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# CHEMICAL REACTION AND THERMO-DIFFUSION EFFECTS ON HYDROMAGNETIC FREE CONVECTIVE WALTER'S MEMORY FLOW WITH CONSTANT SUCTION AND HEAT SINK

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***ABSTRACT***

*An attempt to study the effect of thermo diffusion on unsteady hydromagnetic free convective memory flow of incompressible and electrically conducting fluid with chemical reaction gain importance and attention in recent years. In view of this, the main object of the present investigation is to study the effects of chemical reaction and thermo-diffusion on hydromagnetic free convective fluid flow past an infinite vertical plate in the presence of heat sink. In the course of analysis it is assumed that the magnetic field of uniform strength is applied and induced magnetic field is neglected and also we observe that how various parameters affect the flow past an infinite vertical plate.*

***Keywords**: Chemical Reaction, Memory flow fluid, Constant suction, Heat Sink.*

## 1. INTRODUCTION

The heat and mass transfer with chemical reaction, have lot of application industrial process the problem received considerable attention in recent years in the processes involving drying, evaporation at the surface of the a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and the mass transfer occur simultaneously.

Dekha *et al.* [10] examined the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past a vertical plate with a constant heat and mass transfer. Muthucumaraswamy [23] presented the heat and mass transfer effects on a continuously moving isothermal vertical surface with uniform suction by taking into account the homogeneous chemical reaction of first order.

Viscoelastic flows arise in numerous processes in chemical engineering systems. Such flows possess both viscous and elastic properties and can exhibit normal stresses and relaxation effects.

An extensive range of mathematical models has been developed to simulate the diverse hydrodynamic behavior of these non-Newtonian fluids. An eloquent exposition of viscoelastic fluid models has been presented by Joseph [17]. Examples of such models are the Oldroyd model [24], Johnson-Seagalman model [28], the upper convected Maxwell model [31] and the Walter-B model [42].

Both steady and unsteady flows have been investigated at length in a diverse range of geometric using a wide spectrum of analytical and computational methods. Siddappa and Khapate [36] studied the second order Rivlin-Erickson viscoelastic boundary layer flow along a stretching surface. Rochelle and Peddieson [32] used an implicit difference scheme to analyze the steady boundary-layer flow of a nonlinear Maxwell viscoelastic fluid past a parabola and a paraboloid. Rao and Finlayson [29] used an adaptive finite element technique to analyze viscoelastic flow of a Maxwell fluid.

Abel *et al.* [3] investigated the non-Newtonian viscoelastic boundary layer flow of Walter's liquid-B past a stretching sheet, taking account of non-uniform heat source and frictional heating, Abel and Nandeppanavar [2] effects of non-uniform heat source on MHD flow of viscoelastic fluid of Walter's liquid-B. Abel and Nandeppanavar [1] have investigated the effects of heat transfer in MHD viscoelastic boundary layer flow over a stretching sheet with non-uniform heat source/sink. Gireesh Kumar and Satyanarayana [12] have examined the mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink.

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Pillai *et al.* [25] investigated the effects of work done by deformation in viscoelastic fluid in porous media with uniform heat source, Hayat *et al.* [14] also investigated the effects of work done by deformation in second grade fluid with partial slip condition in this no account of heat source has been taken into consideration and Khan *et al.* (20) also investigated the effects of work done by deformation in Walter's liquid-B but with uniform heat source. Sharma *et al.* [34] have analyzed the Rayleigh-Taylor instability of Walter'B elastic-viscous fluid through porous medium. Thermosolutal instability of Walter's (model-B) visco-elastic rotating fluid permitted with suspended particles and variable gravity field in porous medium was studied by Sharma and Rana [35]. Kesavaiah *et al.* [19] investigated effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction.

The requirements of modern technology have stimulated interest in fluid flow studies which involve the interaction of several phenomena. One such study is related to the effects of free convective flow with mass transfer, which plays an important role in geophysical sciences, astrophysical sciences and in cosmical studies. In view of these applications several researchers [6, 11, 22, 27, 38] have given much attention towards free convecting flows of viscous incompressible fluids past an infinite plate.

In this paper, we make an attempt to study the effect of thermo diffusion on unsteady hydromagnetic free convective memory flow of incompressible and electrically conducting fluid with chemical reaction gain importance and attention in recent years. In view of this, the main object of the present investigation is to study the effects of chemical reaction and thermo-diffusion on hydromagnetic free convective fluid flow past an infinite vertical plate in the presence of heat sink. In the course of analysis it is assumed that the magnetic field of uniform strength is applied and induced magnetic field is neglected and also we observe that how various parameters affect the flow past an infinite vertical plate.

## 2. FORMULATION OF THE PROBLEM

We consider an unsteady hydromagnetic, chemically reacting, free convective flow of incompressible and electrically conducting fluid past an infinite vertical porous plate in the presence of constant suction and heat absorbing sink. Let $x'$ - axis be taken in the vertically upward direction along the infinite vertical plate and $y'$ - axis normal to it. The magnetic field of uniform strength is applied and induced magnetic field is neglected. Boussineq's approximation, for the equations of the flow is governed as:

Continuity equation

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

Momentum equation

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = g\beta(T'-T'_\infty) + g\beta^*(C'-C'_\infty) + \upsilon\frac{\partial^2 u'}{\partial y'^2} - B_1\left(\frac{\partial^3 u'}{\partial t'\,\partial u'^2} + v'\frac{\partial^3 u'}{\partial y'^3}\right) - \sigma B_0^2\frac{u}{\rho} \tag{2}$$

Energy Equation

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = K\frac{\partial^2 T'}{\partial y'^2} + \mathrm{S}(T'-T'_\infty) + \frac{\upsilon}{C_P}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{3}$$

Diffusion equation

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - \mathrm{K}'_\mathrm{r}(C'-C'_\infty) + K_{11}\left(\frac{\partial^2 T'}{\partial y'^2}\right) \tag{4}$$

From (1) we have

$$v' = -v_0 \tag{5}$$

On disregarding the Joulean heat dissipation, the boundary conditions of the problem are:

$$\left.\begin{array}{lll} y'=0:\ u'=0, & T' = T'_\infty + \varepsilon(T'_w - T'_\infty)e^{i\omega' t'}, & C' = C'_\infty + \varepsilon(C'_w - C'_\infty)e^{i\omega' t'} \\ y'\to\infty:\ u'\to 0, & T'\to T'_\infty & C'\to C'_\infty \end{array}\right\} \tag{6}$$

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional quantities are introduced

$$\left.\begin{array}{l} y=\dfrac{y'v_0}{\upsilon},\quad t=\dfrac{t'v_0^2}{4\upsilon},\quad w=\dfrac{4\upsilon\omega'}{v_0^2},\quad \upsilon=\dfrac{\eta_0}{\rho},\quad \Pr=\dfrac{v}{K} \\ S=\dfrac{4S'\upsilon}{v_0^2},\quad M=\dfrac{\sigma B_0^2\upsilon}{\rho v_0^2},\quad K=\dfrac{K_0}{\rho C_P},\quad T=\dfrac{(T'-T'_\infty)}{(T'_w-T'_\infty)}, \\ C=\dfrac{(C'-C'_\infty)}{(C'_w-C'_\infty)},\quad Kr=\dfrac{K'_r\upsilon}{v_0^2},\quad Sc=\dfrac{\upsilon}{D} \\ Gr=\dfrac{\upsilon g\beta(T'_w-T'_\infty)}{v_0^3},\quad Gc=\dfrac{\upsilon g\beta^*(C'_w-C'_\infty)}{v_0^3},\quad Ec=\dfrac{v_0^2}{C_p(T'_w-T'_\infty)} \end{array}\right\} \tag{7}$$

$$Sr=\frac{K_{11}\Delta T}{\upsilon\Delta C},\quad R_m=\frac{B_1v_0^2}{\upsilon^2}$$

In view of the equation (7) the equations (2), (3) and (4) reduced to the following non-dimensional form

$$\frac{1}{4}\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}=Gr(T+N\,C)+\frac{\partial^2 u}{\partial y^2}-R_m\left[\frac{1}{4}\frac{\partial^3 u}{\partial t\partial y^2}-\frac{\partial^3 u}{\partial y^3}\right]-Mu \tag{8}$$

$$\frac{\Pr}{4}\frac{\partial T}{\partial t}-\Pr\frac{\partial T}{\partial y}=\frac{\partial^2 T}{\partial y^2}+\frac{\Pr ST}{4}+\Pr Ec\left(\frac{\partial u}{\partial y}\right)^2 \tag{9}$$

$$\frac{Sc}{4}\frac{\partial C}{\partial t}-Sc\frac{\partial C}{\partial y}=\frac{\partial^2 C}{\partial y^2}-KrScC+ScSr\frac{\partial^2 T}{\partial y^2} \tag{10}$$

The following boundary conditions are:

$$\left.\begin{array}{llll} y=0: & u=0, & T=1+\varepsilon e^{i\omega t}, & C=1+\varepsilon e^{i\omega t} \\ y\to\infty: & u\to 0, & T\to 0, & C\to 0 \end{array}\right\} \tag{11}$$

## 3. SOLUTION OF THE PROBLEM

Equations (8), (9) and (10) are coupled, non-linear partial differential equations and these cannot be solved in closed form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the plate as:

$$\left.\begin{array}{l} u(y,t)=u_0(y)+\varepsilon e^{i\omega t}u_1(y) \\ T(y,t)=T_0(y)+\varepsilon e^{i\omega t}T_1(y) \\ C(y,t)=C_0(y)+\varepsilon e^{i\omega t}C_1(y) \end{array}\right\} \tag{12}$$

where $u_0$, $T_0$ and $C_0$ are mean velocity, mean temperature and mean concentration. Substituting (12) in equations (8), (9) and (10), equating harmonic and non-harmonic terms for mean velocity, mean temperature and mean concentration, after neglecting coefficient of $\varepsilon^2$, we get

Zero order of ε

$$R_m u_0'''+u_0''+u_0'-Mu_0=-Gr[T_0+NC_0] \tag{13}$$

$$T_0''+\Pr T'_0+\frac{\Pr ST_0}{4}=-\Pr Ec(u_0')^2 \tag{14}$$

$$C_0''+ScC_0'-KrScC_0=-ScSrT_0'' \tag{15}$$

First order of ε

$$R_m u_1''' + u_1'' + u_1' - Mu_1 = -Gr[T_1 + NC_1] \tag{16}$$

$$T_1'' + \Pr T'_1 + \frac{\Pr(S - i\omega)T_1}{4} = -2\Pr Ecu_0' u_1' \tag{17}$$

$$C_1'' + ScC_1' - \left(Kr - \frac{i\omega}{4}\right)ScC_1 = -ScSrT_1'' \tag{18}$$

The equations (13) and (16) are third order differential equations due to presence of elasticity.

Therefore $u_0$ and $u_1$ are expanded using Beard and Walters rule [1964]

$$u_0 = u_{00} + R_m u_{01} \tag{19}$$

$$u_1 = u_{10} + R_m u_{11} \tag{20}$$

Zero order of $R_m$

$$u_0'' + u_{00}' - Mu_{00} = -Gr[T_0 + NC_0] \tag{21}$$

$$u_{10}'' + u_{10}' - \left(M - \frac{i\omega}{4}\right)u_{10} = -Gr[T_1 + NC_1] \tag{22}$$

First order of $R_m$

$$u_{01}'' + u_{01}' - Mu_{01} = -u_{00}''' \tag{23}$$

$$u_{11}'' + u_{11}' - \left(M - \frac{i\omega}{4}\right)u_{11} = -u_{10}''' \tag{24}$$

Using the multi-parameter perturbation technique and assuming Ec<<1, we write

$$u_{00} = u_{000} + Ec\, u_{001} \tag{25}$$

$$u_{01} = u_{011} + Ec\, u_{012} \tag{26}$$

$$u_{10} = u_{100} + Ec\, u_{101} \tag{27}$$

$$u_{11} = u_{111} + Ec\, u_{112} \tag{28}$$

$$T_0 = T_{00} + Ec\, T_{01} \tag{29}$$

$$T_1 = T_{10} + Ec\, T_{11} \tag{30}$$

$$C_0 = C_{00} + Ec\, C_{01} \tag{31}$$

$$C_1 = C_{10} + Ec\, C_{11} \tag{32}$$

Using equations (25) to (32) in the equations (14), (15), (17), (18), (21), (22), (23), and (24) and equating the coefficient of $Ec^0$ and $Ec^1$, we get the following set of differential equations:

Zero order of Ec

$$u_{000}'' + u_{000}' - Mu_{000} = -Gr[T_{00} + NC_{00}] \tag{33}$$

$$u_{011}'' + u_{011}' - Mu_{011} = -u_{000}''' \tag{34}$$

$$u_{100}'' + u_{100}' - \left(M - \frac{i\omega}{4}\right)u_{100} = -Gr[T_{10} + NC_{10}] \tag{35}$$

$$u''_{111} + u'_{111} - \left( M - \frac{iw}{4} \right) u_{111} = -u'''_{100} \tag{36}$$

$$T''_{00} + \Pr T'_{00} + \frac{\Pr S}{4} T_{00} = 0 \tag{37}$$

$$T''_{10} + \Pr T'_{10} + \frac{\Pr(S - i\omega)}{4} T_{10} = 0 \tag{38}$$

$$C''_{00} + ScC'_{00} - KrScC_{00} = -ScSrT''_{00} \tag{39}$$

$$C''_{10} + ScC'_{10} - \left( Kr - \frac{i\omega}{4} \right) ScC_{10} = -ScSrT''_{10} \tag{40}$$

First order of Ec

$$u''_{001} + u'_{001} - Mu_{001} = -Gr[T_{01} + NC_{01}] \tag{41}$$

$$u''_{012} + u'_{012} - Mu_{012} = -u'''_{001} \tag{42}$$

$$u''_{101} + u'_{101} - \left( M - \frac{i\omega}{4} \right) u_{101} = -Gr[T_{11} + NC_{11}] \tag{43}$$

$$u''_{112} + u'_{112} - \left( M - \frac{i\omega}{4} \right) u_{112} = -u'''_{101} \tag{44}$$

$$T''_{01} + \Pr T'_{01} + \frac{\Pr S}{4} T_{01} = -\Pr (u'_{000})^2 \tag{45}$$

$$T''_{11} + \Pr T'_{11} + \frac{\Pr(S - i\omega)}{4} T_{11} = -2\Pr u'_{000} u'_{100} \tag{46}$$

$$C''_{01} + ScC'_{01} - KrScC_{01} = -ScSrT''_{01} \tag{47}$$

$$C''_{11} + ScC'_{11} - \left( Kr - \frac{i\omega}{4} \right) ScC_{11} = -ScSrT''_{11} \tag{48}$$

The corresponding boundary conditions are:

$$\left.\begin{aligned} & y = 0: \\ & u_{000} = u_{001} = u_{011} = u_{012} = u_{100} = u_{101} = u_{111} = u_{112} = 0 \\ & T_{00} = 1,\ T_{01} = 0,\ T_{10} = 1,\ T_{11} = 0,\ C_{00} = 1,\ C_{01} = 0,\ C_{10} = 1,\ C_{11} = 0 \\ & y \to \infty: \\ & u_{000} \to u_{001} \to u_{011} \to u_{112} \to u_{100} \to u_{101} \to u_{111} \to u_{112} \to 0 \\ & T_{00} \to 0,\ T_{01} \to 0,\ T_{10} \to 0,\ T_{11} \to 0,\ C_{00} \to 0,\ C_{01} \to 0,\ C_{10} \to 0,\ C_{11} \to 0 \end{aligned}\right\} \tag{49}$$

The differential equations (33) to (48) have been solved subject to boundary conditions (49).

## 4. NUSSELT NUMBER AND SHERWOOD NUMBER

Local rate of heat transfer across the walls (Nusselt Number) is given by

$$(Nu)_{y=0} = \left( \frac{\partial T}{\partial y} \right)_{y=0}$$

$$Nu = \Big[ \{ (-m_1) + Ec(-m_1 a_7 - 2m_3 a_8 - 2m_2 a_9 - 2m_1 a_{10} - (m_2 + m_3)a_{11} - (m_1 + m_2)a_{12} - (m_1 + m_3)a_{13} )\}$$
$$+\varepsilon e^{i\omega t} \{ (-m_4) + Ec(-m_4 a_{51} - (m_3 + m_6)a_{52} - (m_3 + m_5)a_{53} - (m_3 + m_4)a_{54} - (m_2 + m_6)a_{55} - (m_2 + m_5)a_{56}$$
$$-(m_2 + m_4)a_{57} - (m_1 + m_6)a_{58} - (m_1 + m_5)a_{59} - (m_1 + m_4)a_{60} ) \} \Big]$$

The rate of mass transfer across the walls (Sherwood Number) is given by

$$(Sh)_{y=0} = \left( \frac{\partial C}{\partial y} \right)_{y=0}$$

$$Sh = \Big[ \{ (-m_2(1 - a_3) - m_1 a_3) + Ec(-m_2 a_{14} - m_1 a_{15} - 2m_3 a_{16} - 2m_2 a_{17} - 2m_1 a_{18}$$
$$-(m_2 + m_3)a_{19} - (m_1 + m_2)a_{20} - (m_1 + m_3)a_{21} )\}$$
$$+\varepsilon e^{i\omega t} \{(-m_5(1 - a_{47}) - m_4 a_{47}) + Ec(-m_5 a_{61} - m_4 a_{62} - (m_3 + m_6)a_{63} - (m_3 + m_5)a_{64}$$
$$-(m_3 + m_4)a_{65} - (m_2 + m_6)a_{66} - (m_2 + m_5)a_{67} - (m_2 + m_4)a_{68}$$
$$-(m_1 + m_6)a_{69} - (m_1 + m_5)a_{70} - (m_1 + m_4)a_{71} )\}\Big]$$

## 5. RESULTS AND DISCUSSION

In this analysis we investigate the effect of Chemical reaction and Thermo diffusion on convective heat and mass transfer flow of a viscous, electrically conducting fluid past a porous vertical plate in the presence of heat absorbing sink. The non-linear coupled equations governing the flow, heat and mass transfer are solved by employing multi-parameter perturbation technique.

The axial velocity (u) is shown in figures 1-6 for different values of M, N, Sc, Kr, Sr and S.

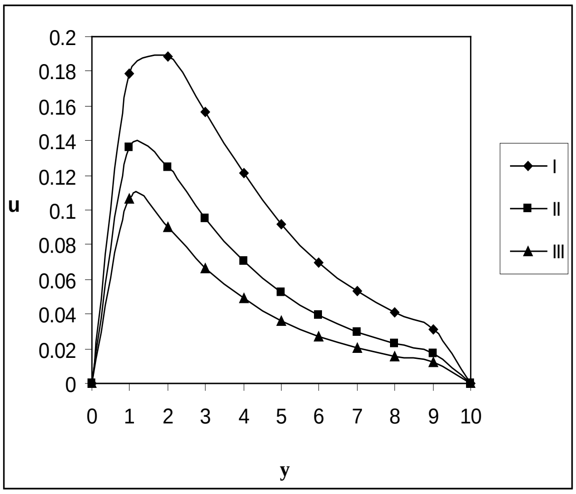


Fig. 1 : Variation of u with M

| | I | II | III |
|---|---|---|---|
| M | 2.3 | 4.3 | 6.3 |

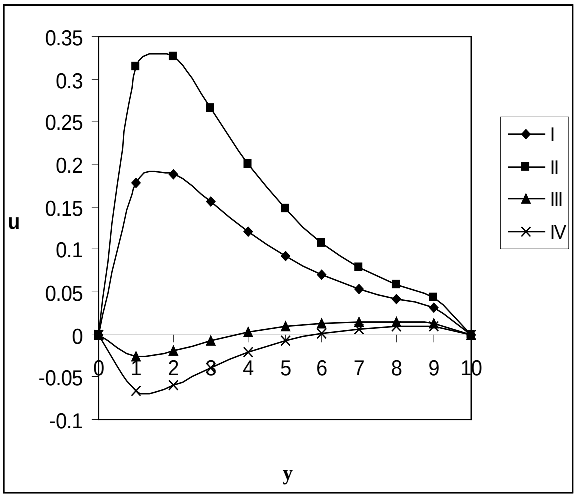


Fig. 2 : Variation of u with N

| | I | II | III | IV |
|---|---|---|---|---|
| N | 1 | 2 | -0.5 | -0.8 |

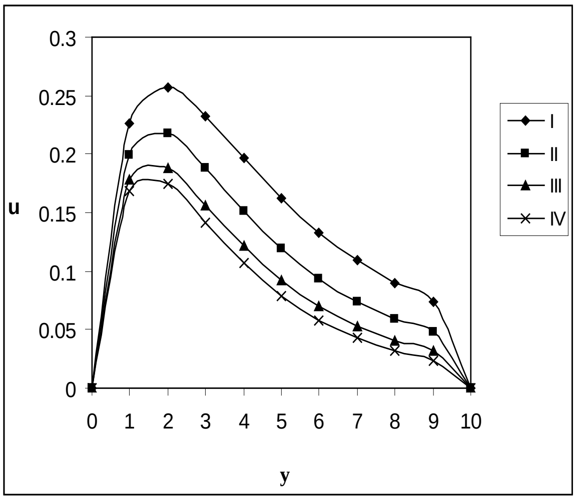


Fig. 3 : Variation of u with Sc

| | I | II | III | IV |
|---|---|---|---|---|
| Sc | 0.24 | 0.6 | 1.3 | 2.01 |

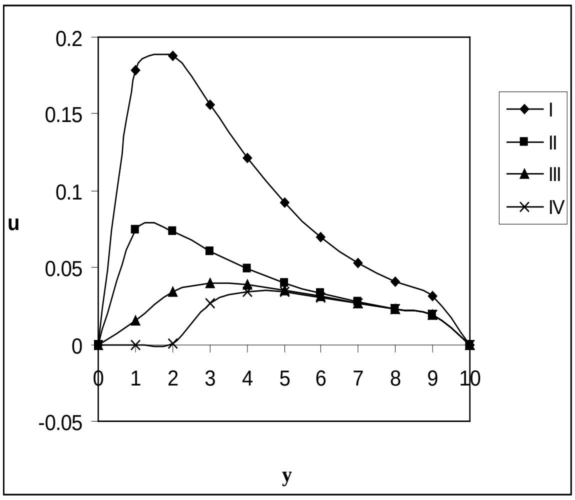


Fig. 4 : Variation of u with Kr

| | I | II | III | IV |
|---|---|---|---|---|
| Kr | 0.5 | 1.5 | 2.5 | 3.5 |

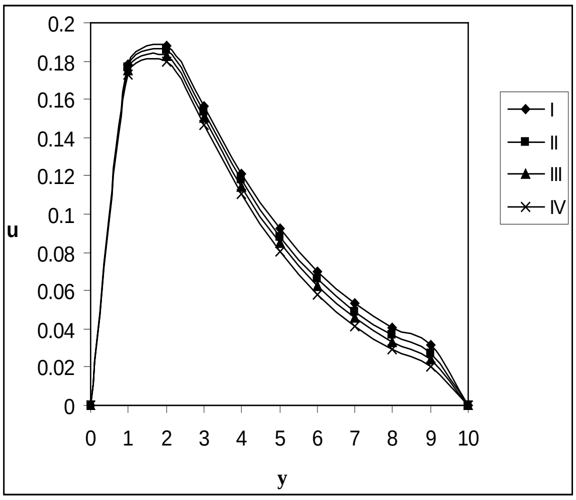


Fig.5 : Variation of u with Sr

| | I | II | III | IV |
|---|---|---|---|---|
| Sr | 0.5 | 0.7 | 0.9 | 1.2 |

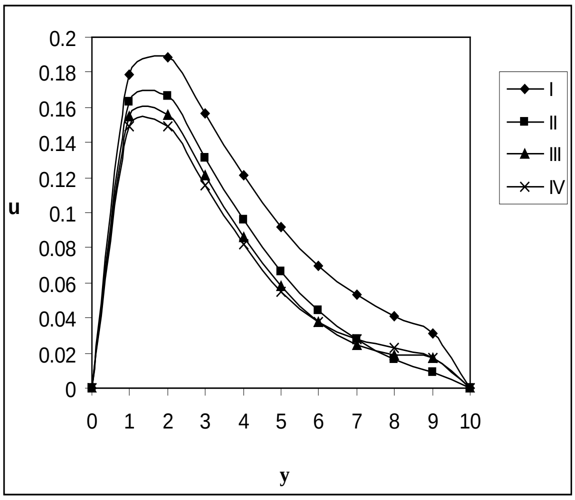


Fig. 6 : Variation of u with S

| | I | II | III | IV |
|---|---|---|---|---|
| S | 0.5 | 1.5 | 2.5 | 3.5 |

The variation of u with Hartmann number M shows that higher the Lorentz force smaller the velocity u in the flow region (fig.1). The variation of u with buoyancy ratio N shows that when molecular buoyancy forces dominate over the thermal buoyancy force |u| enhances with increase N>0 and for N<0, |u| enhances in the vicinity of the boundary y=0 and depreciates far away from the boundary (fig.2). With respect to Sc we notice that lesser the molecular diffusivity smaller |u| in the flow region (fig.3). Fig.4 represents u with Chemical reaction parameter Kr. We notice that |u| experiences an enhancement in the degenerating chemical reaction case. Fig. 5 represents u with Soret parameter Sr. It is found that actual velocity reduces with increase in |Sr|. Fig.6 represents u with heat source parameter S. It is found that higher the suction velocity at the plate smaller| u| in the flow region.

The non-dimensional temperature (T) is exhibited in figures 7-12 we follow the convention that the non-dimensional temperature +ve or –ve according as the actual temperature is greater or lesser than $T_\infty$. The variation of T with M shows that higher the Lorentz force smaller the actual temperature in the flow region (fig. 7). With respect to buoyancy ratio N, we find that the actual temperature experiences an enhancement with increase in |N| irrespective of the direction of the buoyancy forces (fig.8). From fig.9 we find that an increase in Sc results the reduction in T. Thus lesser the molecular diffusivity smaller the actual temperature in entire flow region. Fig.10 represents T with chemical reaction parameter Kr. The actual temperature reduces with increase in Kr≤2.5 and enhances with higher Kr=3.5. With respect to Soret parameter Sr we find that the actual temperature reduces with increase in |Sr| (fig.11). An increase in suction parameter S reduces the actual temperature in the flow region (fig.12).

 

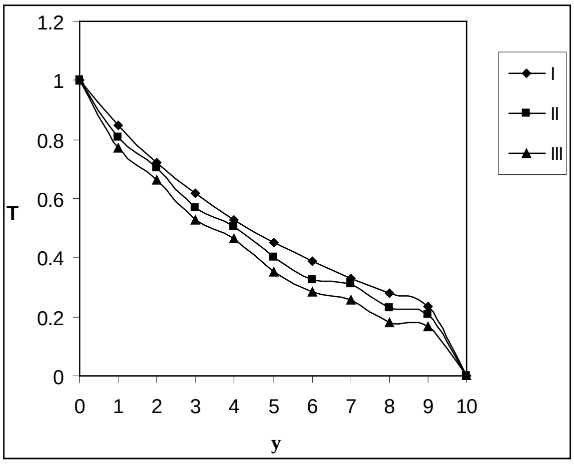


Fig. 7 : Variation of T with M

| | I | II | III |
|---|---|---|---|
| M | 2.3 | 4.3 | 6.3 |

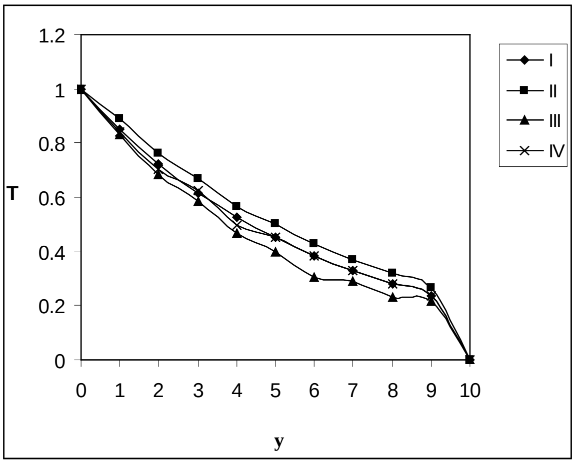


Fig. 8 : Variation of T with N

| | I | II | III | IV |
|---|---|---|---|---|
| N | 1 | 2 | -0.5 | -0.8 |

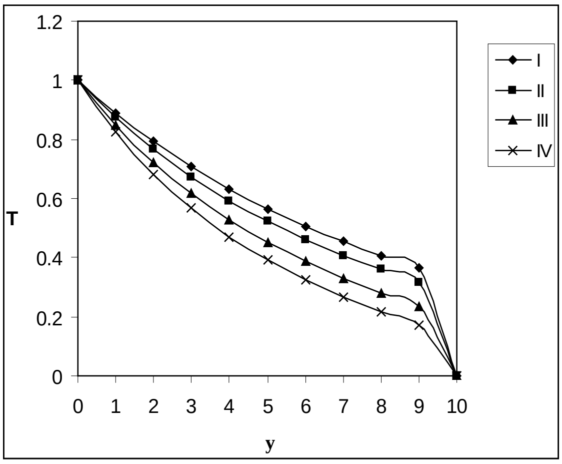


Fig. 9 : Variation of T with Sc

| | I | II | III | IV |
|---|---|---|---|---|
| Sc | 0.24 | 0.6 | 1.3 | 2.01 |

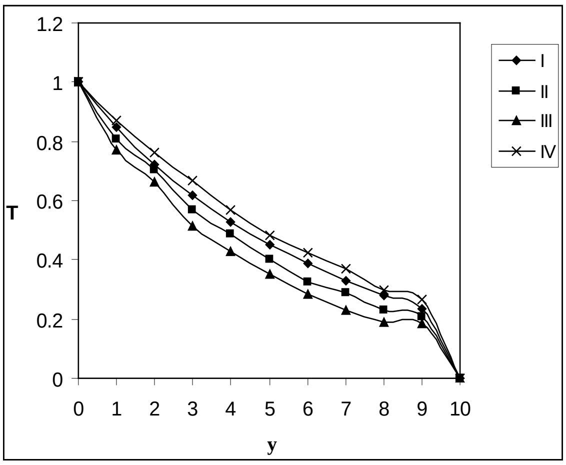


Fig. 10 : Variation of T with Kr

| | I | II | III | IV |
|---|---|---|---|---|
| Kr | 0.5 | 1.5 | 2.5 | 3.5 |

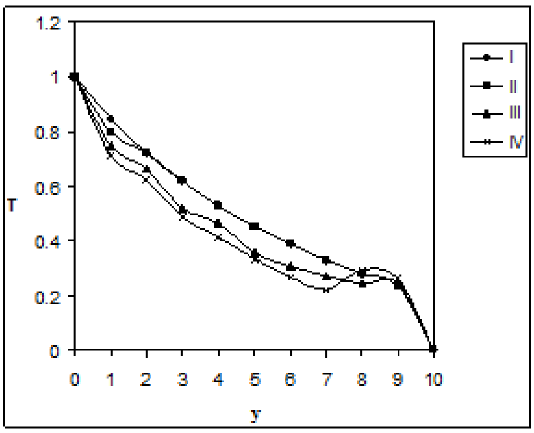


**Fig. 11 : Variation of T with Sr**

| | I | II | III | IV |
|---|---|---|---|---|
| Sr | 0.5 | 0.7 | 0.9 | 1.2 |

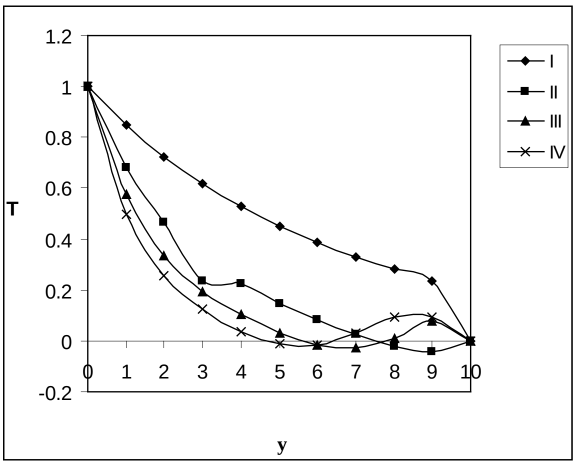


Fig. 12 : Variation of T with S

| | I | II | III | IV |
|---|---|---|---|---|
| S | 0.5 | 1.5 | 2.5 | 3.5 |

The concentration distribution (C) is shown in figures 13-14 for the different values of Sc, Kr. Fig.13 represents C with Schmidt number Sc. We notice that lesser the molecular diffusivity smaller the actual concentration in the flow region. Also it depreciates in the degenerating chemical reaction parameter (Kr) case (fig.14).

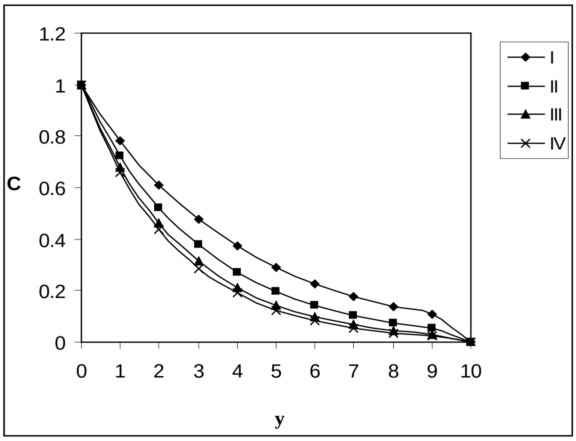


Fig. 13 : Variation of C with Sc

| | I | II | III | IV |
|---|---|---|---|---|
| Sc | 0.24 | 0.6 | 1.3 | 2.01 |

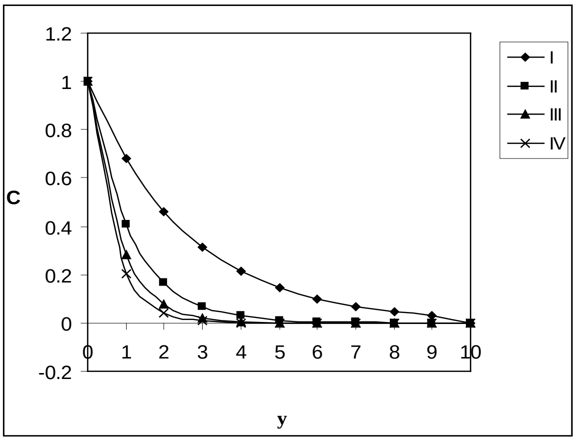


Fig. 14 : Variation of C with Kr

| | I | II | III | IV |
|---|---|---|---|---|
| Kr | 0.5 | 1.5 | 2.5 | 3.5 |

The rate of heat transfer (Nusselt number) at the plate y=0 is shown in tables 1-3 for different values of Sc, N, Kr and Sr. It is found that the rate of heat transfer enhances in magnitude with increase in Sc. When the molecular buoyancy force dominates over the thermal buoyancy force |Nu| depreciates at y=0 irrespective of the direction of the buoyancy forces (table 1). An increase in chemical reaction parameter Kr≤2.5 enhances |Nu| and depreciates with higher Kr≥3.5 (table 2). With respect to Soret parameter Sr we notice that |Nu| enhances with increase in Sr≥0 and for Sr<0 it depreciates with |Sr|≤0.7 and enhances with higher |Sr|=0.9 (table 3).

**Table – 1**
**Average Nusselt number (Nu) at y = 0**

| Sc | I | II | III | IV |
|---|---|---|---|---|
| 0.24 | -0.1171 | -0.1105 | -0.1178 | -0.1166 |
| 0.60 | -0.1358 | -0.1346 | -0.1364 | -0.1363 |
| 1.3 | -0.1667 | -0.1662 | -0.1670 | -0.1669 |
| 2.01 | -0.1962 | -0.1958 | -0.1963 | -0.1960 |
| N | 1 | 2 | -0.5 | -0.8 |

**Table – 2**
**Average Nusselt number (Nu) at y = 0**

| Sc | I | II | III | IV | IV |
|---|---|---|---|---|---|
| 0.24 | -0.1171 | -0.1186 | -0.1188 | -0.1180 | -0.1175 |
| 0.60 | -0.1358 | -0.1362 | -0.1363 | -0.1360 | -0.1354 |
| 1.3 | -0.1667 | -0.1669 | -0.1670 | -0.1660 | -0.1656 |
| 2.01 | -0.1962 | -0.1963 | -0.1966 | -0.1952 | -0.1831 |
| Kr | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 |

**Table – 3**
**Average Nusselt number (Nu) at y = 0**

| Sc | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| 0.24 | -0.1171 | -0.1240 | -0.1322 | -0.0950 | -0.0901 | -0.1052 |
| 0.60 | -0.1358 | -0.1466 | -0.1572 | -0.0804 | -0.0699 | -0.1963 |
| 1.3 | -0.1667 | -0.1885 | -0.2093 | -0.0137 | -0.0134 | -0.0210 |
| 2.01 | -0.1962 | -0.2277 | -0.2575 | -0.0607 | 0.0546 | 0.1218 |
| Sr | 0.5 | 0.7 | 0.9 | -0.5 | -0.7 | -0.9 |

The rate of mass transfer (Sherwood number) at the boundary y=0 is shown in table 4 for different values of Sc and Kr. The variation of Schmidt number Sc shows that lesser the molecular diffusivity smaller the rate of mass transfer (Sh) at y=0. With respect to chemical reaction parameter Kr we notice that the rate of mass transfer experiences an enhancement in the degenerating chemical reaction case.

**Table – 4**
**Sherwood number (Sh) at y = 0**

| Sc | I | II | III | IV | IV |
|---|---|---|---|---|---|
| 0.24 | -0.2466 | -0.4919 | -0.6638 | -0.8043 | -0.9261 |
| 0.60 | -0.3245 | -0.6950 | -0.9610 | -1.1799 | -1.3703 |
| 1.3 | -0.3856 | -0.8903 | -1.2664 | -1.5799 | -1.85454 |
| 2.01 | -0.4145 | -1.0012 | -1.4516 | -1.8314 | -2.1660 |
| Kr | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 |

 

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