International Journal of Mathematical Archive-5(9), 2014, 54-64
IJMA Available online through www.ijma.info ISSN 2229 – 5046

EFFECT OF THERMAL RADIATION, RADIATION ABSORPTION ON DOUBLE DIFFUSIVE HEAT TRANSFER FLOW OF A VISCOUS CHEMICALLY REACTING FLUID IN A NON-UNIFORMLY HEATED VERTICAL CHANNEL WITH HEAT SOURCES

C. Sulochana and Ramesh H.*
Dept. of Mathematics, Gulbarga University, Gulbarga, Karnataka, India.

(Received On: 07-08-14; Revised & Accepted On: 27-08-14)

ABSTRACT

In this paper, we discuss the effect of chemical reaction and radiation absorption on free connective heat and mass transfer flow of a viscous electrically conducting fluid in a non-uniformly heated vertical channel .The walls are maintained at non-uniform temperature and a uniform concentration is maintained on the walls. The coupled equations governing the flow, heat and mass transfer have been solved by using a perturbation technique with the slope of the boundary temperature as a perturbation parameter. The expression for the velocity, the temperature, concentration, the rate of heat and mass transfer are derived and are analysed for different variations of the governing parameters $G, R, M, \alpha, Sc, Q_1, \alpha_1, N, K, P$ *and* x.

***Key Words**: Thermal Radiation, Radiation Absorption, Chemical Reaction, Vertical channel, perturbation technique.*

1. INTRODUCTION

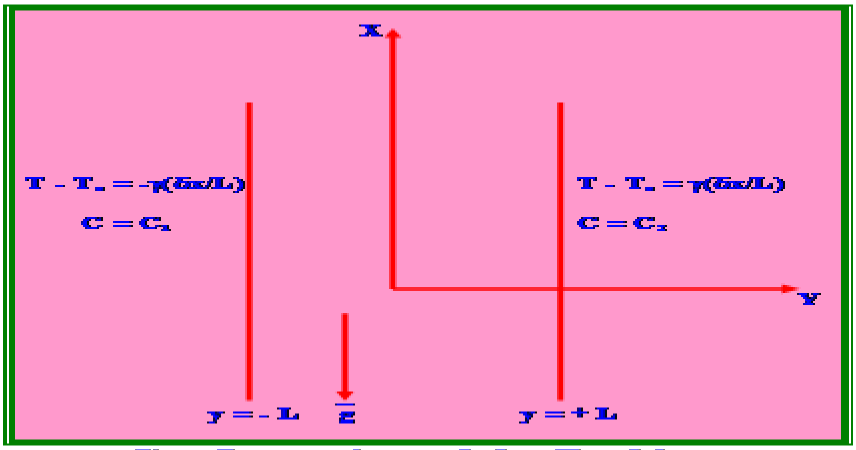
It is evident that in forced or free convection flow in a channel (pipe) a secondary flow can be created either by corrugating the boundaries or by maintaining non-uniform wall temperature. Such a secondary flow can be of interest in a few technological processes. For example, in drawing optic glass fibers of extremely low loss and band width the processes of modified chemical vapour deposition (MCVD) [4, 8] has been suggested in recent times. Performs from which these fibers are drawn are made by passing a gaseous mixture into a fused-silica tube which is heated locally, by an oxy-hydrogen flame particulate of So_2-Geo_2 composition are formed from the mixture and collect on the interior of the tube. Subsequently these are fined to form a vitreous deposit as the flame traversed along the tube. The deposition is carried out in the radial direction through the secondary flow created due to non–uniform wall temperature.

The application of electromagnetic fields in controlling the heat transfer as in aerodynamic heating leads to the study of magneto hydrodynamics heat transfer. The MHD heat transfer has gained significance owing to advancement of space technology. The MHD heat transfer can be divided into sections. One contains problems in which the heating is an incidental by product of the electromagnetic fields as in the MHD generators and pumps etc. and the second contains of problems in which the primary use of electromagnetic fields is to control the heat transfer [11]. Ravindra Reddy [6] has analyzed the effects of magnetic field on the combined heat and mass transfer in channels using finite element techniques.

Ramakrishna Reddy [5] has analyzed the Soret effect on mixed convective Heat and mass transfer flow of an electrically conducting fluid through a porous medium in a vertical channel. Vijayabhaskar Reddy [13] has studied the heat and mass transfer in a vertical channel with non-uniform heated vertical walls. Chin Yong Cheng [1, 2] has studied the convective heat and mass transfer flow through a porous medium with variable wall temperature and concentration. Reddaiah *et.al.* [7] have discussed the effect of radiation on hydromagnetic convective heat transfer flow of a viscous electrically conducting fluid in a non-uniformly heated vertical channel. Deepthi *et.al* [3] have discussed the effect of chemical reaction on convective heat and mass transfer flow of a viscous fluid in a non-uniformly heated vertical channel with heat generating sources. Umadevi *et.al* [12] has discussed the effect of chemical reaction on double-diffusive flow in a non-uniformly heated vertical channel. Sudhakar *et.al* [10] has discussed the effect of thermo-diffusion on convective heat and mass transfer flow in a non-uniformly heated vertical channel with chemical reaction and heat sources. Recently Sree Ranga Vani [9] has discussed the combined influence of chemical reaction, dissipation and radiation absorption on convective heat and mass transfer flow in a non-uniformly heated vertical channel.

Corresponding Author: Ramesh H.*
Dept. of Mathematics, Gulbarga University, Gulbarga, Karnataka, India.

In this paper, we discuss the effect of chemical reaction and radiation absorption on free connective heat and mass transfer flow of a viscous electrically conducting fluid in a non-uniformly heated vertical channel .The walls are maintained at non-uniform temperature and a uniform concentration is maintained on the walls. The coupled equations governing the flow, heat and mass transfer have been solved by using a perturbation technique with the slope of the boundary temperature as a perturbation parameter. The expression for the velocity, the temperature, concentration, the rate of heat and mass transfer are derived and are analysed for different variations of the governing parameters G,R,M,α, Sc,Q_1, α_1, N, K, P and x.



Configuration of the Problem

2. FORMULATION OF THE PROBLEM

Equation of continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

Equation of linear momentum

$$\rho_{\varepsilon}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\overline{\rho g}-\left(\overline{\sigma}\mu_{\varepsilon}^2 H_0^2\right)u \tag{2}$$

$$\rho_{\varepsilon}\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

Equation of Energy

$$\rho_e C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-Q(T-T_e)+Q_1^1(C-C_e)-\frac{\partial}{\partial r}(q_r) \tag{4}$$

Equation of diffusion

$$\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right)=D\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)-k_1\left(C-C_{\varepsilon}\right) \tag{5}$$

Equation of state

$$\rho-\rho_e=-\beta\rho_e(T-T_e)-\beta^*\rho_e(C-C_e) \tag{6}$$

where ρ_e is the density of the fluid in the equilibrium state, T_e, C_e are the temperature and concentration in the equilibrium state,(u, v)are the velocity components along O(x, y) directions, p is the pressure, T, C are the temperature and Concentration in the flow region, $\rho$is the density of the fluid, μ is the constant coefficient of viscosity, C_p is the specific heat at constant pressure, λ is the coefficient of thermal conductivity, σ is the electrically conductivity, μ_e is the magnetic permeability, β is the coefficient of thermal expansion, Q is the strength of the constant internal heat source, β^* is the volume expansion with mass fraction and D_1 is the molecular diffusivity, Q_1 is the radiation absorption coefficient, σ^* is the mean absorption coefficient and β_R is the Stefan Boltzmann constant.

In the equilibrium state

$$0 = -\frac{\partial p_e}{\partial x} - \rho_e g \tag{7}$$

where $p = p_e + p_D$, p_D being the hydrodynamic pressure.

The flow is maintained by a constant volume flux for which a characteristic velocity is defined as

$$Q = \frac{1}{2L}\int_{-L}^{L} u\ dy. \tag{8}$$

The boundary conditions for the velocity and temperature fields are

u = 0, v = 0, $T - T_e = \gamma(\delta x / L)$, C=$C_1$ on y = -L

$$u = 0,\ v = 0, T - T_e = \gamma(\delta x / L), C = C_2 \quad \text{on } y = L \tag{9}$$

In view of the continuity equation we define the stream function ψ as

$$u = -\psi_y,\ v = \psi_x \tag{10}$$

Eliminating pressure p from equations (2) & (3) and using Rosseland approximation the equations governing the flow in terms of ψ are

$$\left[\psi_x\left(\nabla^2\psi\right)_y - \psi_y\left(\nabla^2\psi\right)_x\right] = \nu\nabla^4\psi - \beta g\left(T - T_\varepsilon\right)_y - \beta^* g\left(C - C_\varepsilon\right)_y - \left(\frac{\sigma\mu_\varepsilon^2 H_o^2}{\rho_\varepsilon}\right)\frac{\partial^2\psi}{\partial y^2} \tag{11}$$

$$\rho_e C_p\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = \lambda\nabla^2 T - Q(T - T_0) + Q_1^1(C - C_e) + \frac{16\sigma^2 T_e^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2} \tag{12}$$

$$\left(\frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}\right) = D_1\nabla^2 C - k_1(C - C_e) \tag{13}$$

Introducing the non-dimensional variables in (9) & (10) as

$$x' = x/L,\ y' = y/L,\ \Psi' = \Psi/\nu, \theta = \frac{T - T_e}{\Delta T}, C' = \frac{C - C_2}{C_1 - c_2} \tag{14}$$

the governing equations in the non-dimensional form (after dropping the dashes) are

$$R\left(\frac{\partial(\psi, \nabla^2\psi)}{\partial(x, y)}\right) = \nabla^4\psi + \left(\frac{G}{R}\right)(\theta_y + NC_y) - M^2\frac{\partial^2\psi}{\partial y^2} \tag{15}$$

$$RP_1\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = \frac{\partial^2\theta}{\partial x^2} + \left(1 + \frac{4}{3N_1}\right)\frac{\partial^2\theta}{\partial y^2} - \alpha_1\theta + Q_1 N_2 C \tag{16}$$

$$RSc\left(\frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial c}{\partial y}\right) = \nabla^2 C - \gamma C \tag{17}$$

where

$R = \dfrac{qL}{\nu}$ (Reynolds number)

$G = \dfrac{\beta g \Delta T_e L^3}{\nu^2}$ (Grashof number)

$$P=\frac{\mu C_p}{\lambda}$$ (Prandtl number),

$$Sc=\frac{\nu}{D_1}$$ (Schmidt Number)

$$\alpha=\frac{QL^2}{\lambda}$$ (Heat source parameter)

$$K=\frac{K_1L^2}{D_1}$$ (Chemical Reaction Parameter)

$$N_1=\frac{3\beta_R\lambda}{4\sigma^*T_e^3}$$ (Radiation Parameter)

$$N_2=\frac{3N_1}{3N_1+4}$$

$P_1=PN_2$, $\alpha_1=\alpha N_2$

$$M^2=\frac{\sigma\mu_e^2H_o^2L^2}{\nu^2}$$ (Hartmann Number)

$$Q_1=\frac{Q_1'(C_1-C_2)L^2}{D_1(T-T_e)}$$ (Radiation absorption parameter)

The corresponding boundary conditions are

$$\psi(+1)-\psi(-1)=1$$

$$\frac{\partial\psi}{\partial x}=0,\ \frac{\partial\psi}{\partial y}=0 \quad at\ y=\pm1 \tag{18}$$

$$\theta(x,y)=\gamma(\delta x),\quad C=1 \qquad on \qquad y=-1$$

$$\theta(x,y)=\gamma(\delta x),\quad C=0 \qquad on \qquad y=+1$$

$$\frac{\partial\theta}{\partial y}=0,\frac{\partial C}{\partial y}=0 \quad at \quad y=0 \tag{19}$$

The value of ψ on the boundary assumes the constant volumetric flow in consistent with the hypothesis (8). Also the wall temperature varies in the axial direction in accordance with the prescribed arbitrary function t.

3. ANALYSIS OF THE FLOW

The main aim of the analysis is to discuss the perturbations created over a combined free and forced convection flow due to non-uniform boundary temperature imposed on the boundaries. Introduce the transformation such that

$$\overline{x}=\delta x,\frac{\partial}{\partial x}=\delta\frac{\partial}{\partial\overline{x}}$$

Then

$$\frac{\partial}{\partial x}\approx O(\delta)\to\frac{\partial}{\partial\overline{x}}\approx O(1)$$

For small values of δ<<1, the flow develops slowly with axial gradient of order δ and hence we take $\frac{\partial}{\partial\overline{x}}\approx O(1)$

Using the above transformation the equations (15-17) reduce to

$$\delta R(\frac{\partial(\psi,\nabla_1^2\psi)}{\partial(x,y)})=\nabla_1^4\psi-(\frac{G}{R})(\theta_y+NC_y)-M^2\frac{\partial^2\psi}{\partial y^2} \tag{20}$$

$$\delta P_1R\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right)=\delta^2N_2\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}\right)-\alpha_1\theta+Q_1N_2C \tag{21}$$

$$\delta ScR(\frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y})=\nabla_1^2 C-\gamma C \quad (22)$$

$$\nabla_1^2=\delta^2\frac{\partial^2}{\partial\overline{x}^2}+\frac{\partial^2}{\partial y^2}$$

We adopt the perturbation scheme and write

$$\psi(x,y)=\psi_0(x,y)+\delta\psi_1(x,y)+\delta^2\psi_2(x,y)+............$$
$$\theta(x,y)=\theta_0(x,y)+\delta\,\theta_1(x,y)+\delta^2\,\theta_2(x,y)+................$$
$$\varphi(x,y)=\varphi_0(x,y)+\delta\varphi_1(x,y)+\delta^2\,\varphi_2(x,y)+................ \quad (23)$$

On substituting (23) in (20) - (22) and separating the like powers of δ the equations and respective conditions to the zeroth order are

$$\psi_{0,\,yyyy}-M_1^2\psi_{0,\,yy}=\frac{G}{R}(\theta_{0,y}+NC_{0,y}) \quad (24)$$

$$\theta_{0,yy}-\alpha_1\theta_0=-Q_1N_2\,C_0 \quad (25)$$

$$C_{0,yy}-\gamma\,C_0=0 \quad (26)$$

with

$\psi_0(+1)$-$\Psi(-1)$ = 1,
$\psi_{0,y}$ = 0, $\psi_{0,x}$ =0 at y = ±1 (27)

$$\theta_o=\gamma(\overline{x}),\quad C_0=1\quad on\quad y=-1$$
$$\theta_o=\gamma(\overline{x}),\quad C_0=0\quad on\quad y=1 \quad (28)$$

The first order are

$$\psi_{1,\,yyyy}-M_1^2\psi_{1,\,yy}=\frac{G}{R}(\theta_{1,y}+N\,C_{1,y})+R(\psi_{0,\,y}\,\psi_{0,\,xyy}-\psi_{0,\,x}\,\psi_{0,yyy}) \quad (29)$$

$$\theta_{1,yy}-\alpha\,\theta_0=P_1R\,(\psi_{0,x}\theta_{o,y}-\psi_{0,y}\theta_{ox})-Q_1N_2C_1 \quad (30)$$

$$C_{1,yy}-\gamma_1\,C_0=ScR\,(\psi_{0,x}C_{o,y}-\psi_{0,y}C_{ox}) \quad (31)$$

with

$\psi_{1(+1)}$ - $\psi_{1(-1)}$ = 0
$\psi_{1,y}$ = 0, $\psi_{1,x}$ = 0 at y = ±1 (32)
$\theta_1(\pm1)$ = 0 $C_1(\pm1)$ = 0 at y = ± 1

The equations to the second order are

$$\psi_{2,\,yyyy}-M_1^2\psi_{2,\,yy}=\frac{G}{R}(\theta_{2y}+N\,C_{2,y})+R(\psi_{0,yyt}+\psi_{0,\,x}\,\psi_{1,\,yyy}$$
$$+\psi_{1,\,x}\,\psi_{0,yyy}-\psi_{oy}\psi_{1,xyy}-\psi_{1.y}\psi_{0,xyy}) \quad (33)$$

$$\theta_{21,yy}-\alpha\,\theta_2=P_1R\,(\psi_{0,x}\theta_{1,y}-\psi_{0,y}\theta_{1x}-\psi_{1,y}\theta_{o,x}+\psi_{1,x}\theta_{o,y})-Q_1N_2C_2 \quad (34)$$

$$C_{2,yy}-\gamma_1C_2=ScR\,(\psi_{0,x}C_{1,y}-\psi_{0,y}C_{1x}-\psi_{1,y}C_{o,x}+\psi_{1,x}C_{o,y}) \quad (35)$$

with

$\psi_{2(+1)}$ - $\psi_{2(-1)}$ = 0
$\psi_{2,y}$ = 0, $\psi_{2,x}$ = 0 at y = ±1 (36)
$\theta_2(\pm1)$ = 0 $C_2(\pm1)$ = 0 at y = ± 1 (37)

4. SOLUTION OF THE PROBLEM

Solving the equations (24) - (35) subject to the relevant boundary conditions we obtain

$$C_0=0.5\left(\frac{Ch(\beta_1 y)}{Ch(\beta_1)}-\frac{S\ (h\beta_1 y)}{Sh(\beta_1)}\right)$$

$$\theta_0 = \gamma \frac{Ch(\beta_2 y)}{Ch(\beta_2)} + a_6 \left(Sh(\beta_1 y) - Sh(\beta_1) \frac{Sh(\beta_2 y)}{Sh(\beta_2)} \right) + a_5 \left(Ch(\beta_1 y) - Ch(\beta_1) \frac{Ch(\beta_2 y)}{Ch(\beta_2)} \right)$$

$$\psi_o = a_{21} Ch(M_1 y) + a_{22} Sh(M_1 y) + a_{20} y + a_{21} + f_1(y)$$

$$f_1(y) = a_{15} Sh(\beta_1 y) + a_{16} Ch(\beta_1 y) + a_{17} Sh(\beta_2 y) + a_{18} Ch(\beta_2 y)$$

$$\begin{aligned}
C_1 = {} & a_{45}\left(Ch(\beta_3 y) - Ch(\beta_3) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) + a_{46}\left(Ch(\beta_4 y) - Ch(\beta_4) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) \\
& + a_{47}\left(Sh(\beta_3 y) - Sh(\beta_3) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) + a_{48}\left(Sh(\beta_4 y) - Sh(\beta_4) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) \\
& + a_{49}\left(Ch(\beta_5 y) - Ch(\beta_5) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) + a_{50}\left(Ch(\beta_6 y) - Ch(\beta_6) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) \\
& + a_{51}\left(Sh(\beta_5 y) - Sh(\beta_5) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) + a_{52}\left(Sh(\beta_6 y) - Sh(\beta_6) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) \\
& + a_{53}\left(Sh(\beta_2 y) - Sh(\beta_2) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) + a_{54}\left(Sh(2\beta_1 y) - Sh(2\beta_1) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) \\
& + a_{55}\left(Ch(2\beta_1 y) - Ch(2\beta_1) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) - a_{57}(y^2 Ch(\beta_3 y) \\
& - Ch(\beta_3) \frac{Ch(\beta_1 y)}{Ch(\beta_1)}) + a_{58}\left(ySh(\beta_3 y) - Sh(\beta_3) \frac{Ch(\beta_1 y)}{Ch(\beta_1)} \right) - a_{59}(y^2 Ch(\beta_4 y) \\
& - Ch(\beta_4) \frac{Ch(\beta_1 y)}{Ch(\beta_1)}) + a_{60}\left(ySh(\beta_4 y) - Sh(\beta_4) \frac{Sh(\beta_1 y)}{Sh(\beta_1)} \right) + a_{61}(yCh(\beta_1 y) \\
& - Ch(\beta_{14}) \frac{Sh(\beta_1 y)}{Sh(\beta_1)}) + a_{62}(ySh(\beta_1 y) - Sh(\beta_1) \frac{Ch(\beta_1 y)}{Ch(\beta_1)}) + a_{63}(y^2 - 1) Ch(\beta_1 y) \\
& + a_{64}(y^2 - 1) Sh(\beta_1 y)
\end{aligned}$$

$$\theta_1 = b_{29} Ch(\beta_2 y) + b_{30} Sh(\beta_2 y) + f_2(y)$$

$$\begin{aligned}
f_2(y) = {} & b_5 Ch(\beta_1 y) + b_6 Sh(\beta_1 y) + b_7 ySh(\beta_1 y) + b_8 yCh(\beta_1 y) \\
& + b_9 ySh(\beta_2 y) + b_{10} yCh(\beta_2 y) + b_{11} y^2 Ch(\beta_1 y) + b_{12} y^2 Sh(\beta_1 y) \\
& + b_{13} Ch(2\beta_1 y) + b_{14} Sh(2\beta_1 y) + b_{15} Sh(\beta_4 y) + b_{16} Sh(\beta_3 y) \\
& + b_{17} Ch(\beta_3 y) + b_{18} Ch(\beta_4 y) + b_{19} Ch(\beta_5 y) + b_{20} Ch(\beta_6 y) \\
& + b_{17} Ch(\beta_3 y) + b_{18} Ch(\beta_4 y) + b_{19} Ch(\beta_5 y) + b_{20} Ch(\beta_6 y) \\
& + b_{17} Ch(\beta_3 y) + b_{18} Ch(\beta_4 y) + b_{19} Ch(\beta_5 y) + b_{20} Ch(\beta_6 y)
\end{aligned}$$

$$\psi_1 = k_{92} Ch(M_1 y) + k_{93} Ch(M_1 y) + f_4(y)$$

$$\begin{aligned}
f_4(y) = {} & (k_{44} + k_{77}) Sh(\beta_1 y) + k_{45} + k_{79}) Sh(\beta_2 y) + k_{46} Sh(\beta_3 y) \\
& + k_{47} Sh(\beta_4 y) + k_{48} Sh(\beta_5 y) + k_{49} Sh(\beta_6 y) + k_{50} Sh(\beta_7 y) \\
& + k_{51} Sh(\beta_8 y) + k_{52} Sh(\beta_9 y) + k_{53} Sh(\beta_{10} y) + k_{54} Sh(\beta_{11} y)
\end{aligned}$$

$$
\begin{aligned}
&+k_{55}Sh(\beta_{12}y)+(k_{56}+k_{73})Ch(\beta_2 y)+k_{58}Ch(\beta_3 y)\\
&+k_{59}Ch(\beta_4 y)+k_{60}Ch(\beta_5 y)+k_{61}Ch(\beta_6 y)+k_{62}Ch(\beta_7 y)\\
&+k_{59}Ch(\beta_4 y)+k_{60}Ch(\beta_5 y)+k_{61}Ch(\beta_6 y)+k_{62}Ch(\beta_7 y)\\
&+k_{59}Ch(\beta_4 y)+k_{60}Ch(\beta_5 y)+k_{61}Ch(\beta_6 y)+k_{62}Ch(\beta_7 y)\\
&+k_{71}Ch(2\beta_2 y)+k_{72}ySh(\beta_1 y)+k_{73}ySh(\beta_2 y)+k_{76}yCh(\beta_1 y)\\
&+k_{78}yCh(\beta_2 y)+k_{79}yCh(M_1 y)+k_{81}yCh(M_3 y)+k_{82}yCh(M_4 y)\\
&+k_{83}ySh(M_2 y)+k_{84}ySh(M_1 y)+k_{85}ySh(M_4 y)+k_{86}yCh(2M_1 y)\\
&+k_{87}ySh(2M_1 y)+k_{88}y^2Sh(M_1 y)+k_{89}y^2Ch(M_1 y)+k_{90}y^2Sh(M_2 y)\ +k_{91}y^2
\end{aligned}
$$

5. NUSSELT NUMBER AND SHERWOOD NUMBER

The local rate of heat transfer coefficient (Nusselt number Nu) on the walls has been calculated using the formula

$$Nu=\frac{1}{\theta_m-\theta_w}\left(\frac{\partial\theta}{\partial y}\right)_{y=\pm1}$$

The local rate of mass transfer coefficient (Sherwood Number Sh) on the walls has been calculated using the formula

$$Sh=\frac{1}{C_m-C_w}\left(\frac{\partial C}{\partial y}\right)_{y=\pm1}$$

6. DISCUSSION OF THE RESULTS

In this analysis we discuss effect of chemical reaction and radiation absorption on the heat and mass transfer flow of viscous, electrically conducting fluid in a non-uniformly heated vertical channel in the presence of heat generating sources. We take the Prandtl number P = 0.71 and $\delta = 0.01$.

The axial velocity (u) is shown in figs. 1-3 for different values of Q_1, α_1 and K. The variation of u with radiation absorption parameter Q_1 shows that higher the radiation absorption larger |u| in the flow region [fig.1]. An increase in the amplitude α_1 of the boundary temperature results in an enhancement in |u| [fig.2]. The variation of u with chemical reaction parameter K shows that higher the chemical reaction parameter larger |u| in the entire flow region [fig.3].

The secondary velocity (v) which is due to the non-uniform boundary temperature is shown in figs.4-6 for different parametric values. An increase in $Q_1 \le 4$ results in an enhancement in |v| and for higher $Q_1 \ge 6$, we notice a depreciation in |u| in the left half and enhancement in the right half of the channel [fig.4]. An increase in the amplitude α_1 of the boundary temperature enhances |v| in the left half and depreciates in the right half of the channel [fig.5]. From fig.6 we find that an increase in the chemical reaction parameter $K \le 2.5$ enhances |v| in the left half and depreciates in the right half for higher $K \ge 3.5$ we notice depreciation in |v| in the entire flow region.

The non-dimensional temperature (θ) is shown in figs.7-9 for different parametric values. Actual temperature enhances with increase in the radiation absorption parameter Q_1 [fig.7]. The variation of θ with the amplitude α_1 shows that the actual temperature enhances with increase in $\alpha_1 \le 0.5$ for higher $\alpha_1=0.7$, it enhances in the left half and reduces in the right half and for still higher $\alpha_1=0.9$, it reduces in the left half and enhances in the right half of the channel [fig.8]. With respect to the chemical reaction parameter K we find that higher K results in a depreciation of the actual temperature [fig. 9].

The non-dimensional concentration (C) is shows in figs.10-12 for different parametric values. An increase in Q_1 results in an enhancement in C [fig.10]. The variation of C with α_1 shows that the actual concentration reduces with increase in the amplitude α_1 of the boundary temperature in the entire flow region [fig.11]. From fig.12 we find a depreciation in the concentration with chemical reaction parameter K.

The rate of heat transfer for (Nusselt number) at y = ±1 is shown in tables 1&2 for different values of Q_1, α_1 and K. An increase in Q_1 enhances |Nu| at y = ±1. The Nusselt number reduces at y=+1 and enhances at y=-1 in the degenerating chemical reaction case. The variation of Nu with amplitude α_1 shows that |Nu| depreciates with $\alpha_1 \le 0.5$, and for $\alpha_1 \ge 0.7$, we notice a depreciation in |Nu| for G>0 and enhancement for G<0 [tables 1&2].

The rate of mass transfer Sherwood number (Sh) at y = ±1 is shown in tables 3&4 for different parametric values. |Sh| experiences an enhancement with increase in Q_1 at y = ±1. |Sh| enhances at y=±1 in the degenerating chemical reaction case. An increase in the amplitude α_1 of the boundary temperature reduces |Sh| at y = 1 for G>0 and enhances for G<0. At y = -1[tables 3&4].

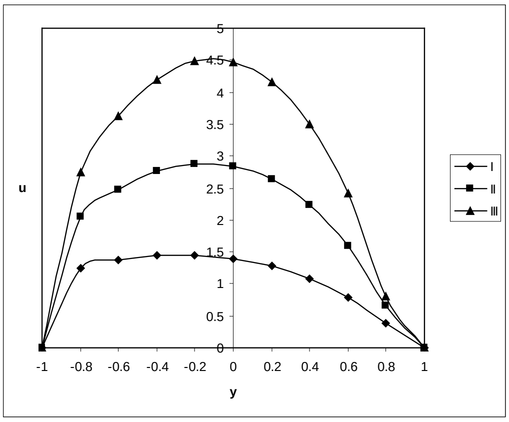


Fig.-1: Variation of u with Q_1

	I	II	III
Q_1	2	4	6

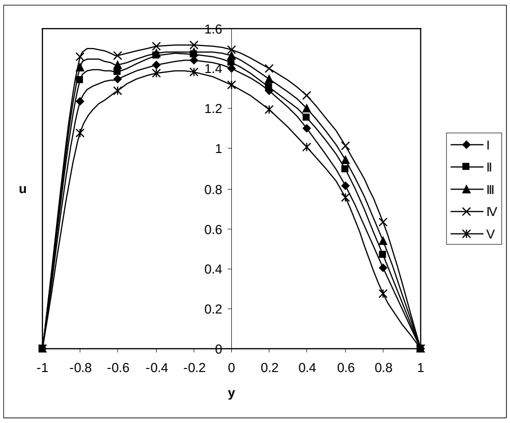


Fig.-2: Variation of u with α_1

	I	II	III	IV	V
α_1	0.1	0.3	0.5	0.7	0.9

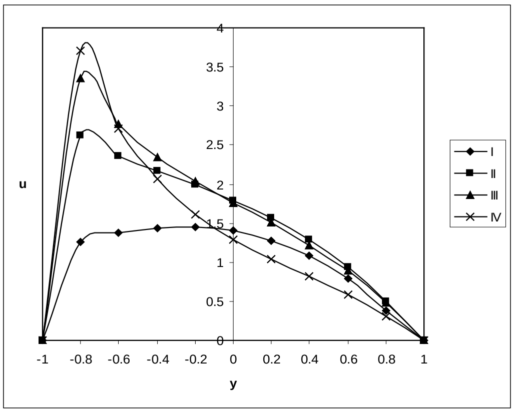


Fig.-3: Variation of u with K

	I	II	III	IV
K	0.5	1.5	2.5	3.5

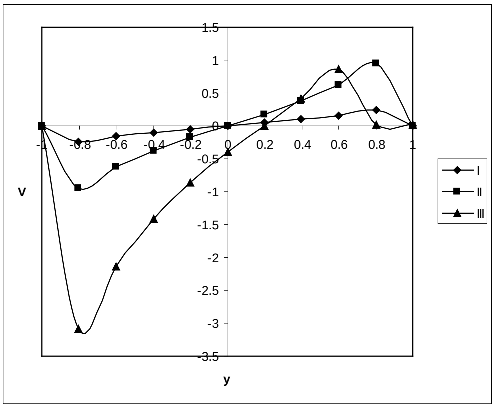


Fig.-4: Variation of v with Q_1

	I	II	III
Q	2	4	6

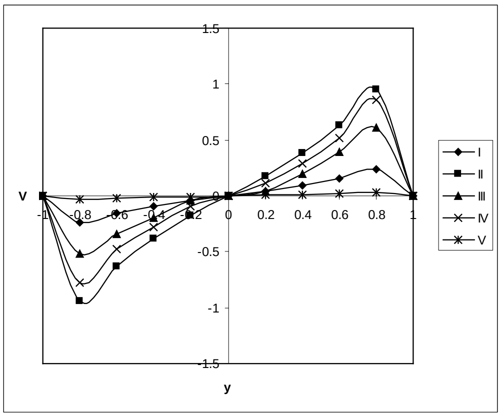


Fig.-5: Variation of v with α_1

	I	II	III	IV	V
α	0.1	0.3	0.5	0.7	0.9

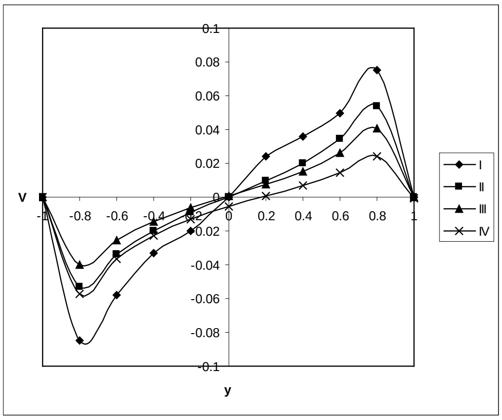


Fig.-6: Variation of v with K

	I	II	III	IV
K	0.5	1.5	2.5	3.5

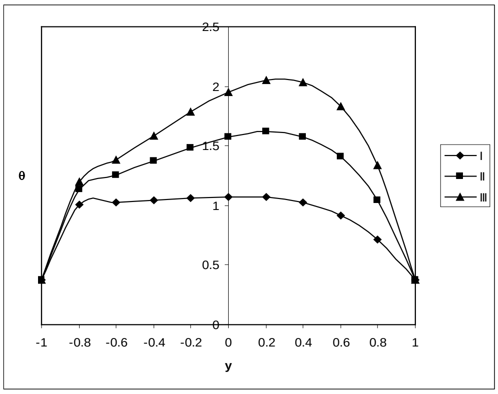


Fig.-7: Variation of θ with Q_1

	I	II	III
Q_1	2	4	6

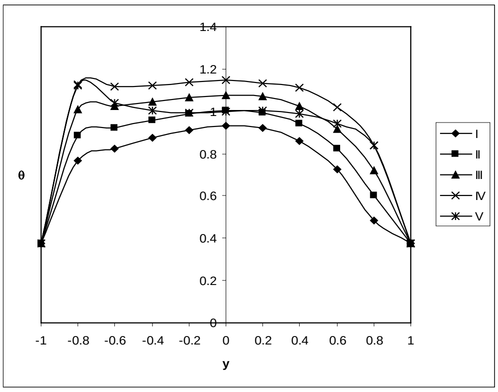


Fig.-8: Variation of θ with α_1

	I	II	III	IV	V
α_1	0.1	0.3	0.5	0.7	0.9

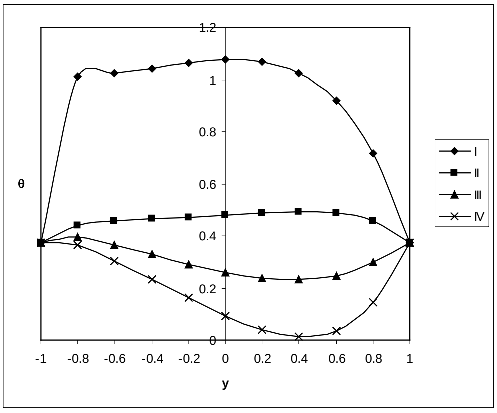


Fig.-9: Variation of θ with K

	I	II	III	IV
K	0.5	1.5	2.5	3.5

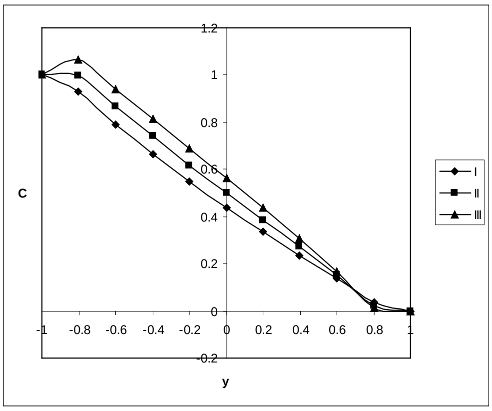


Fig.-10: Variation of C with Q_1

	I	II	III
Q_1	2	4	6

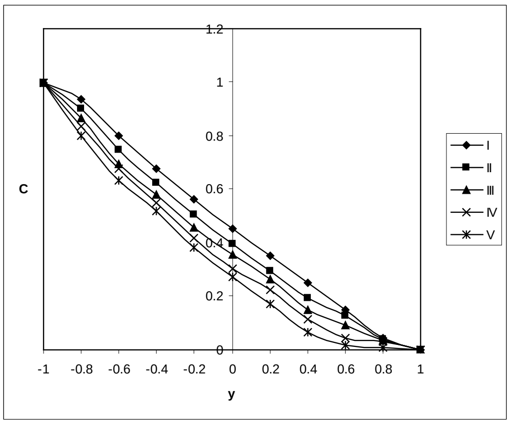


Fig.-11: Variation of C with α_1

	I	II	III	IV	V
α_1	0.1	0.3	0.5	0.7	0.9

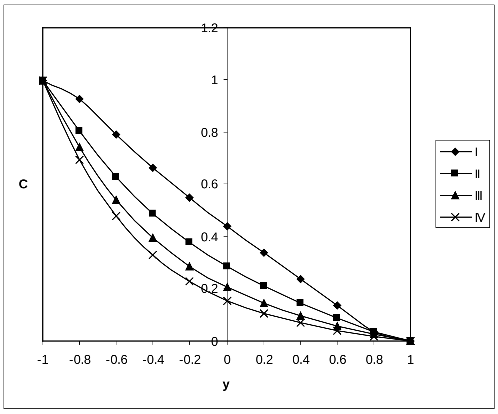


Fig.-12: Variation of C with K

	I	II	III	IV
K	0.5	1.5	2.5	3.5

Table-1: Nusselt Number (Nu) at y = 1

G	I	II	III	IV	V	VI	VII	VIII
10^3	-4.06419	-4.46413	-4.70162	-3.8791	-3.0675	-2.1391	-1.412	-1.02293
3×10^3	-4.02763	-4.10306	-3.98812	-4.0176	-3.8576	-2.1959	-1.477	-1.09265
-10^3	-4.20274	-4.96067	-5.62024	-4.1022	-4.0007	-2.2267	-1.447	-1.0303
-3×10^3	-4.16249	-5.27105	-6.31906	-4.1025	-3.8625	-2.1699	-1.382	-0.96033

Annexure-I

Q_1	2	4	6	2	2	2	2	2
K	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
α_1	0.3	0.3	0.3	0.3	0.3	0.5	0.7	0.9

Table-2: Nusselt Number (Nu) at y = -1

G	I	II	III	IV	V	VI	VII	VIII
10^3	0.37615	0.81601	1.1675	0.56125	0.65282	0.12517	-0.0038	-0.0727
3×10^3	0.45602	1.22009	1.92107	0.50602	0.55602	0.12902	0.0006	-0.06794
-10^3	0.19441	0.27635	0.20861	0.22441	0.29441	-0.02306	-0.1088	-0.15473
-3×10^3	0.19157	-0.07724	-0.53065	0.25157	0.39157	-0.02696	-0.1133	-0.15961

Annexure-II

Q_1	2	4	6	2	2	2	2	2
K	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
α_1	0.3	0.3	0.3	0.3	0.3	0.5	0.7	0.9

Table-3: Sherwood Number (Sh) at y = 1

G	I	II	III	IV	V	VI	VII	VIII
10^3	-0.76622	-1.231	-1.7417	-0.8622	-0.96622	-0.71233	-0.65881	-0.60594
3×10^3	-1.53198	-3.34605	-5.906	-1.63198	-1.73198	-1.34623	-1.16662	-0.99284
-10^3	-0.10614	0.26399	0.60553	-0.12614	-0.16614	-0.15366	-0.20165	-0.25012
-3×10^3	0.46873	1.37673	2.11199	0.56873	0.66873	0.3422	0.21208	0.07823

Annexure-III

Q_1	2	4	6	2	2	2	2	2
K	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
α_1	0.3	0.3	0.3	0.3	0.3	0.5	0.7	0.9

Table-4: Sherwood Number (Sh) at y = -1

G	I	II	III	IV	V	VI	VII	VIII
10^3	1.8274	-1.29367	-3.46119	1.8674	1.9274	2.27405	2.74498	3.24222
3×10^3	-2.86054	-6.97884	-9.07085	-2.89054	-2.96054	-2.12691	-1.29935	-0.35859
-10^3	11.84909	26.25149	72.74061	11.94909	12.04909	10.80342	9.836	8.93836
-3×10^3	48.31897	-61.009	-32.25996	48.61897	49.11897	34.40192	25.49673	19.30916

Annexure-IV

Q_1	2	4	6	2	2	2	2	2
K	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
α_1	0.3	0.3	0.3	0.3	0.3	0.5	0.7	0.9

7. CONCLUSION

The following conclusions are made in this analysis:

- Higher the radiation absorption enhances the axial velocity in the flow region.
- Axial velocity increases when the vertical channel heated non-uniformly.
- Higher the chemical reaction parameter larger is the velocity in the entire flow region.
- Actual temperature enhances with increase in the radiation absorption parameter.
- Higher the chemical reaction parameter lower is the actual temperature.
- The actual concentration reduces with increase in the boundary temperature.
- The concentration reduces with the chemical reaction parameter.

8. REFERENCES

[1] Chin Yong Cheng: Natural convection heat and mass transfer from a vertical truncated cone in a porous medium saturated with a non-Newtonian fluid with variable wall temperature and concentration, Int. Comm. In Heat & Mass Transfer, Vol.36, pp.585-589 (2009).

[2] Chin Yong Cheng: Soret and Dufour effects on heat and mass transfer by natural convection from a vertical truncated cone in a fluid saturated porous medium with variable wall temperature and concentration, Int. Comm. Heat & mass transfer, Vo.37, pp.1031-1035 (2010).

[3] Deepthi,J and Prasada Rao,D.R.V : Effect of chemical reaction on convective heat and mass transfer flow of a viscous fluid in a non-uniformly heated vertical channel with heat generating sources. Int. J. of adv. Sci. & Tech. Res., Issue2, Vol.5, pp.257-277 (2012).

[4] Krishna,D.V,Kolposhchikov, V.L.Martyneko, O.G.Shabunya, S.I.Shnip, A.I and Luikov, A.V: mixed thermal convection of a vertical tube at non-uniform temperature, Accepted for publication.

[5] Ramakrishana Reddy.,: Hydromagentic convection Heat and Mass Transfer through a porous medium in channel/pipes with Soret effect, Ph.D thesis submitted to JNTU,Hyderabad,2007.

[6] RavindraReddy.A:Computational techinques in Hydromagnetic convective flow through porous medium.Ph.D thesis,Anantapur(1997).

[7] Reddaiah,P and Prasada Rao, D.R.V : Effect of radiation on hydromagnetic convective heat transfer flow of a viscous electrically conducting fluid in a non-uniformly heated vertical channel. Int. J. Appl. Math and Mech. 8(9): pp: 99-121 (2012).

[8] Simpkins,P.G, Freenberg Kosiniki,S and Macchesney,J.B: Thermoporosis. The mass transfer mechanism in modified chemical vapour deposition. J.Appl.Phys.V.50 (9), p.5676, (1996).

[9] Sree Ranga Vani, K: Effect of chemical reaction, Radiation and radiation absorption on mixed convective heat and mass transfer flow of a viscous fluid in channels with heat sources. Ph.D Thesis Submitted to Sri Krishnadevaraya University, Anantapur, October (2013).

[10] Sudhakar,P, Bhuvana Vijaya, R and Prasada Rao, D.R.V : Effect of Thermo-diffusion on convective heat and mass transfer flow in a non-uniformly heated vertical channel with chemical reaction and heat sources. Int. J. of Emer. Tre. In Engg.& Dev., Issue 3, Vol.5, pp.179-197 (2013).

[11] Trevisan,O.V and Beajan,A: Mass and Heat transfer by high Rayleigh number convection in a porous medium heated from below ., Int.J..Heat Mass Transfer. V.39.PP.2341-2356(1987).

[12] Umadevi, B, Sreenivasa,G, Bhuvana Vijaya, R and Prasada Rao, D.R.V : Effect of chemical reaction on double-diffusive flow in a non-uniformly heated vertical channel. Int.J.of Appl. Math and MEch 8(x): xx, 2012.

[13] Vijayabhaskar Reddy, P: Combined effect of Radiation and Soret effect on flow of a viscous fluid through a porous medium in a vertical non-uniformly temperature, Jou. Phys and Appl.Phys, V.21, No.3, pp.413-433 (2009).

Source of support: Nil, Conflict of interest: None Declared