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Study of Thermal Radiation and Chemical Reaction on Convective Heat and Mass Transfer Flow of a Walter's Memory Fluid Past a Porous Vertical Plate

V. SURESH BABU[1], G. HARI PRIYA[2] and R. SIVA PRASAD[3]

[1]Professor in Mathematics, Department of Mathematics, G. Pullaiah college of Engineering & Techonology, Kurnool, Andhra Pradesh, (India)

[2]Associate Professor, Gates Institute of Technology, Gooty, Andhra Pradesh, (India)

[3]Professor in Mathematics, Department of Mathematics, Sri Krishna Devaraya University Anantapuram, Andhra Pradesh, (India)

Corresponding author Email: hsvsuresh@gpcet.ac.in[1]

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Abstract

In this paper we make an attempt to study the effect of thermal radiation, dissipation and chemical reaction on unsteady hydro-magnetic free convective heat and mass transfer flow of a Walter's memory fluid past a vertical plate. The non-linear equations governing the flow, heat and mass transfer are solved by using a perturbation technique. The velocity, temperature, concentration, the rate of heat and mass transfer are analyzed for different values of the governing parameters.

Key words: Non-Newtonian fluid, Porous medium, Thermal radiation, Chemical reaction, Memory flow fluid , MHD.

MSC CODES 2010: 76A05,76A10,76DXX,80A20,76E06,76WXX

1. Introduction

Due to the prime importance of heat and mass transfer involving in chemical reaction, industrial process the problem received considerable attention in recent years. Ramesh Babu *et al.*[19] discussed the effect of unsteady MHD free convective flow of a visco-elastic fluid past an infinite vertical porous moving plate with variable temperature and Concentration. Bhavtosh[2] studied the effects of heat and mass flux on MHD free convection flow through a porous medium in presence of radiation and chemical reaction. Kumaresan *et al.*,[14] examined the effect an exact solution on unsteady MHD visco-elastic fluid flow past an infinite vertical plate in the presence of thermal radiation.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[10]. Examples of such models are the Oldroyd model[15,16]. 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[20] studied the second order Rivlin-Erickson viscoelastic boundary layer flow along a stretching surface. Abel and Nandeppanavar[1,9] 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[7,8] have examined the mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink. 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 have given much attention towards free convecting flows of viscous incompressible fluids past an infinite plate. Ramana Murthy *et al.*[18] have discussed the MHD unsteady free convective Walter's memory flow with constant suction and heat sink. Numerical study of transient free convective mass transfer in a Walter's – B viscoelastic flow with wall suction was analyzed by Chang *et al.* [3,4,5,6,8,11,12,13,17].

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 is $\frac{\partial v'}{\partial y'} = 0$ (1)

Momentum equation is

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

Energy Equation is

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

Diffusion equation is

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

From (1) we have

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

Invoking Rosseland approximation for radiative heat flux we get

$$q_r = -\frac{4\sigma^\bullet}{3\beta_R}\frac{\partial(T'^4)}{\partial y} \tag{6}$$

Expanding T'^4 in Taylor's series about T_e and neglecting higher order terms

$$T'^4 \cong 4T_e^3 T' - 3T_e^4 \tag{7}$$

where $\sigma^\bullet$ is the Stefan-Boltzmann constant β_R is the Extinction coefficient.

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

$$\left.\begin{array}{llll} y' = 0: & u' = 0, & T' = T'_\infty + \varepsilon(T'_w - T'_\infty)e^{i\omega' t'}, & C' = C'_\infty + \varepsilon(C'_w - C'_\infty)e^{i\omega' t'} \\ y' \to \infty: & u' \to 0, & T' \to T'_\infty & C' \to C'_\infty \end{array}\right\} \tag{8}$$

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

$$\left.\begin{array}{l} y = \dfrac{y' v_0}{\upsilon}, \quad t = \dfrac{t' v_0^2}{4\upsilon}, \quad \omega = \dfrac{4\upsilon\omega'}{v_0^2}, \quad \upsilon = \dfrac{\eta_0}{\rho}, \quad \Pr = \dfrac{\nu}{K} \\ S = \dfrac{4S'\upsilon}{v_0^2}, \quad M = \dfrac{\sigma B_0^2 \upsilon}{\rho v_0^2}, \quad K = \dfrac{K_0}{\rho C_P}, \quad T = \dfrac{(T' - T'_\infty)}{(T'_w - T'_\infty)}, \\ C = \dfrac{(C' - C'_\infty)}{(C'_w - C'_\infty)}, \quad Kr = \dfrac{K'_r \upsilon}{v_0^2}, \quad Sc = \dfrac{\upsilon}{D} \\ G = \dfrac{\upsilon g\beta(T'_w - T'_\infty)}{v_0^3}, \quad N = \dfrac{\beta^\bullet(C_w - C_\infty)}{\beta(T_w - T_\infty)}, \quad Ec = \dfrac{v_0^2}{C_p(T'_w - T'_\infty)} \\ N_1 = \dfrac{4\sigma^\bullet T_\infty^3}{3\beta_R}, \quad R_m = \dfrac{B_1 v_0^2}{\upsilon^2}, \end{array}\right\} \tag{9}$$

In view of the equation (9) the equations (2), (.3) and (4) reduced to the following non-dimensional form

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = Gr(T + NC) + \frac{\partial^2 u}{\partial y^2} - R_m\left[\frac{1}{4}\frac{\partial^3 u}{\partial t \partial y^2} - \frac{\partial^3 u}{\partial y^3}\right] - Mu \tag{10}$$

$$\frac{\Pr}{4}\frac{\partial T}{\partial t} - \Pr\frac{\partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2} + \frac{\Pr ST}{4} + \Pr Ec\left(\frac{\partial u}{\partial y}\right)^2 + \frac{4}{3N_1}\frac{\partial^2 T}{\partial y^2} \tag{11}$$

$$\frac{Sc}{4}\frac{\partial C}{\partial t} - Sc\frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} - KrScC \tag{12}$$

The following boundary conditions are:

$$\left.\begin{array}{llll} y=0: & u=0, & T=1+\varepsilon e^{i\omega t}, & C=1+\varepsilon e^{i\omega t} \\ y\to\infty: & u\to 0, & T\to 0, & C\to 0 \end{array}\right\} \tag{13}$$

3. Solution of the Problem :

The velocity, temperature and concentration of the fluid in the neighborhood of the plate as:

$$\left.\begin{array}{ll} u(y,t) = u_0(y) + \varepsilon e^{i\omega t}u_1(y) & T(y,t) = T_0(y) + \varepsilon e^{i\omega t}T_1(y) \\ C(y,t) = C_0(y) + \varepsilon e^{i\omega t}C_1(y) & \end{array}\right\} \tag{14}$$

where u_0, T_0 and C_0 are mean velocity, mean temperature and mean concentration. Substituting (14) in equations (11)-(13), equating harmonic and non-harmonic terms for mean velocity, mean temperature and mean concentration, after neglecting coefficient of ε^2, we get

Zero order of ε

$$R_m u_0''' + u_0'' + u_0' - Mu_0 = -Gr[T_0 + NC_0] \tag{15}$$

$$(1+\frac{4}{3N_1})T_0'' + \Pr T'_0 + \frac{\Pr ST_0}{4} = -\Pr Ec(u_0')^2 \tag{16}$$

$$C_0'' + ScC_0' - KrScC_0 = 0 \tag{17}$$

First order of ε

$$R_m u_1''' + u_1'' + u_1' - Mu_1 = -Gr[T_1 + NC_1] \tag{18}$$

$$(1+\frac{4}{3N_1})T_1'' + \Pr T'_1 + \frac{\Pr(S-i\omega)T_1}{4} = -2\Pr Ecu_0'u_1' - Q_1C_1 \tag{19}$$

$$C_1'' + ScC_1' - \left(Kr - \frac{i\omega}{4}\right)ScC_1 = 0 \tag{20}$$

The equations (15) and (18) are third order differential equations due to presence of elasticity.

Therefore u_0 and u_1 are expanded using Beard and Walters rule

$$u_0 = u_{00} + R_m u_{01} \tag{21}$$

$$u_1 = u_{10} + R_m u_{11} \tag{22}$$

Zero order of R_m

$$u_0'' + u_{00}' - Mu_{00} = -Gr[T_0 + NC_0] \tag{23}$$

$$u_{10}'' + u_{10}' - \left(M - \frac{i\omega}{4}\right)u_{10} = -Gr[T_1 + NC_1] \tag{24}$$

First order of R_m

$$u_{01}'' + u_{01}' - Mu_{01} = -u_{00}''' \tag{25}$$

$$u_{11}'' + u_{11}' - \left(M - \frac{i\omega}{4}\right)u_{11} = -u_{10}''' \tag{26}$$

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

$$u_{00} = u_{000} + Ec\ u_{001} \tag{27}$$

$$u_{01} = u_{011} + Ec\ u_{012} \tag{28}$$

$$u_{10} = u_{100} + Ec\ u_{101} \tag{29}$$

$$u_{11} = u_{111} + Ec\ u_{112} \tag{30}$$

$$T_0 = T_{00} + Ec\ T_{01} \tag{31}$$

$$T_1 = T_{10} + Ec\ T_{11} \tag{32}$$

$$C_0 = C_{00} + Ec\ C_{01} \tag{33}$$

$$C_1 = C_{10} + Ec\ C_{11} \tag{34}$$

Using equations (27) - (34) in the equations (16), (17), (19), (20), (23), (24), (25) and (26) and equating the coefficient of Ec^0 and Ec^1, we get the following set of differential equations:

Zero order of Ec

$$u_{000}'' + u_{000}' - Mu_{000} = -Gr[T_{00} + NC_{00}] \tag{35}$$

$$u_{011}'' + u_{011}' - Mu_{011} = -u_{000}''' \tag{36}$$

$$u_{100}'' + u_{100}' - \left(M - \frac{i\omega}{4}\right)u_{100} = -Gr[T_{10} + NC_{10}] \tag{37}$$

$$u_{111}'' + u_{111}' - \left(M - \frac{iw}{4}\right)u_{111} = -u_{100}''' \tag{38}$$

$$C_{00}'' + ScC_{00}' - KrScC_{00} = 0 \tag{39}$$

$$(1 + \frac{4}{3N_1})T_{00}'' + \Pr T_{00}' + \frac{\Pr S}{4}T_{00} = 0 \tag{40}$$

$$C_{10}'' + ScC_{10}' - \left(Kr - \frac{i\omega}{4}\right)ScC_{10} = 0 \tag{41}$$

$$(1 + \frac{4}{3N_1})T_{10}'' + \Pr T_{10}' + \frac{\Pr(S - i\omega)}{4}T_{10} = 0 \tag{42}$$

First order of Ec

$$u_{001}'' + u_{001}' - Mu_{001} = -Gr[T_{01} + NC_{01}] \tag{43}$$

$$u_{012}'' + u_{012}' - Mu_{012} = -u_{001}''' \tag{44}$$

$$u_{101}'' + u_{101}' - \left(M - \frac{i\omega}{4}\right)u_{101} = -Gr[T_{11} + NC_{11}] \tag{45}$$

$$u''_{112} + u'_{112} - \left(M - \frac{i\omega}{4} \right) u_{112} = -u'''_{101} \tag{46}$$

$$C''_{01} + ScC'_{01} - KrScC_{01} = 0 \tag{47}$$

$$(1 + \frac{4}{3N_1})T''_{01} + \Pr T'_{01} + \frac{\Pr S}{4} T_{01} = -\Pr(u'_{000})^2 \tag{48}$$

$$C''_{11} + ScC'_{11} - \left(Kr - \frac{i\omega}{4} \right) ScC_{11} = 0 \tag{49}$$

$$(1 + \frac{4}{3N_1})T''_{11} + \Pr T'_{11} + \frac{\Pr(S - i\omega)}{4} T_{11} = -2\Pr u'_{000} u'_{100} \tag{50}$$

The corresponding boundary conditions are: $y = 0$:

$$\left.\begin{array}{l} u_{000} = u_{001} = u_{011} = u_{012} = u_{100} = u_{101} = u_{111} = u_{112} = 0 \\ T_{00} = 1,\ T_{01} = 0,\ T_{10} = 1,\ T_{11} = 0,\ C_{00} = 1,\ C_{01} = 0,\ C_{10} = 1,\ C_{11} = 0\ y \to \infty \\ u_{000} \to u_{001} \to u_{011} \to u_{112} \to u_{100} \to u_{101} \to u_{111} \to u_{112} \to 0 \\ T_{00} \to 0,\ T_{01} \to 0,\ T_{10} \to 0,\ T_{11} \to 0,\ C_{00} \to 0,\ C_{01} \to 0,\ C_{10} \to 0,\ C_{11} \to 0 \end{array}\right\} \tag{51}$$

The differential equations(35)-(49)have been solved subject to boundary conditions (51) and the solutions are

u(y,t)=

$$\begin{aligned} &(a_4 e^{-m_3 y} + a_5 e^{-m_2 y} + a_6 e^{-m_1 y}) + Ec(a_{40} e^{-m_3 y} + a_{41} e^{-m_2 y} + a_4 2e^{-2m_3 y} + a_4 3e^{-2m_2 y} + a_{41} e^{-2m_1 y} \\ &+ a_{45} e^{-(m_3+m_2)y} + a_{46} e^{-(m_1+m_2)y} + a_{47} e^{-(m_1+m_3)y}) + Rm\{(a_{13} e^{-m_3 y} + a_{14} e^{-m_3 y} + a_{15} e^{-m_2 y} + a_{16} e^{-m_1 y}) \\ &+ Ec(a_{59} e^{-m_3 y} + a_{60} e^{-m_3 y} a_{61} e^{-m_2 y} + a_{62} e^{-2m_3 y} + a_{63} e^{-2m_2 y} + a_{64} e^{-2m_1 y} + a_{65} e^{-(m_3+m_2)y} + \\ &a_{66} e^{-(m_1+m_2)y} + a_{97} e^{-(m_1+m_3)y}) \} + \varepsilon e^{i\omega t} \{(a_{10} e^{-m_6 y} + a_{11} e^{-m_5 y} + a_{12} e^{-m_4 y}) + Ec(a_{48} e^{-m_6 y} + a_{49} e^{-m_5 y} \\ &+ a_{50} e^{-(m_3+m_6)y} + a_{51} e^{-(m_3+m_5)y} + a_{52} e^{-(m_3+m_4)y} + a_{53} e^{-(m_2+m_6)y} + a_{54} e^{-(m_2+m_5)y} + a_{55} e^{-(m_2+m_4)y} \\ &+ a_{56} e^{-(m_1+m_6)y} + a_{57} e^{-(m_1+m_5)y} + a_{58} e^{-(m_1+m_4)y}) + Rm\{(a_{17} e^{-m_6 y} + a_{18} e^{-m_6 y} + a_{19} e^{-m_5 y} + a_{20} e^{-m_4 y}) \\ &Ec(a_{68} e^{-m_6 y} + a_{69} e^{-m_6 y} + a_{70} e^{-m_5 y} + a_{71} e^{-(m_3+m_6)y} + a_{72} e^{-(m_3+m_5)y} + a_{73} e^{-(m_3+m_4)y} + a_{74} e^{-(m_2+m_6)y} \\ &+ a_{75} e^{-(m_2+m_5)y} + a_{76} e^{-(m_2+m_4)y} + a_{77} e^{-(m_1+m_6)y} + a_{78} e^{-(m_1+m_5)y} + a_{79} e^{-(m_1+m_4)y}) \}\} \end{aligned}$$

T(y,t)=

$$\begin{aligned} &(a_2 e^{-m_2 y} + a_3 e^{-m_1 y}) + Ec(a_{22} e^{-m_2 y} + a_{23} e^{-2m_3 y} + a_{24} e^{-2m_2 y} + a_{25} e^{-2m_1 y} + a_{26} e^{-(m_3+m_2)y} \\ &+ a_{27} e^{-(m_1+m_2)y} + a_{28} e^{-(m_1+m_3)y}) + \varepsilon e^{i\omega t} \{(a_8 e^{-m_5 y} + a_9 e^{-m_4 y}) + Ec(a_{30} e^{-m_5 y} + a_{31} e^{-(m_3+m_6)y} \\ &+ a_{32} e^{-(m_3+m_5)y} + a_{33} e^{-(m_3+m_4)y} + a_{34} e^{-(m_2+m_6)y} + a_{35} e^{-(m_2+m_5)y} + a_{36} e^{-(m_2+m_4)y} + a_{37} e^{-(m_1+m_6)y} \\ &+ a_{38} e^{-(m_1+m_5)y} + a_{39} e^{-(m_1+m_4)y}) \} \end{aligned}$$

C(y,t) = $e^{-m1y} + \varepsilon e^{i\omega t}(e^{-m4y})$

4. Nusselt Number And Sherwood Number

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

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

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

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

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

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

5. Results and Discussion

In this analysis we investigate the effect of chemical reaction, thermal radiation on hydromagnetic convective heat and mass transfer flow of Walter Memory fluid through a porous medium past a porous vertical plate.

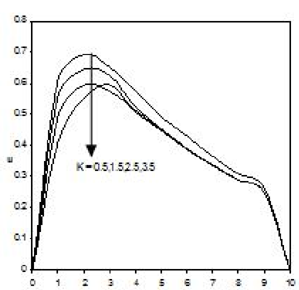

Fig. 1: Variation of u with K
M = 2, D^{-1}= 2, N=1, Sc=1.3, S=0.5
N_1=1.5, ω = 2

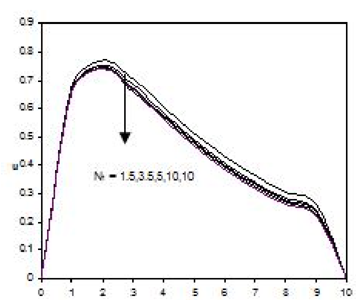

Fig. 2: Variation of u with N_1
G=2, M = 2, D^{-1}= 2, N=1, Sc=1.3
S=0.5 K=0.5, ω = 2

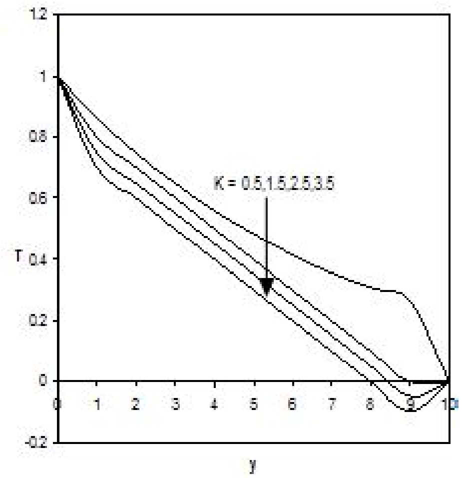

Fig. 3 : Variation of θ with K
M = 2, D^{-1}= 2, N=1, Sc=1.3 S=0.5
N_1=1.5, ω = 2

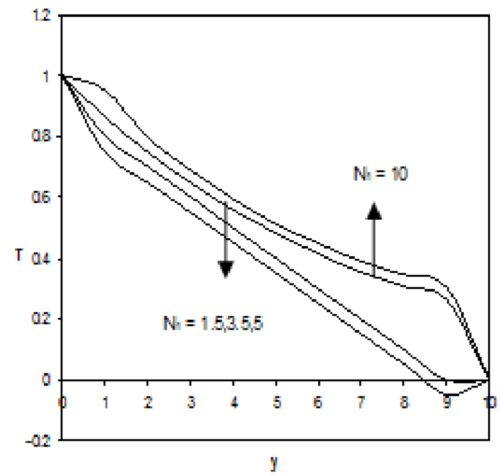

Fig. 4 : Variation of θ with N_1
G=2, M = 2, D^{-1} = 2, N=1, Sc=1.3
S=0.5 K=0.5, ω = 2

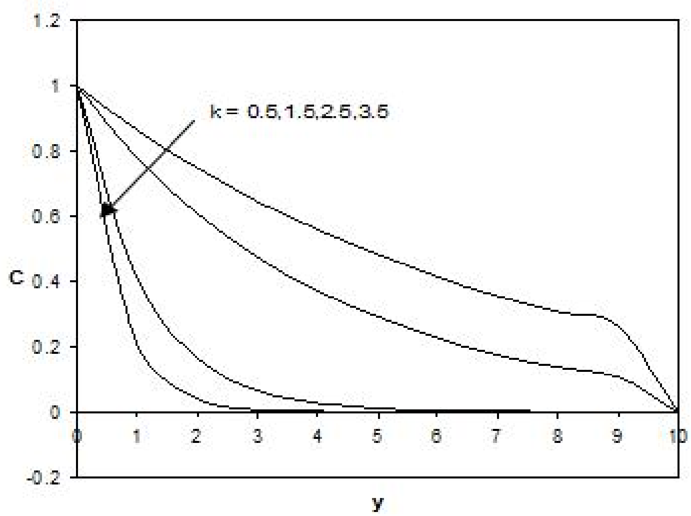

Fig. 5 : Variation of C with K Sc=1.3, ω=2

The axial velocity(u) is shown in figs.1-2 for different values of K and N_1. Fig.1 represents u with chemical reaction parameter K. It is found that |u| reduces in the degenerating chemical reaction case (K>0). The variation of u with radiation parameter N_1 is exhibited in Fig .2. The non-dimensional temperature (θ) is shown in Figs. 3-4 for different parametric values . An increase in the chemical reaction parameter K or radiation parameter N_1 results in a depreciation in the actual temperature (Figs. 3). The non-dimensional concentration (C) is shown in Fig.5 for different value K . From Fig. 5. It can be seen that the actual Concentration reduces with increase in the chemical reaction parameter Kd” 1.5 and enhances with higher K=2.5 and again reduces with still higher K ≥ 3.5.

Table 1 Shear stress (τ) at y = 0

G	I	II	III	IV	V	VI	VII
2	1.2746	1.05645	0.86191	0.53436	1.26239	1.25924	1.25533
5	2.67862	2.46047	2.26593	1.93838	2.6481	2.64023	2.63046
-2	-0.9743	-0.81558	-1.01012	-1.33767	-0.58523	-0.58208	-0.57817
-5	-2.00146	-2.2196	-2.41414	-2.74169	-1.97094	-1.96307	-1.9533
K	0.5	1.5	2.5	3.5	1	1	1
N_1	1.5	1.5	1.5	1.5	3.5	5	10

The skin friction (τ) at y = 0 is evaluated numerically for different values of K and N_1 and are shown in table 1. It represents with chemical reaction parameter K. It is found that the skin friction depreciates with K in the heating case and enhances in the cooling the channel walls. With respect to buoyancy ratio we find that when the molecular buoyancy force dominates over the thermal buoyancy force the skin friction enhance for G > 0 and reduces for G < 0 when the buoyancy forces act in the same direction and for the forces acting in opposite directions, $|\tau|$ reduces for G > 0 and enhances for G < 0. Higher the radio-active heat flux smaller $|\tau|$ at y=0 .

Table 2. Nusselt Number (Nu) at y = 0

Sc	I	II	III	IV	V	VI	VII
0.24	-0.10575	-0.10792	-0.10882	-0.14644	-0.10638	-0.10667	-0.10685
0.6	-0.12047	-0.12201	-0.12648	-0.1266	-0.12104	-0.12129	-0.12146
1.3	-0.14664	-0.14761	-0.1558	-0.16101	-0.14709	-0.14731	-0.14752
2.01	-0.171	-0.17168	-0.18312	-0.19019	-0.17136	-0.17157	-0.17168
N1	1.5	1.5	3.5	10	0.5	0.5	0.5
K	0.5	0.5	0.5	0.5	1.5	2.5	3.5

The rate of heat transfer (Nusselt number) at y = 0 is depicted in table 2 for different parametric values. |Nu| reduces with increase in N>0 and enhances with |N| (<0) . An increase in the suction parameter S or chemical reaction parameter K leads to an enhancement in |Nu| An increase in the frequency ω enhances |Nu| at y=0 . The variation of Nu with D^{-1} shows that lesser the permeability of the porous medium smaller |Nu| at y = 0 .

Table 3. Sherwood Number (Sh) at y = 0

Sc	I	II	III	IV
0.24	-0.2466	-0.4919	-0.6638	-0.8043
0.6	-0.3245	-0.695	-0.961	-1.1799
1.3	-0.3856	-0.8903	-1.2664	-1.5799
2.01	-0.4145	-1.0012	-1.4516	-1.8314
K	0.5	1.5	2.5	3.5

The rate of mass transfer (Sherwood number)is shown in table.3. It is found that |Sh| enhances with increase in chemical reaction parameter K at y=0.

6. Conclusions

- The axial velocity |u| reduces in the degenerating chemical reaction case (K > 0) and depreciates with increase in N_1.

- ❖ An increase in the chemical reaction parameter K or radiation parameter N_1 results in a depreciation in the actual temperature.
- ❖ The non-dimensional concentration (C) reduces with increase in the chemical reaction parameter $K \leq 1.5$ and enhances with higher $K = 2.5$ and again reduces with still higher $K \geq 3.5$.

7. Scope of future work :

The present study of a fluid flow over a vertical surface can be used as the basis for many scientific and engineering applications in case of vertical surfaces.

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