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Thermal and solutal buoyancy effect on magnetohydrodynamics boundary layer flow of a Visco-elastic fluid past a porous plate with varying suction and heat source in the presence of thermal diffusion

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Abstract
An analytical solution is investigated for a fully developed free convective flow of a visco-elastic incompressible electrically conducting fluid past a vertical porous plate bounded by a porous medium in the presence of thermal diffusion, variable suction and variable permeability. A magnetic field of uniform strength is applied perpendicular to the plate and the presence of heat source is also considered. The novelty of the study is to investigate the effect of thermal diffusion on a visco-elastic fluid in the presence of time dependent variable suction. The importance is due to the applications of this kind of visco-elastic fluids in many industries. The coupled dimensionless non-linear partial differential equations are transformed into a set of ordinary differential equations by using multiple parameter perturbation on velocity whereas simple perturbation method on temperature and concentration. With corresponds to these, the expressions for skin friction, Nusselt number and Sherwood number are derived. The numerical computations have been studied through figures and tables. The presence of thermal diffusion increases fluid velocity, whereas the influence of the magnetic field reduces it. In the case of heavier species, it is noticed that concentration increases with an increase in Soret number.

Keywords: MHD, visco-elastic fluid, thermal diffusion, variable suction, variable permeability, vertical porous plate, heat and mass transfer

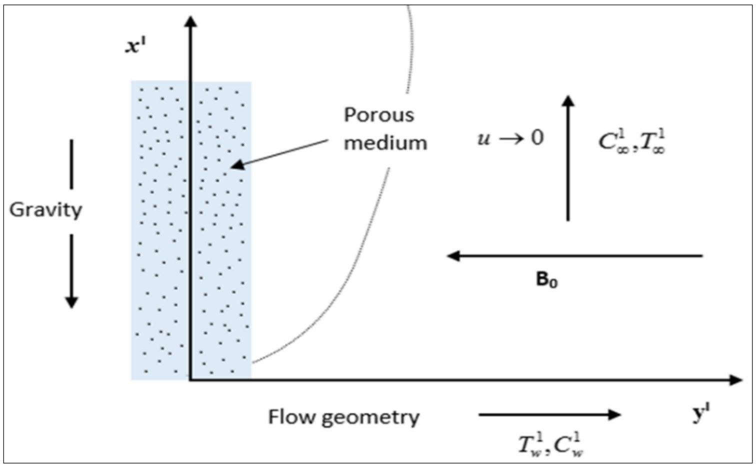
1. Introduction

The knowledge of visco-elastic fluids past a porous media plays vital role in many scientific and engineering applications. Most frequently this flow was basically utilized in the fields of petroleum engineering concerned with the oil, gas and water through reservoir to the hydrologist in the analysis of the migration of underground water. This process in chemical engineering is used for both purification and filtration. Its application is also found in the process of drug permeation through human skin. To recover the water for drinking and irrigation purposes the principles of this flow are followed. Natural convection flow over a vertical surface embedded in porous media also comes across in many engineering areas like the design of nuclear reactors, catalytic reactors, and compact heat exchangers, geothermal energy conversion, the use of fibrous materials, thermal insulation of buildings, heat transfer from storage of agricultural products which generate heat as a result of metabolism, petroleum reservoirs, nuclear wastes, etc. Many researchers [1-6] contributed in studying the application of visco-elastic fluid flow of several types past porous medium in channels of different cross-sections. Mohamad [7] studied the Soret effect on the unsteady magneto hydrodynamics (MHD) free convection heat and mass transfer flow past a vertical moving porous plate in a Darcy medium along with the chemical reaction and generation of heat. Appropriate solutions for a natural convection flow in porous media have been attained and presented by Combarnous and Bories [8], Catton [9], Bejan [10, 11], and Tien and Vafai [12]. Bejan and Khair [13] considered heat and mass transfer by natural convection in a porous medium. Nakayama and Koyama [14] employed an integral method for free convection from a vertical heated surface in a thermally stratified porous medium. The natural convection flow along a vertical heated surface through a porous medium has been analysed by Kaviany and Mittal [15]. Gupta and Sharma [16] attended to study MHD flow of viscous fluid past a porous medium enclosed by an oscillating porous plate in slip flow regime. Magneto hydro dynamic flow of a dusty visco-elastic fluid past a porous medium under the influence of an oscillating porous plate in slip flow regime is analyzed by Singh and Singh [17]. Ali *et al*. [18] paid attention towards the study of radiation effect on natural convection flow along a vertical surface in a gray gas. Chen [19] gave some conclusions on heat and mass transfer in MHD flow with natural convection along a permeable, inclined surface under the influence of variable wall temperature and concentration.

Ravi kumar *et al*. [20] investigated on MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. Reddy *et al*. [21] studied heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink. Raju *et al*. [22] contributed his efforts to study MHD thermal diffusion natural convection flow between heated inclined plates in porous medium. Raju *et al*. [23] put their attention towards Soret effects due to Natural convection between heated inclined plates with magnetic field. Reddy *et al*. [24] studied thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating. Seshaiah *et al*. [25] analyzed the effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source. Ibrahim and Makinde [26] attended a study on chemically reacting MHD boundary layer flow of heat and mass transfer over a moving vertical plate with suction. Kim [27] has considered an unsteady MHD convective heat transfer along a semi-infinite vertical porous moving plate with variable suction. Chemical reaction and radiation absorption effects on free convection flow through porous medium with variable suction in the presence of uniform magnetic field was studied by Sudheer Babu and Satyanarayana [28]. Das *et al*. [29] have considered and made a review on the mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under the influence of oscillatory suction and heat source. Mishra *et al*. [30] considered and pointed out the mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source. Uma *et al*. [31] discussed 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. Recently, Ravi *et al*. [32] studied combined effects of heat absorption and MHD on convective Rivlin-Ericksen fluid flow past a semi-infinite vertical porous plate with variable temperature and suction. Uma *et al*. [33] analyzed combined radiation and Ohmic heating effects on MHD free convective visco-elastic fluid flow past a porous plate with viscous dissipation. Chatterjee [34] investigated on heat transfer enhancement in laminar impinging flows with a non-Newtonian inelastic fluid. Tarun *et al*. [35] studied Laminar natural convection of power-law fluids in a square enclosure submitted from below to a uniform heat flux density. Mokarizadeh *et al*. [36] considered the influence of heat transfer in Couette-Poiseuille flow between parallel plates of the Giesekus viscoelastic fluid. Ferras *et al*. [37] found analytical solutions for Newtonian and inelastic non-Newtonian flows with wall slip. Ben Khelifa *et al*. [38] investigated natural convection in a horizontal porous cavity filled with a non-Newtonian binary fluid of power-law type. Motivate by the above studies, in this paper, a fully developed free convective flow of a visco-elastic incompressible electrically conducting fluid past a vertical porous plate bounded by a porous medium in the presence of thermal diffusion, variable suction and variable permeability is investigated.

2. Formulation of the problem

The unsteady free convection heat and mass transfer flow of a well-known non-Newtonian fluid, namely Walters B visco-elastic 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 $t^l \leq 0$, the plate as fluids are at the same temperature and concentration. When $t^l > 0$, the temperature of the plate is instantaneously raised to T_w^1 and the concentration of the species is set to C_w^1. Under the above assumption with usual Boussinesq's approximation, the governing equations and boundary conditions are given by.



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

$$\frac{\partial T^1}{\partial t^1} + v\frac{\partial T^1}{\partial y^1} = \mathrm{K}\frac{\partial^2 T^1}{\partial y^{1^2}} + S^1(T^1 - T_\infty) \tag{2}$$

$$\frac{\partial C^1}{\partial t^1} + v\frac{\partial C^1}{\partial y^1} = D\frac{\partial^2 C^1}{\partial y^{1^2}} + D_1\frac{\partial^2 T^1}{\partial y^{1^2}} \tag{3}$$

With the boundary conditions

$$\begin{aligned} &u = 0, T^1 = T_w + \varepsilon(T_w - T_\infty)e^{n^1t^1},\ C^1 = C_w + \varepsilon(C_w - C_\infty)e^{n^1t^1} \quad at\ y = 0 \\ &u \to 0, T^1 \to T_\infty, C^1 \to C_\infty \quad as \quad y \to \infty \end{aligned} \tag{4}$$

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

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

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

Where $v_0 > 0$ and $\varepsilon \ll 1$ are positive constants.
Introducing the non-dimensional quantities

$$\begin{aligned} &y = \frac{v_0 y^1}{\upsilon},\ t = \frac{v_0^2 t^1}{4\upsilon},\ w = \frac{4\upsilon w^1}{v_0^2},\ u = \frac{u^1}{v_0},\ T = \frac{T^1 - T_\infty}{T_w - T_\infty},\ C = \frac{C^1 - C_\infty}{C_w - C_\infty}, \\ &S = \frac{\upsilon S^1}{v_0^2},\ Kp = \frac{v_0^2 K_p^1}{\upsilon^2},\ \Pr = \frac{\upsilon}{\mathrm{K}},\ Sc = \frac{\upsilon}{D},\ M^2 = \frac{\sigma B_0^2 \upsilon}{\rho v_0^2},\ Rc = \frac{k_0 v_0^2}{\sigma \upsilon^2}, \\ &n = \frac{4\upsilon n^1}{v_0^2},\ Gc = \frac{\upsilon g \beta^1 (C_w - C_\infty)}{v_0^3},\ Gr = \frac{\upsilon g \beta (T_w - T_\infty)}{v_0^3},\ S_0 = \frac{D_1(T_w - T_\infty)}{\upsilon(C_w - C_\infty)}. \end{aligned} \tag{7}$$

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

$$\begin{aligned} \frac{1}{4}\frac{\partial u}{\partial t} - (1 + \varepsilon e^{nt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + GrT + GcC - M^2 u - \frac{u}{Kp(1 + \varepsilon e^{nt})} \\ - \frac{Rc}{4}\frac{\partial^3 u}{\partial t \partial y^2} + Rc(1 + \varepsilon e^{nt})\frac{\partial^3 u}{\partial y^3} \end{aligned} \tag{8}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - (1 + \varepsilon e^{nt})\frac{\partial T}{\partial y} = \frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2} + ST \tag{9}$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - (1 + \varepsilon e^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + S_0\frac{\partial^2 T}{\partial y^2} \tag{10}$$

With the boundary conditions

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

3. Solution of the problem

In view of the periodic suction, temperature and concentration at the plate let us assume the velocity, temperature, concentration at the neighborhood of the plate be

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{nt} \tag{12}$$

$$T(y,t) = T_0(y) + \varepsilon T_1(y)e^{nt} \tag{13}$$

$$C(y,t) = C_0(y) + \varepsilon C_1(y)e^{nt} \tag{14}$$

Inserting Eqs. (12) – (14) into the Eqs. (8) – (10) and by equating the harmonic and non-harmonic terms, the following set of equations are obtained.

$$Rc\,u_0^{111} + u_0^{11} + u_0^{1} - (M^2 + \frac{1}{Kp})u_0 = -GrT_0 - GcC_0 \tag{15}$$

$$Rc\,u_1^{111} + (1 - Rc\frac{n}{4})u_1^{11} + u_1^{1} - (M^2 + \frac{1}{Kp} + \frac{n}{4})u_1 = -GrT_1 - GcC_1 - \frac{u_0}{Kp} - u_0^{1} - Rcu_0^{111} \tag{16}$$

$$T_0^{11} + \Pr T_0^{1} + \Pr ST_0 = 0 \tag{17}$$

$$T_1^{11} + \Pr T_1^{1} + \Pr(S - \frac{n}{4})T_1 = -\Pr T_0^{1} \tag{18}$$

$$C_0^{11} + ScC_0^{1} = -ScS_0T_0^{11} \tag{19}$$

$$C_1^{11} + ScC_1^{1} - Sc\frac{n}{4}C_1 = -ScC_0^{1} - ScS_0T_1^{11} \tag{20}$$

The boundary conditions now reduce to the following form

$$\begin{aligned} &u_0 = u_1 = 0, \quad T_0 = T_1 = 1, \quad C_0 = C_1 = 1 \quad at \quad y = 0 \\ &u_0 = u_1 \to 0, \quad T_0 = T_1 \to 0, \quad C_0 = C_1 \to 0 \quad as \quad y \to \infty \end{aligned} \tag{21}$$

Eqs. (15) and (16), are of third order differential equations with two boundary conditions only. Hence the perturbation method has been employed using Rc (Rc≪ 1), the elastic parameter as the perturbation parameter.

$$u_0 = u_{00}(y) + R_c u_{01}(y) \tag{22}$$

$$u_1 = u_{10}(y) + R_c u_{11}(y) \tag{23}$$

Zeroth order equations

$$u_{00}^{11} + u_{00}^{1} - a_1 u_{00} = -G_r T_0 - G_c C_0 \tag{24}$$

$$u_{01}^{11} + u_{01}^{1} - a_1 u_{01} = -u_{00}^{111} \tag{25}$$

First order equations

$$u_{10}^{11} + u_{10}^{1} - a_2 u_{10} = -G_r T_1 - G_c C_1 - \frac{1}{K_p}u_{00} - u_{00}^{1} \tag{26}$$

$$u_{11}^{11} + u_{11}^{1} - a_2 u_{11} = -\frac{1}{K_p}u_{01} - u_{01}^{1} - u_{00}^{111} - u_{10}^{111} + \frac{n}{4}u_{10}^{11} \tag{27}$$

The corresponding boundary conditions are

$$\begin{aligned} &u_{00}=0,\ u_{01}=0,\ u_{10}=0,\ u_{11}=0 \qquad at \quad y=0 \\ &u_{00}=0,\ u_{01}=0,\ u_{10}=0,\ u_{11}=0 \qquad as \quad y \to \infty \end{aligned} \tag{28}$$

Solving these differential equations with the help of boundary conditions, we get

$$u(y,t)=A_{28}e^{-m_4 y}+A_{29}e^{-m_1 y}+A_{30}e^{-S_c y}+A_{31}e^{-m_5 y}+A_{32}e^{-m_2 y}+A_{33}e^{-m_3 y} \tag{29}$$

$$T(y,t)=A_{34}e^{-m_1 y}+A_{35}e^{-m_2 y} \tag{30}$$

$$C(y,t)=A_{36}e^{-S_c y}+A_{37}e^{-m_1 y}+A_{38}e^{-m_3 y}+A_{39}e^{-m_2 y} \tag{31}$$

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

$$\tau=\left.\frac{\partial u}{\partial y}\right|_{y=0}=-(m_4 A_{28}+m_1 A_{29}+ScA_{30}+m_5 A_{31}+m_2 A_{32}+m_3 A_{33}) \tag{32}$$

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

$$Nu=-\left.\frac{\partial T}{\partial y}\right|_{y=0}=m_1 A_{34}+m_2 A_{35} \tag{33}$$

Another important physical quantity is the mass transfer coefficient, i.e. the Sherwood number which is in non-dimensional form is given by

$$Sh=-\left.\frac{\partial C}{\partial y}\right|_{y=0}=ScA_{36}+m_1 A_{37}+m_3 A_{38}+m_2 A_{39} \tag{34}$$

3. Results and discussion

The present analysis is focused on the effect of heat and mass transfer on magnetohydro dynamic flow of a visco-elastic fluid through a porous medium with oscillatory suction and heat source to bring out the Soret effect due to natural convection. The general nature of the velocity profile is parabolic with picks near the plate. It is noticed that oscillatory behavior of the profile cannot be seen with the dominating effect of heat source. The outcomes of the present study are verified by comparing with that of Mishra *et al.* [30] and found to be in good agreement in the absence of thermal diffusion. Figures 1 & 2 exhibit the velocity profiles with the effect of Grashof number for heat and mass transfer. It is noticed that the fluid velocity increases and reaches its maximum over a short distance from the plate and then gradually reduce to zero under the increment of both the cases of Grashof number and modified Grashof number. This is due to the presence of thermal and solutal buoyancy which has the tendency of increase in velocity. The effect of Schmidt number on velocity is presented in figure 3, from this figure it is noticed that velocity decreases with the increasing values of Sc. Physically this is true as Schmidt number increases, viscosity of the fluid also increases that results a decrease in velocity. A similar effect is observed in the case of Prandtl number through figure 4. The effect of magnetic parameter on the fluid velocity is illustrated in the figure 5. This is due to the application of transverse magnetic field, which has the tendency of reducing the velocity. This drag force is called as Lorentz force. The effect of porosity parameter and heat source parameter and Soret number on velocity is displayed in figures 6, 7 and 8 respectively. It is seen that the velocity increases as the values of Kp, S and So increases.

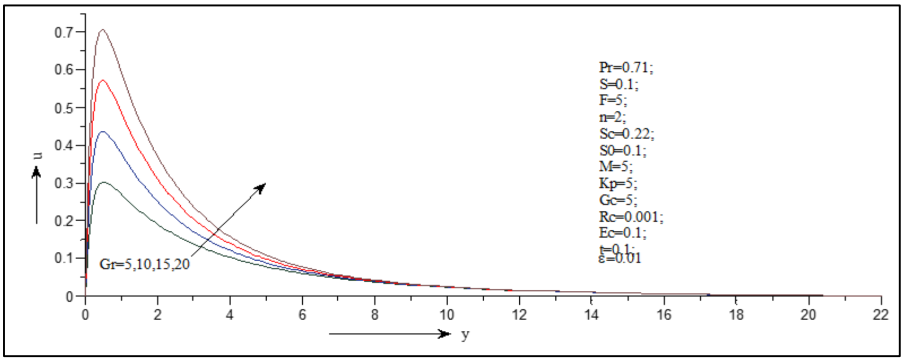


Fig 1: Effect of Grashof number for heat transfer on u

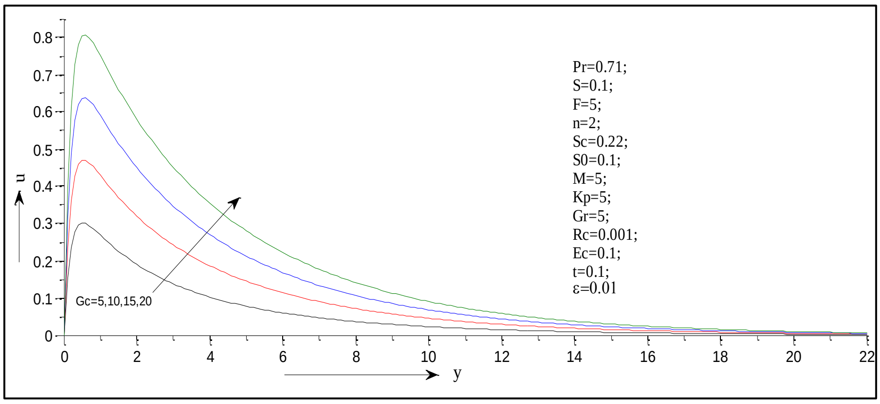


Fig 2: Effect of Grashof number for mass transfer on u

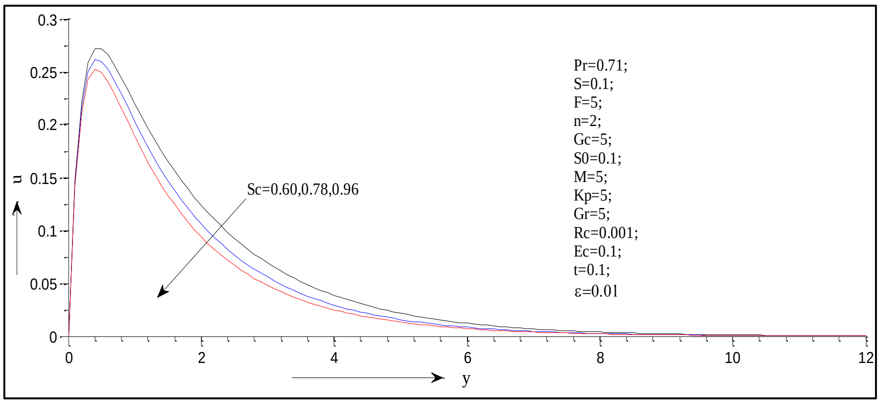


Fig 3: Effect of Schmidt number on u

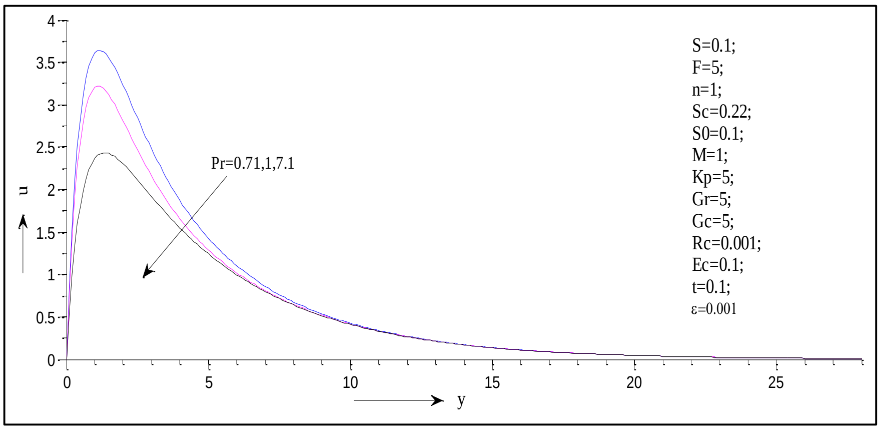


Fig 4: Effect of Prandtl number on u

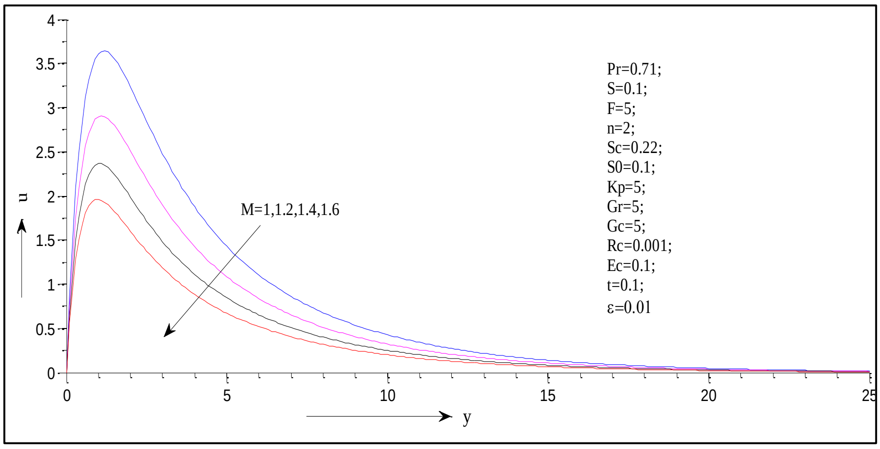


Fig 5: Effect of Magnetic parameter on u

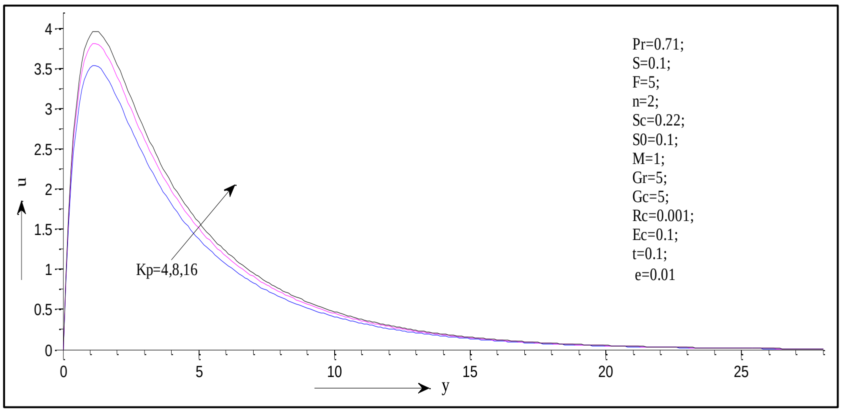


Fig 6: Effect of Porosity parameter on u

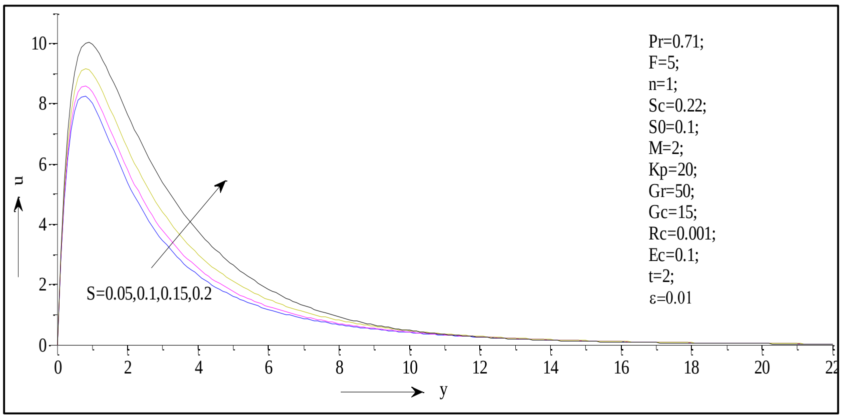


Fig 7: Effect of Heat source parameter on u

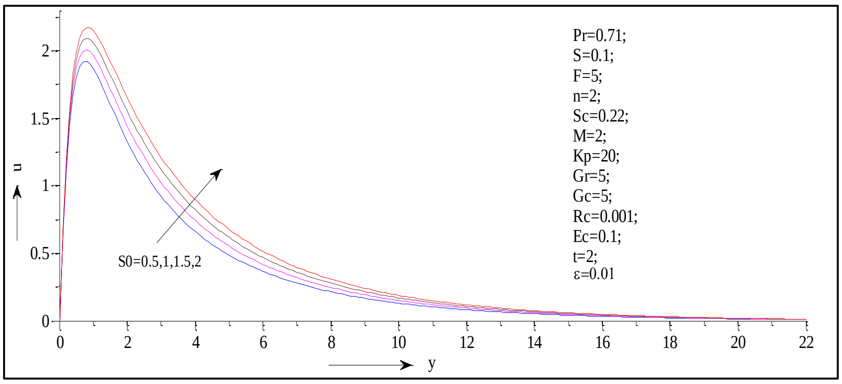


Fig 8: Effect of Soret number on u

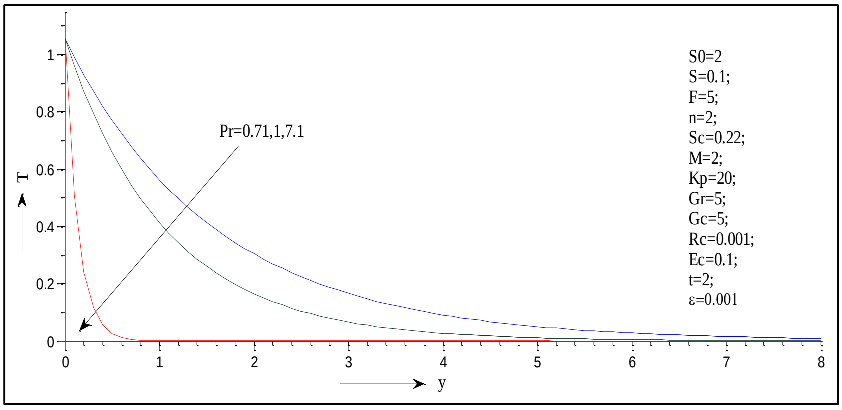


Fig 9: Effect of Prandtl number on T

The effects of prandtl number and heat source/sink parameter on the temperature are presented in the figures 9, 10 respectively. It is observed that there is a reduction of temperature with the increasing values of Pr where as the profiles of temperature rise for the enhancement values of S. Higher Prandtl number fluid causes lower thermal diffusivity which reduces the temperature at all points and hence the thickness of the thermal boundary layer. This result is in good agreement with Mishra *et al*. [30]. The presence of the heat source increases the fluid temperature. In figures 11 and 12, the influence of Schmidt number and Soret number on the species concentration is presented. It is noticed that concentration field become thinner under the effect of Schmidt number where as it has enriched due to the Soret effect. Effect of various physical parameters on Skin friction, Nusselt number and Sherwood number are shown in table1. It is observed that Skin friction increases with an increase of Gr, Gc and So but a reverse effect is noticed in the case of Sc, Pr and M.

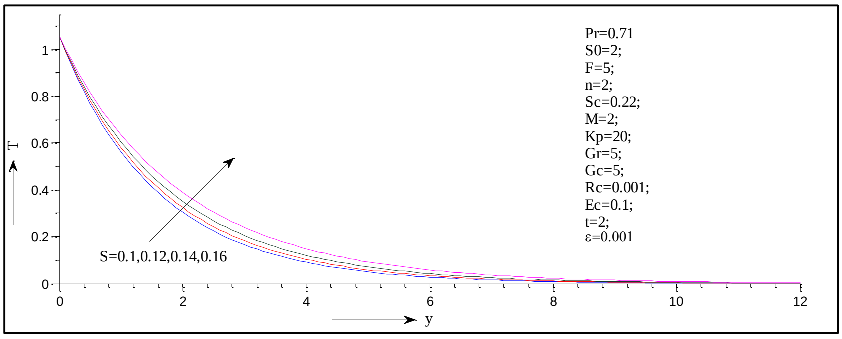


Fig 10: Effect of Heat source parameter on T

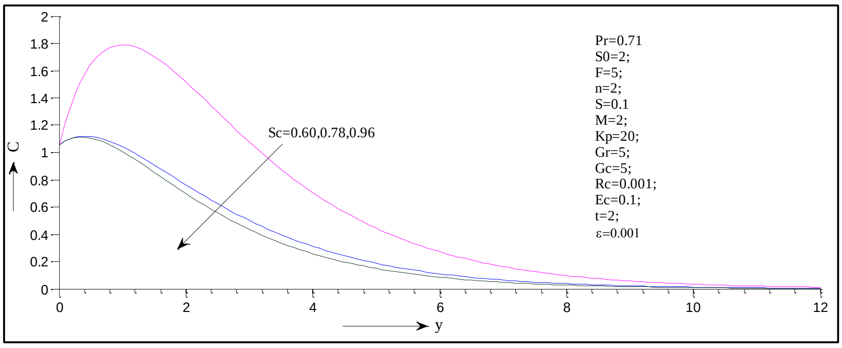


Fig 11: Effect of Schmidt number on C

4. Conclusion

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 increases as Gr, Gc and So increase whereas there is a reverse effect in case of Sc, Pr and M.
- The concentration reduces with an increase in Sc but in the case of So it enhances.
- Skin friction increases with an increase of Gr, Gc and So but a reverse effect is noticed in the case of Sc, Pr and M.
- Nusselt number increases as Pr increases but in the case of S it decreases.
- Sherwood number increases with an increase in Sc and S but a reverse effect is noticed in the case of Pr and So.

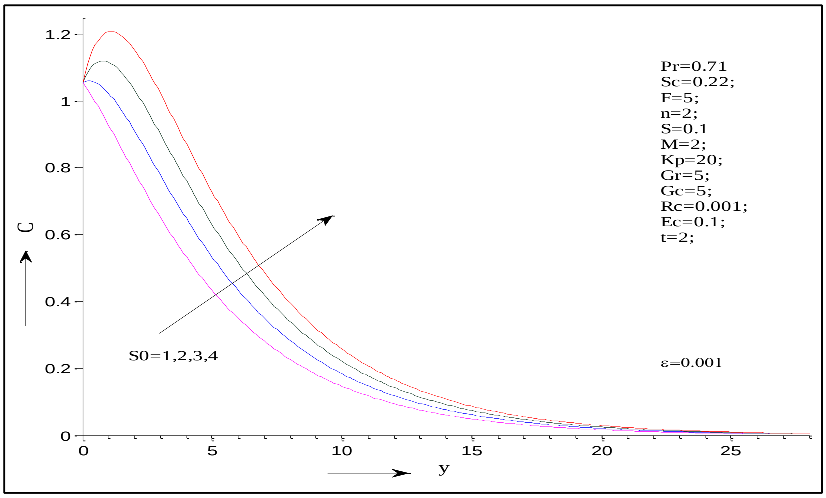


Fig 12: Effect of Soret number on C

Table 1: Effect of various physical parameters on Skin friction, Nusselt number and Sherwood number

Pr	Gr	Gc	Sc	M	Kp	S	S0	τ	Nu	Sh
0.71	5	5	0.22	5	5	0.05	0.1	2.0363	0.6742	0.2119
1	5	5	0.22	5	5	0.05	0.1	1.9857	0.9726	0.2052
7.1	5	5	0.22	5	5	0.05	0.1	1.5217	7.2233	0.0422
0.71	5	5	0.22	5	5	0.05	0.1	2.0363	0.6742	0.2119
0.71	10	5	0.22	5	5	0.05	0.1	3.0067	0.6742	0.2119
0.71	15	5	0.22	5	5	0.05	0.1	3.9743	0.6742	0.2119
0.71	20	5	0.22	5	5	0.05	0.1	4.9520	0.6742	0.2119
0.71	5	5	0.22	5	5	0.05	0.1	2.0363	0.6742	0.2119
0.71	5	10	0.22	5	5	0.05	0.1	3.0999	0.6742	0.2119
0.71	5	15	0.22	5	5	0.05	0.1	4.1657	0.6742	0.2119
0.71	5	20	0.22	5	5	0.05	0.1	5.2316	0.6742	0.2119
0.71	5	5	0.60	5	5	0.05	0.1	1.9614	0.6742	0.5755
0.71	5	5	0.78	5	5	0.05	0.1	1.9299	0.6742	0.7472
0.71	5	5	0.96	5	5	0.05	0.1	1.9006	0.6742	0.9194
0.71	5	5	0.22	1	5	0.05	0.1	9.2443	0.6742	0.2119
0.71	5	5	0.22	1.2	5	0.05	0.1	7.9651	0.6742	0.2119
0.71	5	5	0.22	1.4	5	0.05	0.1	6.9676	0.6742	0.2119
0.71	5	5	0.22	1.6	5	0.05	0.1	6.1760	0.6742	0.2119
0.71	5	5	0.22	1	4	0.05	0.1	9.0692	0.6742	0.2119
0.71	5	5	0.22	1	8	0.05	0.1	9.5267	0.6742	0.2119
0.71	5	5	0.22	1	16	0.05	0.1	9.7824	0.6742	0.2119
0.71	5	5	0.22	1	5	0.05	0.1	9.2443	0.6742	0.2119
0.71	5	5	0.22	1	5	0.1	0.1	9.4304	0.6076	0.2134
0.71	5	5	0.22	1	5	0.15	0.1	9.7326	0.5122	0.2156
0.71	5	5	0.22	1	5	0.2	0.1	10.2111	0.3719	0.2187
0.71	5	5	0.22	1	5	0.05	0.05	9.2149	0.6742	0.2194
0.71	5	5	0.22	1	5	0.05	0.1	9.2443	0.6742	0.2119
0.71	5	5	0.22	1	5	0.05	0.15	9.2737	0.6742	0.2045
0.71	5	5	0.22	1	5	0.05	0.2	9.3031	0.6742	0.1970

Table 2: Comparison of our results with the results of Mishra [30] in the absence of thermal diffusion

Results of Mishra *et al*. [30]		**Results of the present study**	
Sc	Sh	Sc	Sh
0.22	0.219095	0.22	0.2201
0.3	0.298966	0.3	0.3001
0.66	0.658814	0.66	0.6601
0.78	0.776574	0.78	0.7802

Nomenclature

C^1	Species concentration	σ	Electrical conductivity
D	Molecular diffusivity	ω	Non-dimensional frequency of oscillation
Gr	Grashof number of heat transfer	C	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	Kp	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^l	Time
v_o	Constant suction velocity	u^l	Velocity component along x-axis
y	Non-dimensional distance along y-axis	v	Suction velocity
ε	A small positive constant	y^l	Distance along y-axis
β	Volumetric coefficient of expansion for heat transfer	ρ τ	Density of the fluid Skin friction
β^1	Volumetric coefficient of expansion with species concentration	ω^1 S_o	Frequency of oscillation Soret number
υ	Kinematic coefficient of viscosity	w	Condition on porous plate

5. Appendix

$$a_1 = M^2 + \frac{1}{K_p} \qquad a_2 = M^2 + \frac{1}{K_p} + \frac{n}{4} \qquad m_1 = \frac{P_r + \sqrt{P_r^2 - 4P_r S}}{2}$$

$$m_2 = \frac{P_r + \sqrt{P_r^2 - 4P_r(S - \frac{n}{4})}}{2} \quad m_3 = \frac{S_c + \sqrt{S_c^2 + S_c n}}{2} \quad m_4 = \frac{1 + \sqrt{1 + 4a_1}}{2}$$

$$m_5 = \frac{1 + \sqrt{1 + 4a_2}}{2} \qquad A_1 = \frac{\Pr m_1}{m_1^2 - \Pr m_1 + \Pr(S - \frac{n}{4})} \qquad A_2 = \frac{-ScS0m_1^2}{m_1^2 - Scm_1}$$

$$A_3 = \frac{-4}{n} Sc(1 - A_2) \qquad A_4 = \frac{Scm_1 A_2 - ScS0m_1^2 A_2}{m_1^2 - Scm_1 - Sc\frac{n}{4}} \qquad A_5 = \frac{-ScS0m_2^2(1 - A_1)}{m_2^2 - Scm_2 - Sc\frac{n}{4}}$$

$$A_6 = 1 - (A_3 + A_4 + A_5) \qquad A_7 = \frac{-Gr - GcA_2}{m_1^2 - m_1 - a_1} \qquad A_8 = \frac{-Gc(1 - A_2)}{S_c^2 - Sc - a_1}$$

$$A_9 = -(A_7 + A_8) \qquad A_{10} = \frac{m_4^3 A_9}{m_4^2 - m_4 - a_1} \qquad A_{11} = \frac{m_1^3 A_7}{m_1^2 - m_1 - a_1}$$

$$A_{12} = \frac{S_C^3 A_8}{S_c^2 - Sc - a_1} \qquad A_{13} = -(A_{10} + A_{11} + A_{12}) \qquad A_{14} = A_{10} + A_{13}$$

$$A_{15} = \frac{-Gr(1 - A_1) - GcA_5}{m_2^2 - m_2 - a_2} \quad A_{16} = \frac{-GrA_1 - GcA_4 - \frac{1}{Kp}A_7 + m_1 A_7}{m_1^2 - m_1 - a_2} \quad A_{17} = \frac{-GcA_6}{m_3^2 - m_3 - a_2}$$

$$A_{18} = \frac{-GcA_3 - \frac{1}{Kp}A_8 + ScA_8}{S_c^2 - Sc - a_2} \quad A_{19} = \frac{-\frac{1}{Kp}A_9 + m_4 A_9}{m_4^2 - m_4 - a_2} \quad A_{20} = -(A_{15} + A_{16} + A_{17} + A_{18} + A_{19})$$

$$A_{21} = \frac{\frac{-1}{Kp}A_{14} + m_4 A_{14} + m_4^3 A_9 + m_4^3 A_{19} + \frac{n}{4} m_4^2 A_{19}}{m_4^2 - m_4 - a_2}$$

$$A_{22} = \frac{\frac{-1}{Kp}A_{11} + m_1 A_{11} + m_1^3 A_7 + m_1^3 A_{16} + \frac{n}{4} m_1^2 A_{16}}{m_1^2 - m_1 - a_2} \quad A_{23} = \frac{\frac{-1}{Kp}A_{12} + ScA_{12} + S_c^3 A_8 + S_c^3 A_{18} + \frac{n}{4} S_c^2 A_{18}}{S_c^2 - Sc - a_2}$$

$$A_{24} = \frac{m_5^3 A_{20} + \frac{n}{4} m_5^2 A_{20}}{m_5^2 - m_5 - a_2} \qquad A_{25} = \frac{m_2^3 A_{15} + \frac{n}{4} m_2^2 A_{15}}{m_2^2 - m_2 - a_2} \qquad A_{26} = \frac{m_3^3 A_{17} + \frac{n}{4} m_3^2 A_{17}}{m_3^2 - m_3 - a_2}$$

$$A_{27} = -(A_{21} + A_{22} + A_{23} + A_{24} + A_{25} + A_{26})$$

$$A_{28} = A_9 + RcA_{14} + \varepsilon A_{19}e^{nt} + \varepsilon RcA_{21}e^{nt}$$

$$A_{29} = A_7 + RcA_{11} + \varepsilon A_{16}e^{nt} + \varepsilon RcA_{22}e^{nt}$$

$$A_{30} = A_8 + RcA_{12} + \varepsilon A_{18}e^{nt} + \varepsilon RcA_{23}e^{nt}$$

$$A_{31} = \varepsilon A_{20}e^{nt} + \varepsilon Rc(A_{27} + A_{24})e^{nt}$$

$$A_{32} = \varepsilon A_{15}e^{nt} + \varepsilon RcA_{25}e^{nt}$$

6. References

1. Sudhakar B, Venkataramana S. MHD flow of visco elastic fluid past a permeable bed, Reg. Engg. Heat Mass Transfer. 1988; 10(3):221-246.
2. Chaudhary RC, Jain P. Hall effect on MHD mixed convection flow of a viscoelastic fluid past an infinite vertical porous plate with mass transfer and radiation, Theoretical and Applied Mechanics. 2006; 33:281-309.
3. Gouse Mohiddin S, Prasad VR, Varma SVK, Anwar Bég O. Numerical study of unsteady free convective heat and mass transfer in a walters-B viscoelastic flow along a vertical cone, Int. J of Appl. Math and Mech. 2010; 6(15):88-114.
4. Raptis AA, Takhar HS. Heat Transfer from Flow of an Elastico-Viscous Fluid, Int. comm. Heat and mass transfer. 1989; 16:193-917.
5. Singh AK. Heat source and radiation effects on magneto-convection flow of a viscoelasic fluid past a stretching sheet: Analysis with Kummer's functions, International Communications in Heat and Mass Transfer. 2008; 35:637-642.
6. Khan M, Hyder Ali S, Haitao Qi. On accelerated flows of a viscoelastic fluid with the fractional Burgers’ model, Nonlinear Analysis: Real World Applications. 2009; 10:2286-2296.
7. Mohamad RA. Double-diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effect, Applied Mathematical Sciences. 2009; 3(13):629-651.
8. Combarnous MA, Bories SA. Hydro-thermal convection in saturated porous media, Adv. Hydrosci. 1975; 10:231-307.
9. Catton I. Natural convection heat transfer in porous media, in: W. Aung, S. Kakac, S. Viskanta (Eds.), Natural Convection: Fundamentals and Applications, Hemisphere, New York, 1985.
10. Bejan A. The method of scale analysis: Natural convection in porous media, in: W. Aung, S. Kakac, S. Viskanta (Eds.), Natural Convection: Fundamentals and Applications, Hemisphere, Washington, DC, 1985, 548-572.
11. Bejan A. Convective heat transfer in porous media, in: S. Kakac, R.K. Shah, W. Aung (Eds.), Handbook of Single-Phase Convective Heat Transfer, Wiley, New York, 1987, Chapter 16.
12. CL Tien, Vafai K. Convective and radiative heat transfer in porous media, Adv. Appl. Mech. 1989; 27:225-281.
13. Bejan A, Khair KR. Heat and mass transfer by natural convection in a porous medium, Int. J Heat Mass Transfer. 1985; 29:909-918.
14. Nakayama A, Koyama H. An integral method for free convection from a vertical heated surface in a thermally stratified porous medium, Thermo-Fluid Dynamics. 1987; 21:297-300.
15. Kaviany M, Mittal M. Natural convection heat transfer from a vertical plate to high permeability porous media: An experiment and an approximate solution, Int. J. Heat Mass Transfer. 1987; 30:967-977.
16. Gupta M, Sharma S. MHD flow of viscous fluid through a porous medium bounded by an oscillating porous plate in slip flow regime, Acta Ciencia Indica. 1991; 17:389-394.
17. Singh NP, Singh AK, Singh RV. MHD flow of a dusty viscoelastic fluid through a porous medium near an oscillating porous plate in slip flow regime, The Math. Edu. 2000; 34:53-55.
18. Ali MM, Chen TS, Armaly BF. Natural Convection Radiation Interaction in Boundary Layer Flow over Horizontal Surfaces. AIAA Journal. 1984; .22(12):797-1803.
19. Chen CH. Heat and mass transfer in MHD flow by natural convection from a permeable, inclined surface with variable wall temperature and concentration, Acta. Mech. 2004; 172:219-235.
20. Ravikumar V, Raju MC, Raju GSS, Chamkha AJ. MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates”, International Journal of Energy & Technology. 2013; 5(4):1-8. (ISSN 2035-911X).
21. Reddy TS, Reddy OSP, Raju MC, Varma SVK. Heat transfer in hydro magnetic rotating flow of viscous fluid through non-homogeneous porous medium with constant heat source/sink, International journal of mathematical archive. 2012; 3(8):2964-2963, ISSN: 2229 5046.
22. Raju MC, Varma SVK, Ananda Reddy N. MHD Thermal diffusion Natural convection flow between heated inclined plates in porous medium, Journal on Future Engineering and Technology. 2011; 6(2):45-48.
23. Raju MC, Varma SVK, Reddy PV, Sumon Saha. Soret effects due to Natural convection between heated inclined plates with magnetic field, Journal of Mechanical Engineering. 2008; 39:43-48.
24. Ananda Reddy N, Varma SVK, Raju MC. Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating, Journal of Naval Architecture and Marine Engineering. 2009; 6:84-93.
25. Seshaiah B, Varma SVK, Raju MC. The effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source, International Journal of Scientific Knowledge. 2013; 3(2):13-24.
26. Ibrahim SY, Makinde OD. Chemically reacting MHD boundary layer flow of heat and mass transfer over a moving vertical plate with suction, Scientific Research and Essays. 2010; 5(19):2875-2882.
27. Kim JY. Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction,

Int. J. of Engineering Sciences. 2000; 38:833-845.
28. Sudheer Babu M, Satya Narayana PV. Effects of the chemical reaction and radiation absorption on free convection flow through porous medium with variable suction in the presence of uniform magnetic field, J.P. Journal of Heat and mass transfer. 2009; 3:219-234.
29. Das SS, Satapathy A, Das JK, Panda JP. Mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source, Int. J. Heat Mass Transfer. 2009; 52:5962-5969.
30. Mishra SR, Dash GC, Acharya M. Mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source, International Journal of Heat and Mass Transfer. 2013; 57:433-438.
31. Ravi Kumar V, Raju MC, Raju GSS. Combined effects of Heat absorption and MHD on Convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction, Ain Shams Engineering Journal. 2014; 5(3):867-875.
32. Umamaheswar M, Varma SVK, Raju MC. 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. 2013; 61:39-52.
33. Umamaheswar M, Varma SVK, Raju MC. Combined radiation and Ohmic heating effects on MHD free convective visco-elastic fluid flow past a porous plate with viscous dissipation, International journal of current engineering and technology. 2013; 3(5):1636-1640.
34. Chatterjee A. Heat transfer enhancement in laminar impinging flows with a non-Newtonian inelastic fluid, Journal of Non-Newtonian Fluid Mechanics. 2014; 211:50-61.
35. Turan O, Lai J, Poole RJ, Chakraborty N. Laminar natural convection of power-law fluids in a square enclosure submitted from below to a uniform heat flux density, Journal of Non-Newtonian Fluid Mechanics. 2013; 199, 1-96, 80-95.
36. Mokarizadeh H, Asgharian M, Raisi A. Heat transfer in Couette-Poiseuille flow between parallel plates of the Giesekus viscoelastic fluid, Journal of Non-Newtonian Fluid Mechanics. 2013; 196, 1-112, 95-101.
37. Ferrás LL, Nóbrega JM, Pinho FT. Analytical solutions for Newtonian and inelastic non-Newtonian flows with wall slip, Journal of Non-Newtonian Fluid Mechanics, 2012, 175-176, 76-88.
38. Ben Khelifa N, Alloui Z, Beji H, Vasseur P. Natural convection in a horizontal porous cavity filled with a non-Newtonian binary fluid of power-law type, Journal of Non-Newtonian Fluid Mechanics. 2012; 169-170, 15-25.