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THERMO-DIFFUSION EFFECT ON UNSTEADY CONVECTIVE AND MASS TRANSFER FLOW OF A CHEMICALLY REACTING VISCOUS FLUID THROUGH A POROUS MEDIUM IN A VERTICAL CHANNEL WITH RADIATION AND DISSIPATION

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ABSTRACT

In this paper, we investigate the effect of chemical reaction on mixed convective heat and mass transfer flow of a viscous through a porous medium in a vertical channel with heat sources. The equations governing the flow , heat and mass transfer are solved by employing perturbation technique with aspect ratio δ as perturbation parameter. The velocity, temperature and concentration distributions are investigated for different values of Sc, S_0, N_1, γ, Ec. *The rate of heat and mass transfer are numerically evaluated for different variations of the governing parameters.*

Keywords: *Heat and Mass Transfer, Porous Medium, Heat Sources, Chemical reaction, Thermal Radiation and Dissipation.*

1. INTRODUCTION

There are many transport processes in nature and in many industries where flows with free convection currents caused by the temperature differences are affected by the differences in concentration or material constitutions. In a number of engineering applications foreign gases are injected to attain more efficiency, the advantage being the reduction in wall shear stress, the mass transfer conductance or the rate of heat transfer. Gases such as H_2, H_2O, CO_2, etc., are usually used as foreign gases in air flowing past bodies. So the problems of heat and mass transfer past vertical bodies in boundary layer flows have been studied by many of whom the names of Somers[17],Gil *et al*[10], Adeams and Lowell[1] and Gebhart and Peera[9] are worth mentioning. The mass transfer phenomenon in unsteady free convective flow past infinite vertical porous plate was also studied by Soudalgekar and Wavre [19] and Hossain and Begum [11].

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid.

We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects. The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast growth of electronic technology, effective cooling of electronic equipment has become warranted and cooling of electronic equipment ranges from individual transistors to main frame computers and from energy suppliers to telephone switch boards and thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight.

Muthucumaraswamy and Ganesan [12] studied effect of the chemical reaction and injection on flow characteristics in an in steady upward motion of an unsteady upward motion of an isothermal plate. Deka *et at.* [6] studied the effect of the first order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant beat and mass transfer. Chamkha [2] studies the MHD flow of a numerical of uniformly stretched vertical

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permeable surface in the presence of heat generation/absorption and a chemical reaction. The effect of foreign mass on the free-convection flow past a semi-infinite vertical plate were studied by Gebhart *et al* [9]. Chamkha [2] assumed that the plate is embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. Raptis and Perdikis [15] studied the unsteady free convection flow of water near 4 C in the laminar boundary layer over a vertical moving porous plate.

In the theory of flow through porous medium, the role of momentum equations or force balance is occupied by the numerous experimental observations summerised mathematically as the Darcy's law. It is observed that the Darcy's law is applicable as long as the Reynolds number based on average grain(pore) diameter does not exceed a value between 1 and 10.But in general ,the speed of specific discharge in the medium need not be always low. As the specific discharge increases, the convective forces get developed and the internal stress generated in the fluid due to its viscous nature produces distortions in the velocity field. Also in the case of highly porous media such as fibre glass, pappus of dandilion etc., the viscous stress at the surface is able to penetrate into media and produce flow near the surface even in the absence of the pressure gradient. Thus Darcy's law which specifies a linear relationship between the specific discharge and hydraulic gradient is inadequate in describing high speed flows or flows near surfaces which may be either permeable or not. Hence consideration for non-Darcian description for the viscous flow through porous media is warranted. Saffman[16] employing statistical method derived a general governing equations for the flow in a porous medium which takes into account the viscous stress.

$$o = -\nabla p - \left(\frac{\mu}{k}\right)\overline{v} + \mu\nabla^2\overline{v}$$

in which $\mu\nabla^2\overline{v}$ is intended to account for the distortions of the velocity profiles near the boundary. The same equation was derived analytically by Tam [19] to describe the viscous flow at low Reynolds number past a swam of small particles. The generalization of the above study was presented by Yamamoto and Iwamura [22]. The steady two-dimensional flow of viscous fluid through a porous medium bounded by porous surface subjected to a constant suction velocity by taking account of free convection currents (both velocity and temperature fields are constant along x-axis) was studied by Raptis *et al* [14] Combarnous and Borris[5],Chang [4] have recently proved extensive reviews of state of the art of free convection in fluid saturated porous medium.

There is an extensive literature on free convection in porous media, i.e., flows through a porous media under gravitational fields that are driven by gradients of fluid density caused by temperature gradient. Some attention has also been given to investigations of free convection in porous media introduced by a temperature gradient normal to the gravitational field. Raptis [14] has investigated unsteady free convective flow through a porous medium.

Convection fluid flows generated by traveling thermal waves have also received attention due to applications in physical problems. The linearised analysis of these flows has shown that a traveling thermal wave can generate a mean shear flow within a layer of fluid, and the induced mean flow is proportional to the square of the amplitude of the wave. From a physical point of view, the motion induced by traveling thermal waves is quite interesting as a purely fluid-dynamical problem and can be used as a possible explanation for the observed four-day retrograde zonal motion of the upper atmosphere of Venus. Also, the heat transfer results will have a definite bearing on the design of oil-or gas –fired boilers. Vajravelu and Debnath[20] have made an interesting and a detailed study of non-linear convection heat transfer and fluid flows, induced by traveling thermal waves. The traveling thermal wave problem was investigated both analytically and experimentally by Whitehead [21] by postulating series expansion in the square of the aspect ratio(assumed small) for both the temperature and flow fields. Whitehead [21] obtained an analytical solution for the mean flow produced by a moving source theoretical predictions regarding the ratio of the mean flow velocity to the source speed were found to be in good agreement with experimental observations in Mercury which therefore justified the validity of the asymptotic expansion a posterior

Heat generation in a porous media due to the presence of temperature dependent heat sources has number of applications related to the development of energy resources. It is also important in engineering processes pertaining to flows in which a fluid supports an exothermic chemical or nuclear reaction. Proposal of disposing the radioactive waste material b burying in the ground or in deep ocean sediment is another problem where heat generation in porous medium occurs, Foroboschi and Federico [8] have assumed volumetric heat generation of the type

$$\theta = \begin{cases} \theta_0\left(T - T_0\right) & for \quad T > T \\ 0 & for \quad T < T_0 \end{cases}$$

David Moleam [7] has studied the effect of temperature dependent heat source θ=1/ a + bT such as occurring in the electrical heating on the steady state transfer within a porous medium. Chandrasekahr [3], Palm [13] reviewed the extensive work and mentioned about several authors who have contributed to the force convection with heat generating source. Mixed convection flows have been studied extensively for various enclosure shapes and thermal boundary conditions. Due to the super position of the buoyancy effects on the main flow there is a secondary flow in the form of a vortex recirculation pattern.

In this paper we investigate the effect of chemical reaction on mixed convective heat and mass transfer flow of a viscous through a porous medium in a vertical channel with heat sources. The equations governing the flow, heat and mass transfer are solved by employing perturbation technique with aspect ratio δ as perturbation parameter. The velocity, temperature and concentration distributions are investigated for different values of Sc, S_0, N_1, γ, Ec. The rate of heat and mass transfer are numerically evaluated for different variations of the governing parameters.

2. FORMULATION OF THE PROBLEM

We consider the motion of viscous, incompressible fluid through a porous medium in a vertical channel bounded by flat walls. The thermal buoyancy in the flow field is created by a traveling thermal wave imposed on the boundary wall at y=L while the boundary at y = -L is maintained at constant temperature T_1. The walls are maintained at constant concentrations. A uniform magnetic field of strength H0 is applied transverse to the walls. Assuming the magnetic Reynolds to be small we neglect the induced magnetic field in comparison to the applied magnetic field. Assuming that the flow takes place at low concentration we neglect the Duffor effect. The Boussinesq approximation is used so that the density variation will be considered only in the buoyancy force. The viscous and Darcy dissipations are taken into account to the transport of heat by conduction and convection in the energy equation. Also the kinematic viscosity ν, the thermal conducting k are treated as constants. We choose a rectangular Cartesian system 0 (x, y) with x-axis in the vertical direction and y-axis normal to the walls. The walls of the channel are at y = ± L.

The equations governing the unsteady flow and heat transfer are

Equation of linear momentum

$$\rho_e\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\rho g-\left(\frac{\mu}{k}\right)u \tag{1}$$

$$\rho_e\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\left(\frac{\mu}{k}\right)v \tag{2}$$

Equation of continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{3}$$

Equation of energy

$$\rho_e C_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+Q+\mu\left(\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial v}{\partial x}\right)^2\right)\left(\frac{\mu}{\lambda k}\right)(u^2+v^2)-\frac{\partial(q_R)}{\partial y} \tag{4}$$

Equation of Diffusion

$$\left(\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right)=D_1\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)-k_1(C-C_e)+k_{11}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{5}$$

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, Te, Ce 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,ρis the density of the fluid,μ is the constant coefficient of viscosity ,Cp is the specific heat at constant pressure,λis the coefficient of thermal conductivity ,k is the permeability of the porous medium ,D_1 is the molecular diffusivity , k_{11} is the cross diffusivity,β is the coefficient of thermal expansion, β^* is the volume expansion with mass fraction ,k1 is the chemical reaction coefficient, Q is the strength of the constant internal heat source, and qr is the radiative heat flux.

Invoking Rosseland approximation for radiative heat flux

$$q_r = -\frac{4\sigma^{\bullet}}{3\beta_R}\frac{\partial(T'^4)}{\partial y} \tag{7}$$

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

$$T'^4 \cong 4T_e^3 T' - 3T_e^4 \tag{8}$$

where $\sigma^{\bullet}$ is the Stefan-Boltzmann constant β_R is the Extinction coefficient. In the equilibrium state

$$0 = -\frac{\partial p_e}{\partial x} - \rho_e g \tag{9}$$

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

$$q = \frac{1}{L}\int_{-L}^{L} u \, dy. \tag{10}$$

The boundary conditions for the velocity and temperature fields are

u = 0, v = 0 ,$T=T_1$, $C = C_1$ on y = -L

$$u = 0,\ v = 0, T = T_2 + \Delta T_e \, Sin(mx + nt), C = C_2 \text{ on } y = L \tag{11}$$

where $\Delta T_e = T_2 - T_1$ and $Sin(mx+nt)$ is the imposed traveling thermal wave

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

$$u = -\psi_y,\ v = \psi_x \tag{12}$$

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

$$[(\nabla^2\psi)_t + \psi_x(\nabla^2\psi)_y - \psi_y(\nabla^2\psi)_x] = \nu\nabla^4\psi - \beta\, g(T-T_0)_y - \beta^{\bullet}\, g(C-C_0)_y - \left(\frac{\nu}{k}\right)\nabla^2\psi \tag{13}$$

$$\begin{aligned}\rho_e C_p\left(\frac{\partial T}{\partial t} - \frac{\partial\psi}{\partial y}\frac{\partial T}{\partial x} + \frac{\partial\psi}{\partial x}\frac{\partial T}{\partial y}\right) &= \lambda\nabla^2 T + Q + \mu\left(\left(\frac{\partial^2\psi}{\partial y^2}\right)^2 + \left(\frac{\partial^2\psi}{\partial x^2}\right)^2\right)\\ &+\left(\frac{\mu}{k}\right)\left(\left(\frac{\partial\psi}{\partial x}\right)^2 + \left(\frac{\partial\psi}{\partial y}\right)^2\right) + \left(\frac{16\sigma^{\bullet}T_e^3}{\beta_R\lambda}\frac{\partial^2 T}{\partial y^2}\right)\end{aligned} \tag{14}$$

$$\left(\frac{\partial C}{\partial t} - \frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} + \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}\right) = D_1\nabla^2 C - k_1 C + k_{11}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \tag{15}$$

Introducing the non-dimensional variables in (13) - (15) as

$$x' = mx,\ y' = y/L, t' = t\nu m^2, \Psi' = \Psi/\nu, \theta = \frac{T-T_e}{\Delta T_e}, C' = \frac{C-C_1}{C_2-C_1} \tag{16}$$

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

$$\delta R(\delta(\nabla_1^2\psi)_t + \frac{\partial(\psi,\nabla_1^2\psi)}{\partial(x,y)}) = \nabla_1^4\psi - \left(\frac{G}{R}\right)(\theta_y + NC_y) - D^{-1}\nabla_1^2\psi \quad (17)$$

The energy equation in the non-dimensional form is

$$\begin{aligned}\delta P\left(\delta\frac{\partial\psi}{\partial t} - \frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} + \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) &= \nabla_1^2\theta + \alpha + \left(\frac{PR^2E_c}{G}\right)\left(\left(\frac{\partial^2\psi}{\partial y^2}\right)^2 + \delta^2\left(\frac{\partial^2\psi}{\partial x^2}\right)^2\right) \\ &+ (D^{-1})\left(\delta^2\left(\frac{\partial\psi}{\partial x}\right)^2 + \left(\frac{\partial\psi}{\partial y}\right)^2\right) + \frac{4}{3N_1}\frac{\partial^2\theta}{\partial y^2}\end{aligned} \quad (18)$$

The Diffusion equation is

$$\delta Sc\left(\delta\frac{\partial C}{\partial t} - \frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} + \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}\right) = \nabla_1^2 C - kC + \frac{ScSo}{N}\nabla_1^2\theta \quad (19)$$

where

$R = \frac{qL}{\nu}$ (Reynolds number) $\quad G = \frac{\beta g\Delta T_e L^3}{\nu^2}$ (Grashof number)

$\mathrm{P} = \frac{\mu c_p}{k_1}$ (Prandtl number), $\quad D^{-1} = \frac{L^2}{k}$ (Darcy parameter),

$E_c = \frac{\beta g L^3}{C_p}$ (Eckert number) $\quad \delta = mL$ (Aspect ratio)

$\gamma = \frac{n}{\nu m^2}$ (Non-dimensional thermal wave velocity)

$Sc = \frac{\nu}{D_1}$ $(Schimdt\ Number)$ $\quad N = \frac{\beta^*\Delta C}{\beta\Delta T}$ (Buoyancy ratio)

$S_0 = \frac{k_{11}\Delta T}{\nu\Delta C}$ (Soret parameter) $\quad N_1 = \frac{\beta_R\lambda}{4\sigma_\bullet T_e^3}$ (Radiation parameter)

$k = \frac{k_1 L^2}{D_1}$ (Chemical reaction parameter)

$N_2 = \frac{3N_1}{3N_1+4}$ $\quad P_1 = PN_2 \quad \alpha_1 = \alpha N_2 \qquad \nabla_1^2 = \delta^2\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$

The corresponding boundary conditions are

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

$$\frac{\partial\psi}{\partial x} = 0,\ \frac{\partial\psi}{\partial y} = 0 \quad at\ y = \pm 1 \quad (20)$$

$\theta(x,y) = 1,\ C(x,y) = 0$ on y = -1

$\theta(x,y) = Sin(x+\gamma t)$, C(x, y) = 1 on y = 1

$$\frac{\partial\theta}{\partial y} = 0, \frac{\partial C}{\partial y} = 0 \quad at \quad y = 0 \quad (21)$$

The value of ψ on the boundary assumes the constant volumetric flow in consistent with the hyphothesis (10) .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 traveling thermal wave imposed on the boundaries. The perturbation analysis is carried out by assuming that the aspect ratio δ to be small.

We adopt the perturbation scheme and write

$$\psi(x,y,t)=\psi_0(x,y,t)+\delta\psi_1(x,y,t)+\delta^2\psi_2(x,y,t)+...............$$

$$\theta(x,y,t)=\theta_0(x,y,t)+\delta\,\theta_1(x,y,t)+\delta^2\,\theta_2(x,y,t)+.............$$

$$C(x,y,t)=C_0(x,y,t)+\delta C_1(x,y,t)+\delta^2\,C_2(x,y,t)+............. \tag{22}$$

On substituting (22) in (18) - (19) and separating the like powers of δ the equations and respective conditions to the zeroth order are

$$\psi_{0,\,yyyyy}-M_1^2\psi_{0,\,yy}=\frac{G}{R}(\theta_{0,y}+NC_{O,Y}) \tag{23}$$

$$\theta_{o,yy}+\alpha_1+\frac{P_1E_cR^2}{G}(\psi_{o,yy})^2+\frac{P_1E_cM_1^2}{G}(\psi_{o,y}^2)=0 \tag{24}$$

$$C_{O,YY}-(kSc)C_0=-\frac{ScSo}{N}\theta_{0,yy} \tag{25}$$

with $\psi_0(+1)-\Psi(-1)=-1$,

$\psi_{0,y}=0,\ \psi_{0,x}=0$ at $y=\pm1$ (26)

$$\theta_o=1, C_0=0 \quad on \quad y=-1$$

$$\theta_o=Sin(x+\gamma t), C_0=1 \quad on \ \ y=1 \tag{27}$$

and to the first order are

$$\psi_{1,\,yyyyy}-M_1^2\psi_{1,\,yy}=\frac{G}{R}(\theta_{1,Yy}+NC_{1,Y})+(\psi_{0,\,y}\,\psi_{0,\,xyy}-\psi_{0,\,x}\psi_{0,yyy}) \tag{28}$$

$$\theta_{1,yy}=(\psi_{0,x}\theta_{o,y}-\psi_{0,y}\theta_{ox})+\frac{2P_1E_cR^2}{G}(\psi_{0,yy}.\psi_{1,yy})+\frac{2P_1E_cM_1^2}{G}(\psi_{0,y}.\psi_{1,y}) \tag{29}$$

$$C_{1,yy}-(kSc)\,C_1=(\psi_{0,x}C_{o,y}-\psi_{0,y}C_{ox})-\frac{ScSo}{N}\theta_{1,yy} \tag{30}$$

with $\psi_{1(+1)}-\psi_{1(-1)}=0$

$\psi_{1,y}=0$, $\psi_{1,x}=0$ at $y=\pm1$ (31)

$\theta_1(\pm1)=0$, $C_1(\pm1)=0$ at $y=\pm1$ (32)

Assuming Ec<<1 to be small we take the asymptotic expansions as

$$\psi_0(x,y,t)=\psi_{00}(x,y,t)+Ec\psi_{01}(x,y,t)+...........$$
$$\psi_1(x,y,t)=\psi_{10}(x,y,t)+Ec\psi_{11}(x,y,t)+..........$$
$$\theta_0(x,y,t)=\theta_{00}(x,y,t)+\theta_{01}(x,y,t)+...............$$
$$\theta_1(x,y,t)=\theta_{10}(x,y,t)+\theta_{11}(x,y,t)+............$$
$$C_0(x,y,t)=C_{00}(x,y,t)+C_{01}(x,y,t)+............$$
$$C_1(x,y,t)=C_{10}(x,y,t)+C_{11}(x,y,t)+........... \tag{33}$$

Substituting the expansions (33) in equations (23)-(25) and separating the like powers-of Ec we get t1he following

$$\theta_{00,yy}=-\alpha_1,\quad \theta_{00}(-1)=1,\theta_{00}(+1)=SinD_1 \tag{34}$$

$$C_{00,yy}-(kSc)C_{00}=-\frac{ScSo}{N}\theta_{00,yy},\quad C_{00}(-1)=0,C_{00}(+1)=1 \tag{35}$$

$$\psi_{00,yyyy}-M_1^2\psi_{00,yy}=\frac{G}{R}(\theta_{00,y}+NC_{00,y}),$$

$$\psi_{00}(+1)-\psi_{00}(-1)=1,\psi_{00,y}=0,\psi_{00,x}=0\ \ at\ \ y=\pm1 \tag{36}$$

$$\theta_{01,yy}=-\frac{P_1R}{G}\psi^2{}_{00,yy}-\frac{P_1M_1^2}{G}\psi_{00,y}^2,\quad \theta_{01}(\pm1)=0 \tag{37}$$

$$C_{01,yy}-(kSc)C_{01}=-\frac{ScSo}{N}\theta_{01,yy},\quad C_{01}(-1)=0,C_{01}(+1)=0 \tag{38}$$

$$\psi_{01,yyyy}-M_1^2\psi_{01,yy}=\frac{G}{R}(\theta_{01,y}+NC_{01,y})$$

$$\psi_{01}(+1)-\psi_{01}(-1)=0,\psi_{01,y}=0,\psi_{01,x}=0\ \ at\ \ y=\pm1 \tag{39}$$

$$\theta_{10,yy}=GP_1(\psi_{00,y}\theta_{00,x}-\psi_{00,x}\theta_{00,y})\qquad \theta_{10}(\pm1)=0 \tag{40}$$

$$C_{10,yy}-(kSc)C_{10}=Sc(\psi_{00,y}C_{00,x}-\psi_{00,x}C_{00,y})-\frac{ScSo}{N}\theta_{01,yy}\quad C_{10}(\pm1)=0 \tag{41}$$

$$\psi_{10,yyyy}-M_1^2\psi_{10,yy}=\frac{G}{R}(\theta_{10,y}+NC_{10,Y})+(\psi_{00,y}\psi_{00,xyy}-\psi_{00,x}\psi_{00,yyy})$$

$$\psi_{10}(+1)-\psi_{10}(-1)=0,\psi_{10,y}=0,\psi_{10,x}=0\ \ at\ \ y=\pm1 \tag{42}$$

$$\theta_{11,yy}=P_1(\psi_{00,y}\theta_{01,x}-\psi_{01,x}\theta_{00,y}+\theta_{00,x}\psi_{01,y}-\theta_{01,y}\psi_{0,x})-\frac{2P_1R^2}{G}\psi_{00,yy}\psi_{10,yy}$$
$$-\frac{2P_1M_1^2}{G}\psi_{00,y}\psi_{10,y}\ ,\ \theta_1(\pm1)=0 \tag{43}$$

$$C_{11,yy}-(kSc)C_{11}=Sc(\psi_{00,y}C_{01,x}-\psi_{01,x}C_{00,y}+C_{00,x}\psi_{01,y}-C_{01,y}\psi_{0,x})-\frac{ScSo}{N}\theta_{11,yy} \tag{44}$$

$$\psi_{11,yyyy}-M_1^2\psi_{1,yy}=\frac{G}{R}(\theta_{11,y}+NC_{11,Y})+(\psi_{00,y}\psi_{11,xyy}-\psi_{00,x}\psi_{01,yyy}+\psi_{01,y}\psi_{00,xyy}-\psi_{01.x}\psi_{00,yyy})$$
$$\psi_{11}(+1)-\psi_{11}(-1)=0,\psi_{11,y}=0,\psi_{11,x}=0\ \ at\ \ y=\pm1 \tag{45}$$

4. SOLUTION OF THE PROBLEM

Solving the equations (34) - (36) subject to the relevant boundary conditions we obtain

$$\theta_{oo}(y,t)=\left(\frac{\alpha_1}{2}\right)(1-y^2)+\frac{Sin(D_1)}{2}(y+1)+0.5\,(1-y)$$

$$C_{00}=0.5\left(\frac{Sinh(\beta_1 y)}{Sinh(\beta_1)}+\frac{Cosh(\beta_1 y)}{Cosh(\beta_1)}\right)+a_3\left(1-\frac{Cosh(\beta_1 y)}{Cosh(\beta_1)}\right)$$

$$\psi_{oo}(y,t)=a_{11}Cosh(M_1 y)+a_{12}Sinh(M_1 y)+a_{13}y+a_{14}+\varphi_1(y)$$

$$\varphi_1(y)=a_6 y+a_7 y^2++a_8 y^3-a_{10}Ch(\beta_1 y)-\ a_{11}Sh(\beta_1 y)$$

$$\begin{aligned}\theta_{01}(y,t)&=0.5a_{19}(y^2-1)+\frac{a_{20}}{4M_1^2}(Ch(2M_1 y)-Ch(2M_1))+\frac{a_{21}}{4\beta_1^2}(Ch(2\beta_1 y)\\&-Ch(2\beta_1))+\frac{a_{22}}{M_1^2}(Ch(M_1 y)-Ch(M_1))+a_{36}(ySh(M_1 y)\\&-Sh(M_1))+a_{37}(ySh(\beta_1 y)-Sh(\beta_1))+\frac{a_{23}}{\beta_1^2}(\ (Ch(\beta_1 y)-Ch(\beta_1))+\frac{a_{24}}{M_1^2}(ySh(M_1 y)\\&-Sh(M_1))-\frac{2a_{24}}{M_1^3}(a_{40}(Ch(M_1 y)-Ch(M_1))+\frac{a_{25}}{\beta_2^2}(Ch(\beta_2 y)-Ch(\beta_2))+\frac{a_{26}}{\beta_3^2}(Ch(\beta_3 y)\\&-Ch(\beta_3))+\frac{a_{27}}{12}(y^4-1)-Ch(\beta_3))+\frac{a_{28}}{30}(y^6-1)\end{aligned}$$

$$\begin{aligned}C_{01}(y,t)&=a_{31}\left(1-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)+\ a_{32}\left(y-\frac{Sh(\beta_1 y)}{Sh(\beta_1)}\right)+\ a_{33}\left(y^2-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)\\&+a_{34}\left(y^4-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)+a_{354}a_{33}\left(y^6-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)+a_{36}(Ch(2M_1 y)\\&-Ch(2M_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)})+a_{37}\left(Ch(2\beta_1 y)--Ch(2\beta_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)\\&+a_{38}\left(Ch(M_1 y)-Ch(M_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)+a_{39}(ySh(\beta_1 y)\\&-Sh(\beta_1)\frac{Sh(\beta_1 y)}{Sh(\beta_1)})+\ a_{40}\left(y^2Ch(M_1 y)-Ch(M_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)\\&+a_{41}\left(Ch(\beta_2 y)-Ch(\beta_2)\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)+a_{42}\left(Ch(\beta_3 y)-Ch(\beta_3)\frac{Ch(\beta_1 y)}{Ch(\beta_1)}\right)\end{aligned}$$

$$\psi_{01}(y,t)=a_{58}+a_{57}y+a_{55}Ch(M_1 y)+a_{56}Sh(2\beta_2 y)+\varphi_2(y)$$

$$\begin{aligned}\varphi_2(y)&=a_{43}+a_{44}y+a_{45}y^3+a_{46}y^5+a_{47}Sh(2M_1 y)+a_{48}Sh(2\beta_1 y)+a_{49}Sh(M_1 y)\\&+a_{50}yCh(M_1 y)+a_{51}yCh(\beta_1 y)+\ a_{52}y^2Sh(M_1 y)+\ a_{53}Sh(\beta_2 y)+a_{54}Sh(\beta_3 y)\end{aligned}$$

$$\theta_{10}(y,t) = a_{77}y^2 + a_{78}y^3 + a_{79}y^4 + a_{80}y^5 + a_{817}Ch((\beta_1 y) + a_{82}Sh(\beta_1 y)$$
$$+a_{83}Ch(M_1 y) + a_{84}Sh(M_1 y) + a_{85}yCh(M_1 y) + a_{86}ySh(M_1 y)$$
$$+a_{87}yCh(\beta_1 y) + a_{88}ySh(\beta_1 y) + a_{89}y + a_{90}$$

$$C_{10}(y,t) = b_{14}Ch(\beta_1 y) + b_{15}Sh(\beta_1 y) + \varphi_3(y)$$

$$\varphi_3(y) = b_1 + b_2Ch(2\beta_2 y) + b_{35}Sh(2\beta_1 y) + (b_4 y + b_6 y^2 + b_8 y^3)Ch(\beta_1 y)$$
$$+(b_5 y + b_7 y^2 + b_9 y^3)Sh(\beta_1 y) + b_{10}Sh(\beta_2 y) + b_{11}Sh(\beta_3 y) + b_{12}Ch(\beta_2 y) + b_{13}Ch(\beta_3 y)$$

$$\psi_{10} = b_{80}Ch(M_1 y) + b_{81}Sh(M_1 y) + b_{82}y + b_{83} + \varphi_4(y)$$

$$\varphi_4(y) = b_{53}y^2 + b_{54}y^3 + b_{55}y^4 + b_{56}y^5 + b_{57}y^6 + (b_{58} + b_{64}y + b_{66}y^2 + b_{71}y^3$$
$$+b_{73}y^4)Sh(\beta_1 y) + (b_{59} + b_{65}y + b_{67}y^2 + b_{70}y^3 + b_{72}y^4)Ch(\beta_1 y)$$
$$+(b_{60}y + b_{63}y^2 + d_{46}y^3)Ch(M_1 y) + (b_{61}y + b_{62}y^2)Sh(M_1 y)$$
$$+b_{75}yCh(2M_1 y) + b_{74}ySh(2M_1 y) + b_{76}Sh(\beta_2 y) + b_{77}Sh(\beta_3 y) + b_{78}Ch(\beta_2 y) + b_{78}Ch(\beta_3 y)$$

where $a_1, a_2, ...a_{105}, b_1, b_2, ...b_{79}$, are constants.

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

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

$$(Nu)_{y=-1} = \frac{(d_3 + Ecd_5 + \delta\, d_7)}{(\theta_m - 1)}$$

$$\theta_m = d_8 + Ecd_9 + \delta\, d_{10}$$

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

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

$$(Sh)_{y=+1} = \frac{(d_{11} + Ecd_{13} + \delta\, d_{15})}{(C_m - 1)} \qquad (Sh)_{y=-1} = \frac{(d_{12} + Ec\, d_{14}\delta\, d_{16})}{(C_m)}$$

$C_m = d_{17} + Ec\, d_{18} + \delta\, d_{19}$ where d_1,….d_{77} constants.

6. DISCUSSION OF THE RESULTS

In this analysis we investigate the effect of chemical reaction, thermo-diffusion, dissipation and thermal radiation on convective heat and mass transfer flow through a porous medium in a vertical channel. The equations governing the flow, heat and mass transfer are solved by using a perturbation technique with the aspect ratio δ as a perturbation parameter.

The axial velocity (u) is shown in figures 1 - 9 for different values of Sc, S_0, N_1, γ, Ec. With respect to Sc, it is found that lesser the molecular diffusivity larger |u| in the flow region. |u| enhances with increase in the Soret parameter $S_0 > 0$ and depreciates with $|S_0|$ (<0) (fig 4). It can be seen from the profiles that |u| depreciates with increase in the strength of the heat source while it enhances with that of heat sink. From fig (6) we find that higher the radiative heat flux lesser |u| in the flow region. Fig (7) represents u with chemical reaction parameter γ. The axial velocity reduces in the degenerating chemical reaction case. The effect of dissipation (Ec) on u is shown in fig (8).

The secondary velocity (v) which is due to the non – uniform boundary temperature is shown in figures 13 - 17 for different parametric values. With respect to Sc, it can be seen that lesser the molecular diffusivity larger |v| and for further lowering of the molecular diffusivity smaller |v| in the flow region. |v| depreciates with increase in the Soret parameter $S_0 > 0$ and enhances with $|S_0|$ (<0) (fig 5). The magnitude of v experiences an enhancement with increase in the strength of the heat source /sink. The variation of v with radiation parameter N_1, shows that higher the radiative heat flux larger |v| in the flow region (fig 6). From fig (8) we find that |v| enhances in the left half and reduces in the right half of the channel with increase in the chemical reaction parameter.

The non – dimensional temperature (θ) is exhibited in figures 9 – 13 for different parametric values. We follow the convention that the non – dimensional temperature is positive or negative according as the actual temperature is greater / lesser than T_2, temperature on the right wall y = +1. With respect to Sc, it can be seen that lesser the molecular diffusivity smaller the actual temperature in the flow region (fig 9). The actual temperature enhances with increase in the Soret parameter $|S_0|$ (fig 10). The actual temperature enhances with increase in the strength of the heat source and reduces with that of heat sink (fig.11). From fig (12) we find that higher the radiative heat flux larger the actual temperature. The variation of θ with γ shows that the actual temperature reduces with increase in $\nleq$ 1.5 and enhances with higher $\ngeq$ 2.5 (fig 12). The variation of θ with Ec shows that higher the dissipative heat larger the actual temperature (fig 13).

The concentration (C) is exhibited in figures 14 – 18 for different parametric values. We follow the convention that the non – dimensional concentration is positive or negative according as that actual concentration is greater / lesser than C_2, concentration on the right wall y = +1 . With respect to Sc, we find that the actual concentration reduces with increase in Sc. Thus lesser the molecular diffusivity lesser the actual concentration (fig 14). From fig (15) it can be seen that the actual concentration reduces with increase in the soret parameter $S_0 > 0$ and enhances with $|S_0|$ (<0). Higher the radiative heat flux smaller the actual concentration. From fig (17 & 18), we find that the actual concentration reduces with increase in γ or Ec.

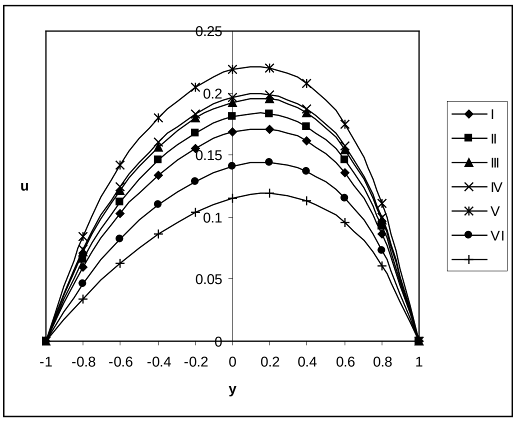

Fig. 1 : Variation of u with Sc & S_0

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	1.3	1.3	1.3
S_0	0.5	0.5	0.5	0.2	1	-0.5	-1.5

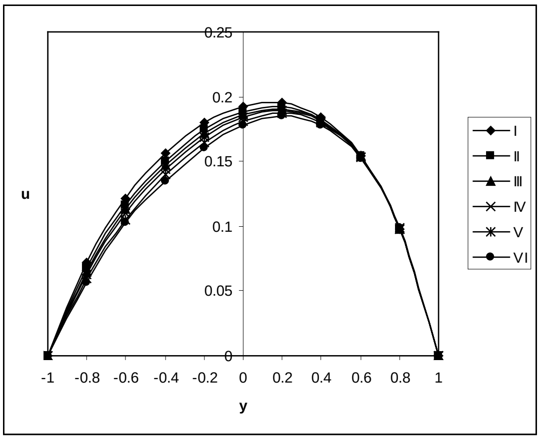

Fig. 2 : Variation of u with N_1

	I	II	III	IV	V	VI
N_1	1.5	2.5	3.5	5	10	100

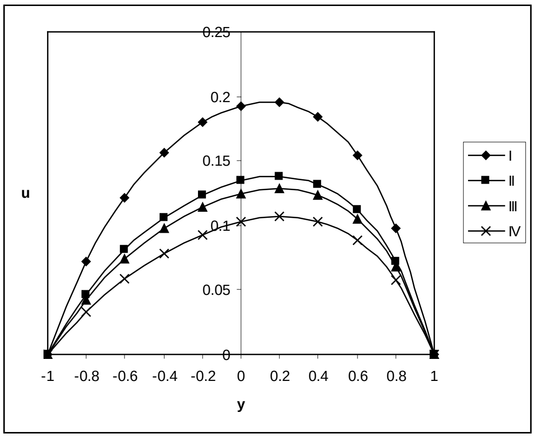

Fig. 3 : Variation of u with γ

	I	II	III	IV
γ	0.5	1.5	2.5	3.5

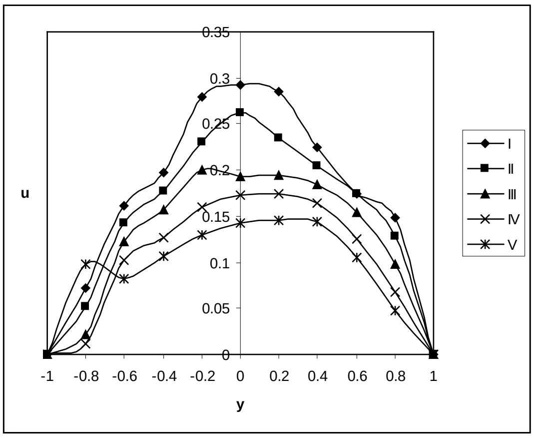

Fig. 4 : Variation of u with Ec

	I	II	III	IV	V
Ec	0.01	0.03	0.05	0.07	0.09

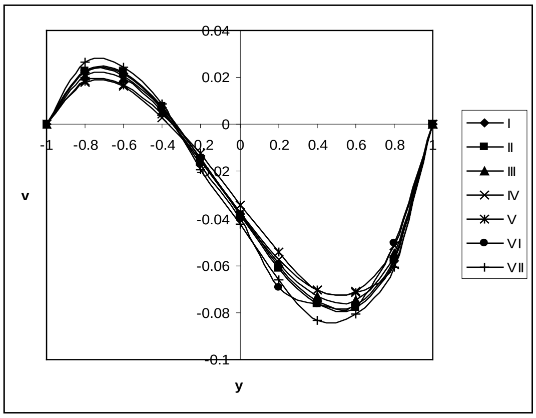

Fig. 5 : Variation of v with Sc & S_0

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	1.3	1.3	1.3
S_0	0.5	0.5	0.5	0.2	1	-0.5	-1.5

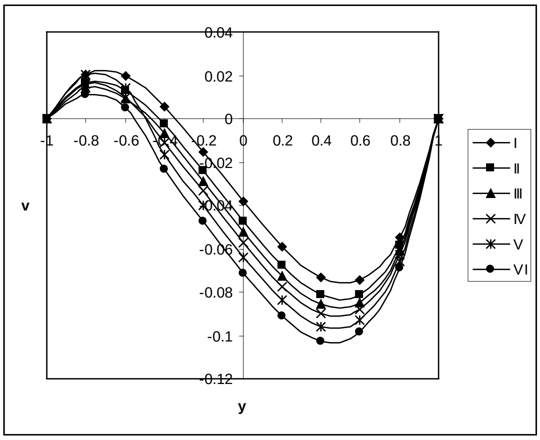

Fig. 6 : Variation of v with N_1

	I	II	III	IV	V	VI
N_1	1.5	2.5	3.5	5	10	100

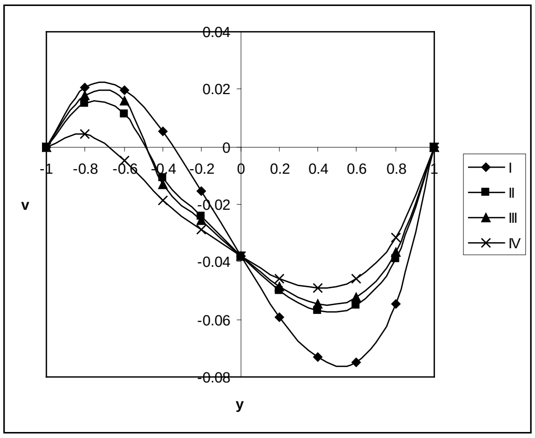

Fig. 7 : Variation of v with γ

	I	II	III	IV
γ	0.5	1.5	2.5	3.5

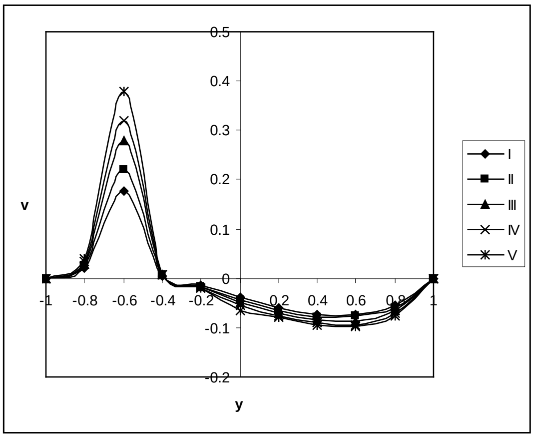

Fig. 8 : Variation of v with Ec

	I	II	III	IV	V
Ec	0.01	0.03	0.05	0.07	0.09

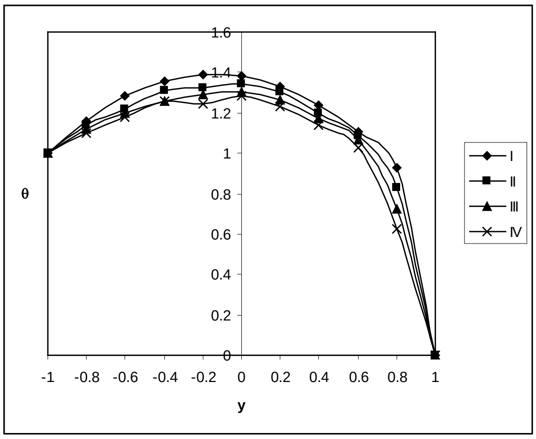

Fig. 9 : Variation of θ with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

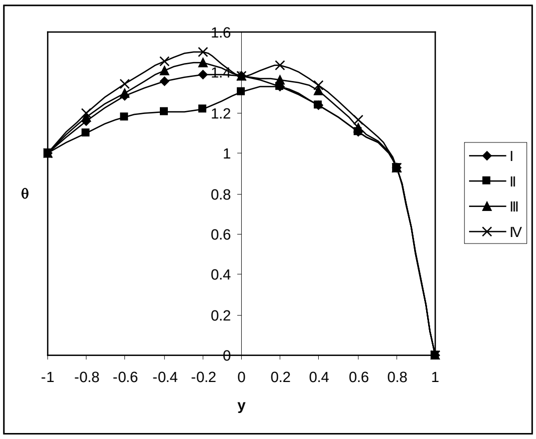

Fig. 10 : Variation of θ with S_0

	I	II	III	IV
S_0	0.2	1	-0.5	-1.5

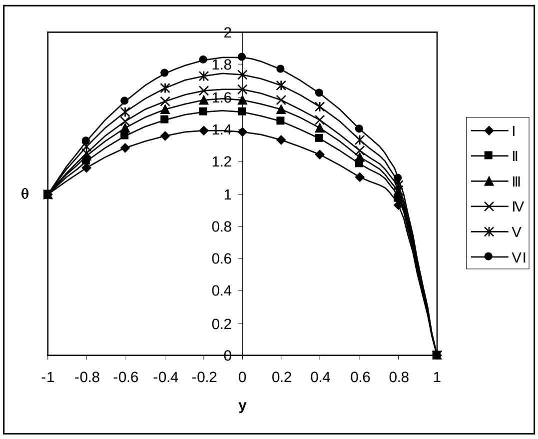

Fig. 11 : Variation of θ with N_1

	I	II	III	IV	V	VI
N_1	1.5	2.5	3.5	5	10	100

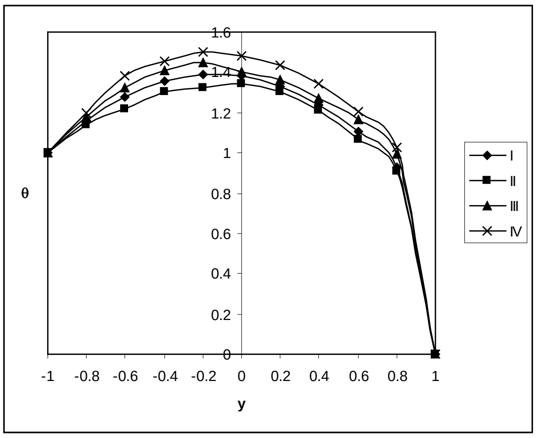

Fig. 12 : Variation of θ with γ

	I	II	III	IV
γ	0.5	1.5	2.5	3.5

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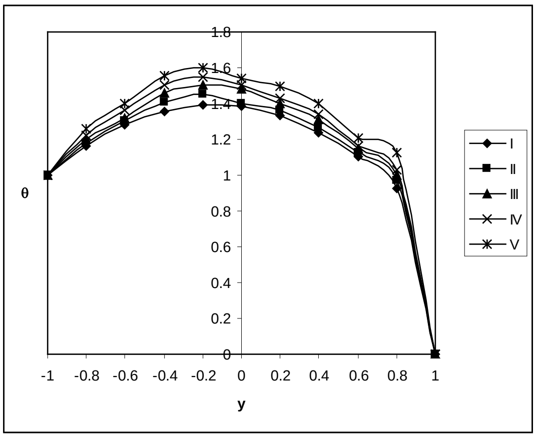

Fig. 13 : Variation of θ with Ec

	I	II	III	IV	V
Ec	0.01	0.03	0.05	0.07	0.09

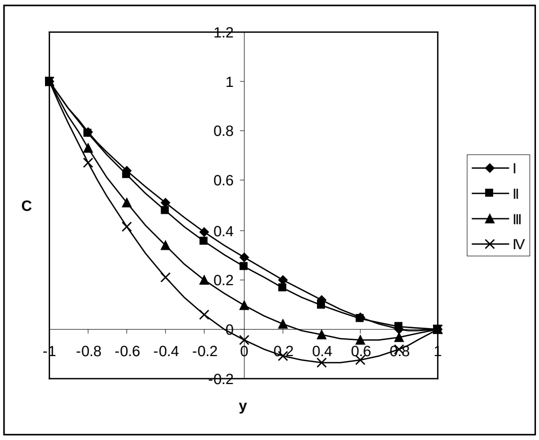

Fig. 14 : Variation of C with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

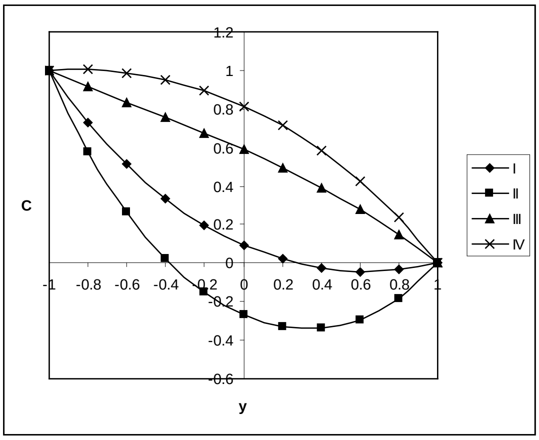

Fig. 15 : Variation of C with S_0

	I	II	III	IV
S_0	0.2	1	-0.5	-1.5

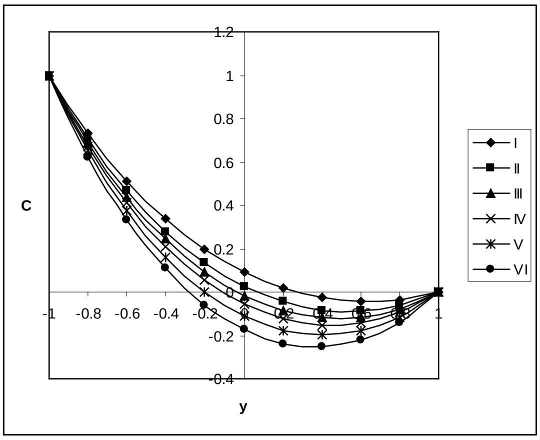

Fig. 16 : Variation of C with N_1

	I	II	III	IV	V	VI
N_1	1.5	2.5	3.5	5	10	100

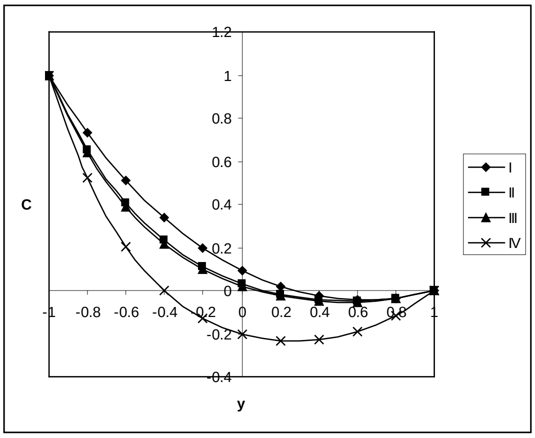

Fig. 17 : Variation of C with γ

	I	II	III	IV
γ	0.5	1.5	2.5	3.5

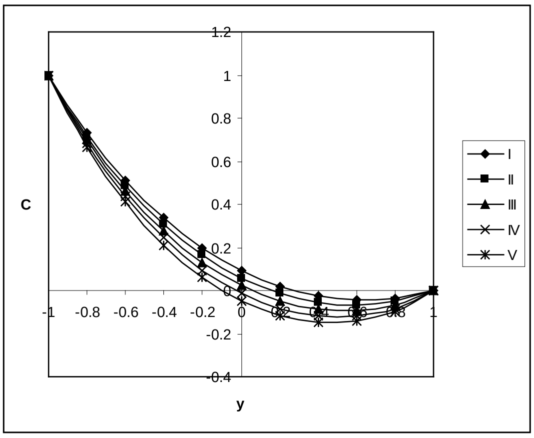

Fig. 18 : Variation of C with Ec

	I	II	III	IV	V
Ec	0.01	0.03	0.05	0.07	0.09

The rate of heat transfer (Nusselt number) at the boundaries $y = \pm 1$ is exhibited for different parametric values. It is found that the rate of heat transfer enhances with increase in |G| at both the walls. With respect to Sc we find that |Nu| enhances with increase in Sc at $y = \pm 1$. |Nu| enhances at $y = \pm 1$ with increase in $S_0 > 0$ while for $|S_0|$ (<0), it enhances at y = +1 and reduces at y = -1. When the molecular buoyancy force dominates over the thermal buoyancy force |Nu| enhances when the buoyancy forces act in the same direction and for the forces acting in opposite directions, |Nu| enhances at y = +1 and reduces at y = -1(Tables 1 & 3). With respect to N_1, and γ we find that the rate of heat transfer depreciates with increase in N_1 at $y = \pm 1$ while an increase in γ, it enhances at y = +1 and reduces at y = -1 (Tables 3 & 10). Higher the dissipative heat lesser |Nu| at both the walls.

The rate of mass transfer (Sherwood number) at $y = \pm 1$ for different parametric values. It is found that the rate of mass transfer depreciates at $y = \pm 1$ with increase in G > 0 and for G < 0, |Sh| reduces at y = +1 and enhances at y = -1. With respect to Sc we find that lesser the molecular diffusivity larger |Sh| at $y = \pm 1$. For an increase in $S_0 > 0$, |Sh| enhances at y = +1 and at y = -1, it reduces in the heating case and enhances in the cooling case. For an increase in $|S_0|$ (<0), we notice an enhancement in |Sh| at y= ±1. With respect to buoyancy ratio N, we find that |Sh| at y = +1, enhances for G > 0 and reduces for G < 0 and at y = -1, it reduces for G > 0 and enhances for G < 0 when the buoyancy forces act in the same direction and for the forces acting in opposite directions, |Sh| reduces for G > 0 and enhances for G < 0 at y = +1 and enhances at y = -1 for all G (Tables 5 & 7). An increase in the radiation parameter N_1 leads to an enhancement in |Sh| at y = +1 and depreciates at y = -1. An increase in the chemical reaction parameter $\gamma \leq 2.5$ reduces |Sh| and enhances with higher $\gamma \geq 3.5$ at y=+1 while at y = -1, |Sh| enhances with γ (Tables 6 & 8). We find that the rate of mass transfer at y = +1, depreciates with increase in Ec ≤ 0.07 and enhances with higher Ec ≥ 0.09. At y = -1, |Sh| reduces in the heating case and enhances in the cooling case.

Nusselt Number at y = +1 (Table 1)

G	I	II	III	IV	V	VI	VII
10^3	-2.3398	-8.7318	-9.8042	-12.6204	-7.8907	-8.5890	-9.6639
$3x10^3$	10.6670	-21.3393	-12.8066	-10.9553	-12.9723	-19.2786	-31.2778
-10^3	-3.2072	-4.6843	-5.3683	-5.9434	-5.9402	-4.9163	-4.9676
$-3x10^3$	-2.6847	-4.4720	-5.5055	-6.4696	-7.2017	-4.5176	-4.8638
Sc	**0.24**	**0.6**	**1.3**	**2.01**	**1.3**	**1.3**	**1.3**
S_0	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**-0.5**	**-1**

Nusselt Number at y = +1 (Table 2)

G	I	II	III	IV	V	VI	VII	VIII
10^3	-7.8042	-4.5520	-4.1977	-3.8793	-3.6705	-8.4116	-10.3199	-26.4912
$3x10^3$	-12.8066	-7.4168	-7.0409	-6.8418	-6.9040	-11.2511	-14.6581	-58.5151
-10^3	-5.3683	-3.5285	-3.2933	-3.0704	-2.9121	-6.6663	-8.1237	-11.3755
$-3x10^3$	-5.5055	-4.0183	-3.8550	-3.7277	-3.6742	-6.9069	-9.0139	-16.7630
N_1	**1.5**	**3.5**	**5**	**10**	**100**	**1.5**	**1.5**	**1.5**
γ	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**2.5**	**3.5**

Nusselt Number at y = -1 (Table 3)

G	I	II	III	IV	V	VI	VII
10^3	-0.4263	-0.8635	-0.9186	-1.1369	-1.1721	-0.7785	-0.6834
$3x10^3$	-0.2175	-0.4462	-0.6428	-0.8678	-1.1020	-0.4209	-0.3822
-10^3	0.4155	0.7910	0.8645	1.1270	1.2513	0.9005	0.7129
$-3x10^3$	0.2048	0.3848	0.7426	0.8148	0.4021	0.4146	0.3219
Sc	**0.24**	**0.6**	**1.3**	**2.01**	**1.3**	**1.3**	**1.3**
S_0	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**-0.5**	**-1**

Nusselt Number at y = -1 (Table 4)

G	I	II	III	IV	V	VI	VII	VIII
10^3	-0.9186	0.6465	0.4913	0.3880	0.3295	-0.8745	-0.6420	-0.4660
$3x10^3$	-0.6428	0.5656	0.4814	0.3859	0.3554	-0.5787	-0.5654	-0.4963
-10^3	0.8645	0.2904	0.2455	0.2080	0.1826	-0.7870	-0.6076	-0.4804
$-3x10^3$	0.7426	0.2274	0.1963	0.1689	0.1496	-0.3900	-0.1167	0.0451
N_1	**1.5**	**3.5**	**5**	**10**	**100**	**1.5**	**1.5**	**1.5**
γ	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**2.5**	**3.5**

Sherwood Number at y = +1 (Table 5)

G	I	II	III	IV	V	VI	VII
10^3	-0.3340	-0.3507	-0.4040	-0.4563	-0.5745	0.0731	0.3855
$3x10^3$	-0.3824	-0.3932	-0.4015	-0.4353	-0.5939	0.0083	0.1731
-10^3	-0.2238	-0.2768	-0.3550	-0.4228	-0.4633	0.0864	0.7057
$-3x10^3$	-0.1611	-0.2231	-0.2995	-0.3635	-0.3644	0.0284	0.7378
Sc	**0.24**	**0.6**	**1.3**	**2.01**	**1.3**	**1.3**	**1.3**
S_0	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**-0.5**	**-1**

Sherwood Number at y = +1 (Table 6)

G	I	II	III	IV	V	VI	VII	VIII
10^3	-0.4040	-0.4634	-0.4809	-0.5036	-0.5261	-0.3060	-0.2571	-0.5649
$3x10^3$	-0.4015	-0.4378	-0.4432	-0.4443	-0.4653	-0.2786	-0.2285	-0.7331
-10^3	-0.3550	-0.3834	-0.3891	-0.3937	-0.3938	-0.2994	-0.2477	0.6688
$-3x10^3$	-0.2995	-0.3600	-0.4325	-0.5776	-0.6873	-0.2646	-0.2101	0.5833
N_1	**1.5**	**3.5**	**5**	**10**	**100**	**1.5**	**1.5**	**1.5**
γ	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**2.5**	**3.5**

Sherwood Number at y = -1 (Table 7)

G	I	II	III	IV	V	VI	VII
10^3	-0.6267	-0.8741	-1.2280	-1.5052	-1.1480	-0.3479	2.0522
$3x10^3$	-0.5048	-0.7998	-1.2026	-1.5161	-0.9026	-0.1396	1.6340
-10^3	-0.9192	-1.1241	-1.4635	-1.7266	-1.7840	-0.4319	-3.1872
$-3x10^3$	-1.0956	-1.3163	-1.7050	-1.9969	-2.1720	-0.2381	-4.8894
Sc	**0.24**	**0.6**	**1.3**	**2.01**	**1.3**	**1.3**	**1.3**
S_0	**0.5**	**0.5**	**0.5**	**0.5**	**1**	**-0.5**	**-1**

Sherwood Number at y = -1 (Table 8)

G	I	II	III	IV	V	VI	VII	VIII
10^3	-1.2280	-1.2686	-1.2842	-1.3092	-1.3421	-2.1826	-3.2433	-3.6580
$3x10^3$	-1.2026	-1.3202	-1.3800	-1.4883	-1.6513	-2.3119	-3.4308	-4.0303
-10^3	-1.4635	-1.6508	-1.7237	-1.8386	-1.9863	-2.2366	-3.1724	-4.7641
$-3x10^3$	-1.7050	-2.2333	-2.4912	-2.9696	-3.7514	-2.4297	-3.2765	-4.0617
N_1	**1.5**	**3.5**	**5**	**10**	**100**	**1.5**	**1.5**	**1.5**
γ	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**1.5**	**2.5**	**3.5**

7. REFERENCES

[1]. Adams,J.A and Lowell, R.L: Int. J. Heat and Mass transfer, V.11. p.1215 (1968).
[2]. Chamkha,A,J., Takhar,H.S and Soundalgekar,V.M : Chem. Engng.J., V.84, p.104 (2003).
[3]. Chandrasekhar, S: Hydrodynamic and Hydromagnetic stability, clarandon press, oxford (1961).
[4]. Cheng, P: Advances in heat transfer, V.14, PP.1-205 (1979).
[5]. Combarnous,M and Bories,S.A :Adv. Hydro Sciences,V.10,p.231,(1975).
[6]. Das U.N, Deka R.K. and Soundalgekar V.M. (1996) Radiation effects on flow past an impulsively started vertical plate – an exact solution, J. Theo. Appl. Third Mech., Vol.1, pp. 111-115.
[7]. David Moleam: Int. J. Heat and Mass transfer,V.19, p.529(1976).
[8]. Foraboschi,F.P and Federico,J.P:Heat transfer in laminar flow of non-newtonian heat generating fluid, Int. J. Heat and Mass transfer ,V.7, p.315(1964).
[9]. Gebhart,B and Peera,L: Int. J. Heat and Mass transfer , V.15, p.269(1971).
[10]. Gill,W.N,Delesal,E and Zec,D.W: Int. J. Heat and Mass transfer, V.8, p.1131 (1965).
[11]. Hossain,M.A and Begum,R.A: Appl. Space Sci,V.15, p.145(1985).
[12]. Muthukumaraswamy, R: Acta Mechnica, V.155, p.65(2002).
[13]. Palm,E : Ann –REV: Fluid Mech., V.7, P.39 (1975).
[14]. Raptis, A. Kafousis, N and Massalas , C. Reg. J, Energy Heat Mass Transfer, V.3, pp.279-283(1995).
[15]. Raptis, A.A: Free convection and mass transfer effects in the oscillary flow past an infinite moving vertical isothermal plate with constant suction and heat source Aerophysics and space science, V.86.pp.45-53 (1982).
[16]. Saffman, P.G: On the boundary conditions at the free surface of a porous medium, stud. Application Maths,. V.2 , p.93 (1971).
[17]. Somers, E.V.:J.Appl.Mech,V.23,p.295(1956).
[18]. Soundelgekar,V.M and Wavre,P.P: Heaqt and mass transfer, V.20, p.1363 (1977).
[19]. Tam, C.K.W: The drag on a cloud of spherical particle, in a low Reynolds number flow, J. Fluid Mech. V.51, P.273 (1969).
[20]. Vajravelu, K and Debnath, L: Non –Linear study of convective heat transfer and fluid flows induced by traveling thermal waves , Acta Mech, V.59, PP-233-249 (1986).
[21]. Whitehead, J.A: Geo Physics fluid dynamics V.3, PP.161-180 (1972).
[22]. Yamamoto,K and Iwamura,N : J. Engg. Math., pp.1041-1054,(1976).

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