Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2013
(ICMERE2013) 1 – 3 May 2014, Chittagong, Bangladesh

ICMERE2013-PI-252

HEAT AND MASS TRANSFER IN MHD FREE CONVECTION FLOW OVER AN INCLINED STRETCHING PLATE WITH HALL CURRENT

Mohammad Ali [1,*], Mohammad Shah Alam [2], Ashutose Saha [3], Md. Abdul Alim[4] and S M Humayun Kabir[5]

[1-3] Department of Mathematics,
Chittagong University of Engineering and Technology (CUET), Chittagong-4349, Bangladesh.
[4]Department of Mathematics,
Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh.
[5]Department of Mechanical Engineering,
Chittagong University of Engineering and Technology (CUET), Chittagong-4349, Bangladesh.

[1,*]ali.mehidi93@gmail.com, [2]Shahalammaths@gmail.com, [3]asha61@yahoo.com,
[4]maalim@math.buet.ac.bd, [5]dalimuou@yahoo.com.

Abstract*- The present paper is an investigation of heat and mass transfer of a steady flow of an incompressible electrically conducting fluid over an inclined stretching plate under the influence of an applied uniform magnetic field. The effects of Hall current are taken into account in this study where the flow is generated due to a linear stretching plate. Using suitable similarity transformations the governing equations of the problem are reduced to couple nonlinear ordinary differential equations and are solved numerically by Runge- Kutta fourth-fifth order method using symbolic software MATLAB. The numerical results concerned with the effects of various parameters of the flow fields on the velocity, secondary velocity temperature, and concentration profiles are investigated and presented graphically. The results have possible technological applications in liquid-based systems involving stretchable materials.*

Keywords: MHD, Heat and mass transfer, Inclined Stretching plate, Chemical reaction, Hall current.

1. INTRODUCTION

The study of boundary layer flow and mass and heat transfer over an inclined stretching plate has generated much interest in recent years in view of its significant applications in industrial manufacturing processes such as glass-fiber, aerodynamic extrusion of plastic sheets, cooling of metallic sheets in a cooling bath, which would be in the form of an electrolyte and polymer sheet extruded continuously from a die are few practical applications of moving surfaces. Glass blowing, continuous casting, paper production, hot rolling, wire drawing, drawing of plastic films, metal and polymer extrusion, metal spinning and spinning of fibers also involve the flow due to stretching surface. During its manufacturing process a stretched sheet interacts with the ambient fluid thermally and mechanically. Both the kinematics of stretching and the simultaneous heating or cooling during such processes has a decisive influence on the quality of the final products [1]. In recent years, MHD flow problems have become more important industrially. Indeed, MHD laminar boundary layer behavior over a stretching surface is a significant type of flow having considerable practical applications in chemical engineering, electrochemistry and polymer processing. In the extrusion of a polymer sheet from a die, the sheet is sometimes stretched. By drawing such a sheet in a viscous fluid, the rate of cooling can be controlled and the final product of the desired characteristics can be achieved. This problem has also an important bearing on metallurgy where magnetohydrodynamic (MHD) techniques have recently been used. Crane [2] first introduced the study of steady two-dimensional boundary layer flow caused by a stretching sheet whose velocity varies linearly with the distance from a fixed point in the sheet. Later on several researchers: Gupta and Gupta [3], Rajagopal et al. [4], Siddapa and Abel [5], Chen and Char [6], Laha et al. [7], Vajravelu and Nayfeh [8], Sonth et al. [9], and Tan et al. [10] studied various aspects of this problem, such as the heat, mass and momentum transfer in viscous flows with or without suction or blowing. The influence of a uniform transverse magnetic field on the motion of an electrically conducting fluid past a stretching sheet was investigated by Pavlov [11], Chakraborty and Gupta [12], Kumari et al. [13], Andersson [14], Andersson et al. [15], and Char [16]. The effect of chemical reaction on free-convective flow and mass transfer of a viscous, incompressible and electrically conducting fluid over a stretching sheet was investigated by Afify [17] in the presence of transverse magnetic field. Cortell [18] studied the magneto hydrodynamics flow of a power-law fluid over a stretching sheet. Abel and Mahesh [19] presented an analytical and numerical solution for heat transfer in a steady laminar flow of an incompressible viscoelastic fluid over a stretching sheet with power-law surface temperature, including the effects of variable thermal conductivity and non-uniform heat source and radiation. Samad and Mohebujjaman [20] investigated the case along a vertical stretching sheet in presence of magnetic field and heat generation. Jhankal and Kumar [21] studied MHD boundary layer flow past a stretching plate with heat transfer. As many natural phenomena and engineering problems are worth being subjected to MHD analysis, the effect of transverse magnetic field on the laminar flow over a stretching surface was studied by a number of researchers [22-23]. Singh [16] studied heat and mass transfer in MHD boundary layer flow past an Inclined Plate with Viscous Dissipation in Porous Medium. Hall effects on MHD boundary layer flow over a continuous semi-infinite flat plate moving with a uniform velocity in its own plane in an incompressible viscous and electrically conducting fluid in the presence of a uniform transverse magnetic field were investigated by Watanabe and Pop [24]. Aboeldahab and Elbarbary [25] studied the Hall current effects on MHD free-convection flow past a semi-infinite vertical plate with mass transfer. The effect of Hall current on the steady magnetohydrodynamics flow of an electrically conducting, incompressible Burger's fluid between two parallel electrically insulating infinite planes was studied by Rana et al. [26]. Since the study of heat and mass transfer is important in some cases, in the present paper we studied the Hall effects on the steady MHD free-convective flow and mass transfer over an inclined stretching sheet in the presence of a uniform magnetic field. The boundary layer equations are transformed by a similarity transformation into a system of coupled non-linear ordinary differential equations and which are solved numerically by shooting iteration technique along with Runge- Kutta fourth-fifth order method. Numerical calculations were performed for various values of the magnetic parameter, Hall parameter and the relative effect of chemical diffusion on thermal diffusion parameters. The results are discussed from the physical point of view. Such a study is also applicable to the elongation to the bubbles and in bioengineering where the flexible surfaces of the biological conduits, cells and membranes in living systems are typically lined or surrounded with fluids which are electrically conducting (e.g., blood) and being stretched constantly.

2. MATHEMATICAL FORMULATION OF THE PROBLEM

Consider a two dimensional steady laminar MHD viscous incompressible electrically conducting fluid along an inclined stretching plate with an acute angle γ. X direction is taken along the leading edge of the inclined stretching plate and y is normal to it and extends parallel to x-axis. A magnetic field of strength B_0 is introduced to the normal to the direction to the flow. The uniform plate temperature T_w ($>T_\infty$), where T_∞ is the temperature of the fluid far away from the plate. Let u, v and w be the velocity components along the x and y axis and secondary velocity component along the z axis respectively in the boundary layer region. The sketch of the physical configuration and coordinate system are shown in Fig.1.

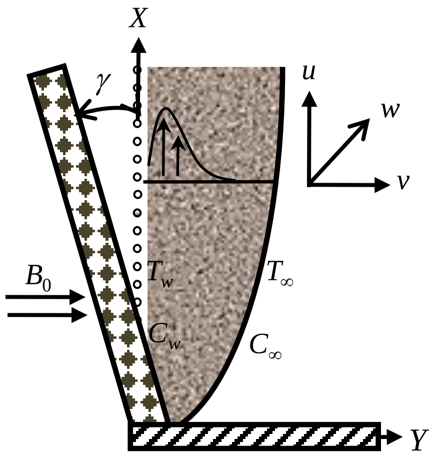

Fig.1 Physical configuration and coordinate system.

Under the above assumptions and usual boundary layer approximation, the dimensional governing equations of continuity, momentum, concentration and energy under the influence of externally imposed magnetic field are:

Equation of continuity: $$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \quad (1)$$

Momentum equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)\cos\gamma+ g\beta^*(C-C_\infty)\cos\gamma-\frac{\sigma B_0^2\mu_e}{\rho(1+m^2)}(u+mw) \quad (2)$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}=\nu\frac{\partial^2 w}{\partial y^2}+\frac{\sigma B_0^2\mu_e}{\rho(1+m^2)}(mu - w) \quad (3)$$

Energy Equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{c_p}\left[\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}\right)^2\right] \quad (4)$$

Concentration Equation:

$$u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D\frac{\partial^2 c}{\partial y^2}-K_0(C-C_\infty)^n \quad (5)$$

Boundary conditions are:

$$u=bx,\ v=w=0, T=T_w, C=C_w \quad \text{at} \quad y=0$$
$$u=0, w=0, T=T_\infty, C=C_\infty \quad \text{as} \quad y\to\infty$$

To convert the governing equations into a set of similarity equations, we introduce the following transformation:

$$u = bxf'(\eta), v = -\sqrt{b\nu}f(\eta), w = bxg_0(\eta), \eta = y\sqrt{\frac{b}{\nu}},$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

From the above transformations, the non-dimensional, nonlinear and coupled ordinary differential equations are obtained as

$$f''' + ff'' - f'^2 + G_r\theta\cos\gamma + G_c\varphi\cos\gamma - \frac{M}{1+m^2}\left(f' + mg_0\right) = 0 \quad (6)$$

$$g_0'' + fg_0' - \left(f' + \frac{M}{1+m^2}\right)g_0 + \frac{Mm}{1+m^2}f' = 0 \quad (7)$$

$$\theta'' + P_r f\theta' + P_r E_c\left(f''^2 + g_0'^2\right) = 0 \quad (8)$$

$$\varphi'' + S_c f\varphi' - S_c\zeta\varphi^n = 0 \quad (9)$$

Where the notation primes denote differentiation with respect to η and the parameters are defined as

$$G_r = \frac{g\beta(T_w - T_\infty)}{b^2 x}, P_r = \frac{\mu}{\alpha}, M = \frac{\sigma B_0^2}{\rho b},$$

$$E_c = \frac{c_p b^2 x^2}{\nu^2(T_w - T_\infty)}, \zeta = \frac{K_0(C_w - C_\infty)^{n-1}}{b},$$

$$g_c = \frac{g\beta^*(C_w - C_\infty)}{b^2 x}, S_c - \frac{\nu}{D_m}, \alpha = \frac{K}{\rho c_p}$$

The transform boundary conditions:

$$f = 0, f' = 1, g = 0, \theta = \varphi = 1 \quad \text{at } \eta = 0$$

$$f = f' = g = \theta = \varphi = 0 \quad \text{as } \eta \to \infty$$

3. RESULTS AND DISCUSSION

The system of ordinary differential equations (6)-(9) subject to the boundary conditions is solved numerically by shooting iteration technique along with Runge- Kutta fourth-fifth order method using symbolic software. We have formulated the effect of Hall Parameter (m), Magnetic parameter (M), Prandtle number (P_r), Eckert number (E_c), Scmidt number (S_c), Grashof number (G_r) and reaction parameter (ξ) of an incompressible fluid over an inclined stretching plate. The numerical calculation for the distribution of primary velocity, secondary velocity, temperature and concentration across the boundary layer for different values of the parameters are carried out. For the purpose of our computation, we have chosen the various values of parameters. Fig.2-Fig.9 depicts the variation of velocity profiles for different values of various parameters. From the Fig.2 it is seen that the velocity starts from minimum value at the surface and increase till it attain peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is more prominent at the point of peak value, because the presence of M in an electrically conducting fluid introduces a force called Lorentz force which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. Thus we conclude that M be used to control the flow characteristic. From Fig.7 it is observed that the secondary velocity increase with an increase in the M. From Fig.5 it is seen that as G_r increases the velocity field decreases. This cause the velocity buoyancy effects to decreases yielding a reduction in the fluid velocity. The reductions and the velocity profiles are accompanied by simultaneous reductions in the velocity boundary layers. From Fig. 6 the velocity decreases as the increase in E_c. From Fig. 3 the velocity increases as the increase in m but from Fig. 8 it is observed that an increasing in Hall parameter leads to decrease in secondary velocity profiles. This is due to the facts that the effective conductivity increases with the increase in Hall parameter which raises the magnetic damping force hence decreasing the velocity. From Fig.4 it is observed that in the neighborhood of the plate the primary velocity decrease and far away from the plate the velocity increase for the inclination of the plate but Fig.9 indicates that the secondary velocity increases as increase of inclination of the plate. Fig.10 shows that temperature increase for increasing values of M because of decreasing heat flux. As results boundary layer thickness increases. Similar trend is observed in Fig.11 for increasing values of m because of excess heating consequently decreases heat flux. As a result boundary layer thickness increases in the case of fluid withdrawing as well as for fluid injecting. Therefore m and M can be used to control heat transfer characteristic. From Fig.12 and Fig. 14 it is seen that temperature decrease for increasing values of E_c and γ. Fig.13 illustrates the temperature profiles for various values of P_r. It is observed that the temperature decrease as an increasing the P_r. the reason is that smaller values of P_r are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of P_r. Hence in the case of smaller P_r the thermal boundary layer is thicker and the rate of heat transfer is reduced. Fig.15 – Fig.18 display the effect of M, m, γ and ξ respectively. For various values of M, m, γ and ξ concentration profile decrease but the variation of concentration is negligible for M and m. In Fig.19 it is observed that concentration profile decrease for increasing values of mass diffusion parameter S_c because increasing in S_c decreases molecular diffusivity which results a decrease of the concentration boundary layer. Hence the concentration of the species is lower for large values of S_c.

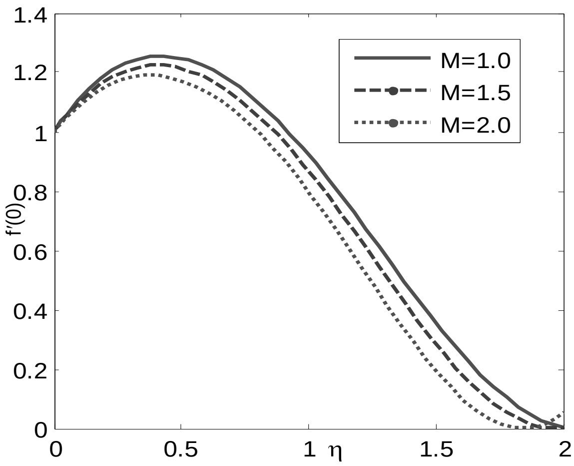

Fig. 2. Velocity profile for various values of M and m=1.0, $\gamma = 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, ξ=0.5, E_c=2.0, n=2

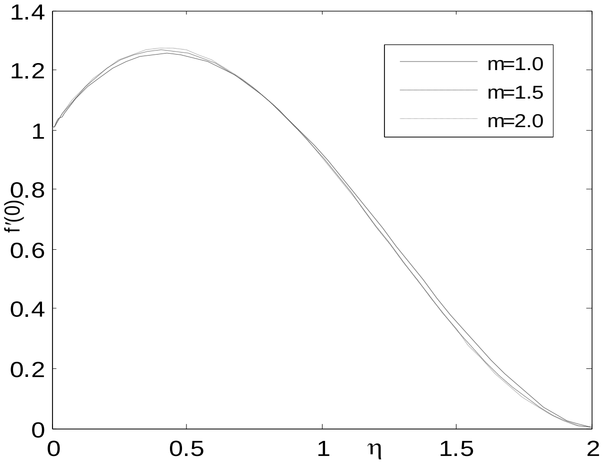

Fig. 3. Velocity profile for various values of m and M=1.0, $\gamma = 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, ξ=0.5, E_c=2.0, n=2

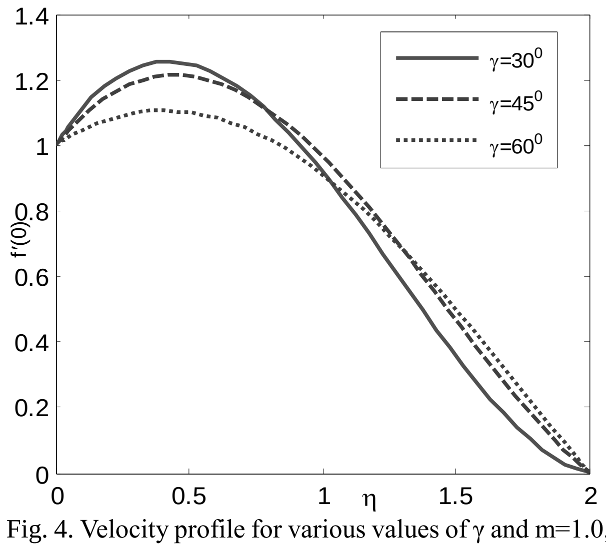

Fig. 4. Velocity profile for various values of γ and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, ξ=0.5, E_c=2.0, n=2

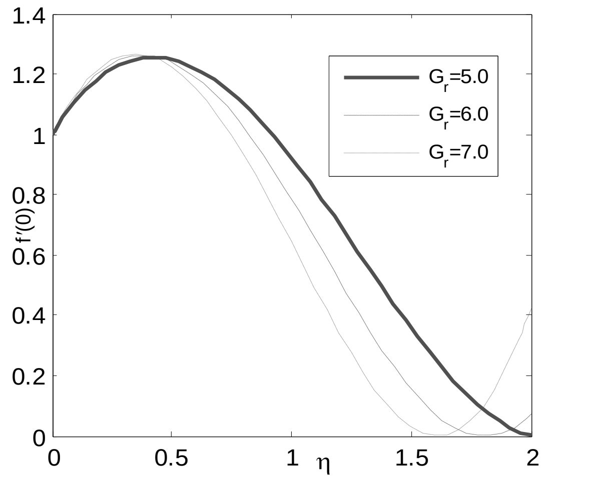

Fig. 5. Velocity profile for various values of G_r and m=1.0, $\gamma = 30^0$, P_r=1.0, M =1.0, G_c=1.0, S_c=0.22, ξ=0.5, E_c=2.0, n=2

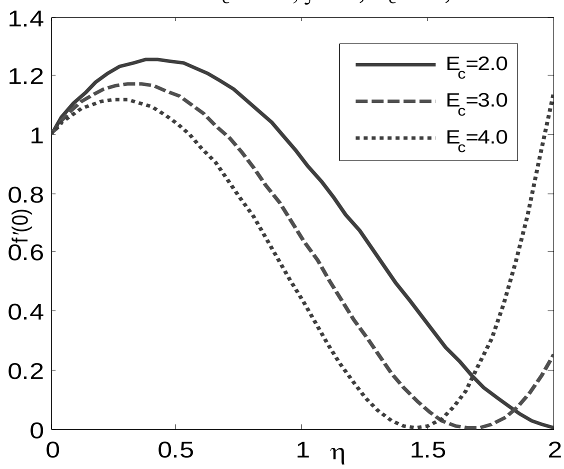

Fig. 6. Velocity profile for various values of E_c and m=1.0, $\gamma = 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, ξ=0.5, M =1.0, n=2

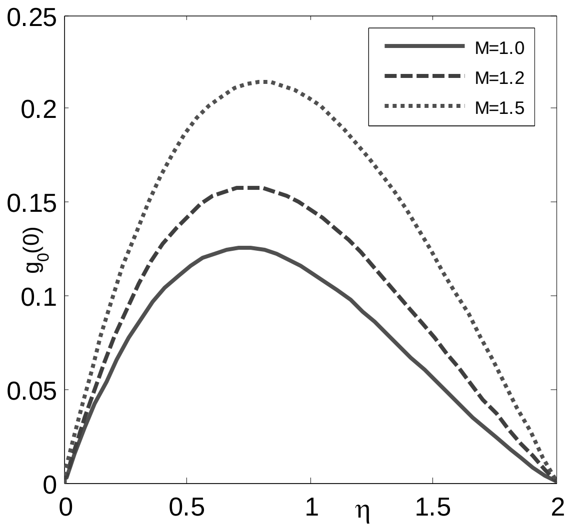

Fig. 7. Secondary Velocity profile for various values of M and m=1.0, $\gamma = 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, ξ=0.5, E_c=2.0, n=2

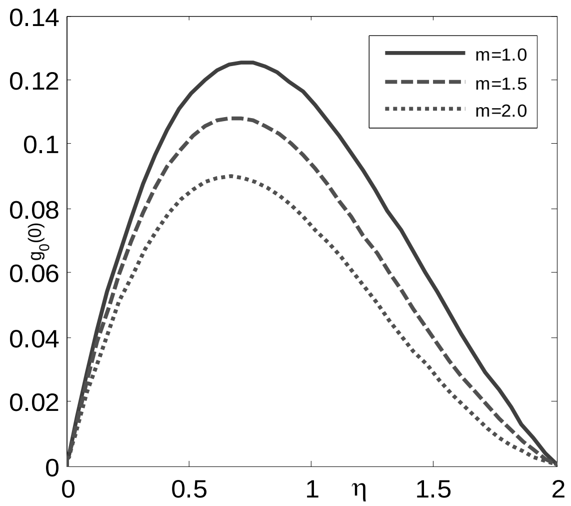

Fig. 8.Secondary Velocity profile for various values of m and M=1.0, $\gamma= 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

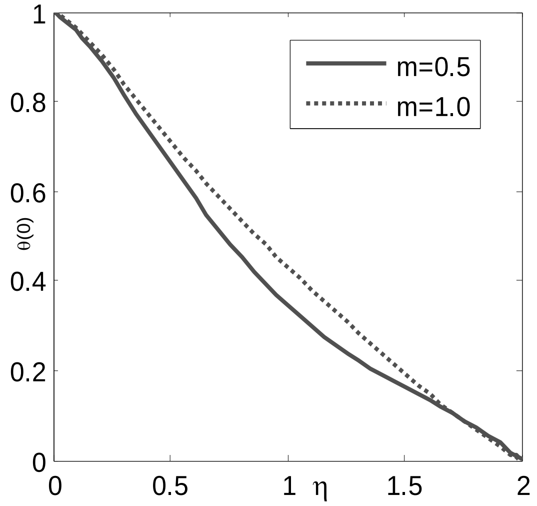

Fig. 11. Temperature profile for various values of m and M=1.0, $\gamma= 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

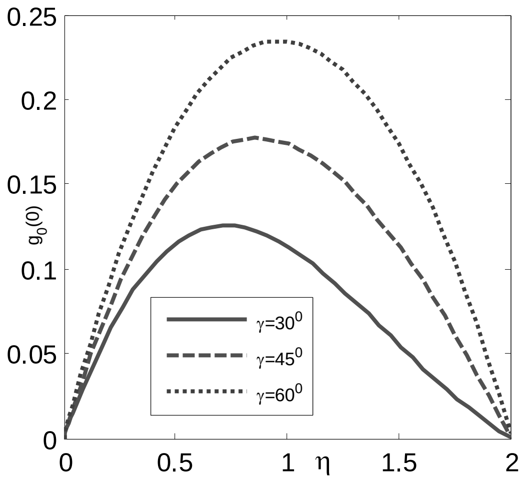

Fig. 9.Secondary Velocity profile for various values of γ and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

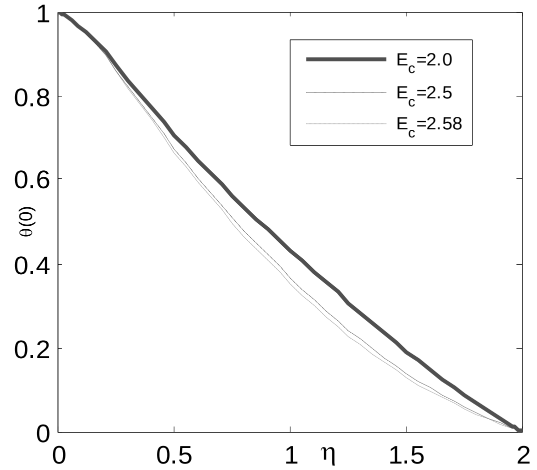

Fig. 12. Temperature profile for various values of E_c and m=1.0, $\gamma= 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, M =1.0,n=2

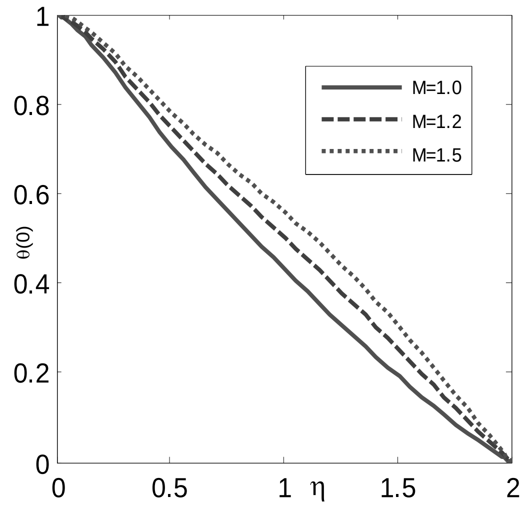

Fig. 10. Temperature profile for various values of M and m=1.0, $\gamma= 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

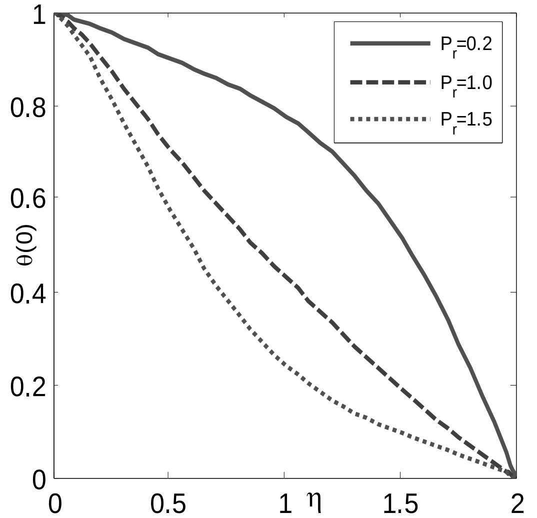

Fig. 13. Temperature profile for various values of P_r and m=1.0, $\gamma= 30^0$, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, M =1.0,n=2,E_c=2.0

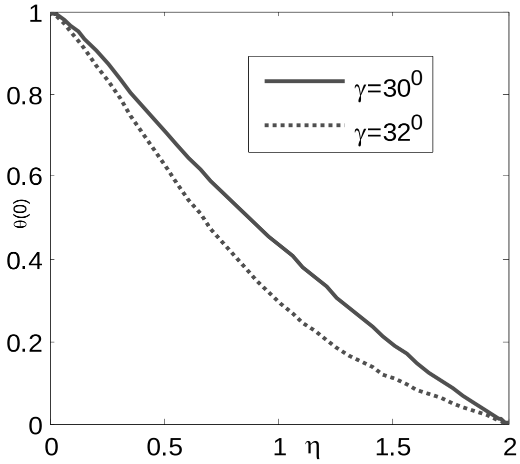

Fig. 14. Temperature profile for various values of γ and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

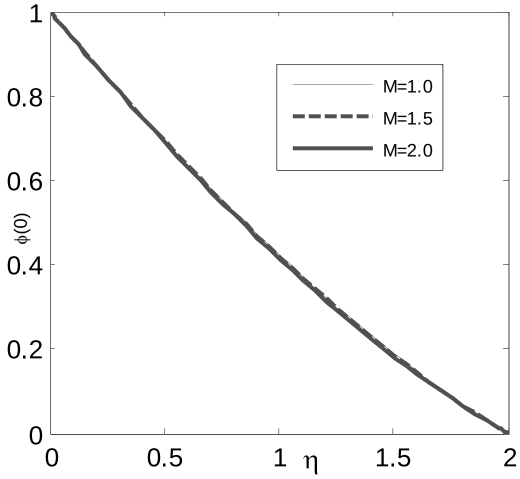

Fig. 15. Concentration profile for various values of M and m=1.0, γ= 30^0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

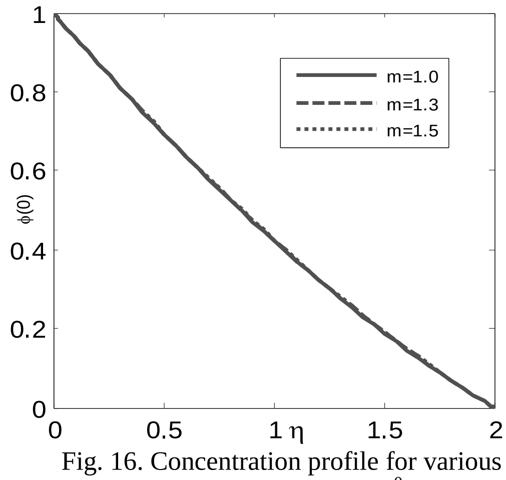

Fig. 16. Concentration profile for various values of m and M=1.0, γ= 30^0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

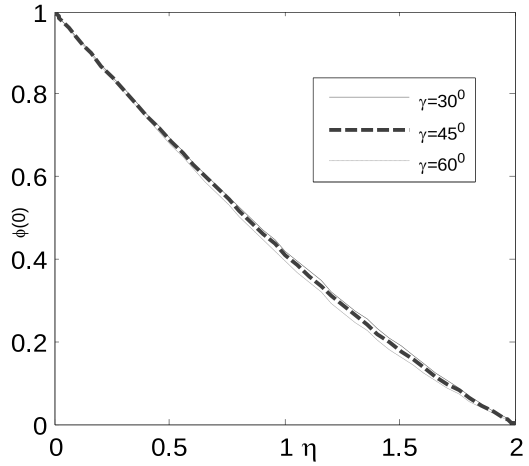

Fig. 17. Concentration profile for various values of γ and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22,ξ=0.5, E_c=2.0,n=2

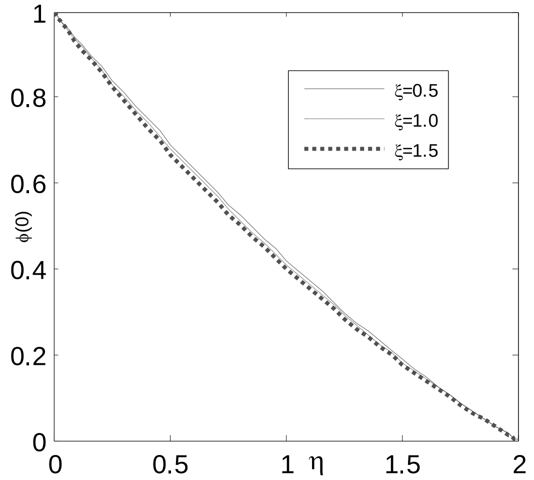

Fig. 18. Concentration profile for various values of ξ and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, S_c=0.22, E_c=2.0,n=2, γ= 30^0

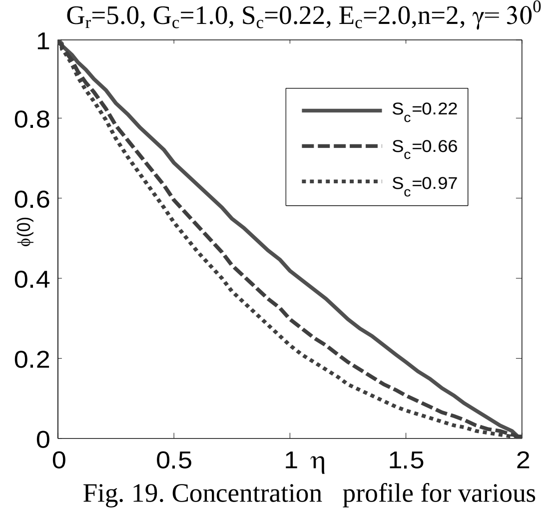

Fig. 19. Concentration profile for various values of S_c and m=1.0, M = 1.0, P_r=1.0, G_r=5.0, G_c=1.0, ξ=0.5, E_c=2.0,n=2, γ= 30^0

4. CONCLUSION

In this Paper the effects of Hall current parameter on free-convective flow heat and mass transfer of a viscous, incompressible and electrically conducting fluid over an inclined stretching plate have been studied in the presence of magnetic field. Numerical solutions are obtained through shooting method. The observations are that the velocity profile decreases with the increase in the magnetic parameter M, which is significant, but the velocity increases with the increase in the Hall parameter m and the velocity decreases with the increase in the inclination γ near the plate and increases far away from the plate. The secondary velocity fields increases with the increase of magnetic parameter M, but secondary velocity decreases with the increase of Hall parameter m The temperature increases for increasing values of M and m. but decreases for the values of γ, E_c and P_r. The concentration decreases for the increase of M, m, ξ, S_c and γ.

5. ACKOWLEDGEMENT

We are thankful to HEQEP, to get enough support from Simulation lab under Mathematics Department, CUET which helped us completing our work successfully. Also, we would like to extend our sincere regards to VC and Pro-VC of CUET for their timely support to establish the Simulation lab.

.

6. REFERENCES

[1] E. Magyari and B. Keller, "Heat and mass transfer in the boundary layers on an exponentially stretching continuous surface", *Journal of Physics D: Applied Physics,* vol. 32, pp. 577-585, 1999.

[2] L. J. Crane, "Flow past a stretching sheet", *Journal of Applied Mathematics and Physics,* vol. 21, pp. 645-647, 1970.

[3] P. S. Gupta and A. S. Gupta, "Heat and Mass transfer on a stretching sheet with suction or blowing", *Canadian Journal of Chemical Engineering*, vol. 55, pp.744-746, 1977.

[4] K. R. Rajagopal, T. Y. Na, and A. S. Gupta, "Flow of a viscoelastic fluid over a stretching sheet", *Rheologica Acta*, vol. 23, pp.213-215, 1984.

[5] B. Siddapa and M. S. Abel, "Non-Newtonian flow past a stretching plate", *Journal of Applied Mathematics and Physics*, vol. 36, pp. 890-892, 1985.

[6] C. K. Chen and M. Char, "Heat transfer on a continuous stretching surface with suction or blowing", *Journal of Mathematical Analysis and Applications*, vol. 35, pp. 568-580, 1988.

[7] M. K. Laha, P. S. Gupta, and A. S. Gupta AS, "Heat transfer characteristics of the flow of an incompressible viscous fluid over a stretching sheet", *Heat and Mass Transfer,* vol. 24, pp. 151-153, 1989.

[8] K. Vajravelu and J. Nayfeh, "Convective heat transfer at a stretching sheet", *Acta Mechanica*, vol. 96, pp. 47-54, 1992.

[9] S. M. Sonth, S. K. Khan, M. S. Abel, and K. V. Prasad, " Heat and mass transfer in a visco-elastic fluid flow over an accelerating surface with heat source/sink and viscous dissipation", *Heat and Mass Transfer,* vol. 38, pp. 213-220, 2002.

[10] Y. Tan , X. C. You, Xu Hang, and S. J.Liao, "A new branch of the temperature distribution of boundary layer flows over an impermeable stretching plate", *Heat and Mass Transfer,* vol. 44, pp. 501-504, 2008.

[11] K. B. Pavlov, "Magnetohydrodynamic flow of an incompressible viscous fluid caused by the deformation of a plane surface", *Magnetic Gidrondin*, vol.4, pp.146-152, 1974.

[12] A. Chakrabarti and A. S. Gupta, "Hydro magnetic flow of heat and mass transfer over a stretching sheet", *Quarterly of Applied Mathematics*, vol. 33, pp. 73-78, 1979.

[13] M. Kumari, H. S. Takhar, and G. Nath, "MHD flow and heat transfer over a stretching surface with prescribed wall temperature or heat flux", *Warme Stoffubertrag,* vol. 25, pp. 331-336, 1990.

[14] H. I. Andersson, "MHD flow of a visco-elastic fluid past a stretching surface" , *Acta Mechanica,* vol. 95, pp. 227-230, 1992.

[15] H. I. Andersson, K. H. Bech, and B. S. Dandapat, "Magnetohydrodynamic flow of a Power-law fluid over a stretching surface" , *International Journal of Non-Linear Mechanics*, vol. 27, pp. 929-936, 1992.

[16] P. K. Singh, "Heat and mass transfer in MHD boundary layer flow past an inclined plate with viscous dissipation in porous medium", *International Journal of Scientific & Engineering Research*, vol. 3, issue. 6, 2012.

[17] A. A. Afify, "MHD free-convective flow and mass transfer over a stretching sheet with chemical reaction" , *Heat and Mass Transfer,* vol.40, pp. 495-500, 2004.

[18] R. Cortell, "A note on magnetohydrodynamic flow of a power-law fluid over a stretching sheet", *Applied Mathematics and Computation,* vol. 168, pp. 557-566, 2005.

[19]M. S. Abel and N. Mahesha, "Heat transfer in MHD viscoelastic fluid flow over a stretching sheet with variable thermal conductivity, non-uniform heat source and radiation", *Applied Mathematical Modeling,* vol. 32, pp. 1965-1983, 2008.

[20]M. A. Samad, and M. Mohebujjaman, "MHD heat and mass transfer free convection flow along a vertical stretching sheet in presence of magnetic field with heat generation", *Research Journal of Applied Sciences, Engineering and Technology*, vol. 1, no. 3, pp. 98-106, 2009.

[21] A. K. Jhankal, and M. Kumar, "MHD Boundary Layer Flow Past a Stretching Plate With Heat Transfer", *The International Journal of Engineering and Science,* vol. 2 , no. 3, pp. 9-13, 2013.

[22] A. Chakrabarthi and A. S. Gupta, "A note on MHD flow over a stretching permeable surface", *Quarterly of Applied Mathematics,* vol. 37, pp. 73-78, 1979.

[23] T. Chiam, "Magneto hydrodynamic boundary layer flow due to a continuous moving flat plate", *Computer & Mathematics with Applications,* vol. 26, pp.1-8, 1993.

[24] T. Watanabe and I. Pop, "Hall effects on

magnetohydrodynamic boundary layer flow over a continuous moving flat plate", *Acta Mechanica,* vol. 108:, pp. 35-47, 1995.

[25] E.M. Abo-Eldahab and E. M. E. Elbarbary, "Hall current effect on magnetohydrodynamic free-convection flow past a semi-infinite vertical plate with mass transfer" , *International Journal of Engineering Science*, vol. 39 , pp. 1641-1652, 2001.

[26] M. A. Rana , A. M. Siddiqui, and N. Ahmed N, "Hall effect on Hartmann flow and heat transfer of a Burger's fluid" , *Physics Letters A*, vol. 372, pp. 562-568, 2009.

7. NOMENCLATURE

Symbol	**Meaning**
MHD	Magnetohydrodynamics
c_p	Specific heat of with constant pressure
g	Gravitational acceleration
g_0	Secondary Velocity
f'	Velocity Profile
M	Magnetic parameter
m	Hall parameter
ν	Kinematic viscosity
γ	Inclination of the Plate
η	Similarity variable
α	Thermal diffusivity
β	Thermal Expansion Coefficient
β^*	Coefficient of expansion with concentration
ρ	Density
σ	Fluid electrical conductivity
θ	Dimensionless temperature
u	Velocity component in x-direction
v	Velocity component in y-direction
w	Secondary Velocity
T	Temperature
K_0	Reaction rate constant
D_m	Thermal molecular diffusivity
C	Concentration
C_∞	Concentration of the fluid outside the boundary layer
n	Order of reaction
P_r	Prandle number
G_r	Grashof number
G_c	Modified Grashof number
E_c	Eckert number
S_c	Schmidt number
ξ	Non-dimensional chemical reaction parameter
B_0	Constant magnetic field intensity
T_w	Temperature at the Plate
T_∞	Temperature of the fluid outside the boundary layer
Subscripts	
w	Quantities at wall
∞	Quantities at the free stream