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Effect of thermo diffusion and chemical reaction on convective heat and mass transfer flow of a rotating micro polar fluid with hall effect past a vertical plate

V. Suresh Babu*[1] U. Rajeswara Rao[2] and D. R. V. Prasada Rao[2]

[1] Department of Mathematics (GEBH), Ravindra college of Engg. for women, Kurnool, A.P., India

[2]Department of Mathematics, Sri Krishnadevaraya University, S. V. Puram, Anantapuramu, A.P., India

****Corresponding Author's Email: vustepallisuresh@gmail.com***

A R T I C L E I N F O

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A B S T R A C T

In this paper, we investigate the effect of combined influence of Hall effect chemical reaction thermo diffusion and rotation on Hydro magnetic convective Heat & mass transfer flow of a micro polar fluid through a porous medium bounded by a semi-infinite porous plate in the presence of heat generating sources. The dimensionless grouping equations for this investigation on solved using small perturbation approximation. The effects of various dimensionless parameters entering to the problem on the velocity & temperature concentration micro rotation profiles across the boundary layer are investigated to graphs. Also the result of the couple stress coefficient, the rate of heat & mass transfer at the wall are evaluated for different variations of the parameters.

Introduction:

The theory of micropolar fluids was first introduced and formulated by Eringen [9]. This theory displays the effect of local rotary inertia and couple stress. This theory is expected to provide a mathematical model for the non-Newtonian fluid behavior observed in certain fluid such as exotic lubricants, polymeric fluid. Colloidal fluids, liquid crystals, dirty oils, animal blood, etc., which is more realistic and important from a technological point of view. The theory of thermomicropolar fluids was developed by Eringen [10], by extending his theory of micropolar fluid. Physically, they represent fluids consisting of randomly oriented particles suspended in a viscous medium (Lukaszawicz[18]).

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. Possible applications of this type flow can be found in many industries, like design of chemical processing equipment, damage of crops due to freezing, food processing and cooling towers. Deka et. al. [8] investigated the effect of first order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer. Ibrahim et al [15] obtained the analytical solution for unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and chemical reaction. Rahman et al.[27] studied heat transfer in micropolar fluid with temperature dependent fluid properties along a non-stretching sheet. Rahman et al.[28-29] considered heat transfer in micropolar fluid along an inclined plate with variable fluid properties under different boundary conditions. Damesh et al.[5] have investigated heat and mass transfer free convective flow adjacent to a continuous moving vertical porous plate for incompressible micropolar fluid in the presence of heat generation/absorption and a first order chemical reaction. Rahman and AL-Lawatia[30] developed the problem by considering higher order of chemical reaction.

In all these investigation, the effect of thermal radiation on the flow and heat transfer have not been provided. The effects of radiation on MHD flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for design of reliable equipment, nuclear plants, gas turbines and various propulsion devices or aircraft, missiles, satellites and space vehicles. Satter and Hamid [1] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Makinde [20] examined the transient free convection interaction with thermal radiation of an absorbing emitting fluid along moving vertical permeable plate. Rahman and Satter [31] studied transient convective flow of micropolar fluid past a continuous moving porous plate in the presence of radiation. The effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction has been studied by Ibrahim et al. [15]. Rahman and Sultana [32] examined radiative heat flux with variable heat flux in a porous medium. Bakr [3] presented an analysis on MHD free convection and mass transfer adjacent to moving vertical plate for micropolar fluid in a rotating frame of reference in presence of heat generation/absorption and a chemical reaction. He has studied the effect of thermal radiation and chemical reaction on unsteady MHD free convection heat and mass transfer flow of a micropolar fluid past a vertical porous plate in a rotating frame of reference. It is assumed that the plate is embedded in a uniform porous medium and oscillates in time with a constant frequency in the presence of a transverse magnetic field. The governing equations are solved analytically using perturbation technique. Numerical results are reported for various values of the physical parameters of interest. Olajuwon et al [23] have studied unsteady free convection heat and mass transfer in a MHD micro polar fluid in the presence of thermo diffusion and thermal radiation. Olanrewaju et al [24] have studied effects of thermal radiation on magnetohydromynamic (MHD) flow of a micro polar fluid towards a stagnation point on a vertical plate.

Radhakrishnamachary [26] analyzed the flow of micropolar fluid through a constricted channel. Rees and Pop [34] discussed the free convection boundary layer flow of a micropolar fluid from a vertical flat plate. Recently Muthuraj and Srinivas [16] investigated fully developed MHD flow of a micropolar and viscous fluids in a vertical porous space using HAM. Kim [17] investigated the effects of heat and mass transfer in the MHD micropolar fluid flow past a vertical moving plate. The simultaneous effects of heat and mass transfer with chemical reaction are of great importance to engineers and scientists because of its occurrence in many branches of science and engineering. The effects of the chemical reaction and mass transfer on MHD unsteady free convection flow past an infinite/semi infinite vertical was analyzed by [2,6,11,22,33,34]. When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driven potential are important. It has been found that the energy flux can be generated not only by temperatures gradients but by composition gradient as well. The energy caused by a composition gradient is called the Duffer or the diffusion-thermo effect, the Dufor effect is neglected in this study because it is of a smaller order of magnitude than the volumetric heat generation effect which exerts a stronger effect on the energy flux generation. Also the mass fluxes can be created by the temperature gradients and this is called the Scoret or thermal diffusion effect.

Recently Satyanarayana et al [36] have investigated the effect of thermo-diffussion and joule heating on hydro magnetic convective heat and mass transfer flow of a micropolar fluid to a porous medium. Das [6] has studied the effect of first order chemical reaction in thermal radiation hydro magnetic free convective heat & mass transfer flow of a micropolar fluid bounded by the semi infinite porous plate with constant heat source in a rotating frame of reference.

In most of the cases, the Hall term is ignored by applying Ohm's law as it has no marked effect for small magnetic fields. However, to study the effects of strong magnetic fields on the electrically conducting fluid flow, we see that the influence of the electromagnetic force is noticeable and causes anisotropic electrical conductivity in the plasma. This anisotropy in the electrical conductivity of the plasma produces a current known as the Hall current. The Hall Effect is important when the magnetic field is strong or when the collision frequency is low, causing the Hall parameter to be significant. The effects of Hall current on the fluid flow in rotating channels have many engineering applications in flows of laboratory plasmas, in MHD power generation, in MHD accelerators, and in several astrophysical and geophysical situations. Thus, in a rotating system the effects of Hall current on MHD flow in parallel plate channels have been investigated by many researchers. The combined effect of free and forced convection on MHD flow in a rotating porous channel have been investigated by Prasad et al. [25]. Mandal and Mandal [19] have studied the effect of Hall current on MHD Couette flow between thick arbitrarily conducting plates in a rotating system. Hayat et al [12] discussed the boundary value problem for oscillating rotating flows of MHD oldroyd – B fluid in a porous space. Suneetha et al [13] have discussed the unsteady rotating MHD flow of an incompressible second grade fluid in a porous space. In this chapter we discuss hall effects on the unsteady rotating magneto hydro dynamics flow of an incompressible homogeneous second grade fluid through a porous half space.

In this paper, we investigate the effect of combined influence of Hall effect, chemical reaction thermo diffusion and rotation on hydro magnetic convective Heat and Mass transfer flow of a micro polar fluid through a porous medium bounded by a semi-infinite porous plate in the presence of heat generating sources. The dimensionless grouping equations for this investigation on solved using small perturbation approximation. The effects of various dimensionless parameters entering to the problem on the velocity & temperature concentration micro rotation profiles across the boundary layer are investigated to graphs. Also the result of the couple stress coefficient, the rate of heat and mass transfer at the wall are evaluated for different variations of the parameters.

Formulation and Solution of the Problem:

We consider the unsteady three dimensional flow of an incompressible, viscous, electrically conducting micropolar fluid past a semi-infinite vertical permeable moving plate subjected to a constant transverse magnetic field Bo in the presence of thermal and concentration buoyancy effects with chemical reaction and thermal radiation. It is assumed that there is no applied voltage which implies the absence of an electric field .The flow is assumed to be in the x-direction which is taken along the plate in the upward direction and z-direction is normal to it. Also it is assumed that the whole system is rotate with a constant frame Ω in a micropolar fluid about z-axis. The fluid is assumed to be gray, absorbing-emitting but not scattering medium. The radiation heat flux in x-direction is considered negligible in comparison that the z-direction. Due to the semi-infinite plate surface assumption, furthermore, the flow variables are functions z and time only.

When the strength of the magnetic field is very large we include the Hall current so that the generalized Ohm's law is modified to

$$\bar{J} + \omega_e \tau_e \bar{J} x \bar{H} = \sigma(\bar{E} + \mu_e \bar{q} x \bar{H}) \quad (1)$$

where q is the velocity vector. H is the magnetic field intensity vector. E is the electric field, J is the current density vector, ω_e is the cyclotron frequency, τ_e is the electron collision time,σ is the fluid conductivity and μ_e is the magnetic permeability. Neglecting the electron pressure gradient, ion-slip and thermo-electric effects and assuming the electric field E=0, equation (1) reduces

$$j_x - mH_0 J_y = -\sigma\mu_e H_0 w \quad (2)$$

$$J_y + mH_0 J_x = \sigma\mu_e H_0 u \quad (3)$$

where m=$\omega_e \tau_e$ is the Hall parameter.

On solving equations (2) &(3) we obtain

$$j_x = \frac{\sigma\mu_e H_0}{1+m^2 H_0^2}(mH_0 u - w) \quad (4)$$

$$j_y = \frac{\sigma\mu_e H_0}{1+m^2 H_0^2}(u + mH_0 w) \quad (5)$$

where u, w are the velocity components along x and z directions respectively,

The Momentum equations are

$$u_t - w_o(1-\varepsilon A e^{nt})u_z - 2\Omega v = (\nu+\nu_r)u_{yy} + \mu_e H_o J_y + \beta g(T-T_\infty) + \beta^{\bullet} g(C-C_\infty) - \nu_r \omega_{1,z} \quad (6)$$

$$v_t - w_o(1-\varepsilon A e^{nt})v_z + 2\Omega u = (\nu+\nu_r)v_{yy} - \mu_e H_o J_x + \nu_r \omega_{2,z} \quad (7)$$

Substituting Jx and Jy from equations (4) & (5)in equations (6)&(7) we obtain

$$u_t - w_o(1-\varepsilon A e^{nt})u_z - 2\Omega v = (\nu+\nu_r)u_{yy} + \frac{\sigma\mu^2{}_e H^2{}_0}{1+m^2 H_0^2}(u + mH_0 w)J_y + \beta g(T-T_\infty) + \beta^{\bullet} g(C-C_\infty) - \nu_r \omega_{2,z} \quad (8)$$

$$v_t - w_o(1-\varepsilon A e^{nt})v_z + 2\Omega u = (\nu+\nu_r)v_{yy} - \frac{\sigma\mu^2{}_e H^2{}_0}{1+m^2 H_0^2}(mH_0 u - w)J_x + \nu_r \omega_{1,z} \quad (9)$$

$$\frac{\partial\omega_1}{\partial t} - w_0(1+\varepsilon e^{nt})\frac{\partial\omega_1}{\partial z} = \frac{\mathrm{A}}{\rho j}\frac{\partial^2\omega_1}{\partial z^2} \quad (10)$$

$$\frac{\partial\omega_2}{\partial t} - w_0(1+\varepsilon e^{nt})\frac{\partial\omega_2}{\partial z} = \frac{\mathrm{A}}{\rho j}\frac{\partial^2\omega_2}{\partial z^2} \quad (11)$$

The energy equation is

$$\rho C_p\left(\frac{\partial T}{\partial t} - w_0(1+\varepsilon e^{nt})\frac{\partial T}{\partial z}\right) = k_f \frac{\partial^2 T}{\partial z^2} + Q(T_e - T) \quad (12)$$

The diffusion equation is

$$\left(\frac{\partial C}{\partial t} - w_o(1+\varepsilon e^{nt})\frac{\partial C}{\partial z}\right) = D_1\frac{\partial^2 C}{\partial z^2} - \gamma(C - C_e) + k_{11}\frac{\partial^2 T}{\partial z^2} \quad (13)$$

The equation of state is

$$\rho - \rho_0 = -\beta(T - T_o) - \beta^{\bullet}(C - C_o) \quad (14)$$

Where T,C are the temperature and concentration in the fluid. kf is the thermal conductivity, Cp is the specific heat constant pressure,D1 is molecular diffusivity, β is the coefficient of thermal expansion, $\beta^{\bullet}$ is the coefficient of volume expansion ,Q is the strength of the heat source and qr is the radiative heat flux.

The boundary conditions are

$$\left.\begin{array}{l} u = v = 0, \omega_1 = \omega_2 = 0, T = T_\infty, C = C_\infty \quad for\ t \le 0 \\ u = U_r(1+\varepsilon\exp(nt)), v = 0,, \omega_1 = -0.5\frac{\partial v}{\partial z}, \omega_2 = 0.5\frac{\partial u}{\partial z}, \\ T = T_w + \varepsilon(T_w - T_\infty)e^{nt}, C = C_w + \varepsilon(C_w - C_\infty)e^{nt}\ on\ z = 0 \\ u = v = 0, \omega_1 = 0, \omega_2 = 0, T = T_\infty, C = C_\infty\ as\ z \to \infty, t > 0 \end{array}\right| \quad (15)$$

On introducing the non-dimensional variables

$$\left.\begin{array}{l} z' = \frac{zU_r}{\nu}, t' = \frac{tU_r^2}{\nu}, u' = \frac{u}{U_r}, v' = \frac{v}{U_r}, n' = \frac{n\nu}{U_r^2}, \omega_1' = \frac{\omega_1\nu}{U_r^2}, \omega_2' = \frac{\omega_2\nu}{U_r^2}, \\ \theta = \frac{T - T_\infty}{T_w - T_\infty}, C' = \frac{C - C_\infty}{C_w - C_\infty} \end{array}\right| \quad (16)$$

the equations (2.8),(2.9),(2.11)&(2.12) reduces to

$$\left.\begin{array}{l} u_t - S(1+\varepsilon e^{nt})u_z - Rv = (1+\Delta)u_{yy} - \frac{M^2}{1+m^2}(u + mw) + \\ + G(\theta + NC) - \omega_{2,z} \end{array}\right| \quad (17)$$

$$v_t - S(1+\varepsilon e^{nt})v_z + Ru = (1+\Delta)v_{yy} + \frac{M^2}{1+m^2}(mu - w) + \omega_{1,z} \quad (18)$$

$$\frac{\partial\omega_1}{\partial t} - S(1+\varepsilon e^{nt})\frac{\partial\omega_1}{\partial z} = \lambda\frac{\partial^2\omega_1}{\partial z^2} \quad (19)$$

$$\frac{\partial\omega_2}{\partial t} - S(1+\varepsilon e^{nt})\frac{\partial\omega_2}{\partial z} = \lambda\frac{\partial^2\omega_2}{\partial z^2} \quad (20)$$

$$(\theta_t - S(1+\varepsilon e^{nt})\theta_z = \theta_{zz} - \alpha\theta \qquad (21)$$

$$(C_t - S(1+\varepsilon e^{nt})C_z = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - kr\,C + S_o\frac{\partial^2 T}{\partial z^2} \qquad (22)$$

where

$R = \dfrac{2\Omega\nu}{U_r^2}$ (Rotation parameter)

$M = \dfrac{B_0}{U_r}\sqrt{\sigma\nu/\rho}$ (Magnetic parameter)

$P_r = \dfrac{\mu C_p}{k_f}$ (Prandtl number)

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

$S_0 = \dfrac{k_{11}(T_w - T_\infty)}{D_1(C_w - C_\infty)}$ (Sore tparameter)

$G = \dfrac{\beta g\nu(T_w - T_\infty)}{U_r^3}$ (Grashof number)

$N = \dfrac{\beta^\bullet(C_w - C_\infty)}{\beta(T - T_\infty)}$ (Buoyancy ratio)

$S = \dfrac{w_o}{U_r}$ (Suction parameter)

$m = \omega_e t_e$ (Hall parameter)

$\alpha = \dfrac{Q\nu^2}{U_r^2}$ (Heat source parameter)

$kr = \dfrac{\gamma\nu^2}{U_r^2}$ (Chemical reaction parameter)

$\lambda = \dfrac{\Delta}{\mu j}$ (Micro rotation parameter)

$\Delta = \dfrac{\nu_r}{\nu}$ (Viscosity ratio parameter)

The transformed boundary conditions are

$$\left.\begin{array}{ll} u = v = 0, \omega_1 = \omega_2 = 0, \theta = 0, C = 0 & for\ t \le 0 \\ u = (1+\varepsilon\exp(nt)), v = 0, \omega_1 = -0.5\dfrac{\partial v}{\partial z}, \omega_2 = 0.5\dfrac{\partial u}{\partial z}, & \\ \theta = 1+\varepsilon e^{nt}, C = 1+\varepsilon e^{nt} & on\ z = 0 \\ u = v = 0, \omega_1 = 0, \omega_2 = 0, \theta = 0, C = 0 as\ \ z \to \infty, t > 0 & \end{array}\right| \qquad (23)$$

We now simplify the equations (17)-(20) by putting the fluid velocity and angular velocity in the complex form as

q=u+iv , ω=ω1+iω2

and we obtain

$$\left.\begin{array}{l} q_t - S(1+\varepsilon e^{nt})q_z + iRq = (1+\Delta)q_{yy} - \dfrac{M^2(1-im)}{1+m^2}q + i\omega_z \\ \qquad + G(\theta + NC) \end{array}\right| \qquad (24)$$

$$\frac{\partial\omega}{\partial t} - S(1+\varepsilon e^{nt})\frac{\partial\omega}{\partial z} = \lambda\frac{\partial^2\omega}{\partial z^2} \qquad (25)$$

$$(\theta_t - S(1+\varepsilon e^{nt})\theta_z = \theta_{zz} - \alpha\theta \qquad (26)$$

$$(C_t - S(1+\varepsilon e^{nt})C_z = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} + S_o\frac{\partial^2 T}{\partial z^2} \qquad (27)$$

The corresponding boundary conditions are

$$\left.\begin{array}{l} q = 0, \omega = 0, \theta = 0, C = 0\ for\quad t \le 0 \\ q = 1+\varepsilon e^{nt}, \omega = 0.5\dfrac{\partial q}{\partial z,}\ \ \theta = 1+\varepsilon e^{nt}, C = 1+\varepsilon e^{nt}\ \ at\ z = 0 \\ q = 0, \omega = 0, \theta = 0, C = 0\ \ as\ z \to \infty\quad for\ t > 0 \end{array}\right| \qquad (28)$$

Nusselt Number and Sherwood Number:

The rate of heat transfer (Nusselt Number) at z=0 is given by

$$Nu_{z=0} = \left(\frac{\partial\theta_0}{\partial z} + \varepsilon e^{nt}\frac{\partial\theta_1}{\partial z}\right)_{z=0}$$

$$= -m_1 + \varepsilon e^{nt}a_{20}$$

The rate of mass transfer (Sherwood Number) at z=0 is given by

$$Sh_{y=0} = \left(\frac{\partial C_0}{\partial z} + \varepsilon e^{nt}\frac{\partial C_1}{\partial z}\right)_{z=0} \quad \text{where}$$

$$= a_{21} + \varepsilon e^{nt}a_{22}$$

$a_1, a_2, \ldots, a_{24}$ are constants.

Discussion:

In this analysis we discuss the effect of Hall currents, thermo-diffusion and chemical reaction effects on the mixed convective heat and mass transfer flow of a micropolarfluid past a vertical porous flat. The axial velocity (u) is exhibited in 1-6 for different values of M, m, So, K, R, λ and Δ.

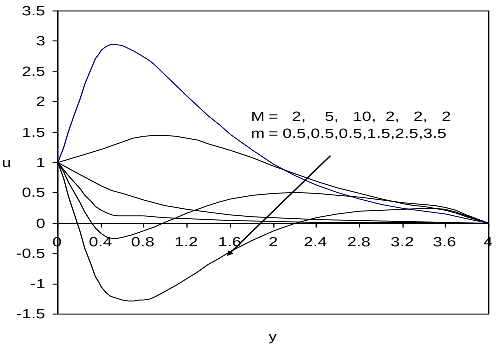

Fig. 1 : Variation of u with M & m
$G=10^3$, N=1, Sc=1.3, S_0=0.5 S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

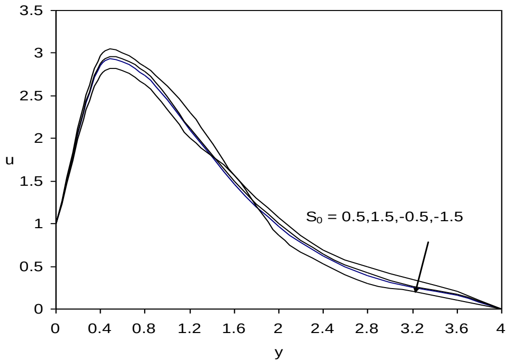

Fig. 2 : Variation of u with S_0
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

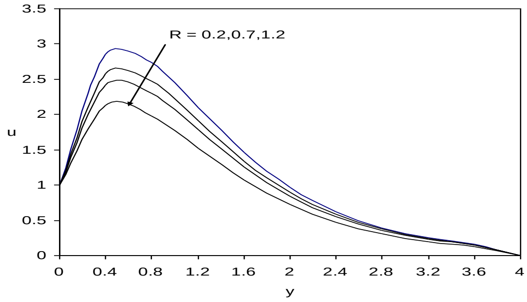

Fig. 3 : Variation of u with R
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5
S=0.1, α = 2, K=0.5, λ = 0.2, Δ = 0.1

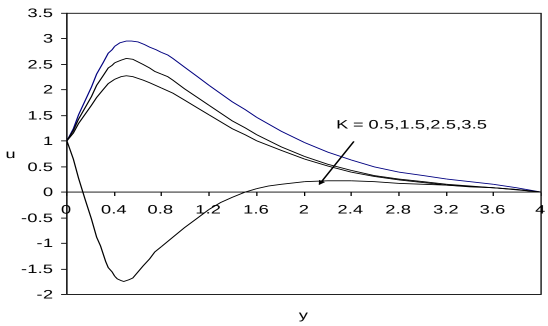

Fig. 4 : Variation of u with K
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5 S=0.1
α = 2, R=0.2, λ = 0.2, Δ = 0.1

Fig. 1 represents 'u' with Hartman number M and Hall parameter 'm'. It can be seen from the graph that u depreciates with increase in 'M' and 'm'. 'u' changes its sign from vertically downwards to vertically upwards for 'm' ≥2.5 in the vicinity of the leading edge and this region of transition enlarges with higher m. An increase in the Soret parameter |So| enhances 'u' in the flow region (fig. 2). An increase in the rotation parameter R reduces |u| in the flow suction (fig.3). The effect of chemical reaction parameter K on 'u' is depected in fig.4. It can be seen from the profiles that the axial velocity reduces in the degenerating chemical reaction case. Fig. 5 represents u with microrotation parameter λ. It is found that higher the micro rotation λ larger the axial velocity. The effective of viscosity ratio parameter Δ on 'u' is shown in fig. 6. It is noticed that from the profiles that he axial velocity enhances with increase in Δ≤0.7 and for higher Δ≥ 0.9, |u| enhances in the region (0.0, 0.8) and depreciates far away from the boundary.

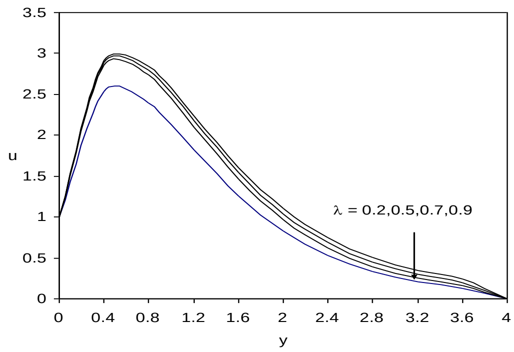

Fig.5 : Variation of u with λ
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5
S=0.1, α = 2, R=0.2, K=0.5, Δ = 0.1

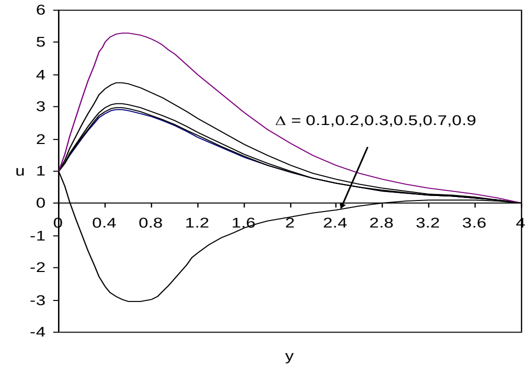

Fig. 6 : Variation of u with Δ
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5
S=0.1, α = 2, R=0.2, K=0.5, λ = 0.2

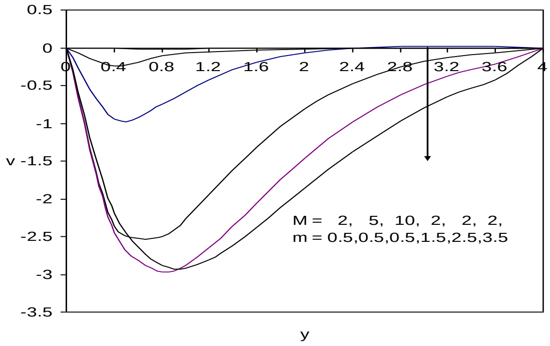

Fig. 7 : Variation of v with M & m
$G=10^3$, N=1, Sc=1.3, S_0=0.5 S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

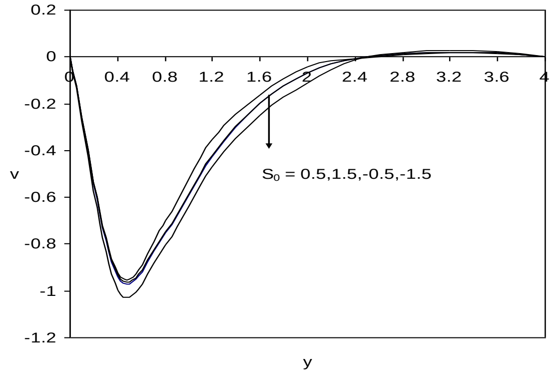

Fig. 8 : Variation of v with S_0
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

The secondary velocity (v) is shown in figs. 7-12 for different parametric values. Fig.7 represents v with M and 'm'. Higher the Lorentz force smaller the secondary velocity in the flow region. The variation of 'u' with Hall parameter 'm' shows that |v| enhances with increase in m≤2.5 and depreciates with higher m≥3.5. An increase in the Soret parameter So>0 enhances |v| and depreciates with |So| (<0) (fig. 8). An increase in the rotation parameter R ≤ 0.7 enhances |v| and for higher R ≥ 1.2, |v| enhances except in the viciniity of the plate (fig. 9). Fig. 10 represents v with chemical reaction parameter K. It can be seen from the profiles that |v| experiences an enhancement in the degenerating chemical reaction case. An increase in the microrotation parameter λ ≤ 0.7 leads to a depreciation in |v| and for higher $\lambda \geq 0.8$, |v| depreciates in the region (0.4,1.6) and enhances far away from the wall (fig.11). From fig. 12 we find that |v| depreciates with increase in $\Delta \leq 0.1$ and for higher $\Delta \geq 0.3$, we notice an enhancement in |v| in the entire flow region.

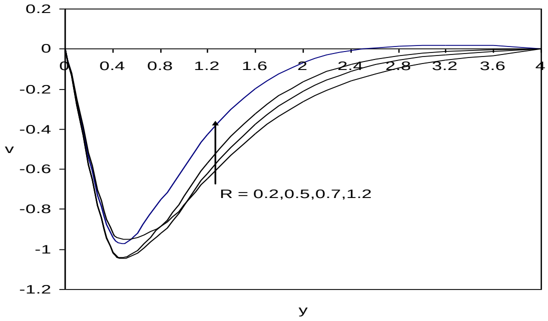

Fig. 9 : Variation of v with R
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5
S=0.1, α = 2, K=0.5, λ = 0.2, Δ = 0.1

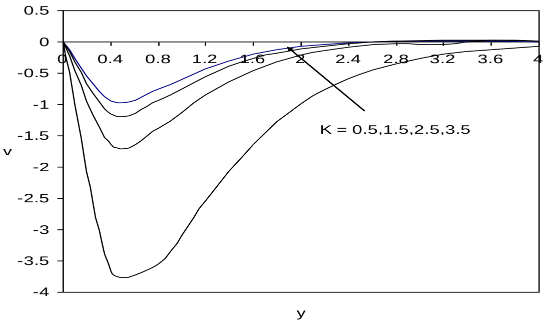

Fig. 10 : Variation of v with K
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5 S=0.1
α = 2, R=0.2, λ = 0.2, Δ = 0.1

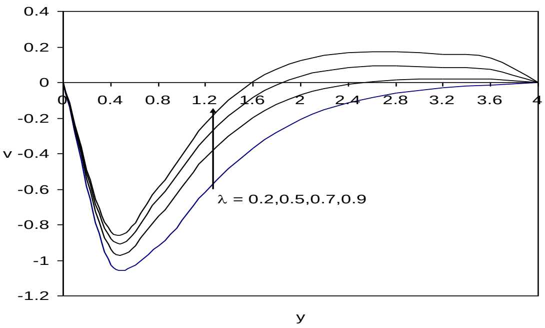

Fig. 11 : Variation of v with λ
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5,
S=0.1α = 2, R=0.2, K=0.5, Δ = 0.1

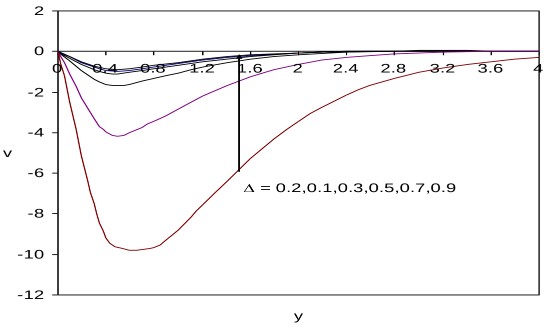

Fig. 12 : Variation of v with Δ
$G=10^3$, M = 2, m = 0.5, N=1, Sc=1.3, S_0=0.5
S=0.1, α = 2, R=0.2, K=0.5, λ = 0.2

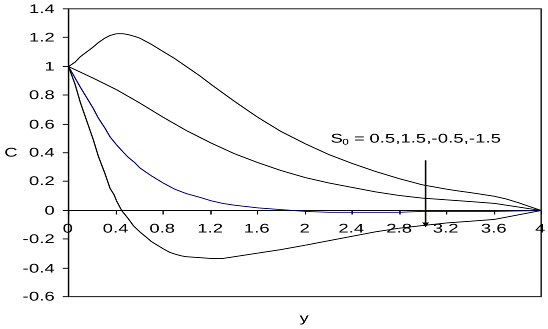

Fig. 13 : Variation of C with S_0
N=1, Sc=1.3, S=0.1, α = 2, K=0.5

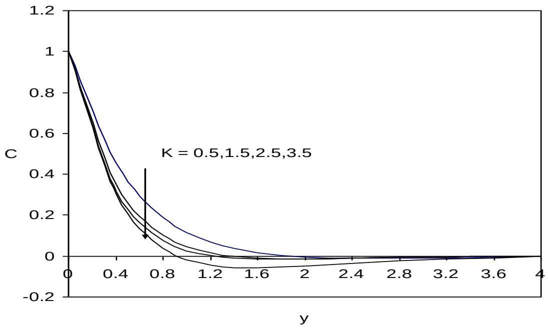

Fig. 14 : Variation of C with K
N=1, S_0=0.5, Sc=1.3, S=0.1, α = 2

The concentration distribution (C) is shown in figs 13-14 for different parametric values. We follow the convention that the non-dimensional concentration is positive or negative according as the actual concentration is greater / lesser than T_∞. The actual concentration depreciates with increase in So > 0 and enhances with |So|(<0) (fig. 13). Fig.14 represents C with chemical reaction parameter K. It is observed that the actual concentration reduces with increase in $K \leq 1.5$, enhances with higher $K \geq 2.5$ and still higher K=3.5, it depreciates in the region (0.4, 0.8) and reduces far away from the boundary.

The micro rotation distribution (ω) is shown in figs. 15-16 for different parametric values. The microrotation experiences an enhancement with increase in the Hall parameter (m) (fig. 15). It can be seen that the micro rotation enhances with So > 0 and reduces with |So| (<0)(fig.16).

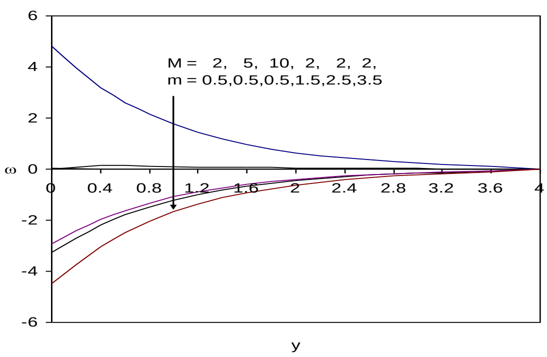

Fig. 15 : Variation of ω with M & m
$G=10^3$, N=1, Sc=1.3, S_0=0.5 S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

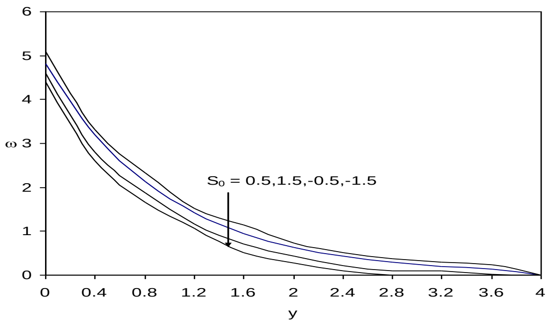

Fig. 16 : Variation of ω with S_0
$G=10^3$, M = 2, m = 0.5, N=1, S=0.1
α = 2, R=0.2, K=0.5, λ = 0.2, Δ = 0.1

The rate of heat transfer (Nusselt number) at y=0 is shown in table 1 for different parametric values. The rate of heat transfer depreciates with G>0 and enhances with G<0. An increase in m results in a depreciation in |Nu|. The variation of Nu with Soret parameter So shows that |Nu| reduces with So >0 and enhances with |So|(<0) for G>0 and for G<0, it enhances with So>0 and reduces with |So| (<0). The rate of heat transfer enhances for G>0 and reduces for G<0 with increase in K≤1.5 and for higher K≥2.5, we notice that the porosity of the boundary enhances the rate of heat transfer at y=0. An increase in the rotation parameter R enhances |Nu| for G>0 and reduces for G<0. An increase in Δ enhances |Nu| in the heating case and reduces in the cooling case (table.1).

The rate of mass transfer (Sherwood number) at y=0 is shown in table 2 for different values of So and K. It is found that an increase in α enhances the rate of mass transfer. With respect to So we find that |Sh| enhances with increase in |So|. An increase in chemical reaction parameter K leads to an enhancement in |Sh|. (table.2)

The couple stress coefficient (C,ω) at y=0 is exhibited in table 3 for different parametric values. It is found that | C,ω | enhances with increase in |G|. Higher the Lorantz force larger |Cω| for G>0 and smaller for G<0. An increase in the Hall parameter m≤2.5 depreciates |Cω| and enhances with higher m≥3.5. It enhances with So>0 and reduces with |So| (<0). An increase in K≤2.5 reduces |Cω| and for higher K≥3.5, it enhances at y=0. Higher the porosity of the wall larger |Cω| at y=0. We find that |Cω| reduces with rotation parameter R /micro- rotation parameter λ and enhances with viscosity ratio parameter Δ.

Table: 1. Nusselt Number (Nu) at y = +1

G	I	II	III	IV	V	VI	VII	VIII	IX	X
10^2	-3.08873	-1.52702	-1.45484	-1.5992	-1.67138	-1.58959	-1.57285	-1.52762	-1.53218	-1.53491
$2x10^2$	-1.45831	-1.45831	-1.32068	-1.59595	-1.73358	-1.57777	-1.54581	-1.45948	-1.4681	-1.47329
-10^2	-1.66443	-1.66443	-1.72316	-1.6057	-1.54697	-1.61324	-1.62695	-1.6639	-1.66033	-1.65815
$-2x10^2$	-1.73313	-1.73313	-1.85732	-1.60895	-1.48476	-1.62507	-1.654	-1.73204	-1.7244	-1.71976
m	0.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
S_0	0.5	0.5	1.5	-0.5	-1.5	0.5	0.5	0.5	0.5	0.5
K	0.5	0.5	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
R	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.2
Δ	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.7

Table: 2. Sherwood Number (Sh) at y = +1

α	I	II	III	IV	V	VI
2	-0.93065	-3.58235	-0.26318	1.3964	-267281	-2.50265
4	-0.9964	-4.65248	0.09353	2.4665	-2.58892	-2.78963
6	-1.04782	-5.49776	0.37529	3.3118	-2.85323	-3.09142
So	0.5	1.5	-0.5	-1.5	0.5	0.5
K	0.5	0.5	0.5	0.5	1.5	2.5

Table: 3. Couple Stress (Cw) at y = +1

G	I	II	III	IV	V	VI	VII	VIII	IX	X
10^2	-5.999	-1.23603	-7.27288	-4.72565	-3.45204	-4.27389	-3.68983	-5.999	-5.33257	-7.5578
$2x10^2$	-13.06	-3.29668	-15.49244	-10.63141	-8.20089	-9.71168	-8.51659	-13.06	-11.71774	-16.19442
-10^2	8.126	2.88529	9.16624	7.08585	6.04566	6.60171	5.96368	8.126	7.43777	9.71543
$-2x10^2$	15.189	4.94594	17.38579	12.99161	10.79451	12.03951	10.79044	15.189	13.82294	18.35205
m	0.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
S_0	0.5	0.5	1.5	-0.5	-1.5	0.5	0.5	0.5	0.5	0.5
K	0.5	0.5	0.5	0.5	0.5	1.5	2.5	0.5	0.5	0.5
R	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.2
Δ	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.7

Conclusions:

- Higher the micro rotation λ larger the axial velocity
- An increase in the microrotation parameter $\lambda \leq 0.7$ leads to a depreciation in |v| and for higher $\lambda \geq 0.8$, |v| depreciates in the region (0.4,1.6) and enhances far away from the wall
- The actual concentration reduces with increase in $K \leq 1.5$, enhances with higher $K \geq 2.5$ and still higher K=3.5, it depreciates in the region (0.4, 0.8) and reduces far away from the boundary.
- The rate of heat transfer enhances for G>0 and reduces for G<0 with increase in $K \leq 1.5$ and for higher $K \geq 2.5$, we notice that the porosity of the boundary enhances the rate of heat transfer at y=0.
- An increase in chemical reaction parameter K leads to an enhancement in |Sh|.
- An increase in $K \leq 2.5$ reduces |Cω| and for higher $K \geq 3.5$, it enhances at y=0

References:

1. Abdus Sattar MD. Kalim MD.Hamid, Unsteady free-convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate, J. Math. Phys. Sci. 30 ,pp25–37(1996)
2. Anjalidevi S.P., Kandasamy R., Effects of chemical reaction heat and mass transfer on laminar flow along a semi-infinite horizontal plate, Heat Mass Transfer , 35 ,465-467 (1999)
3. Bakr A.A., Effects of chemical reaction on MHD free convection and mass transfer flow of a micropolar fluid with oscillatory plate velocity and constant heat source in a rotating frame of reference, Commun. Nonlinear Sci. Numer. Simul. 16 ,pp698–710(2011).
4. Bhargava R., Takhar H.S.,Numerical study of heat transfer characteristics of the micropolar boundary layer near a sagnation points on a moving wall,int.J.Eng.Sci.38,383-394(2000).
5. Damseh R.A. , AL-Odat M.Q. , Chamkha A.J., Benbella Shannak A. , Combined effect of heat generation or absorption and first order chemical reaction on micropolar fluid flows over a uniform stretched permeable surface, Int. J. Thermal Sci. 48,1658–1663(2009).
6. Das K et al.,Effect of chemical reaction and thermal radiation on heat and mass transfer flow of MHD micropolar fluid in a rotating frame of reference,Vol.54(2011)
7. Das, U.N. Deka R.K, soundalgekar, V.M. Effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction, Forsch, Ingenieurwes. 60,pp284-287(1994).
8. Deka R, Das U.N.,V.M.Soundalgekar,Effects of mass transfer flow past an impulsively started infinite vertical plate with constant heat flux and chemical vertical plate,Forch.Ingenieurwes.60,284-287(1994)
9. Eringe A.C.n,Theory of micropolar fluids,J.Math.Mech.16,pp1-18(1964)
10. Eringen A.C,Theory of thermomicro fluids,J.Math.Anal.Appl.,Vol.38,pp.480-496.(1972)
11. Gireesh Kumar. J. , Satya Narayana P.V. and.Ramakrishna S, Effects of the chemical reaction and mass transfer on MHD unsteady free convection flow past an infinite vertical plate with constant suction and heat sink, Ultra science,21,pp639-650(2009).
12. Hayat T.,Fetecau,Sajid,Analytical solution for MHD transient rotating flow of a second grade fluid in a porous space,Non linear mech.Volu.9,pp 1619-1627.(2008)
13. Hayat. T., Khan S.B. and.Khan M ,The influence of Hall current on the rotating oscillating flows of a fluid in a porous medium, Nonlinear dynamics,Vol.47,pp.353-362(2007)
14. Hossain M.A. , Takhar H.S. , Radiation effect on mixed convection along a vertical plate with uniform surface temperature, Heat MassTransfer 31 pp243–248(1996).
15. Ibrahim F.S. Elaiw A.M. , Bakr, A.A. Influence of viscous dissipation and radiation on unsteady MHD mixed convection flow of micropolar fluids, Appl. Math. Inf. Sci. 2 pp143–162(2008).
16. Kim Y.J. vertical moving plate in a porous medium , TransPorous Media,56, pp.17–37(2004).
17. Kim, Heat and mass transfer in MHD micropolar flow over a R.Muthuraj , S.Srinivas, Fully developed MHD flow of a micropolar and viscous fluids in a vertical porous space using HAM , Int. J. of Appl. Math and Mech. 6 ,pp 55-78(2010).
18. Lukaszewicz A.C, Micropolar fluids-theory and applications. Boston: Birkhauser (1999).
19. Makinde O.D., Free convection flow with thermal radiation and mass transfer past a moving vertical porous plate, Int. Commun. Heat Mass Transfer 32,1411–1419(2005).
20. Mandal G. and Mandal K. K, "Effect of Hall Current on MHD Couette Flow between Thick Arbitrarily Conduc-ting Plates in a Rotating System", Journal of the Physical Society of Japan, Vol. 52, No. 2, pp. 470-477(1983).
21. Muthu. P, Rathish Kumar B.V. , Peeyush Chandra, Peristaltic motion of micropolar fluid in circular cylindrical tubes: Effect of wall properties, Applied Mathematical Modelling, 32,pp 2019-2033 (2008)
22. Muthucumaraswamy R., Ganesan, P. First order chemical reaction on flow past an impulsively started vertical plate with uniform heat and mass flux, Acta Mechanica, 147 pp1-13(2001).
23. Olajuwon B.L., Oahimire J.I., : Unsteady free convection Hea nad Mass transfer in a MHD micropolar fluid in the presence of thermo diffusion and thermal radiation. International Journal of Pure and Applied Mathematics, Vol.(84), No.2, (2013).
24. Olanrewaju, P.O., Okedayo, G.T., Gbadeyan, J.A., : Effects of thermal radiation on magneto hydro dynamic (MHD) flow of a micro polar fluid towards a stagnation point on a vertical place, Int.J. of App.Sci. and Tech., Vol.1, No.6, (2011)
25. Prasad Rao, D. R. V. Krishn D. V. and Debnath L. , "Combined Effect of Free and Forced Convection on MHD Flow in a Rotating Porous Channe," International Journal of Mathematics and Mathematical Sciences, Vol.5, No. 1, pp. 165-182(1982).
26. Radhakrishnamacharya G. , Flow of Micropolar Fluid through a Constricted Channel, Int. J. Engg. Sci.15 ,179-185(1977).
27. Rahman M.M , Rahman M.A. Samad M.A., Alam M.S., Heat transfer in micropolar fluid along a non-linear stretching sheet with temperature dependent viscosity and variable surface temperature, Int. J. Thermophys. 30 ,pp1649–1670. (2009)

28. Rahman M.M, Aziz A, Al-Lawatia M. , Heat transfer in micropolar fluid along an inclined permeable plate with variable fluid properties, Int J. Ther Sci. 49, pp993–1002(2010).
29. Rahman M.M. , Al-Lawatia M. , Effects of higher order chemical reaction on micropolar fluid flow on a power law permeable stretched sheet with variable concentration in a porous medium, Can.J.Chem.Eng.88, pp23–32(2010).
30. Rahman M.M. , Convective flows of micropolar fluids from radiate isothermal porous surfaces with viscous dissipation and Joule heating, Commun. Nonlinear Sci. Numer. Simul. 14 , pp3018–3030(2009).
31. Rahman M.M. , Sattar, M.A. Transient convective flow of micropolar fluid past a continuously moving vertical porous plate in the presence of radiation, Int. J.Appl. Mech. Eng. 12 ,pp 497–513(2007).
32. Rahman M.M. , Uddin M.J., Aziz A., Effects of variable electric conductivity and non-uniform heat source (or sink) on convective micropolar fluid flow along an inclined flat plate with surface heat flux, Int. J. Ther Sci. 48, 2331–2340 (2009)
33. Ramireddy G., Satya Narayana P.V.,.Venkataramana S, Peristaltic transport of a conducting fluid in an inclined asymmetric channel, Applied Mathematical Sciences, 4 pp.1729-1741(2010).
34. Rees D.and Pop I., Free convection boundary-layer flow of a micropolar fluid from a vertical flat plate, IMA Journal of Applied Mathematics, 61,pp179-197(1998).
35. Satya Narayana P.V and Sravanthi, C.S.Simultaneous effects of Soret and Ohmic heating on MHD free convective heat and mass transfer flow of micropolar fluid with porous medium,Vol.48,pp.9379-9386(2012)
36. Satya Narayana P.V., Kesavaiah D.Ch. and Venkataramana S., Viscous dissipation and thermal radiation effects on an unsteady MHD convection flow past a semi- infinite vertical permeable moving porous plate, International Journal of Mathematical Archive, 2(4) 476-487(2011).