EFFECT OF DISSIPATION AND THERMODIFFUSION ON CONVECTIVE HEAT AND MASS TRANSFER FLOW OF A VISCOUS FLUID IN A NON UNIFORMLY HEATED VERTIC AL CHANNEL BOUNDED BY FLAT WALLS

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ABSTRACT

In this paper we discuss the effect of dissipation and thermo diffusion on convective heat and mass transfer flow of a viscous fluid, in a non uniformly heated vertical channel bounded by flat walls. A non-uniform temperature is imposed on the walls and the concentration on these walls is taken to be constant. The viscous dissipation is taken in to account in the energy equation assuming the slope of the boundary temperature to be small. We solve the governing momentum, energy and diffusion equations by a perturbation technique. The velocity, the temperature, the concentration, the rate of heat transfer and Shear wood Number have been analyzed for different variations of the governing parameters. The dissipative effects on the flow, heat and mass transfer are clearly brought out.

KEYWORDS: *Dissipation, Thermo diffusion, Heat and Mass Transfer.*

INTRODUCTION

Flows which arise due to the interaction of the gravitational force and density differences caused by the simultaneous diffusion of thermal energy and chemical species have many applications in geophysics and engineering. Such thermal and mass diffusion plays a dominant role in a number of technological and engineering systems. The combined effect of thermal and mass diffusion in channel flows has been studied in the recent times by a few authors (10, 12, 16, 19, 24, 23, 26, and 27).

Flow through porous media is very prevalent in nature. In the theory of flow through a porous medium, the role of momentum equation or force balance is occupied by the numerous experimental observations summarized mathematically as the Darcy's law. Thus 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 (24) employing statistical method derived a general governing equation for the flow in a porous medium which takes into account the viscous stress. Later another modification has been suggested by Brinkman (9).

$$0 = -\nabla P - \frac{\mu}{k}\bar{v} + \mu \nabla^2 \bar{v}$$

in which , $\mu \nabla^2 \bar{v}$ is intended to account for the distortions of the velocity profiles near the boundary. The Volumetric heat generation has been assumed to be constant (1,2,3,4,5,7,9,19,20) or a function of space variable (6,8,13,14,15,17). For example a hypothetical core-disruptive accident in a liquid metal fast breeder reactor (LMFBR) could result in the setting of fragmented fuel debris as horizontal surfaces below the core.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 may be of interest in a few technological process.

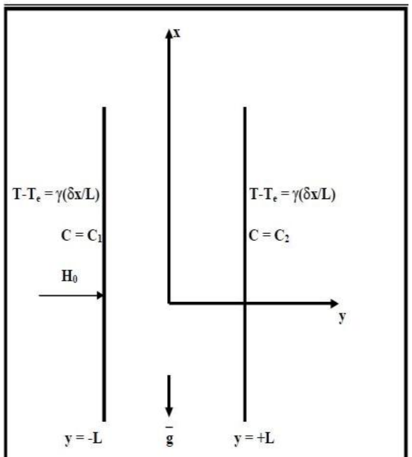
All the above mentioned studies are based on the hypothesis that the effect of dissipation is neglected. This is possible in case of ordinary fluid flow like air and water under gravitational force. But this effect is expected to be relevant for fluids with high values of the dynamic viscous flows. The effect of viscous dissipation on natural convection has been studied for some different cases including the natural convection from horizontal cylinder. The natural convection from horizontal cylinder embedded in a porous media has been studied by Fand and Brucker (11).

The effect of viscous dissipation has been studied by Nakayama and Pop (18) for steady free convection boundary layer over non-isothermal bodies of arbitrary shape embedded in porous media.

They used integral method to show that the viscous dissipation results in lowering the level of the heat transfer rate from the body. Recently Prasad (22) has discussed the effect of dissipation on the mixed convective heat and mass transfer flow of a viscous fluid through a porous medium in a vertical channel bounded by flat walls.

FORMULATION OF THE PROBLEM

We analyze the steady motion of viscous, incompressible fluid through a porous medium in a vertical channel bounded by flat walls which are maintained at a non-uniform wall temperature in the presence of a constant heat source and the concentration on these walls are taken to be constant. The Boussinesq approximation is used so that the density variation will be considered only in the buoyancy force. The viscous, Darcy dissipations and the joule heating are taken into account in the energy equation. Also the kinematic viscosity □, 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.



Configuration of the Problem

The equations governing the steady flow, heat and mass transfer are

Equation of continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (2.1)$$

Equation of linear momentum:

$$\rho_e\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\rho g-(\sigma\mu_e^2H_o^2)u \qquad (2.2)$$

$$\rho_e\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \qquad (2.3)$$

Equation of Energy:

$$\rho_e C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+Q+\mu\left(\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial v}{\partial x}\right)^2\right)+ +(\sigma\mu_e^2H_o^2)(u^2+v^2) \qquad (2.4)$$

Equation Diffusion:

$$\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right)=D_1\left(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial y^2}\right)+k_{11}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \qquad (2.5)$$

Equation of State:

$$\rho-\rho_e=-\beta\rho_e(T-T_e)-\beta^{\bullet}\rho_e(C-C_e) \qquad (2.6)$$

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,$\rho$is the density of the fluid,μ is the constant coefficient of viscosity , Cp is the specific heat at constant pressure,$\lambda$is the coefficient of thermal conductivity ,k is the *is the magnetic* permeability of the porous medium, β is the coefficient of thermal expansion, $\beta^{\bullet}$ is the coefficient of expansion with mass fraction , D1 is the molecular diffusivity ,Q is the strength of the constant internal heat source , qr is the radiative heat flux and k11 is the cross diffusivity.

In the equilibrium state

$$0 = -\frac{\partial p_e}{\partial x} - \rho_e g \qquad (2.7)$$

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

$$Q = \frac{1}{2L}\int_{-L}^{L} u\, dy \qquad (2.8)$$

The boundary conditions for the velocity and temperature fields are

u = 0, v = 0 on y = ±L

$T - T_e = \gamma_1(\delta x / L)$ on y = ±L, C = C1 on y = -L, C = C2 on y = +L (2.9)

γ_1 is chosen to be twice differentiable function,□ is a small parameter characterizing the slope of the temperature variation on the boundary.

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

$u = -\psi_y,\ v = \psi_x$

the equation governing the flow in terms of Ψ are

$$[\frac{\partial \psi}{\partial x}\frac{\partial(\nabla^2\psi)}{\partial y} - \frac{\partial \psi}{\partial y}\frac{\partial(\nabla^2\psi)}{\partial x}] = \nu(\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2})^2 - \beta g \frac{\partial T}{\partial y} - \beta^{\bullet} g \frac{\partial C}{\partial y} - (\frac{\sigma \mu_e^2 H_o^2}{\rho})\frac{\partial^2 \psi}{\partial y^2} \qquad (2.10)$$

$$\rho_e c_p(\frac{\partial \psi}{\partial y}\frac{\partial T}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial T}{\partial y}) = \lambda(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) + \mu((\frac{\partial^2\psi}{\partial y^2})^2 + (\frac{\partial^2\psi}{\partial x^2})^2) + \sigma\mu_e^2 H_o^2((\frac{\partial\psi}{\partial y})^2 + (\frac{\partial\psi}{\partial x})^2) \qquad (2.11)$$

$$(\frac{\partial \psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial C}{\partial y}) = D_1(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}) + k_{11}(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) \qquad (2.12)$$

Introducing the non-dimensional variables in (2 .10)- (2.12) as

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$$(x',\ y') = (x, y)/L,\ (u', v') = (u, v)/U, \theta = \frac{T - T_e}{\Delta T_e}, C^{\bullet} = \frac{C - C_1}{C_2 - C_1}$$

$$p' = \frac{p_D}{\rho_e U^2}, \qquad \gamma' = \frac{\gamma}{\Delta T_e} \qquad (2.13)$$

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

$$R\frac{\partial(\psi, \nabla^2\psi)}{\partial(x, y)} = \nabla^4\psi + (\frac{G}{R}(\theta_y + NCy) - M^2\frac{\partial^2\psi}{\partial y^2} \qquad (2.14)$$

and the energy diffusion equations in the non-dimensional form are

$$P_1R(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}) = (\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}) + \frac{P_1R^2E_c}{G}((\frac{\partial^2\psi}{\partial y^2})^2 + (\frac{\partial^2\psi}{\partial x^2})^2) + M^2((\frac{\partial\psi}{\partial y})^2 + (\frac{\partial\psi}{\partial x})^2) \qquad (2.15)$$

$$RSc(\frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}) = (\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}) + \frac{ScS_o}{N}(\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}) \qquad (2.16)$$

Where

$R = \frac{UL}{\nu}$ (Reynolds number), $G = \frac{\beta g \Delta T_e L^3}{\nu^2}$ (Grashof number), $M^2 = \frac{\sigma\mu_e^2 H_o^2 L^2}{\upsilon^2}$ (Hartmann Number),

$P = \frac{\mu c_p}{k_1}$ (Prandatl number), $E_c = \frac{\beta g L^3}{C_p}$ (Eckert number), $N = \frac{\beta^{\bullet}\Delta C}{\beta \Delta T}$ (Buoyancy Number),

$Sc = \frac{\nu}{D_1}$ (Schmidt number), $S_0 = \frac{k_{11}\beta^{\bullet}}{\beta\nu}$ (Soret parameter)

The corresponding boundary conditions are

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

$$\frac{\partial\psi}{\partial x} = 0,\ \frac{\partial\psi}{\partial y} = 0 \quad at\ y = \pm 1 \qquad (2.17a)$$

$$\theta(x, y) = f(\delta x) \quad on\ \ y = \pm 1 \qquad (2.17b)$$

$$C = 0 \quad on\ y = -1$$

$$C = 1\ on\ y = 1 \qquad (2.17c)$$

$$\frac{\partial\theta}{\partial y} = 0, \frac{\partial C}{\partial y} = 0 \quad at \quad y = 0 \qquad (2.18)$$

The value of Ψ on the boundary assumes the constant volumetric flow in consistent with the hypothesis (2.8) .Also the wall temperature varies in the axial direction in accordance with the prescribed arbitrary function $\gamma(x)$.

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 slowly varying temperature imposed on the boundaries. We introduce the transformation

$$\bar{x} = \delta\, x$$

With this transformation the equations (2.14) - (2.16) reduce to

$$R\delta \frac{\partial(\psi, F^2\psi)}{\partial(x,y)} = F^4\psi + \frac{G}{R}(\theta_y + NC_y) - M^2\frac{\partial^2\psi}{\partial y^2} \tag{3.1}$$

and the energy &diffusion equations in the non-dimensional form are

$$P_1 R\delta\left(\frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = F^2\theta + \left(\frac{P_1 R^2 E_c}{G}\right)\left(\left(\frac{\partial^2\psi}{\partial y^2}\right)^2 + \delta^2\left(\frac{\partial^2\psi}{\partial x^2}\right)^2\right) + \\ + (M^2)\left(\delta^2\left(\frac{\partial\psi}{\partial x}\right)^2 + \left(\frac{\partial\psi}{\partial y}\right)^2\right) \tag{3.2}$$

$$\delta R Sc\left(\frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}\right) = F^2 C + \frac{ScSo}{N}F^2\theta \tag{3.3}$$

where

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

for small values of the slope δ,the flow develops slowly with axial gradient of order δ and hence we take

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

We follow the perturbation scheme and analyze through first order as a regular perturbation problem at finite values of R,G,P ,Sc and D^{-1}

Introducing the asymptotic expansions

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

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

$$C(x,y) = C_0(x,y) + \delta C_1(x,y) + \delta^2 C_2(x,y) + \ldots. \tag{3.4}$$

On substituting (3.4) in (3.1) – (3.3) and separating the like powers of δ the equations and respective conditions to the zeroth order are

$$\psi_{0,yyyyy} - M_1^2\psi_{0,yy} = -\frac{G}{R}(\theta_{0,y} + NC_{0,y}) \tag{3.5}$$

$$\theta_{0,yy} = -\frac{P_1 R^2 Ec}{G}\psi_{0,yy}^2 - \frac{P_1 M_1^2 Ec}{G}\psi_{0,y}^2 \tag{3.6}$$

$$C_{0,yy} = -\frac{S_C S_0}{N}\theta_{0,yy} \tag{3.7}$$

with $\psi_0(+1) - \psi(-1) = 1$

$\psi_{0,y} = 0,\ \psi_{0,x} = 0$ at $y = \pm 1$ (3.7a)

$\theta_0(\pm 1) = \gamma(x)$ at $y = \pm 1$

$C_0(-1) = 0 \quad C_0(+1) = 1$ (3.7b)

and to the first order are

$$\psi_{1,yyyyy} - M_1^2\psi_{1,yy} = -\frac{G}{R}(\theta_{1,y} + NC_{1,y}) + R(\psi_{0,y}\psi_{0,xyy} - \psi_{0,x}\psi_{0,yyy}) \tag{3.8}$$

$$\theta_{1,yy} = P_1 R(\psi_{0,x}\theta_{0,y} - \psi_{0,y}\theta_{0,x}) - \frac{P_1 Ec}{G}(R^2\psi_{1,yy}^2 + M_1^2\psi_{1,y}^2) \tag{3.9}$$

$$C_{1,yy} = RSc(\psi_{0,y} C_{0,x} - \psi_{0,x} C_{0,y}) - \frac{S_C S_0}{N}\theta_{1,yy} \tag{3.10}$$

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

$\psi_{1,y} = 0,\ \psi_{1,x} = 0$ at $y = \pm 1$ (3.11)

$\theta_1(\pm 1) = 0$ at $y = \pm 1$ (3.12)

$C_0(-1) = 0,\ C_0(+1) = 0$ (3.13)

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

$$\psi_0(x,y) = \psi_{00}(x,y) + Ec\,\psi_{01}(x,y) + \dots\dots\dots\ .$$

$$\psi_1(x,y) = \psi_{10}(x,y) + Ec\,\psi_{11}(x,y) + \dots\dots\dots\ ..$$

$$\theta_0(x,y) = \theta_{00}(x,y) + Ec\,\theta_{01}(x,y) + \dots\dots\dots\ \dots..$$

$$\theta_1(x,y) = \theta_{10}(x,y) + Ec\,\theta_{11}(x,y) + \dots\dots\dots\ \dots..$$

$$C_0(x,y) = C_{00}(x,y) + EcC_{01}(x,y) + \dots\dots\dots\ \dots..$$

$$C_1(x,y) = C_{10}(x,y) + EcC_{11}(x,y) + \dots\dots\dots\ \dots.. \tag{3.14}$$

Substituting the expansions (3.14) in equations (3.5)-(3.13) and separating the like powers of Ec we get the following equations

$$\theta_{00,yy} = -1 \quad , \quad \theta_{00}(\pm 1) = f(\bar{x}) \tag{3.15}$$

$$C_{00,yy} = -\frac{S_C S_0}{N}\theta_{0,yy} \quad , \quad C_{00}(-1) = 0, C_{00}(+1) = 1 \tag{3.16}$$

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

$$\psi_{00}(+1) - \psi_{00}(-1) = 1, \psi_{00,y} = 0, \psi_{00,x} = 0 \quad at \quad y = \pm 1 \tag{3.17}$$

$$\theta_{01,yy} = -\frac{P_1 M_1^2}{G}\psi^2_{00,y} - \frac{P_1 R^2}{G}\psi^2_{00,yy} \quad , \quad \theta_{01}(\pm 1) = 0 \tag{3.18}$$

$$C_{01,yy} = -\frac{S_C S_0}{N}\theta_{01,yy} \quad , \quad C_{01}(\pm 1) = 0 \tag{3.19}$$

$$\left.\begin{aligned} &\psi_{01,yyyy} - M_1^2\psi_{01,yy} = -\frac{G}{R}(\theta_{01,y} + NC_{01,y}) \ , \\ &\psi_{01}(+1) - \psi_{01}(-1) = 0, \\ &\psi_{01,y} = 0, \psi_{01,x} = 0 \quad at \quad y = \pm 1 \end{aligned}\right\} \tag{3.20}$$

$$\theta_{10,yy} = RP_1(\psi_{00,y}\theta_{00,x} - \psi_{00,x}\theta_{00,y}) \qquad \theta_{10}(\pm 1) = 0 \tag{3.21}$$

$$C_{10,yy} = RP_1(\psi_{00,y}C_{00,x} - \psi_{00,x}C_{00,y}) - \frac{S_C S_0}{N}\theta_{10,yy} \qquad C_{10}(\pm 1) = 0 \tag{3.22}$$

$$\left.\begin{aligned} &\psi_{10,yyyy} - M_1^2\psi_{10,yy} = -\frac{G}{R}(\theta_{10,y} + NC_{10,y}) + \\ &+ R(\psi_{00,y}\psi_{00,xyy} - \psi_{00,x}\psi_{00,yyy}) \ , \\ &\psi_{10}(+1) - \psi_{10}(-1) = 0, \psi_{10,y} = 0, \psi_{10,x} = 0 \quad at \quad y = \pm 1 \end{aligned}\right\} \tag{3.23}$$

$$\theta_{11,yy} = RP_1(\psi_{00,y}\theta_{1,x} - \psi_{1,x}\theta_{00,y}) \quad , \quad \theta_1(\pm 1) = 0 \tag{3.24}$$

$$C_{11,yy} = RSc\ (\psi_{00,y}C_{00,x} - \psi_{1,x}C_{00,y}) \quad , \quad C_{11}(\pm 1) = 0 \tag{3.25}$$

$$\left.\begin{aligned} &\psi_{11,yyyy} - M_1^2\psi_{1,yy} = -\frac{G}{R}(\theta_{11,y} + NC_{11,y}) + R(\psi_{00,y}\psi_{11,xyy} \\ &-\psi_{00,x}\psi_{01,yyy} + \psi_{01,y}\psi_{00,xyy} - \psi_{01,x}\psi_{00,yyy}), \\ &\psi_{11}(+1) - \psi_{11}(-1) = 0, \psi_{11,y} = 0, \psi_{11,x} = 0 \quad at \quad y = \pm 1 \end{aligned}\right\} \tag{3.26}$$

SOLUTION OF THE PROBLEM

Solving the equations (3.15) - (3.23) subject to the relevant boundary conditions, we obtain

$$\theta_{00} = 0.5(1-y^2) + \gamma(\bar{x}),$$

$$C_{00} = 0.5(y+1)$$

$$\psi_{00} = a_4Ch(M_1y) + a_5Sh(M_1y) + a_6y + a_7 + a_3y^3 + d_2y^2$$

$$\theta_{01} = 0.5PM_1^2(y^2-1)$$

$$C_{01} = a_6(y^2-1)$$

$$\psi_{01} = a_{10}Sh(M_1y) + a_{11}y + a_{12} + a_8y^3$$

$$\theta_{10} = a_{24}y^2 + a_{25}y^3 + a_{26}y^4 + a_{27}y^5 + a_{28}y^6 + (a_{20} + ya_{22})Ch(M_1y) + (a_{21} + ya_{23})Sh(M_1y)$$

$$\begin{aligned} C_{10} = {} & a_{31}(y^2-1) + a_{32}(y^3-y) + a_{33}(y^4-1) + a_{34}(y^5-y) + a_{35}(y^6-1) + (a_{36} + ya_{38})(Ch(M_1y) \\ & - Ch(M_1)) + a_{37}(Sh(M_1y) - yShM_1) + a_{39}(ySh(M_1y) - Sh(M_1)) \end{aligned}$$

$$\psi_{10} = b_8Ch(M_1y) + b_9Sh(M_1y) + b_{10}y + b_{11} + \phi(y)$$

$$\begin{aligned} \phi(y) = {} & a_{70}y^2 + a_{71}y^3 + a_{72}y^4 + a_{73}y^5 + a_{74}y^6 + a_{75}y^7 + (b_1y + b_3y^2 + b_5y^3)Ch(M_1y) \\ & + (b_2y + b_4y^2 + b_6y^4)Sh(M_1y) + b_7y^4Sh(M_1y) \end{aligned}$$

$$\begin{aligned} \theta_{11} = {} & b_{15}y^2 + b_{16}y^3 + b_{17}Ch(2M_1y) + b_{18}Sh(2M_1y) + b_{19}y^4 + b_{20}y^6 \\ & + b_{21}y^8 + b_{22}y^{10} + b_{23}y^{11} + b_{23}y^{11} + b_{24}y^{12} + b_{25}y^8Sh(2M_1y) \\ & + b_{26}y^7Ch(2M_1y) + b_{27}y^6Sh(2M_1y) + b_{28}y^5Ch(2M_1y) \\ & + b_{29}y^4Sh(2M_1y) + b_{30}y^3Ch(2M_1y) + b_{31}y^2Sh(2M_1y) \\ & + b_{32}yCh(2M_1y) + b_{33}Sh(2M_1y) + b_{34}y + b_{35} \end{aligned}$$

$$\psi_{11} = b_{54} + b_{55}y + b_{56}Ch(M_1y) + b_{57}Sh(M_1y) + \phi_1(y)$$

$$\begin{aligned} \phi(y) = {} & b_{34}y^{14} + b_{35}y^{13} + b_{36}y^{12} + b_{37}y^{11} + b_{38}y^{10} + b_{39}y^9 + b_{40}y^6 + b_{41}y^5 \\ & + b_{42}y^4 + b_{43}y^3 + b_{44}Ch(2M_1y) + b_{45}Sh(2M_1y) + b_{46}y^8Ch(2M_1y) \\ & + b_{47}y^7Sh(2M_1y) + b_{48}y^6Ch(2M_1y) + b_{49}y^5Sh(2M_1y) \\ & + b_{50}y^4Ch(2M_1y) + b_{51}y^3Sh(2M_1y) + b_{52}y^2Ch(2M_1y) \\ & + b_{53}ySh(2M_1y) \end{aligned}$$

NUSSELT NUMBER AND SHERWOOD NUMBER

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

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

and the corresponding expressions are

$$(Nu)_{y=+1} = \frac{(d_{10} + \delta(d_{11} + d_{12}))}{(d_8 - \gamma(x) + \delta d_9)} \qquad (Nu)_{y=-1} = \frac{(-d_{10} + \delta(d_{12} - d_{11}))}{(d_8 - \gamma(x) + \delta d_9)},$$

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

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

and the corresponding expressions are

$$(Sh)_{y=+1} = \frac{(d_{13} + \delta d_{15})}{(\theta_m - 1)} \qquad (Sh)_{y=-1} = \frac{(d_{14} + \delta d_{16})}{(\theta_m)},$$

$$\theta_m = d_{17} + \delta d_{17}$$

where $d_1, d_2, \ldots\ldots\ldots\ldots, d_{23}$ are constants.

DISCUSSION OF THE NUMERICAL RESULTS

The primary aim of this analysis is to discuss "The effect of thermo diffusion and dissipation on convective heat and mass transfer flow of a viscous electrically conducting fluid in a non-uniformly heated vertical channel. The Velocity, Temperature, Concentration is discussed for different values of G, M, N, S_C, S_0, E_C, α and x.The axial velocity u is shown in figures 1-2 for different values of G, M, N, S_C, S_0, E_C, α and x. Fig-1 represents the variation of u with Grashof number G. The actual axial flow is in the vertically downward directed and hence u<0 is the actual velocity u>0 represents the reversal flow. It is found that u exhibits a reversal flow in the region 0≤y≤0.8 for G>0 and it occurs in the region 0.8≤y≤-0.2 for G<0. The region of a reversal flow enlarges with increase in |G| also the magnitude of u experience an enhancement with increase |G| in the entire flow region with maximum attained at y=-0.6. The variation of u with Hartman number M shows that a reversal flow which appears in the second half with M=2 extends towards the first half for higher M≥4 (fig-2). The secondary velocity v which is due to the non-uniform boundary temperature is exhibited in figures 3-4 for different values of parameters. The variation of v with amplitude α of the non-uniform boundary temperature shows that |v| enhances in the first half and depreciates in the second half with increase in amplitude α (fig-3). Moving along the axial direction of channel |v| enhances with increase in x<π/2 depreciates at x= π and again enhances at x=2 π (fig-4).The non dimensional temperature (θ) is shown in the figures 5-6 for different values of parameters. The variation of θ with S_C shows that lesser the molecular diffusivity smaller the actual temperature for the lowering of the molecular diffusivity and for still lowering of molecular diffusivity lesser the actual temperature (fig-5). In fig.6 we notice that the actual temperature depreciates with increase in S_0>0 and enhances | S_0|. The non dimensional concentration (C) is shown in the figures 7-8 for different values of parameters. In fig.7 we notice that the actual concentration enhances with N>0 Also higher the dissipative heat smaller the actual concentration in the flow region (fig-8).

The average Nusselt number (Nu) is evaluated numerically at y=±1 for a different values of G, M, N, S_0, E_C, α and x. It is found that Table (1 & 2) higher the thermal buoyancy /Lorentz force lesser the rate of heat transfer at y=±1. Also higher the dissipative heat larger the rate of heat transfers at both the boundaries (Table 3 & 4).The Sherwood number (Sh) is exhibited in tables for different parametric values. It is found that in table (5 & 6) the variation of Sh with Hartman number M shows that higher the Lorentz force (M≤4) larger the rate of mass transfer and for further higher Lorentz force (M≥6) smaller |Sh| at y=+1 and while at y=-1 it enhances with M for all G.Moving along the axial direction of the channel the rate of mass transfer depreciates at y=+1 and enhances at y=-1 in the heating case and in the cooling case a reversed effect is observed in the behavior of |Sh| at y=±1 with x≤ π and for higher x≥ 2π. |Sh| enhances at y=+1 and reduces at y=-1 for G>0 while for G<0. |Sh| reduces at y=+1 and enhances at y=-1 (table7&8).

REFERENCES

1. Ajay Kumar Singh : MHD free convection and mass transfer flow with Hall effect, viscous dissipation, Joule heating and thermal diffusion, Ind. J.pure & Application Physics V.41.PP.24-35(2003).
2. Bejamin Gebhort, Yogesh Jaluria, Roop-L Mahjan and Bhagat Samnokia :Buoyancy induced flows and transfport, Springer –Verlog, berling (1988).
3. Bejan ,A and Khair, K.R : Heat and Mass transfer by natural convection in a porous medium , Int. J. Heat and Mass transfer ,V.28,PP.908-918 (1985).
4. Bejan ,A, Convection heat transfer, New York; John wiley (1984).
5. Bird, R.S : J. Soc. Plastic enginnering,V.11,P.7 (1955).
6. Chambre, P.L : Application Science Research, A.E, PP.393 (1957).
7. Chandrasekhar, S: Hydrodynamic and Hydromagnetic stability, clarandon press, oxford (1961).

8. Chen, T.s, Yuh, C.F and Moutsoglo, A: Int. Heat and Mass transfer, V.23,PP.527-537 (1980).
9. Cheng, P :Advances in heat transfer, V.14, PP.1-205 (1979).
10. Chritopher Philips ,G : Heat and Mass Transfer froma film into steady shear flow, J.I.Mech. Application Mathematics.,, V.43, P.1 (1990).
11. Fand ,R.M and Bruckar, J. Int. J. Heat Mass transfer, PP. 723-732 (1996).
12. Gebhart ,B. and Pera .L : The natural convection flows resulting from the combined buoyancy effects of natural mass diffusion , Int. J. Heat mass transfer, V.15, pp.2025-2050 (1971).
13. Gill, W.M and Casal, A.D : S.Amer, Inst. Chemical. Engineering , V.13,P.137 (1962).
14. Greosh, R.J and less ,R.D : Trans Amer Soc. Mech. Engng., V.8,P.667 (1958).
15. Helman ,J.K., Babeller, B and Babrov, H : Trans. Amer, Sec, Mech, Engn., V.78,P .32 (1950).
16. Katousias, N and Raptis ,A : Letters in heat and mass transfer, 8,P.417 (1981).
17. Low, G.M : J. Aero Sci, V.22, P.239 (1955).
18. Nakayama, A and Pop, Int. Comms. Heat Mass Transfer, V.16, P. 173 (1989).
19. Nelson ,D.J. and Wood, B.D : Combined heat and mass transfer natural convection between vertical parallel plates, Int. J. Heat mass transferV.32, PP.1779-1781 (1989).
20. Ostrach, S.NACA, TN,P.3141 (1954).
21. Palm,E : Ann –REV: Fluid Mech., V.7 ,P.39 (1975).
22. Prasad ,P.M.V : Hydromagnetic convective heat and mass transfer through a Porous medium in channels/pipes, Ph.D thesis, S.K.University, Anantapur, India(2006).
23. Raptis ,A.A : Effect of mass transfer on the hydromagnetic flow past a vertical limiting surface, Astrophysiscs and space science , V.92,PP.135-142 (1983).
24. 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).
25. Saffman, P.G : On the boundary conditions at the free surface of a porous medium, stud. Application Maths,. V.2 , p.93 (1971).
26. Soundalegkar, V.M : Proc. Ind.Acad. Sci. Act. A.83, P.194 (1976).
27. Sparrow, E.M. and Azevedo, L.F : Buoyancy effects on horizontal boundary layer flow and heat transfer, Int. J. heat mass transfer, V.86, PP. 508-511 (1964).

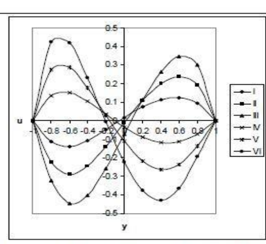

Fig. 1 : Variation of u with G

	I	II	III	IV	V	VI
G	10^3	$2x10^3$	$3x10^3$	10^3	$-2x10^3$	$-3x10^3$

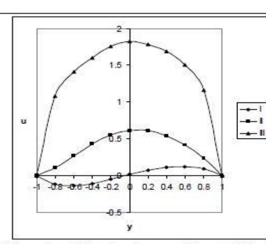

Fig. 2 : Variation of u with M

	I	II	III
M	2	4	6

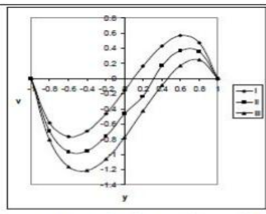

Fig. 3 : Variation of v with α

	I	II	III
α	0.1	0.3	0.5

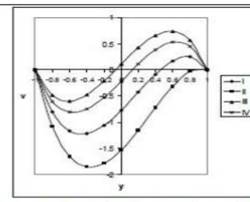

Fig. 4 : Variation of v with x

	I	II	III	IV
x	$\pi/4$	$\pi/2$	π	2π

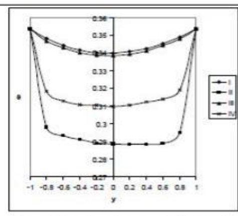

Fig. 5 : Variation of θ with S_c

	I	II	III	IV
S_c	1.3	2.0	0.2	0.6

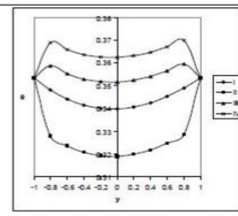

Fig. 6 : Variation of θ with S_0

	I	II	III	IV
S_0	0.5	1	-0.5	-1

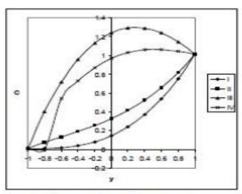

Fig. 7 : Variation of C with

	I	II	III	IV
N	1	2	-0.5	-0.8

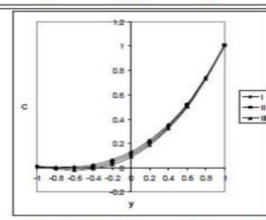

Fig. 8 : Variation of C with Ec

	I	II	III
Ec	0.3	0.5	0.7

TABLE – 1

NUSSELT NUMBER (Nu) AT y = +1

G	I	II	III
10^3	-9.665124	-0.917081	-0.344227
$2x10^3$	-3.343816	-0.415662	-0.163793
$3x10^3$	-2.394744	-0.265582	-0.106365
$-1 x 10^3$	1.911655	0.711099	0.313068
$-2 x 10^3$	1.045793	0.386587	0.164296
$-3 x 10^3$	0.679972	0.268718	0.112747
M	2	4	6

TABLE – 2

NUSSELT NUMBER (Nu) AT y = -1

G	I	II	III
10^3	3.037865	0.911512	0.336862
$2x10^3$	1.151089	0.410629	0.156859
$3x10^3$	0.690324	0.260773	0.099681
$-1 x 10^3$	-1.588182	-0.715445	-0.319913
$-2 x 10^3$	-0.953111	-0.391327	-0.171560
$-3 x 10^3$	-0.699783	-0.273675	-0.120308
M	2	4	6

TABLE – 3

NUSSELT NUMBER (Nu) AT y = +1

G	I	II	III
10^3	-3.047634	-3.047634	-3.047634
$2x10^3$	-1.158501	-1.158501	-1.158501
$3x10^3$	-0.696999	-0.696999	-0.696999
$-1 x 10^3$	1.583087	1.583087	1.583087
$-2 x 10^3$	0.947002	0.947002	0.947002
$-3 x 10^3$	0.693063	0.693063	0.693063
Ec	0.1	0.3	0.5

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TABLE – 4

NUSSELT NUMBER (Nu) AT y = -1

G	I	II	III
10^3	3.037865	3.307865	3.037865
$2x10^3$	1.151089	1.151089	1.151089
$3x10^3$	0.690324	0.690324	0.690324
$-1 x 10^3$	-1.588182	-1.588182	-1.588182
$-2 x 10^3$	-0.953111	-0.953111	-0.953111
$-3 x 10^3$	-0.699783	-0.699783	-0.699783
Ec	0.1	0.3	0.5

TABLE – 5

SHERWOOD NUMBER (Sh) AT y = +1

G	I	II	III
10^3	-1.193681	-2.116599	-2.106974
$2x10^3$	-1.190005	-2.120543	-2.119588
$3x10^3$	-1.186361	-2.124485	-2.132200
$-1 x 10^3$	-1.201130	-2.108710	-2.081745
$-2 x 10^3$	-1.204903	-2.104765	-2.069130
$-3 x 10^3$	-1.208711	-2.100819	-2.056514
M	2	4	6

TABLE –6

SHERWOOD NUMBER (Sh) AT y = -1

G	I	II	III
10^3	1.124991	-10.830360	-44.968760
$2x10^3$	1.119850	-10.795410	-44.478380
$3x10^3$	1.114739	-10.760400	-43.986820
$-1 x 10^3$	1.135358	-10.90070	-45.946000
$-2 x 10^3$	1.140586	-10.934830	-46.432870
$-3 x 10^3$	1.145843	-10.969530	-46.918560
M	2	4	6

TABLE –7

SHERWOOD NUMBER (Sh) AT y = +1

G	I	II	III	IV
10^3	-2.116477	-2.114007	-2.110450	-2.117445
$2x10^3$	-2.117285	-2.112348	-2.105240	-2.119220
$3x10^3$	-2.118091	-2.110691	-2.100041	-2.120991
$-1 x 10^3$	-2.114860	--2.117334	-2.120899	-2.113891
$-2 x 10^3$	-2.114049	-2.119001	-2.126139	-2.112110
$-3 x 10^3$	-2.113237	-2.120671	-2.131390	-2.110327
x	$\frac{\pi}{4}$	$\frac{\pi}{2}$	π	2π

TABLE – 8

SHERWOOD NUMBER (Sh) AT y = -1

G	I	II	III	IV
10^3	-6.943790	-6.967701	-7.002221	-6.934435
$2x10^3$	-6.959844	-7.007972	-7.077607	-6.941038
$3x10^3$	-6.976057	-7.048715	-7.154073	-6.947701
$-1 x 10^3$	-6.912149	-6.888539	-6.854600	-6.921409
$-2 x 10^3$	-6.896557	-6.849633	-6.782322	-6.914983
$-3 x 10^3$	-6.881115	-6.811167	-6.711037	-6.908615
x	$\frac{\pi}{4}$	$\frac{\pi}{2}$	π	2π