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HALL CURRENT EFFECTS ON FREE CONVECTION FLOW AND MASS TRANSFER PAST SEMI- INFINITE VERTICAL FLAT PLATE

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ABSTRACT: *Heat and mass transfer along a semi-infinite vertical flat plate under the combined buoyancy force effect and species diffusion was investigated and Hall current effects were taken into account. The nonlinear boundary layer equations with the boundary conditions were linearized and then solved using finite difference method. The numerical results for the velocity profiles temperature profiles and concentration profiles were presented graphically for various values of the hall current parameters (Lo) ranging from 0.0 to 1.0.*

KEYWORDS: Semi-infinite, Hall current, Finite difference method, Profiles

INTRODUCTION

MHD studies the motion of electrically conducting fluid in the presence of a magnetic field. This motion leads to induced electric currents on which mechanical forces are exerted by magnetic field. The induced electric currents in turn produce induced magnetic field which affect the original magnetic field. This study has been given much attention due to its varied applications such as the cooling of nuclear reactors, cooling of electronic devices, the solar energy collection, temperature plasmas among others.

The first research in magneto hydrodynamics (MHD) flows was done by Faraday in 1839 that performed an experiment with mercury flowing in a glass tube between the poles of a magnet and proposed the use of tidal currents in the terrestrial magnetic field for power generation. Prasada et al (1985) solved the problem of MHD flow with wavy porous boundary, the influence of the heat source, parameters, suction velocity and waviness of the boundary on the flow field was numerically analyzed. Kumar et al (1990) presented their study on compressible magneto hydrodynamic boundary layer in the stagnation region of a sphere. The effects of the induced magnetic field, mass transfer and viscous dissipation were taken into account. Rao et al (1987) studied the heat transfer in a porous medium in the presence of transverse magnetic field. The effects of the heat source parameter and Nusselt number were analyzed. They discovered that the effect of increasing porous parameter is to increase the Nusselt number.

KO and Gladden (1998) investigated the conjugate heat transfer analysis of concentric tube heat exchange using a high-order finite difference technique. Ram (1991) used the finite difference method to analyze the MHD stokes problem for a vertical plate and ion-slip currents. Kumar and Singh (1990) presented the role of porosity and magnetic field on fluid flow past an exponentially accelerated vertical plate. In the analysis, magnetic lines of force were assumed to be fixed relative to the plate. Solutions for the velocity and skin friction were obtained by Laplace transform techniques. Dash and Asha (1990) presented magneto hydrodynamic unsteady free convection effect on the flow past an exponentially accelerated vertical plate. They observed that exponential acceleration of the plate has no significant contribution over the impulsive motion. Dash and Das (1990) considered heat transfer in viscous flow a long a plane wall with periodic suction and heat source. The effects of various parameters on the heat transfer in a three-dimensional laminar boundary layer past a flat plate in the presence of a heat source when a sinusoidal transverse suction velocity is applied to the walls were studied.

Ram et al (1990) analyzed the effects of hall current and wall temperature oscillation on convective flow in a rotation fluid through porous medium bounded by an infinite vertical limiting surface. The effect of various parameters on the velocity and shear stress were determined.

Hong-Sen. and Huang (1996) investigated some transformations for natural convection on a vertical flat plate embedded in porous media with prescribed wall temperature. They analyzed transformation for boundary layer equation for two dimensional steady natural convection a long a vertical flat plate, embedded in a porous media with prescribed wall temperature. Ram et al (1995) solved the MHD stokes problem of convective flow for a vertical infinite plate in a dissipative rotating fluid with Hall current, an analysis of the effects of various parameters on the concentration, velocity and temperature profiles was done.

Kinyanjui et al (2001) presented their work on MHD free convection heat and mass transfer of a heat generating fluid past an impulsively stated infinite vertical porous plate with Hall current and radiation absorption. An analysis of the effects of the parameters on skin friction, rates of mass and heat transfer was reported. Gupta and Rajesh (2001) studied three-dimensional flow past a porous plate and established the effects of Hartmann number and suction parameter on velocity and skin friction. Kwanza et al (2003) presented their work on MHD strokes free convection flow past an infinite vertical porous plate subjected to a constant heat flux with ion-slip and radiation absorption. The concentration, velocity and temperature distributions were discussed and result were presented in tables and graphs. Adel et al (2003) investigated heat and mass transfer along a semi-infinite vertical flat plate under the combined buoyancy force effects of thermal and species diffusion in the presence of a strong non-uniform magnetic field. The similarity equations were solved numerically by using a forth-order Runge-Kutta scheme with the shooting method. Emad *et al* (2001) studied Hall current effect on magneto hydrodynamics free-convection flow past a semi-infinite vertical plate with mass transfer. They discussed the effects of magnetic parameter, Hall parameter and the relative buoyancy force effect between species and thermal diffusion on the velocity, temperature and concentration.Youn (2000) investigated the unsteady two-dimensional laminar flow of a viscous incompressible electrically conducting fluid in the vicinity of semi-infinite vertical porous moving plate in the presence of a transverse magnetic field. The plate moves with constant velocity in the direction of fluid flow, and the free stream velocity follows the exponentially increasing small permutation law, the effect of increasing values of the suction velocity parameter results into a slight increase in surface skin friction for lower values of plate moving velocity. It was also observed that for several values of Prandtl number, the surface heat transfer decreases by increasing the magnitude of suction velocity. Ali (2004) considered unsteady, two dimensional, laminar, boundary-layer flow of a viscous, incompressible, electrically conducting and heat absorbing fluid along a semi-infinite vertical permeable moving plate in the presence of a uniform transverse magnetic field. Thermal and concentration buoyancy were discussed.

The dimensionless governing equations for this investigation are solved analytically using two- term harmonic and non-harmonic functions. It was found that when Grashof number increased, the concentration buoyancy effect was enhanced and thus, fluid velocity increased. However, the presence of heat absorption effects caused reductions in the fluid temperature which resulted in a decrease in the fluid velocity. Also, when the Schmidt number was increased, the concentration level was decreased, resulting in a decreased fluid velocity in addition, it was observed that the skin friction

Morales et al (2005) analyzed magnetic reconnection at the earth's magneto pause to estimate the importance of the Hall effect during the merging of inter planetary and magneto-spheric magnetic field lines. They found that the Hall effect is crucial during the initial stages of the merging of terrestrial and interplanetary field lines at the magneto pause, inducing a faster reconnection process. Emad *et al* (2005) studied the effects of viscous dissipation and Joule heating on MHD free convection flow past a semi-infinite vertical flat plate in the presence of the combined effect of Hall and ion-slip current for the case of the power-law variation of the wall temperature. They found the magnetic field acts as a retarding force on the tangential flow but have a propelling effect on the induced lateral flow. The skin-friction factor for the lateral flow increases as the magnetic field increases. The skin- friction factor for the tangential and lateral flows are increased while the Nusselt number is decreased if the effect of viscous dissipation, Joule heating and heat generation are considered Hall and ion-slip terms were ignored in applying Ohm's law as it has no marked effect for small and moderate values of the magnetic field. Jordon (2007) analyzed the effects of thermal radiation and viscous dissipation on MHD free-convection flow over a semi-infinite vertical porous plate. The network simulation method was used to solve the boundary-layer equations based on the finite difference method. It was found that an increase in viscous dissipation leads to an increase of both velocity and temperature profiles, an increase in the magnetic parameter leads to an increase in the temperature profiles and a decrease in the velocity profiles. Finally an increase in the suction parameter leads to an increase in the local skin-friction and Nusselt number. Osalusi et al (2007) studied the effects of Ohmic heating and viscous dissipation on unsteady MHD and slip flow over a porous rotating disk with variable properties in the presence of Hall and ion-slip currents. The variable fluid properties taken into consideration were density, viscosity and thermal conductivity which were all depending on the temperature. They observed that as the magnetic interaction parameter increases the shear stress in radial direction and the rate of heat transfer decreases while it increases the shear stress in tangential direction. The reason for this trend is that the magnetic field reduces the radial and axial velocities but increases tangential velocity.

Okelo (2007) investigated, unsteady free convection incompressible fluid past a semi-infinite vertical porous plate in the presence of a strong magnetic field inclined at an angle α to the plate with Hall and ion-slip currents effect. The effects of modified Grashof number, suction velocity, the angle of inclination, time, Hall current, ion-slip current, Eckert number, Schmidt number and heat source parameter on the convectively cooled or convectively heated plate restricted to laminar boundary layer were studied. He found that an increase in mass diffusion

parameter Sc causes a decrease in the concentration profiles, absence of suction velocity or an increase in t leads to an increase in the concentration profiles, an increase in Eckert number Ec causes an increase in temperature profiles and also an increase in the angle of inclination α leads to an increase in primary velocity profiles but a decrease in secondary velocity profiles. He presented the results in tables and graphs.
The research work cited above is the motivation of the current work. In this study we consider Hall effects on free convection flow and mass transfer past a semi-infinite vertical flat plate subjected to a strong non-uniform magnetic field normal to the plate.

Problem Formulation
In this study a steady free convection flow and mass transfer of a viscous, incompressible and electrically conducting fluid past a heated semi-infinite vertical plate subjected to a strong, non-uniform Magnetic field normal to the plate is studied.

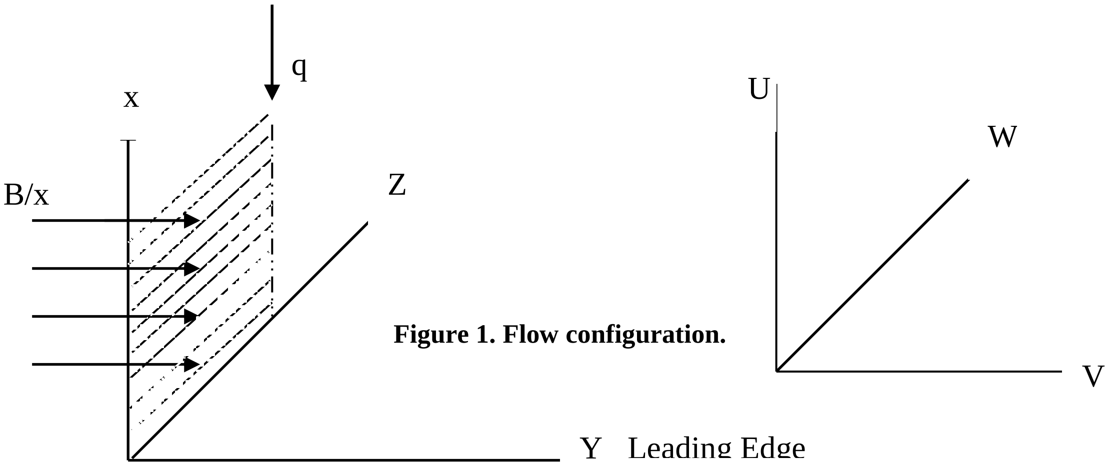

Figure 1. Flow configuration.

We use rectangular Cartesian coordinates (x y z), taking x and y as the coordinates parallel and normal to a flat plate, respectively.
The leading edge of the plate should be taken as coincident with the Z-axis.
Fig 1 shows the flow configuration together with the co-ordinate system used
The effects of Hall current give rise to a force in the Z-direction, which induces a cross flow in that direction, and hence the flow becomes three dimensional.
In this study we consider an incompressible fluid and the equation of continuity reduces to

$$div\,\vec{q} = 0 \quad thus \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad \ldots\ldots 1.1$$

Since there is no variation of flow in the Z-direction then
Equation (3.1) reduces to

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad \ldots\ldots 1.2$$

Since the fluid is in motion it posses momentum, hence we consider the Equation of momentum.

$$\rho \frac{\partial \vec{q}}{\partial t} + \rho(\vec{q}.\nabla)\vec{q} = -\frac{\partial p}{\partial x} + \rho\nu\nabla^2 \vec{q} - \rho g + \vec{J} \times \vec{B} \qquad \ldots\ldots 1.3$$

The flow is steady thus

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$$\frac{\partial \vec{q}}{\partial t}=0$$

Equation (3.3) becomes

$$\rho(\vec{q}.\nabla)\vec{q}=-\frac{\partial p}{\partial x}+\rho v\nabla^2\vec{q}-\rho g+\vec{J}\times\vec{B} \quad \text{.....................................1.4}$$

The velocity profiles at various x-positions depend on y-co-ordinates

$$(\vec{q}.\nabla)\vec{q}=u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y} \quad \text{..1.5}$$

$$v\nabla^2\vec{q}=v\frac{\partial^2 u}{\partial y^2} \quad \text{...1.6}$$

Substituting equation (1.5) and (1.6) in equation (1.4) yield

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\rho v\frac{\partial^2 u}{\partial y^2}-\rho g+\vec{J}\times\vec{B} \quad \text{.................................1.7}$$

To determine the pressure gradient from equation (3.7) the momentum equation is evaluated at the edge of the boundary layer where $\rho\to\rho_\infty$ and $U\to 0$.This is because at the boundary layer the velocity of the fluid is at its minimum.

The pressure term in x direction

$-\frac{\partial p}{\partial x}=-\rho_\infty g$ results from the change in elevation .Combining the pressure term and the body force term gives

$$-\rho g-(-\rho_\infty g)=\rho_\infty g-\rho g=g(\rho_\infty-\rho)$$

Equation (1.7) becomes

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\rho v\frac{\partial^2 u}{\partial y^2}-g(\rho_\infty-\rho)+\vec{J}\times\vec{B} \quad \text{.......................1.8}$$

The volumetric co-efficient β of thermal expansion is defined as

$$\beta=\frac{1}{V}\left(\frac{\Delta V}{\Delta T}\right)=\frac{1}{V}\left(\frac{\partial V}{\partial\rho}\frac{\partial\rho}{\partial T}\right)$$

$$V=\frac{Mass}{Density}\ for\,unit\,mass, V=\frac{1}{\rho} \quad \frac{\partial V}{\partial\rho}=-\frac{1}{\rho^2}\ thus\ \beta=\rho\left(-\frac{1}{\rho^2}\frac{\partial\rho}{\partial T}\right)=-\frac{1}{\rho}\frac{\partial\rho}{\partial T}$$

Similarly the volumetric coefficient of the expansion with concentration is given by

$$\beta^*=\frac{1}{\rho}\left(\frac{\Delta\rho}{\Delta C}\right)=\frac{1}{\rho}\left(\frac{\rho_\infty-\rho}{C_\infty-C}\right)$$

$$\beta^*=\frac{1}{\rho}\left(\frac{\rho_\infty-\rho}{C-C_\infty}\right)$$

Thus the total change in density is

$$\Delta\rho=\beta\rho(T-T_\infty)+\beta^*\rho(C-C_\infty) \quad \text{...3.9}$$

Substituting equation (3.9) in (3.8) result to

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\nu\frac{\partial^2 u}{\partial y^2}+g\rho\beta\left(T-T_\infty\right)+g\rho\beta^*(C-C_\infty)+\vec{J}\times\vec{B} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.10$$

The term $\vec{J}\times\vec{B}$ can be simplified as

$$\vec{J}\times\vec{B}=\begin{vmatrix} i & j & k \\ \vec{J}_x & 0 & \vec{J}_z \\ 0 & \vec{B}_y & 0 \end{vmatrix}=i\left\{0-\left(\vec{B}_y\right)\left(\vec{J}_z\right)\right\}+k\left\{\left(\vec{B}_y\right)\left(\vec{J}_x\right)\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.11$$

The equation of conservation of electric charge div $\vec{J}$ =0 gives $\vec{J}_y$ =constant, which is zero since $\vec{J}_y$ =0 at the plate which is electrically non-conducting thus $\vec{J}_y$ =0 everywhere in the flow. Substituting equation (3.11) in equation (3.10) and writing the result in component form yields

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\nu\frac{\partial^2 u}{\partial y^2}+g\beta\left(T-T_\infty\right)+g\beta^*(C-C_\infty)-\frac{\left(\vec{B}_y\right)\left(\vec{J}_z\right)}{\rho} \quad \ldots\ldots\ldots 1.12$$

$$\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}\right)=\nu\frac{\partial^2 w}{\partial y^2}+\frac{\left(\vec{B}_y\right)\left(\vec{J}_x\right)}{\rho} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.13$$

The generalized Ohm's law including the effects of Hall currents according to Cowling (1957) is given by

$$\vec{J}+\frac{\omega_e\tau_e}{H_0}\left(\vec{J}\right)\times\left(\vec{H}\right)=\sigma\left[\left(\vec{E}\right)+\mu_e\left\{\left(\vec{q}\right)\times\left(\vec{H}\right)\right\}+\frac{1}{e\eta_e}\nabla.p_e\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots 1.14$$

For short circuit problem the applied electric field $\vec{E}$ =0 and for a partially ionized gases the electron pressure gradient may be neglected. Equation (1.14) becomes

$$\vec{J}+\frac{\omega_e\tau_e}{H_0}\left(\vec{J}\right)\times\left(\vec{H}\right)=\sigma\left[\mu_e\left\{\left(\vec{q}\right)\times\left(\vec{H}\right)\right\}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.15$$

Where $L_0 = \omega_e\tau_e$ (Hall parameter)

ω_e is the cyclotron frequency of the electrons

τ_e is the collision time of the electrons

$H_0=|H|$ is the magnitude of the Magnetic field (This assumption holds when the magnetic Reynolds number is less than one)

Equation (1.15) can be written as

$$\vec{J} + \frac{L_0}{H_0}\left(\vec{J}\right)\times\left(\vec{H}\right) = \sigma\left[\mu_e\left\{\left(\vec{q}\right)\times\left(\vec{H}\right)\right\}\right] \quad \text{.......................................1.16}$$

$$\begin{pmatrix} \vec{J}_x \\ 0 \\ \vec{J}_z \end{pmatrix} + \frac{L_0}{H_0}\begin{vmatrix} i & j & k \\ \vec{J}_x & 0 & \vec{J}_z \\ 0 & H_0 & 0 \end{vmatrix} = \sigma\mu_e\begin{vmatrix} i & j & k \\ u & v & 0 \\ 0 & H_0 & 0 \end{vmatrix} \quad \text{.......................................1.17}$$

From equation (1.17)

$$\vec{J}_x - L_0\vec{J}_z = 0 \quad \text{.......................................1.18}$$

$$\vec{J}_z + L_0\vec{J}_x = \sigma\mu_e u H_0 \quad \text{.......................................1.19}$$

Solving equation (1.18) and (1.19) simultaneously to get $\vec{J}_x$ and $\vec{J}_z$

$$\left.\begin{aligned} L_0(\vec{J}_x) - L_0^2(\vec{J}_z) &= 0 \\ L_0(\vec{J}_x) + (\vec{J}_z) &= \sigma\mu_e u H_0 \end{aligned}\right\} \quad \text{.......................................1.20}$$

From which

$$\vec{J}_z = \frac{\sigma\mu_e u H_0}{(1+L_0^2)} \quad \text{.......................................1.21}$$

$$\vec{J}_x = \frac{L_0\sigma\mu_e u H_0}{(1+L_0^2)} \quad \text{.......................................1.22}$$

Substituting $\vec{J}_z$ and $\vec{J}_x$ equations (1.12) and (1.13) respectively yields

$$\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = v\frac{\partial^2 u}{\partial y^2} + g\beta\left(T - T_\infty\right) + g\beta^*(C - C_\infty) - \frac{\mu_e H_0}{\rho}\left(\frac{\sigma\mu_e u H_0}{1+L_0^2}\right)$$

On simplifying results to

$$\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = v\frac{\partial^2 u}{\partial y^2} + g\beta\left(T - T_\infty\right) + g\beta^*(C - C_\infty) - \frac{\sigma\mu_e^2 H_0^2 u}{\rho(1+L_0^2)} \quad \text{.....................1.23}$$

$$\left(u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y}\right) = v\frac{\partial^2 w}{\partial y^2} + \frac{L_0\sigma\mu_0^2 H_0^2 u}{\rho(1+L_0^2)} \quad \text{.......................................1.24}$$

Considering the energy equation given by

$$\rho c_p\frac{DT}{Dt} = k\nabla^2 T + \phi$$

$$\rho\left(\frac{\partial T}{\partial t}+(q.\nabla)T\right)=\frac{k}{c_p}\nabla^2 T+\phi \qquad \text{1.25}$$

Since the fluid flow is steady and the electrical dissipation ϕ is assumed negligible equation (1.25) becomes

$$(q.\nabla)T=\frac{k}{\rho c_p}\nabla^2 T \qquad \text{1.26}$$

Since there is no variation of heat transfer in the z-direction equation (1.26) can be re-written as

$$\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} \qquad \text{1.27}$$

Also assuming that the axial diffusion effects are negligible then the mass transfer equation becomes

$$\left(u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}\right)=D\frac{\partial^2 C}{\partial y^2} \qquad \text{1.28}$$

Non-Dimensionalization

The non-dimensionalization of the equations is an important procedure for numerical as well as experimental studies of fluid flow. It is an important process because the results obtained for a surface experiencing one set of conditions can be applied to a geometrically similar surface experiencing entirely different conditions. These conditions may vary with the nature of the fluid, the fluid velocity or the size of the surface. An appropriate scheme not only express experimental and analytical result in the most efficient form but also make the solution bounded for example temperature and velocity can be non-dimensionalized so that the value ranges from 0 to 1.The main rationale in non-dimensionalization is to reduce to reduce the number of parameters particularly when dealing with incompressible fluids. This is because in compressible fluids the number of non-dimensionalized parameters is equivalent to the dimensional parameters.

In order to bring out the essential features of the flow problems in MHD, it is desirable to find important non-dimensional parameters which characterize these flow problems, some important parameters used in this study are defined below.

Reynolds number Re

It is the ratio of inertia force to the viscous force. If for any flow this number is less than one the inertia force is negligible and on the other hand if it is large, one can ignore viscous force and so the fluid can be taken as inviscid .It is given by Re= $\frac{\rho UL}{\mu}=\frac{UL}{\nu}$

Prandtl number, Pr

It is the ratio of viscous force to thermal force. The Prandtl number is large when thermal conductivity is less than one and viscosity is large, and is small when viscosity is less than one and thermal conductivity is large. Pr= $\frac{\mu c_p}{k}$

Grashof number, Gr
This is another non-dimensional number, which usually occurs in natural convention problems. It is defined as the ratio of buoyancy forces to viscous forces. The larger it is the stronger is the convective current.

$$Gr = \frac{\nu g \beta (T_w^+ - T_\infty^+)}{U^3}$$

Eckert number, Ec
This is the ratio of the kinetic energy to thermal energy.

$$Ec = \frac{U^2}{c_p (T_w^+ - T_\infty^+)}$$

Hartmann number, M

It is the ratio of magnetic force to the viscous force, $M^2 = \frac{\sigma \mu_e^2 H_0^2 \nu}{U^2 \rho}$

Schmidt number, Sc
This provides a measure of the relative effectiveness of momentum and mass transport by diffusion in the velocity and concentration boundary layers respectively. $Sc = \frac{\nu}{D}$
In this study, all the variables with the superscript (+) plus will represent dimensional variables for example u^+ denote dimensional velocity while u non-dimensional velocity.
Non-Dimensionalization is based on the following sets of general scaling variables

$$x = \frac{x^+ U}{\nu},\ y = \frac{y^+ U}{\nu},\ u = \frac{u^+}{U},\ v = \frac{v^+}{U}, w = \frac{w^+ U}{U},\ \theta = \frac{T^+ - T_\infty^+}{T_s^+ - T_\infty^+},\ C = \frac{C^+ - C_\infty^+}{C_s^+ - C_\infty^+},$$

$T_w^+ - T_\infty^+$ *is the temperature difference between the surface and free stream temperature.*

$C_w^+ - C_\infty^+$ *is the concentration difference between the concenration at the surface and the free stream concentration.*

U is the characteristic velocity
Writing equation (1.23) in non-dimensional form

$$u^{+}\frac{\delta u^{+}}{\delta x^{+}}=u^{+}\frac{\delta u^{+}}{\delta x}\frac{\delta x}{\delta x^{+}}=uU\frac{\delta(uU)}{\delta x}\times\frac{U}{\nu}=\frac{uU^{3}}{\nu}\frac{\delta u}{\delta x}$$

$$v\frac{\delta u^{+}}{\delta y^{+}}=vU\frac{\delta u^{+}}{\delta y}\frac{\delta y}{\delta y^{+}}=Uv\frac{\delta(uU)}{\delta y}\times\frac{U}{\nu}=\frac{vU^{3}}{\nu}\frac{\delta u}{\partial y}$$

$$\nu\frac{\delta^{2}u^{+}}{\delta y^{+2}}=\nu\frac{\delta}{\delta y^{+}}\left(\frac{\delta u^{+}}{\delta y^{+}}\right)=\nu\frac{\delta}{\delta y^{+}}\left(\frac{U^{2}}{\nu}\frac{\delta u}{\delta y}\right)=\nu\frac{\delta}{\delta y}\left(\frac{U^{2}}{\nu}\frac{\delta u}{\delta y}\right)\frac{\delta y}{\delta y^{+}}=\frac{U^{3}}{\nu}\frac{\delta^{2}u}{\delta y^{2}}$$

Since $T^{+}-T_{\infty}^{+}=\left(T_{w}^{+}-T_{\infty}^{+}\right)\theta$ *and* $C^{+}-C_{\infty}^{+}=\left(C_{w}^{+}-C_{\infty}^{+}\right)C$

Hence have

$$\frac{uU^{3}}{\nu}\frac{\delta u}{\delta x}+\frac{vU^{3}}{\nu}\frac{\delta u}{\delta y}=\left[\frac{U^{3}}{\nu}\frac{\delta^{2}u}{\delta y^{2}}\right]+g\beta\left(T_{w}^{+}-T_{\infty}^{+}\right)\theta+g\beta^{*}\left(C_{w}^{+}-C_{\infty}^{+}\right)C-\frac{uU\mu_{e}^{2}\sigma H_{0}^{2}}{\rho\left(1+L_{0}^{2}\right)}$$

On dividing by $\frac{U^{3}}{\nu}$, *result to*

$$u\frac{\delta u}{\delta x}+v\frac{\delta u}{\delta y}=\frac{\delta^{2}u}{\delta y^{2}}+\frac{\nu g\beta\left(T_{w}^{+}-T_{\infty}^{+}\right)\theta}{U^{3}}+\frac{\nu g\beta^{*}\left(C_{w}^{+}-C_{\infty}^{+}\right)C}{U^{3}}-\frac{u\sigma\mu_{e}^{2}H_{0}^{2}\nu}{U^{2}\rho\left(1+L_{0}^{2}\right)}\qquad\text{.........3.29}$$

Writing equation (1. 24) in non-dimensional form

$$u^{+}\frac{\delta w^{+}}{\delta x^{+}}=uU\frac{\delta w^{+}}{\delta x}\frac{\delta x}{\delta x^{+}}=uU\frac{\delta(wU)}{\delta x}\times\frac{U}{\nu}=\frac{uU^{3}}{\nu}\frac{\partial w}{\delta x}$$

$$v\frac{\delta w^{+}}{\delta y^{+}}=vU\frac{\delta w^{+}}{\delta y}\frac{\delta y}{\delta y^{+}}=vU\frac{\delta(wU)}{\delta y}\times\frac{U}{\nu}=\frac{U^{3}v}{\nu}\frac{\partial w}{\delta y}$$

$$\nu\frac{\delta^{2}w^{+}}{\delta y^{+2}}=\nu\frac{\delta}{\delta y^{+}}\left(\frac{\delta w^{+}}{\delta y^{+}}\right)=\nu\frac{\delta}{\delta y}\left(\frac{U^{2}}{\nu}\frac{\delta w}{\delta y}\right)\frac{\delta y}{\delta y^{+}}=\frac{U^{3}}{\nu}\frac{\delta^{2}w}{\delta y^{2}}$$

substituting the above in equation (3.24) *and simplifying, result to,*

$$u\frac{\delta w}{\delta x}+v\frac{\delta w}{\delta y}=\frac{\delta^{2}w}{\delta y^{2}}+\frac{uvL_{0}\mu_{e}^{2}\sigma H_{o}^{2}}{U^{2}\rho\left(1+L_{0}^{2}\right)}\qquad\text{.........3.30}$$

Writing equation (3. 27) in non-dimensional form

$$\theta=\frac{T^{+}-T_{\infty}^{+}}{T_{w}^{+}-T_{\infty}^{+}},\ C=\frac{C^{+}-C_{\infty}^{+}}{C_{w}^{+}-C_{\infty}^{+}},\ \frac{\partial\theta}{\partial T^{+}}=\frac{1}{T_{w}^{+}-T_{\infty}^{+}}$$

$T_{w}^{+}-T_{\infty}^{+}$ *is the temperature difference between the surface and free stream temperature.*

$C_{w}^{+}-C_{\infty}^{+}$ *is the concentration difference between the concenration at the surface and the free stream concentration.*

$$u^{+}\frac{\partial T^{+}}{\partial x^{+}}=uU\frac{\partial T^{+}}{\partial\theta}\frac{\partial\theta}{\partial x}\frac{\partial x}{\partial x^{+}}=\frac{uU^{2}}{\nu}(T_{w}^{+}-T_{\infty}^{+})\frac{\partial\theta}{\partial x}$$

$$v\frac{\partial T^{+}}{\partial y^{+}}=vU\frac{\partial T^{+}}{\partial\theta}\frac{\partial\theta}{\partial y}\frac{\partial y}{\partial y^{+}}=\frac{vU^{2}}{\nu}(T_{w}^{+}-T_{\infty}^{+})\frac{\partial\theta}{\partial y}$$

$$\frac{\partial^{2}T^{+}}{\partial y^{+2}}=\frac{\partial}{\partial y^{+}}\left[\frac{\partial T^{+}}{\partial y^{+}}\right]=\frac{\partial}{\partial y}\left[\frac{U}{\nu}(T_{w}^{*}-T_{\infty}^{*})\frac{\partial\theta}{\partial y}\right]\frac{\partial y}{\partial y^{+}}=\frac{U^{2}}{\nu^{2}}(T_{w}^{+}-T_{\infty}^{+})\frac{\partial^{2}\theta}{\partial y^{2}}$$

Substituting the above in equation (3.27) and simplifying result to

$$u\frac{\delta\theta}{\delta x}+v\frac{\delta\theta}{\delta y}=\frac{\kappa}{\mu c_{p}}\left[\frac{\delta^{2}\theta}{\delta y^{2}}\right]\ldots\ldots\ldots\ldots\ldots\ldots 1.31$$

Writing equation (3.28) in non-dimensional form

$$u^{+}\frac{\delta C^{+}}{\delta x^{+}}=uU^{2}\frac{\delta C^{+}}{\delta C}\frac{\delta C}{\delta x}\frac{\delta x}{\delta x^{+}}=\frac{uU^{2}}{\nu}(C_{w}^{+}-C_{\infty}^{+})\frac{\delta C}{\delta x}$$

$$v^{+}\frac{\delta C^{+}}{\partial y^{+}}=vU\frac{\delta C^{+}}{\delta C}\frac{\delta C}{\delta y}\frac{\delta y}{\delta y^{+}}=\frac{vU^{2}}{\nu}(C_{w}^{+}-C_{\infty}^{+})\frac{\delta C}{\delta y}$$

$$\frac{\delta^{2}C^{+}}{\delta y^{+2}}=\frac{\delta}{\delta y^{+}}\left[\frac{\delta C^{+}}{\delta y^{+}}\right]=\frac{\delta}{\delta y}\left[\frac{U}{\nu}(C_{w}^{+}-C_{\infty}^{+})\frac{\delta C}{\delta y}\right]\frac{\delta y}{\delta y^{+}}=\frac{U^{2}}{\nu^{2}}(C_{w}^{+}-C_{\infty}^{+})\frac{\delta^{2}C}{\delta y^{2}}$$

Substituting the above in equation (1.28) and simplifying result to

$$u\frac{\delta C}{\delta x}+v\frac{\delta C}{\delta y}=\frac{D}{\nu}\left[\frac{\delta^{2}C}{\delta y^{2}}\right]\ldots\ldots\ldots\ldots\ldots\ldots 1.32$$

Equations (1.29) to (1.32) can be reduced further by dimensionless parameters as

$$u\frac{\delta u}{\delta x}+v\frac{\delta u}{\delta y}=\frac{\partial^{2}u}{\partial y^{2}}+Gr\theta+GcC-\frac{M^{2}u}{(1+L_{0}^{2})}\ldots\ldots\ldots\ldots 1.33$$

$$u\frac{\delta w}{\delta x}+v\frac{\delta w}{\delta y}=\frac{\partial^{2}v}{\partial y^{2}}+\frac{M^{2}L_{0}u}{(1+L_{0}^{2})}\ldots\ldots\ldots\ldots 1.34$$

$$u\frac{\delta\theta}{\delta x}+\frac{\delta\theta}{\delta y}=\frac{1}{\Pr}\left[\frac{\partial^{2}\theta}{\partial y^{2}}\right]\ldots\ldots\ldots\ldots 1.35$$

$$u\frac{\delta C}{\delta x}+\frac{\delta C}{\delta y}=\frac{1}{Sc}\left[\frac{\partial^{2}C}{\partial y^{2}}\right]\ldots\ldots\ldots\ldots 1.36$$

NUMERICAL METHOD OF SOLUTION

In this study the equations governing free convection fluid flow are non-linear and thus their exact solution is not possible; in order to solve these equations a fast and stable method for the solution of finite difference approximation has been developed. The difference method used should be consistent, stable and convergent. A method is convergent if, as more grid points are taken or step size decreased, the numerical solution convergence to the exact solution. A method is stable if the effect of any single fixed round-off error is bounded and finally a method is consistent if the truncation error tends to zero as the step size decreases.
The numerical error arises because in most computations we cannot exactly compute the difference solution as we encounter round off errors. In fact in some cases the exact solutions

may differ considerably from the difference solution .If the effects of the round off error remains bounded as the mesh point tend to infinity with fixed step size then the difference method is said to be stable. In order to approximate equations (1.33) to (1.36) by a set of finite difference equations, we first define a suitable mesh.

Definition of mesh

In order to give a relation between the partial derivatives in the differential equation and the function values at the adjacent nodal points, we use a uniform mesh. Let the x-y plane be divided into a network of uniform rectangular cells of width Δy and height Δx, as shown below.

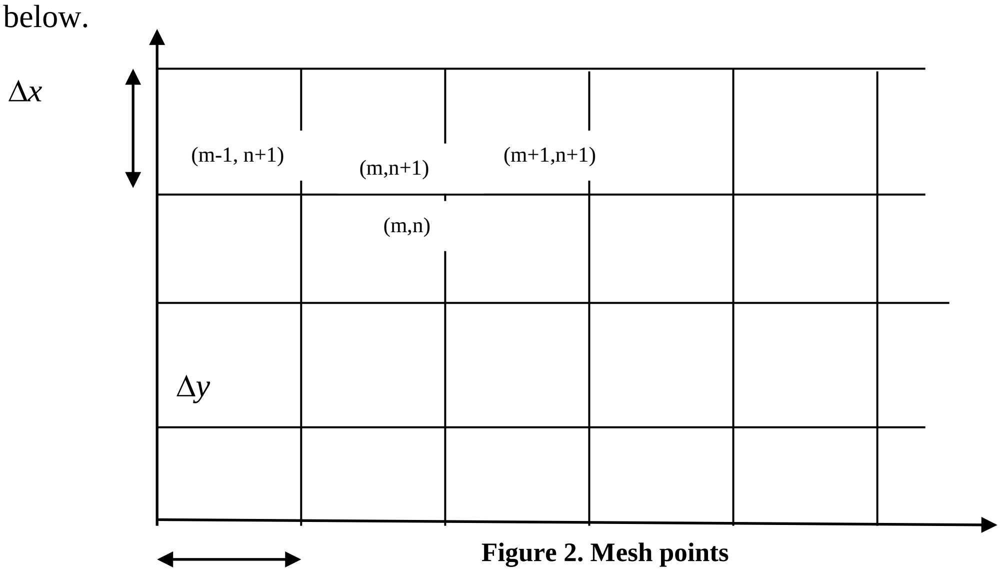

Figure 2. Mesh points

Let m and n refer to y and x respectively. If we let Δy represent increment in y and Δx represent increment in x then y= m Δy and x = n Δx .The finite difference approximations of the partial derivatives appearing in equations (3.33) to (3.36) are obtained by Taylor series expansion of the dependent variable.

$$\psi(m-1,n)=\psi(m,n)-\psi^{'}(m,n)\Delta y+\frac{1}{2}\psi^{''}(m,n)(\Delta y)^2-\frac{1}{6}\psi^{'''}(m,n)(\Delta y)^3+\dots\dots\dots 4.1$$

$$\psi(m+1,n)=\psi(m,n)+\psi^{'}(m,n)\Delta y+\frac{1}{2}\psi^{''}(m,n)(\Delta y)^2+\frac{1}{6}\psi^{'''}(m,n)(\Delta y)^3+\dots\dots\dots 4.2$$

On eliminating $\psi^{''}$ from equation (3.1) and (3.2) yields

$$\psi^{'}=\frac{\psi(m+1,n)-\psi(m-1,n)}{2\Delta y}+Hot \quad \dots\dots\dots 3.3$$

On eliminating $\psi^{'}$ from equation (4.1) and (4.2) results to

$$\psi^{''}=\frac{\psi(m+1,n)-2\psi(m,n)+\psi(m,n)}{(\Delta y)^2}+Hot \quad \dots\dots\dots 3.4$$

Similarly

$$\psi' = \frac{\phi(m,n+1)-\psi(m,n-1)}{2\Delta x} + Hot \ldots\ldots 3.5$$

$$\psi'' = \frac{\psi(m,n+1)-2\psi(m,n)+\psi(m,n-1)}{(\Delta x)^2} + Hot \ldots\ldots 3.6$$

Substituting finite difference equations for the first and second derivatives in equations (3.33) to (3.36) the final set of the governing equations are,

$$u_{(m,n)}\left[\frac{u_{(m,n+1)}-u_{(m,m-1)}}{2\Delta x}\right]+v_{(m,n)}\left[\frac{u_{(m+1,i)}-u_{(m-1,n)}}{2\Delta y}\right]=\left[\frac{u_{(m+1,n)}-2u_{(m,n)}+u_{(m-1,n)}}{(\Delta y)^2}\right]+$$

$$Gr\theta_{(m,n)}+GcC_{(m,n)}-\frac{M^2u(m,n)}{1+L_0^2}$$

$$u_{(m,n)}\left[\frac{w_{(m,n+1)}-w_{(m,n-1)}}{2\Delta x}\right]+v(m,n)\left[\frac{w_{(m+1,n)}-w_{(m-1,n)}}{2\Delta y}\right]=\left[\frac{w_{(m+1,n)}-2w_{(m,n)}+w_{(m-1,n)}}{(\Delta y)^2}\right]$$

$$+\frac{M^2L_0u(m,n)}{(1+L_0^2)}$$

$$u_{(m,n)}\left[\frac{\theta_{(m,n+1)}-\theta_{(m,n-1)}}{2\Delta x}\right]+v_{(m,n)}\left[\frac{\theta_{(m+1,n)}-\theta_{(m-1,n)}}{2\Delta y}\right]$$

$$=\frac{1}{pr}\left[\frac{\theta_{(m+1,n)}-2\theta_{(m,n)}+\theta^n_{(m-1,n)}}{(\Delta y)^2}\right]\ldots\ldots 4.9$$

$$u_{(m,n)}\left[\frac{C_{(m,n+1)}-C_{(m,n-1)}}{2\Delta x}\right]+v_{(m,n)}\left[\frac{C_{(m+1,n)}-C_{(m-1,n)}}{2\Delta y}\right]$$

$$=\frac{1}{Sc}\left[\frac{C_{(m+1,n)}-2C_{(m,n)}+C^n_{(m-1,n)}}{(\Delta y)^2}\right]\ldots\ldots 4.10$$

The boundary conditions take the form

$At\ z=0 \quad u=1,\ v=1, w=0\ ,\theta=1,\ C=1$

$As\ y\to\infty \quad u=0,\ v=0, w=0\ \ \theta=0,\ \ C=0$

$At\ x=0 \quad u=1,\ v=0, w=0\ \ \theta=0,\ \ C=0$

The computations are performed using small values of $\Delta y\ and\ \Delta x$, in this research $\Delta y=\Delta x=0.1$.We fixed y = 4.1 from which m = 41 as corresponding to $y\ at$ infinity therefore set $u_{(41,n)}=v_{(41,n)}=w_{(41,n)}=0=C_{(41,n)}=\theta_{(41,n)}=0$

In the computations the Prandtl number is taken as 0.71 which corresponds to air, magnetic parameter $M^2=10$ which signifies a strong magnetic field and the Grashof number, Gr>0(+0.4) corresponding to convective cooling of the plate. The Hall parameter L_0 is varying from, 0, 0.3, 0.7 and 1.0

To ensure stability and convergence of the finite difference method, this program is run using smaller values of Δy *and* Δx such 0.001, 0.0005 and.0.00015 it was observed that there was no significant changes in the results, which ascertain that the finite difference method used in the problem converges and is stable .

Observation and discussion of results

A program was written and run for various values of velocities, temperatures and concentrations for the finite difference equation 4.7 to 4.10 using different values of the parameters .

The primary velocity (u), secondary velocity (w), temperature (θ) and concentration profiles are presented graphically in figures 3-6 and tables 1-4

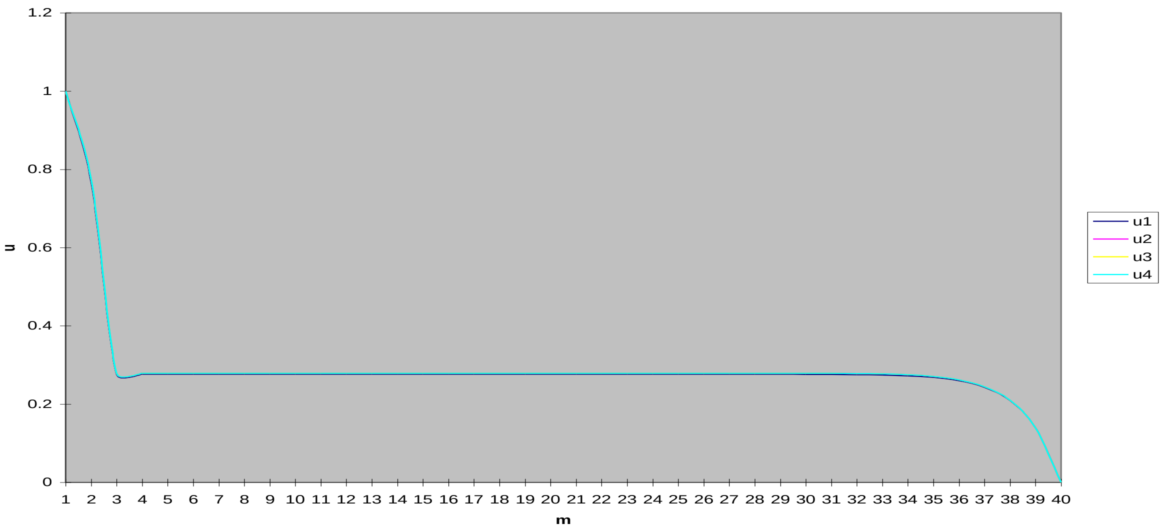

Figure 3. Primary velocity profiles

m	u1	u2	u3	u4
0	1	1	1	1
1	0.765845	0.773249	0.773315	0.773323
2	0.276415	0.279089	0.279113	0.279116
3	0.276415	0.279089	0.279113	0.279116
4	0.276415	0.279089	0.279113	0.279116
5	0.276415	0.279089	0.279113	0.279116
6	0.276415	0.279089	0.279113	0.279116
7	0.276415	0.279089	0.279113	0.279116
8	0.276415	0.279089	0.279113	0.279116
9	0.276415	0.279089	0.279113	0.279116
10	0.276415	0.279089	0.279113	0.279116
11	0.276415	0.279089	0.279113	0.279116
12	0.276415	0.279089	0.279113	0.279116
13	0.276415	0.279089	0.279113	0.279116

14	0.276415	0.279089	0.279113	0.279116
15	0.276415	0.279089	0.279113	0.279116
16	0.276415	0.279089	0.279113	0.279116
17	0.276415	0.279089	0.279113	0.279116
18	0.276415	0.279089	0.279113	0.279116
19	0.276415	0.279089	0.279113	0.279116
20	0.276415	0.279089	0.279113	0.279116
21	0.276415	0.279088	0.279112	0.279115
22	0.276414	0.279087	0.279111	0.279114
23	0.276412	0.279085	0.279109	0.279112
24	0.276409	0.279081	0.279105	0.279108
25	0.276402	0.279073	0.279097	0.2791
26	0.276387	0.279057	0.279081	0.279084
27	0.276359	0.279025	0.279049	0.279052
28	0.2763	0.27896	0.278984	0.278987
29	0.276182	0.278829	0.278853	0.278856
30	0.275941	0.278566	0.27859	0.278593
31	0.275453	0.278038	0.278062	0.278064
32	0.274461	0.276977	0.276999	0.277002
33	0.272449	0.274843	0.274865	0.274867
34	0.268365	0.270555	0.270574	0.270577
35	0.260077	0.261936	0.261953	0.261955
36	0.243261	0.244618	0.244631	0.244632
37	0.20915	0.209832	0.209838	0.209839

Table 1: Primary velocity profiles

From Figure 3 and table 1 it was observed that as the Hall current parameter (Lo) increases primary velocity profiles also increases but away from the plate the primary velocity profiles becomes constant

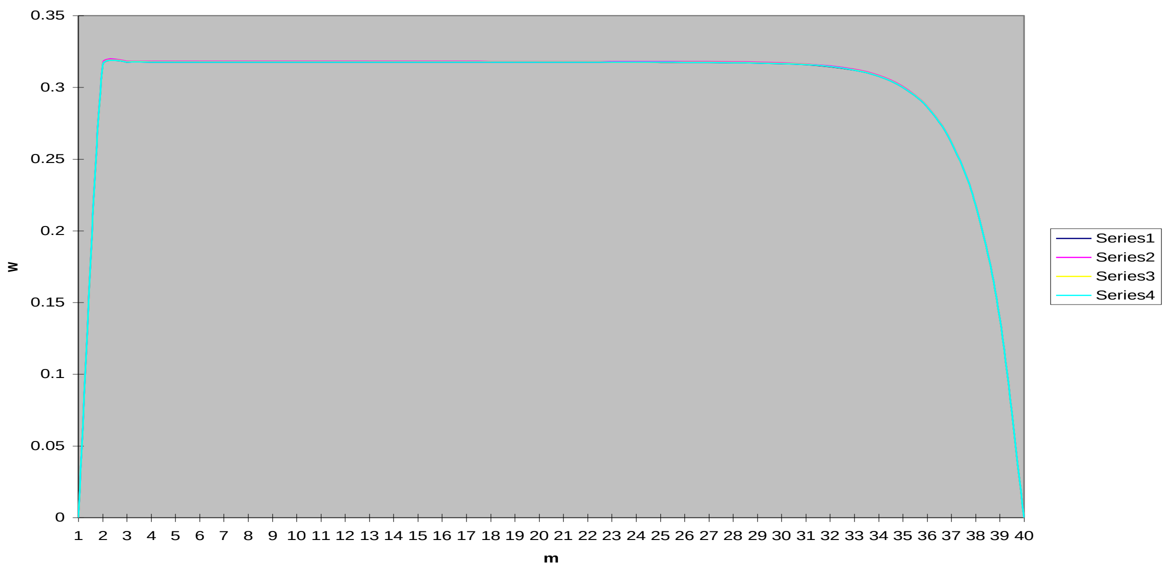

Figure 4: Secondary velocity profiles

From figure 4 and table 2 it was observed that as Hall current parameter increases from 0.7 to 1.0 secondary velocity profiles decreases

m	w1	w2	w3	w4
0	0	0	0	0
1	0.315569	0.316634	0.315898	0.315638
2	0.317493	0.318095	0.317679	0.317532
3	0.317493	0.318095	0.317679	0.317532
4	0.317493	0.318095	0.317679	0.317532
5	0.317493	0.318095	0.317679	0.317532
6	0.317493	0.318095	0.317679	0.317532
7	0.317493	0.318095	0.317679	0.317532
8	0.317493	0.318095	0.317679	0.317532
9	0.317493	0.318095	0.317679	0.317532
10	0.317493	0.318095	0.317679	0.317532
11	0.317493	0.318095	0.317679	0.317532
12	0.317493	0.318095	0.317679	0.317532
13	0.317492	0.318095	0.317679	0.317531
14	0.317492	0.318095	0.317679	0.317531
15	0.317492	0.318095	0.317679	0.317531
16	0.317492	0.318095	0.317679	0.317531
17	0.317492	0.318094	0.317678	0.317531
18	0.317491	0.318093	0.317677	0.31753
19	0.31749	0.318092	0.317676	0.317529
20	0.317487	0.31809	0.317674	0.317526
21	0.317483	0.318086	0.31767	0.317522
22	0.317476	0.318078	0.317662	0.317515
23	0.317463	0.318065	0.317649	0.317502
24	0.31744	0.318042	0.317626	0.317479
25	0.317398	0.318	0.317585	0.317437
26	0.317324	0.317926	0.31751	0.317363
27	0.317192	0.317793	0.317378	0.317231
28	0.316956	0.317555	0.317142	0.316995
29	0.316534	0.317132	0.31672	0.316574
30	0.315781	0.316375	0.315966	0.315821
31	0.314437	0.315023	0.31462	0.314477
32	0.312034	0.31261	0.312215	0.312075
33	0.307742	0.308298	0.307918	0.307783
34	0.300072	0.300596	0.300239	0.300112
35	0.286361	0.286835	0.286514	0.2864
36	0.261853	0.262248	0.261982	0.261888
37	0.218042	0.218325	0.218136	0.218069
38	0.139755	0.139894	0.139802	0.139769
39	0	0	0	0

Table 2: Secondary velocity profiles

From figure 4 and table 2 it was observed that as Hall current parameter increases from 0.7 to 1.0 secondary velocity profiles decreases

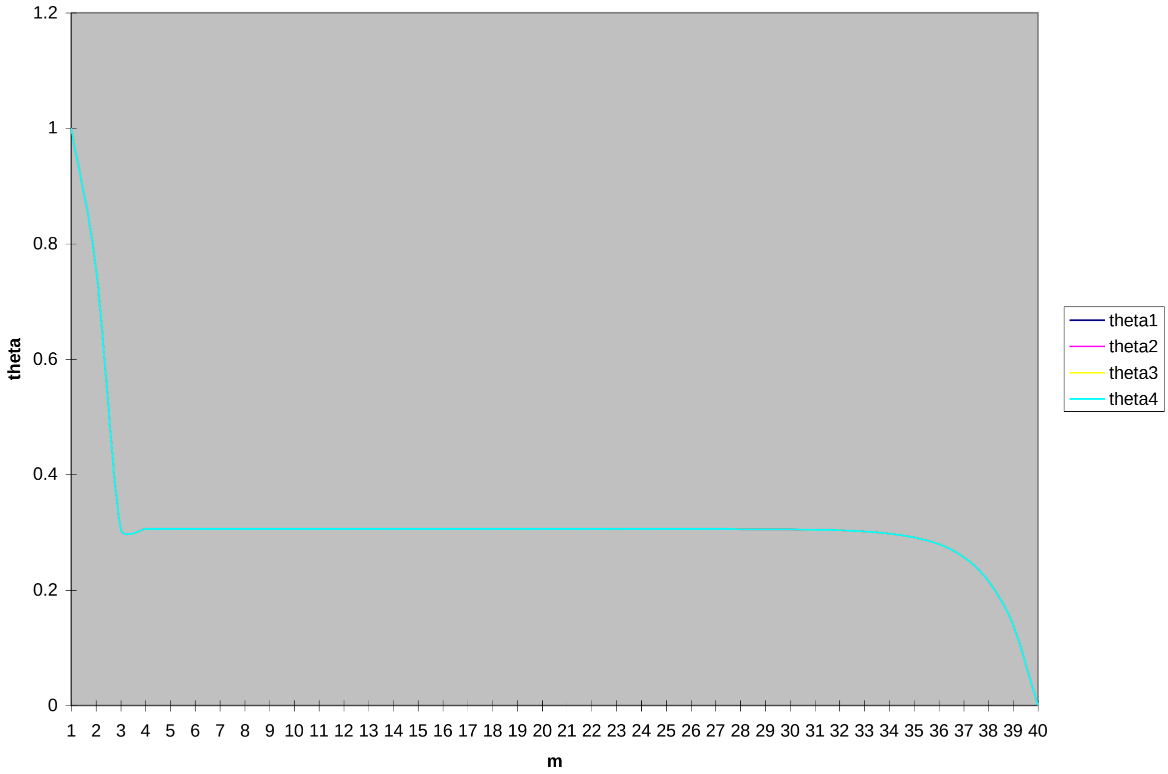

Figure 5: Temperature profiles

M	theta1	theta2	theta3	theta4
0	1	1	1	1
1	0.756855	0.756797	0.756797	0.756797
2	0.305625	0.305609	0.305609	0.305609
3	0.305625	0.305609	0.305609	0.305609
4	0.305625	0.305609	0.305609	0.305609
5	0.305625	0.305609	0.305609	0.305609
6	0.305625	0.305609	0.305609	0.305609
7	0.305625	0.305609	0.305609	0.305609
8	0.305625	0.305609	0.305609	0.305609
9	0.305625	0.305609	0.305609	0.305609
10	0.305625	0.305609	0.305609	0.305609
11	0.305625	0.305609	0.305609	0.305609
12	0.305625	0.305609	0.305609	0.305609
13	0.305625	0.305609	0.305609	0.305609
14	0.305625	0.305609	0.305609	0.305609
15	0.305625	0.305609	0.305609	0.305609
16	0.305624	0.305609	0.305608	0.305608
17	0.305624	0.305608	0.305608	0.305608
18	0.305624	0.305608	0.305608	0.305608
19	0.305623	0.305607	0.305607	0.305607

20	0.305622	0.305606	0.305606	0.305606
21	0.30562	0.305604	0.305604	0.305604
22	0.305615	0.3056	0.305599	0.305599
23	0.305607	0.305592	0.305592	0.305592
24	0.305593	0.305577	0.305577	0.305577
25	0.305566	0.305551	0.30555	0.30555
26	0.305517	0.305501	0.305501	0.305501
27	0.305427	0.305411	0.305411	0.305411
28	0.30526	0.305244	0.305244	0.305244
29	0.304952	0.304937	0.304936	0.304936
30	0.304384	0.30437	0.304369	0.304369
31	0.303338	0.303324	0.303324	0.303324
32	0.301409	0.301396	0.301396	0.301396
33	0.297852	0.29784	0.29784	0.29784
34	0.291292	0.291283	0.291282	0.291282
35	0.279193	0.279186	0.279186	0.279186
36	0.256877	0.256873	0.256873	0.256873
37	0.215718	0.215716	0.215716	0.215716
38	0.139826	0.139826	0.139826	0.139826
39	0	0	0	0

Table 3: Temperature Profiles

From Figure 5 and table 3 it was observed that an increase in Hall current parameter (Lo) has no effect in temperature profiles.

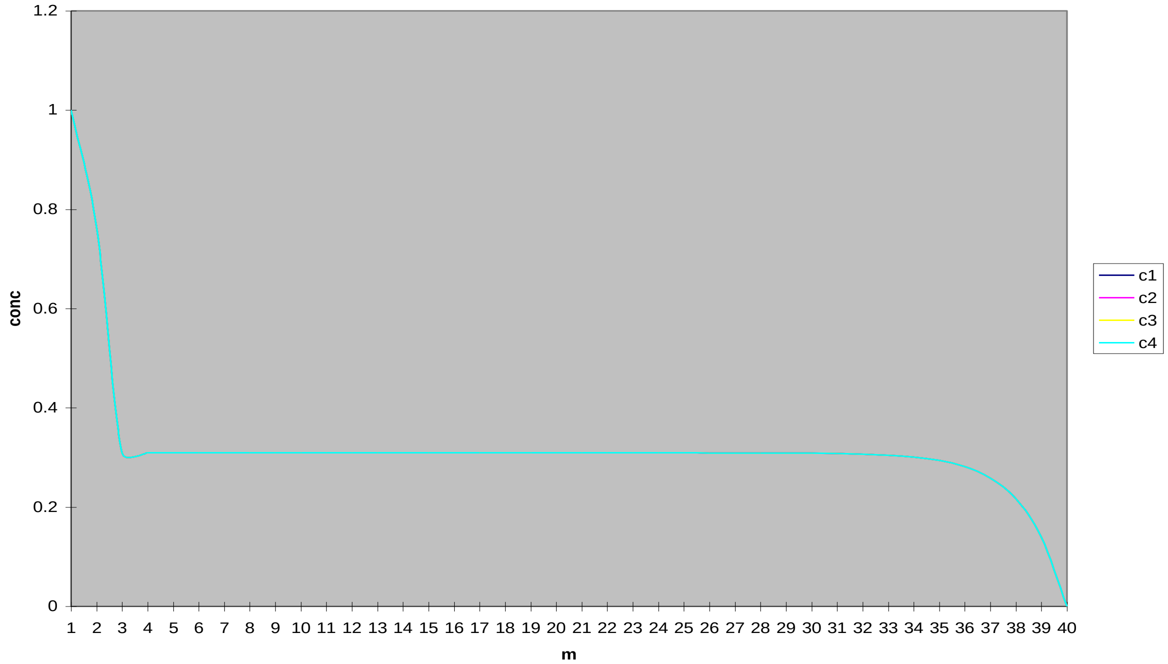

Figure 6: Concentration profiles

m	c1	c2	c3	c4
0	1	1	1	1
1	0.76189	0.761898	0.761898	0.761898
2	0.309212	0.309193	0.309193	0.309193
3	0.309212	0.309193	0.309193	0.309193
4	0.309212	0.309193	0.309193	0.309193
5	0.309212	0.309193	0.309193	0.309193
6	0.309212	0.309193	0.309193	0.309193
7	0.309212	0.309193	0.309193	0.309193
8	0.309212	0.309193	0.309193	0.309193
9	0.309212	0.309193	0.309193	0.309193
10	0.309212	0.309193	0.309193	0.309193
11	0.309212	0.309193	0.309193	0.309193
12	0.309212	0.309193	0.309193	0.309193
13	0.309212	0.309193	0.309193	0.309193
14	0.309212	0.309193	0.309193	0.309193
15	0.309212	0.309193	0.309193	0.309193
16	0.309211	0.309193	0.309193	0.309193
17	0.309211	0.309193	0.309193	0.309193
18	0.309211	0.309192	0.309192	0.309192
19	0.30921	0.309192	0.309191	0.309191
20	0.309208	0.30919	0.30919	0.30919
21	0.309206	0.309187	0.309187	0.309187
22	0.309201	0.309182	0.309182	0.309182
23	0.309191	0.309173	0.309173	0.309173
24	0.309175	0.309156	0.309156	0.309156
25	0.309144	0.309126	0.309126	0.309126
26	0.309088	0.30907	0.30907	0.30907
27	0.308986	0.308968	0.308968	0.308968
28	0.3088	0.308782	0.308782	0.308782
29	0.30846	0.308443	0.308443	0.308443
30	0.30784	0.307823	0.307823	0.307823
31	0.306708	0.306692	0.306692	0.306692
32	0.304642	0.304627	0.304627	0.304627
33	0.300868	0.300856	0.300855	0.300855
34	0.293979	0.293968	0.293968	0.293968
35	0.281395	0.281388	0.281388	0.281388
36	0.258413	0.258409	0.258409	0.258409
37	0.21644	0.216438	0.216438	0.216438
38	0.139804	0.139804	0.139804	0.139804
39	0	0	0	0

Table 4: Concentration profiles.

From Figure 6 and table 4 it was observed that the Hall current parameter has no effect on concentration profile.

DISCUSSION OF THE RESULTS

The Hall current parameter, Lo, is directly proportional to the product of cyclotronic frequency and collision time. Therefore an increase in the Hall current parameter, Lo, leads to an increase in cyclotronic frequency or collision time and since they are directly proportional this leads to an increase in spiraling velocity hence increase in primary velocity profiles.
The decrease in secondary velocity profiles is as a result of the retardation nature of the magnetic force which retards the motion of particles in that direction. The constant region in most of the figures is attributed to the fact that away from the plate there is no velocity, temperature and concentration gradients.

CONCLUSION AND RECOMMENDATIONS

This section presents the conclusion from the results obtained and recommends problems for further research in future.

IMPLICATION TO RESEARCH AND PRACTICE

Study of heat transfer in porous medium has paramount importance because of its potential applications in soil physics , geo -hydrology, filtration of solids from liquids, chemical engineering and biological systems. Mass transfer plays important role in many industrial processes for example , the removal of pollutants from plant discharges streams by absorptions, the stripping of gases from waste water anon neutron diffusion within nuclear reactors. Electrically conducting fluids are available in nature, but their conductions vary greatly. The best conductors of electricity are liquid metals , which are utilized in technological casting and liquid – metal cooling loops of nuclear reactors.
Operating principles of certain MHD devices utilizes the interactions between velocity field, magnetic field and electric field. Any device designed in this manner is capable of performing the functions of various machines. The particular where these principles are applied include MHD generator, MHD flow meter MHD pump and heat exchanger.

CONCLUSION

An analysis of the effect of Hall current parameter on the velocities, temperature and concentration profiles on free convection fluid flow and mass transfer past a semi- infinite vertical flat plate has been carried out. In all the cases considered, the applied magnetic field was resolved into two components and our work was restricted to laminar boundary layer.
The equations governing the flows considered in our problem are non-linear therefore in order to obtain their solution an efficient finite difference scheme has been developed as applied in chapter four. The mesh system used in the problem considered in our case is uniformly divided. The results obtained for a chosen value of time increment is compared with values of a smaller time increment and it was noted that there are no significant difference, which implies that the method is stable and convergent. The results obtained for various values of Hall current parameter were presented graphically and in table form.
It can be concluded that an increase in Hall current parameter leads to an increase in primary velocity profiles and a decrease in velocity profiles but has no effect on the temperature and concentration profile.

Finally in the power industries among the method of generating electric power is one in which electric energy is tapped directly from a moving conducting fluid. This class of flow has many applications in the design of MHD generators, pumps and flow meters.
Flow in these devices will be accompanied by heat either dissipated internally through viscous heating or joule heating.
We strong recommend that the designers of these devices should take into consideration the Hall current parameter.

RECOMMENDATIONS

This work considered Hall current effect on a steady free convection flow and mass transfer of a viscous, incompressible and electrically conducting fluid past a heated semi-infinite vertical flat plate subjected to a strong, non-uniform Magnetic field normal to the plate. It is recommended that this work can be extended by considering the following

(1) Variable suction/ injection
(2) Fluid flow in the turbulent boundary layer
(3) Varied viscosity
(4) Variable thermal conductivity
(5) Viscous and ohmic dissipation
(6) Experimental investigation of the same problem.

REFERENCES

Adel A.Megahed, Soliman R. Komy, Ahemed A. Afify. Similarity analysis in magneto hydrodynamics: Hall effects on free convection flow and mass transfer past a semi-infinite vertical flat plate. International journal of Non-linear mechanics 38(2003) 513-520.

Chaturvedi,N.:Polarization in MHD power generator ,Energy Convers .Mgmt vol.30,no.1,p 49(1990)

Chaturvedi.: MHD flow past an infinite porous plate with variable suction, Energy Convers .Mgmt vol.37,no.5,p.623-627(1996)

Cowling, T.G. Magneto Hydrodynamics, New York: Interscience,(1957)

Dash, G.C. and Ojha, B.k.: MHD unsteady free convection effects on the flow past an exponentially accelerated vertical plate, Model.Simul. ControlB, vol.27, no.1, p.1-10(1990)

Dash, G.C. and Das, D.P.: Heat transfer in viscous flow along a plane wall with periodic suction and heat source, Model.Simul. control B,vol.27,no.2,p.47-55(1990)

Emad M. Aboeldahab, Elsayed M.E Elbarbary: Hall current effect on magneto hydrodynamic free-convention flow past a semi-infinite vertical plate with mass transfer. International Journal of Engineering Science 39 (2001) 1641-1652.

Faraday, M.: Experimental researches in electricity, Richard and John Edward Taylor (1939).

Gupta, G.O and Rajesh, J.: MHD three dimensional flow past a porous plate; Indian Journal of pure and Applied mathematics, Vol. 32, no, 3, P. 377 (2001)

Hong-sen kou and Huang, Der-kuen.: Some transformations for natural convection on a vertical flat plate embedded in porous media with prescribed wall temperature, Int. commun. Heat mass Transf. vol. 23,no .2, p.273-286 (1996)

Jordan J.Z: Network simulation method applied to radiation and viscous dissipation effects on MHD unsteady free convection over vertical porous plate. Applied Mathematical Modeling 31(2007)2019-2033

Kinyajui, M., Kwanza, J.K. and Uppal, S.M: MHD free convection heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with Hall current and radiation absorption, Energy convers. Mgmt Vol. 42 P. 917 – 931 (2001).

Kinyanjui, M. Charturvedi, N. and Uppal, S.M.: MHD Strokes problem for a vertical infinite plate in a dissipative rotating fluid with Hall Current, energy convers. Mgmt. Vol. 39, no. 5/6, p. 541 – 548 (1998).

Ko, C.L. and Gladden, H.J. Conjugate Heat transfer analysis of concentric –tube heat exchangers usinga higher -order finite- difference Technique,J.Ind./Math.Soc.,vol.48,part 2(1998)

Kumar, B. and Sigh, R.P: Role of porosity and magnetic field on free convention flow past an exponentially accelerated vertical porous plate, model. Simul. Control B, vol. 31, no. 3, P.35-43 (1990).

Kwanza, J.K. Kinyanjui, M. and Uppal, S.M: MHD stokes force convection flow past an infinite vertical porous plate subjected to constant heat flux with ion-slip current and radiation absorption, far East J. App Math. 12(2) P. 105-131 (2003).

Marales L.F, Dasso S, Gomez O.D and Mininni P.:Hall effect on magnetic reconnection at the Earth's magnetopause .journal of Atmospheric and Solar –Terrestrial Physics 67(2005) 1821-1826

Moreau, R.:Magnetohydrodynamics, kluwer academic publishers Netherlands (1990) pg 56-65

Osalusi E. Side J. Harris R.:The effects of Ohmic heating and viscous dissipation on unsteady MHD and slip flow over a porous rotating disk with variable properties in the presence of Hall and Ion-slip currents. Int. Commun. Heat Mass Transfer. (2007),doi;10.1016/j.icheatmasstransfer.2007.05.009

Pai,S.I.: Magnetogasdynamics and plasma dynamics, Wien Springer-Verlag (1962) pg 420-450

Okelo .J.A; Heat and Mass transfer past a semi-infinite vertical porous plate in MHD flows, Ph.D dissertation, Jomo Kenyatta university of Agriculture and technology 2008.

Prasada, R and Sivaprasad, R.; MHD flow in a channel with wavy porous boundary ,Proc. Indian natl. Acad.Vol.51A,no.2,p.391-406,(1985)

Ram, P.C., Kinyanjui, M. and Takhar, H. S.: MHD Stokes Problem of Convective Flow from A vertical infinite Plate in A Rotating Fluid, J. MHD. Plas. /3 Research. Vol. 5, no 2P. 91 – 106 (1995)

Ram, P.C: Effects of Hall current and wall temperature Oscillation on convective flow in a rotating fluid through porous medium, Waerme and Stoffuebertrag. Vol. 25, no 4, p 205-208 (1990).

Ram ,P.C.:Finite difference analysis of the MHD stokes problem of a vertical plate with Hall and Ion-slip currents , and Astrophys space science 176;263-270(!991)

Rao,P.S. and Maurthy,M.V.R.:Transient MHD flow through a rectangular channel ,Proc.Indian Natl.Sci.Acad.Part A,vol 53,no.330-339(1987)

Shercriff,J.A.:A text book of magnetohydrodynamics,Pergamon press,(1965)

Youn J. Kim: Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. International Journal of Engineering Science 38(2000) 822-845.