2710**
0.71	1.5	0.5	0.22	1	0.5	17.4113	**5.2710**
0.71	2	0.5	0.22	1	0.5	17.4047	**5.2710**
0.71	0.5	1	0.22	1	0.5	17.4082	**5.2710**
0.71	0.5	3	0.22	1	0.5	17.3431	**5.2710**
0.71	0.5	5	0.22	1	0.5	17.2780	**5.2710**
0.71	0.5	0.5	0.22	1	0.5	18.3717	**5.2710**
0.71	0.5	0.5	0.45	1	0.5	18.3717	**8.2768**
0.71	0.5	0.5	0.9	1	0.5	18.3717	**12.5727**
0.71	0.5	0.5	0.22	2	0.5	18.3717	**3.5911**
0.71	0.5	0.5	0.22	3	0.5	18.3717	**0.2754**
0.71	0.5	0.5	0.22	4	0.5	18.3717	**-3.0402**
0.71	0.5	0.5	0.22	1	1	18.3717	**5.2811**
0.71	0.5	0.5	0.22	1	1.5	18.3717	**5.2913**
0.71	0.5	0.5	0.22	1	2	18.3717	**5.3014**

Table 3: Comparison of our results with the results of Chandra Reddy et al. [43] in the absence of chemical reaction and radiation absorption

Results of Chandra Reddy et al. [43]		Results of the present study	
Sc	Sh	Sc	Sh
0.22	0.2201	0.22	0.22014
0.3	0.3001	0.3	0.3002
0.66	0.6601	0.66	0.6598
0.78	0.7802	0.78	0.7801

Nomenclature:

C^l	Species concentration
D	Molecular diffusivity
Gr	Grashof number of heat transfer
σ	Electrical conductivity
ω	Non-dimensional frequency of oscillation
	Non-dimensional Species concentration

K^1	Permeability of the medium	Gc	Grashof number for mass transfer
K	Thermal diffusivity	G	Acceleration due to gravity
Rc	Elastic parameter	K	Porosity parameter
Nu	Nusselt number	M	Magnetic parameter
S	Heat source parameter	B_0	Magnetic field of uniform strength
Sh	Sherwood number	Pr	Prandtl number
T	Non-dimensional temperature	Sc	Schmidt number
T	Non-dimensional time	T^1	Temperature of the field
U	Non-dimensional velocity	t^1	Time
v_o	Constant suction velocity	u^1	Velocity component along x-axis
Y	Non-dimensional distance along y-axis	V	Suction velocity
ε	A small positive constant	y^1	Distance along y-axis
B	Volumetric coefficient of expansion for heat transfer	P	Density of the fluid
		T	Skin friction
β^1	Volumetric coefficient of expansion with species concentration	ω^1	Frequency of oscillation
		S_o	Soret number
Y	Kinematic coefficient of viscosity	W	Condition on porous plate
Km	Radiation absorption parameter	Kr	Chemical reaction parameter

The effects of Prandtl number and heat source/sink parameter on the temperature are presented in figures 8 and 9 respectively. It is observed that there is a reduction in temperature with the increasing values of Pr. Figs. 11 and 12, the influence of Soret number and Schmidt number on the species concentration is presented. It is noticed that concentration boundary layer become thinner under the effect of Schmidt number where as it has enriched due to Soret effect. Effects of various physical parameters on skin friction are shown in table 1, Nusselt number and Sherwood number are shown in in table 2. It is observed that skin friction increases with an increase Gr, Gc and K. But reverse effect is noticed in the case of Rc and M. Nusselt number and Sherwood number increase with an increase in Pr, Kr and Sc but reverse effect is noticed in the case of K, M, Q and S_0.

V. CONCLUSIONS

In the present study the effect of thermal diffusion due to natural convection on MHD flow of a visco-elastic fluid past a porous plate with variable suction and heat source/sink is analyzed. The governing equations for the velocity field, temperature and concentration by perturbation technique in terms of dimensionless parameters. The findings of this study are as follows.

- Velocity increase as Gr, Gc, K, are increases and Velocity decrease in case of Rc and M increase.
- Temperature decrease as Pr increase but in the case of Km and Q temperature increase.
- The Concentration reduces with an increase in Sc, Kr but in the case of So it enhances.
- Skin friction increases with an increase of Gr, Gc, and K but a reverse effect is noticed in the case of M and Rc.
- Nusselt number increases as Pr increases but in the case of Q, Km it decreases.
- Sherwood number increases with an increase of Sc and Kr but a reverse effect is noticed in the case of S_0..

REFERENCES

[1] T. Hayat, M. Sajid, Analytic solution for axi-symmetric flow and heat transfer of a second grade fluid past a stretching sheet, Int. J. Heat Mass Transfer, 50 (2007) 75–84.

[2] M. Sajid, T. Hayat, Influence of thermal radiation on the boundary layer flow due to an

[3] exponentially stretching sheet, Int. Commun. Heat Mass Transfer 35 (2008) 347–356.

[4] B. Bidin, R. Nazar, Numerical solution of the boundary layer flow over an exponentially stretching sheet with thermal radiation, Eur. J. Sci. Res. 33 (4) (2009) 710–717.

[5] T. Akyildiz, D.A. Siginer, K. Vajravelu, J.R. Cannon, R.A. Van Gorder, Similarity solutions of the boundary layer equations for a nonlinearly stretching sheet, Math. Methods Appl. Sci. (2009), http://dx.doi.org/10.1002/mma.1181 (www.interscience.wiley.com).

[6] D. Pal, Mixed convection heat transfer in the boundary layer on an exponentially stretching surface with magnetic field, Appl. Math. Comput. 217 (2010) 2356–2369.

[7] B. Mamtha, M. C. Raju, S. V. K.Varma, Thermal diffusion effect on MHD mixed convection unsteady flow of a micro polar fluid past a semi-infinite vertical porous plate with radiation and mass transfer, International Journal of Engineering Research in Africa, Vol. 13 (2015) pp 21-37.

[8] A. Ishak, MHD boundary layer flow due to an exponentially stretching sheet with radiation effect,SainsMalaysiana, 40 (2011) 391–395.

[9] B. Sahoo, S. Poncet, Flow and heat transfer of a third grade fluid past an exponentially stretching sheet with partial slip boundary condition, Int. J. Heat Mass Transfer, 54 (2011) 5010– 5019.

[10] S. Mukhopadhyay, R.S.R. Gorla, Effects of partial slip on boundary layer flow past a permeable exponential stretching sheet in presence of thermal radiation, Heat Mass Transfer (2012), http://dx.doi.org/10.1007/s00231-012-1024-8.

[11] V. Ravikumar , M. C. Raju, G. S. S. Raju., MHD three dimensional Couette flow past a porous plate with heat transfer, IOSR Jour. Maths., Vol. 1, no.3, pp. 3-9, 2012.

[12] P. Singh, Jangid, N. S. Tomerand, D. Sinha, Effects of thermal radiation and magnetic field on unsteady stretching permeable sheet in presence of free stream velocity, International Journal of information and Mathematical Science, 6:3 (2010) 63-69.

[13] M. C. Raju, S. V. K. Varma, R. R. K. Rao, "Unsteady MHD free convection and chemically reactive flow past an infinite vertical porous plate", i-manager Journal of Future Engineering and Technology, Vol.8 (3), 2013, 35-40.

[14] M. Umamaheswar, S. V. K.Varma, M. C. Raju, "Unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and Ohmic heating", International journal of Advanced Science and Technology, Vol. 61, pp. 39-52, 2013. http://dx.doi.org/10.14257/ijast.2013.61.05

[15] M. Umamaheswar, M. C. Raju, S.V.K. Varma, Analysis of MHD transient free convection flow of a Newtonian fluid past an infinite vertical porous plate, Frontiers in Heat and Mass Transfer, 6 - 18 (2015). DOI: http://dx.doi.org/10.5098/hmt.6.18

[16] M. Umamaheswar, M. C. Raju and S. V. K. Varma, MHD convective heat and mass transfer flow of a Newtonian fluid past a vertical porous plate with chemical reaction, radiation absorption and thermal diffusion, International Journal of Engineering Research in Africa Vol. 19 (2016), 37-56.

[17] M. Umamaheswar, M. C. Raju, S. V. K. Varma, Effects of Time Dependent Variable Temperature and Concentration Boundary Layer on MHD Free Convection Flow Past a Vertical Porous Plate in the Presence of Thermal Radiation and Chemical Reaction, Int. J. Appl. Comput. Math.,Vol. 3 (2), 679-692. 2017

[18] M. Umamaheswar, S. V. K. Varma, M. C. Raju, A.J. Chamkha., Unsteady MHD Free Convective Double Diffusive Visco-Elastic Fluid Flow Past an Inclined Permeable Plate in the presence of viscous dissipation and heat absorption, Special topics and Reviews in Porous media: An international Journal., Vol.6 (4). 2016, pp. 333-342.

[19] M. Umamaheswar, M. C. Raju, S. V. K. Varma and J. G. Kumar., Numerical investigation of MHD free convection flow of a non-Newtonian fluid past an impulsively started vertical plate in the presence of thermal diffusion and radiation absorption, Alexandria Eng. J. (2016), 55 (3), 2005-2014.

[20] M. Umamaheswar, S. V. K. Varma, M. C. Raju, Numerical study of Magneto-Convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration in the presence of Soret and Dufour effects, IOSR Journal of Mathematics, Volume 12, Issue 2 Ver. I (Mar. -Apr.2016), PP 109-120.

[21] P. G. Reddy, M. Umamaheswar, M. C. Raju, S. V. K. Varma "Magneto-convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration", International Journal of Mathematics Trends and Technology, V31 (1):26-33 March 2016.

[22] M. C. Raju, S. V. K.Varma, A. J. Chamkha, "Unsteady free convection flow past a periodically accelerated vertical plate with Newtonian heating", International Journal of Numerical Methods for Heat and Fluid flow, 2016 Vol. 26 No. 7, 2016, pp. 2119-2138.

[23] V. Ravikumar, M.C.Raju and G.S.S.Raju, Heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source, Int. J. Contemp. Math. Sciences, 7 (2012) 1597 – 1604.

[24] S. K. Ghosh, G. C. Shit , Mixed Convection MHD flow of viscoelastic fluid in a porous medium past a hot vertical plate, 2 (2012) 5.

[25] Misra, J. C., Shit, G. C., Biomagnetic viscoelastic fluid flow over a stretching sheet ‖ , Applied Mathematics and Computation, 210 (2009) 350-361.

[26] S. Kapoor, P Alam, R. Gupta, L.M. Tiwari, S Aggarwal., Analytical study of MHD natural convective flow of incompressible fluid flow from a vertical flat plate in porous medium., IEEE conference proceeding., ICMSAO, (2011) 1-6

[27] C. H. Chen, Combined effects of Joule heating and viscous dissipation on MHD flow past a permeable, stretching surface with free convection and radiative heat transfer, ASME Journal of Heat Transfer, 132 (2010) 1-3.

[28] A.K. Singh and R. S. R. Gorla, Free convective heat and mass transfer with Hall current, Joule heating and thermal diffusion, Heat and Mass Transfer, 45 (2009) 1341-1349.

[29] P. C. Reddy., M. C. Raju, G. S. S. Raju. Thermal and Solutal Buoyancy Effect on MHD Boundary Layer Flow of a Visco-Elastic Fluid Past a Porous Plate with Varying Suction and Heat Source in the Presence of Thermal Diffusion. J Appl Computat Math, 4(5) (2015) 1-7.

[30] V. Ravikumar, M. C. Raju, G. S. S. Raju, Combined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate, Ain Shams Engineering Journal, (2014) 5 (3), 867–875.

[31] P. C. Reddy, M. C. Raju and G. S. S. Raju, Soret and Dufour effects on MHD free convection flow of Rivlin-Ericksen fluid past a semi-infinite vertical plate, Advances and Applications in Fluid Mechanics, 19 (2), 401-414, 2016.

[32] P. C. Reddy, M. C. Raju., G. S. S. Raju, C. M. Reddy, Diffusion thermo and thermal diffusion effects on MHD free convection flow of Rivlin- Ericksen fluid past a semi-infinite vertical plate, Bulletin of Pure and Applied Sciences. Vol.36E (Math & Stat.), No.2, 2017. P.266-284