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Study on MHD Boundary Layer Flow of Combined Heat and Mass Transfer Over a Moving Inclined Plate in a Porous Medium With Suction and Viscous Dissipation in Presence of Hall Effect

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ABSTRACT

The Hall effects on the steady MHD boundary layer flow of an incompressible fluid of combined heat and mass transfer over a moving inclined plate in a porous media with suction and viscous dissipation has studied. An external magnetic field is applied perpendicular to the surface and the fluid motion is subjected to a uniform suction and injection. A closed form solutions of the equations governing the flow are obtained for the velocity, secondary velocity, and temperature and concentration profiles. The dimensionless governing equations are solved using R-K method along with shooting technique. The velocities, temperature and concentration profiles are presented graphically for different values of governing flow parameters. The results presented graphically illustrate that primary velocity field decrease due to increase of magnetic parameter, angle of inclination, permeability parameter and suction parameter while secondary velocity also decrease for magnetic parameter, Hall parameter and permeability parameter. Other parameters increase the velocities of the fluid flow. Temperature field increases in the presence of Magnetic parameter, Grashof number, Modified Grashof number and permeability parameter and decreases for Prandtl number and suction parameter. Also, concentration profiles decreases for increasing the values of magnetic parameter, Hall parameter, Schmid number and suction parameter but there is no effect on concentration of the remaining parameters. Also the skin friction coefficient, the local Nusselt number and the local Sherwood number are presented in Tables 1-3.

Keywords: Hall Effect, MHD, Porous media, Suction, Dissipation

INTRODUCTION

The study of boundary layer flow heat and mass transfer over an inclined plate has generated much interest from astrophysical, renewable energy systems and also hypersonic aerodynamics researchers for a number of decades. MHD flow problems have become important in industrial manufacturing processes such as plasma studies, chemical

engineering, electrochemistry, polymer processing, petroleum industries, Magneto-hydrodynamics power generator cooling of clear reactors, boundary layer control in aerodynamics. Several researchers have studied the effects of magnetic field on mixed, natural and forced convection heat and mass transfer problems. This problem has also an important bearing on metallurgy where magneto-hydrodynamic (MHD) techniques have recently been used. The study of effects of porous boundaries on heat and mass transfer is important because of its many engineering applications in the field of chemical and geophysical sciences. Permeable porous plates are used in the filtration processes and also for a heated body to keep its temperature constant and to make the heat transfer from the surface more effective. Previous studies deal with the studies concerning non-Newtonian flows and heat transfer in the absence of magnetic fields, but presently we find several industrial applications such as polymer technology and metallurgy (Chakrabarti and Gupta 1979), where the magnetic field is applied in the viscoelastic fluid flow. (Sarpakaya 1961) was mostly first researcher to investigate MHD flows of non-Newtonian fluids, (Andersson 1992) investigated the flow problem of electrically conducting viscoelastic fluid past a flat and impermeable elastic sheet and later his work is extended by many authors (Prasad et al 2010; Abel and Mahesha 2008; Seddeek 2007; Joshi et al 2001; Veenae et al 2004; Hasimoto 1957) discussed the boundary layer growth on a heat plate with suction or injection. (Mishra and Dash 1974) studied free convection of non-permeable fluid between parallel walls. (Vajravelu 1979) studied natural convection at a heated semi-infinite vertical plate with internal heat generation. (Pop and Soundalgekar 1980) investigated free convection flow past an accelerated infinite plate. (Singh 1983) analyzed the MHD free convective flow past an accelerated vertical porous plate by finite difference method. (Rapits et al. 1987) studied the unsteady free convective flow through a porous medium adjacent to a semi-infinite vertical plate using finite difference scheme. (Singh and Dikshit 1988) studied hydromagnetic flow past a continuously moving semi-infinite plate at large suction. (Singh and Soundalgekar 1990) investigated transient free convection in cold water past an infinite vertical porous plate. (Sattar 1994) discussed free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with time dependent temperature and concentration. (Acharya et al. 1995) investigated the effect of chemical and thermal diffusion with Hall current on unsteady hydromagnetic flow near an infinite vertical porous plate. (Dash and Das 1999) analyzed the effect of Hall current MHD free convection flow along an accelerated porous heated plate with mass transfer and internal heat generation. (Soundalgekar et al. 1974) studied transient free convection flow of a viscous dissipative fluid past a semi-infinite vertical plate. (Cookey et al. 2003) studied the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. (Sharma and Mishra 2002) analyzed the effect of mass transfer in unsteady MHD flow and heat transfer past an infinite porous vertical moving plate. (Panda et al. 2003) discussed unsteady free convective flow and mass transfer of a rotating elastic viscous liquid through porous media past a vertical porous plate. (Das et al 2006) studied unsteady free convection and mass transfer boundary layer flow past an accelerated infinite vertical porous plate with suction. (Sharma and Singh 2008) investigated unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. The aim of the paper is to investigate steady MHD boundary layer flow of an incompressible fluid of combined heat and mass transfer over a moving inclined plate in a porous media with suction and viscous dissipation in presence of Hall current. The governing equations are solved both analytically and

numerically using Runge-kutta forth-fifth order method along with shooting technique. The effect of the parameters on the velocity, temperature and the concentration distributions of the flow filed are discussed and shown through graphs. The results are analysed for various physical parameters such as of the porous medium, magnetic field, Local thermal Grashof number, Local solutal Grashof number, Schmidt number, Prandtl number, Eckert number, Hall parameter on the flow, heat and mass transfer characteristics.

MATHEMATICAL FORMULATION OF THE PROBLEM

Let us consider a two dimensional steady laminar MHD viscous incompressible electrically conducting fluid along an inclined plate with an acute angle γ . X- direction is taken along the leading edge of the inclined 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 Figure-1.

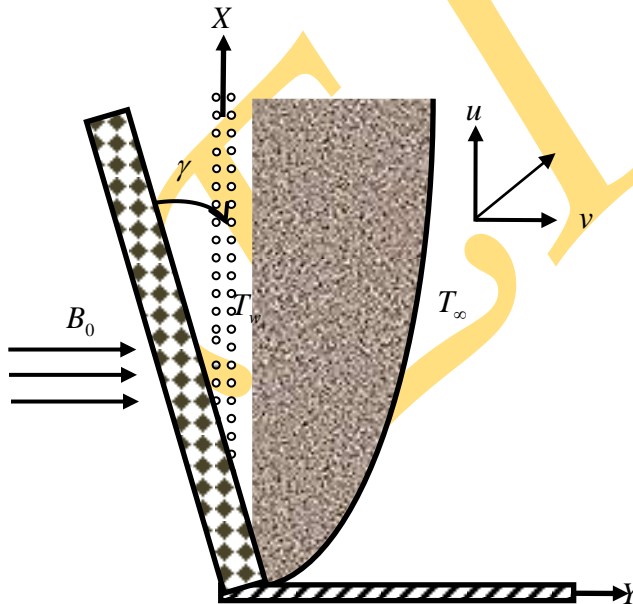


Figure-1 Physical configuration and coordinate system.

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:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

Momentum equation:

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

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

Energy Equation:

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

Concentration Equation:

$$u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = D \frac{\partial^2 c}{\partial y^2} \quad (5)$$

Boundary conditions are :

$$u = Ax, v = V, w = 0, T = T_w = T_x + ax,$$

$$C = C_w = c_x + bx \quad \text{at } y = 0$$

$$u = 0, w = 0, T = T_\infty, C = C_\infty \quad \text{as } y \rightarrow \infty$$

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

$$w = Ag_0(\eta), \eta = y \sqrt{\frac{A}{vx}}, \psi = \sqrt{vAx}f(\eta), k^* = \frac{vx}{Ak}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, F_w = \frac{2V}{\sqrt{vA}}$$

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

$$f''' + \frac{1}{2}ff' + G_r\theta\cos\gamma + G_c\phi\cos\gamma - \frac{M^2}{1+m^2}f' - Mg_0 - Kf = 0 \quad (6)$$

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

$$\theta'' + \frac{1}{2}P_r f\theta' + E_c[f'^2 + g_0'^2] = 0 \quad (8)$$

$$\phi'' + \frac{1}{2}S_c f\phi' = 0 \quad (9)$$

The transform boundary conditions:

$$f = -F_w, g_0 = 0, f' = 1, \theta = \phi = 1 \quad \text{at } \eta = 0$$

$$f = f' = g_0 = \theta = \phi = 0 \quad \text{as } \eta \rightarrow \infty$$

RESULTS AND DISCUSSION

In order to get a physical insight of the problem, a representative set of numerical results are shown graphically in Figure-2 to Figure-27 to illustrate the influence of physical parameters viz., the suction parameter F_w , magnetic parameter M , Hall parameter m , thermal conductivity K , buoyancy parameter G_r & G_c , Eckert number E_c , Schmidt number S_c , Prandlt Number P_r and inclination parameter γ on the velocity, secondary velocity, temperature and concentration profiles. Figure-2 to Figure-9 shows the effects of various parameters on dimensionless primary velocity profile. The effects of M and m on the primary and secondary velocity profiles are shown in Fig. 2, Fig.10, Fig.3 and Fig.11. It can be clearly seen that an increase in the magnetic parameter decreases the primary velocity and also the secondary velocity. This result agrees with the expectations, since the magnetic field exerts a retarding effect on the free convective flow. This field may control the flow characteristics, an increase in M results in thinning of the boundary layer. The effect of the Hall parameter has a minor increasing effect on the primary velocity, whereas the major decreasing effect on the secondary velocity. Fig.17, Fig.20, & Fig.21 depicts the temperature and concentration profiles for M and m . From these figure it is observed that temperature increases for increasing values of M but negligible decreasing effect on concentration for increasing values M and m . Figure-4 shows the dimensionless velocity profile for various values of γ . It is observed that for the effects of γ the velocity decreases. From Fig. 5 to Fig. 7 it is observed that the velocity profile is increased for the effect of P_r , G_r , and G_c that is the flow accelerated corresponding to an increase of these parameters but velocity is decreased for various values of K and F_w which shown in Fig.8 and Fig.9. On the other hand from Fig.12 and Fig.13 it is seen that, as expected secondary velocity increases with the increasing values of the parameters G_r and G_c that is these parameters acts as an influence forces. As a result the boundary layer thickness increases but Fig.14 shows the dimensionless secondary velocity profiles for different values of K . It is seen that, as expected secondary velocity decreases with an increase in K . Fig.15 illustrates the influence of physical parameters P_r on the temperature profile. It is observed that in air and salt water the variation of temperature is slower than fresh water for the effect of P_r . From Fig.28 it is seen that temperature is decreased in the increasing values of F_w . From Fig.16 and Fig.18 it is observed that temperature profile increases for increasing values of G_r and G_c . From Fig.19 it is interesting to note that the temperature profile is decreased for $K \leq 2$ but when $K \geq 3$ then it is increased. Fig.22 to Fig.25 it is observed that there is no effect on concentration profile of the parameters G_r , G_c , P_r and K . From Fig.26 and Fig.27 it is seen that the concentration is decreased for the increasing values of S_c and F_w . Tables 1–3 exhibit the behaviour of $f''(0)$, $-\theta'(0)$, and $-\phi'(0)$, for various values of magnetic parameter, Hall parameter, Pr and tl number, angle of inclination, Permeability parameter, Grashof Number, Modified Grashof number and Suction/injection parameter. From Table- 1, it is observed that $f''(0)$ is decreased for various values of $M, \gamma, K,$ and F_w and increased for increasing values of m, P_r, G_r, G_c and F_w . From Table- 2, it is observed that $\theta'(0)$, is decreased with the increasing values of K, P_r and F_w but increased for increasing values of

M , G_r , G_c and K . From Table- 3, we see that $\varphi'(0)$, is decreased with the increase of M , m , S_c and F_w and there is no effect for G_r , G_c , P_r and K .

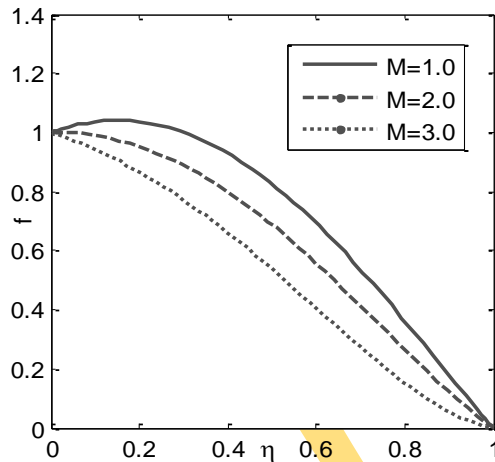


Fig.2 Primary velocity profile for various values of M and $m = 0.2$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

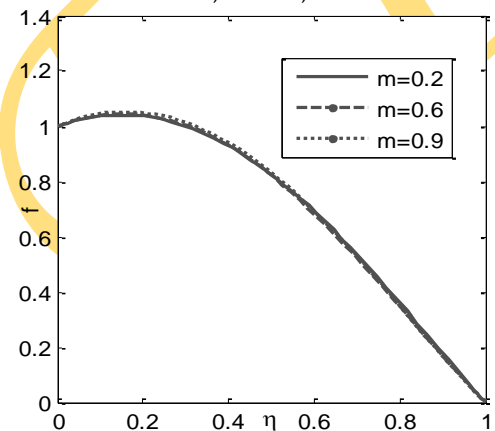


Fig.3 Primary velocity profile for various values of m and $M = 1.0$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

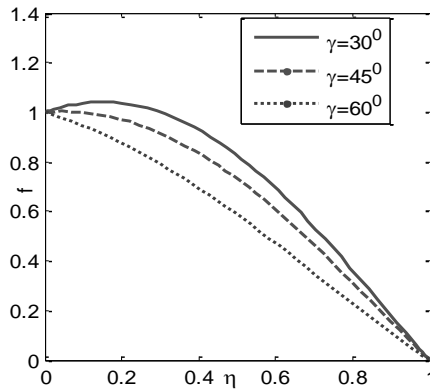


Fig.4 Primary velocity profile for various values of γ and $M = 1.0, m = 0.2, P_r = 0.71, G_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

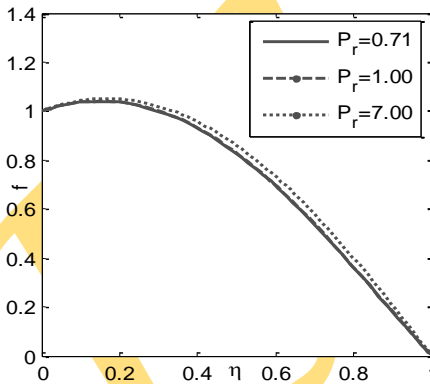


Fig.5 Primary velocity profile for various values of P_r and $m = 0.2, \gamma = 30^\circ, M = 1.0, G_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

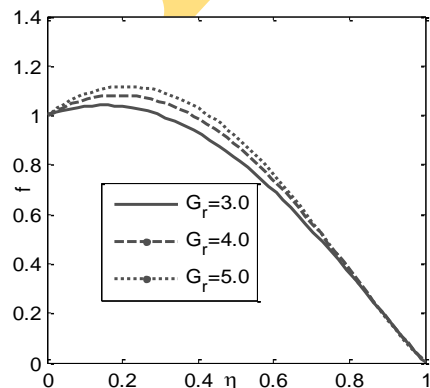


Fig.6 Primary velocity profile for various values of G_r and $m = 0.2, \gamma = 30^\circ, M = 1.0, P_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

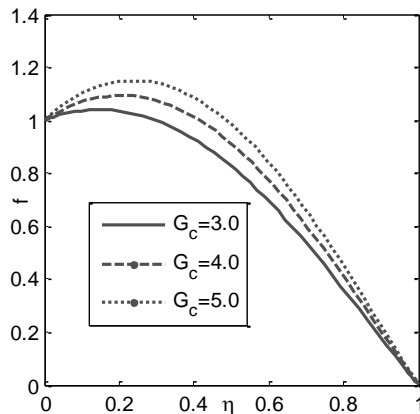


Fig.7 Primary velocity profile for various values of G_c and $m = 0.2$, $\gamma = 30^\circ$, $M = 1.0$, $P_r = G_r = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

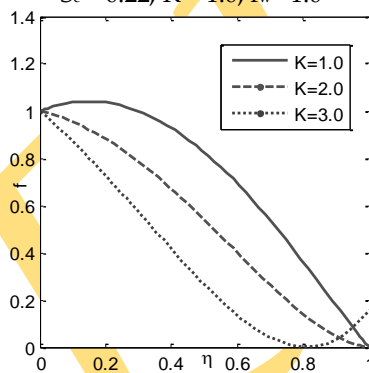


Fig.8 Primary velocity profile for various values of K and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $\gamma = 30^\circ$, $f_w = 1.0$

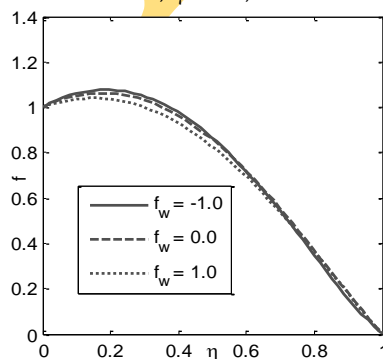


Fig.9 Primary velocity profile for various values of f_w and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $\gamma = 30^\circ$, $K = 1.0$

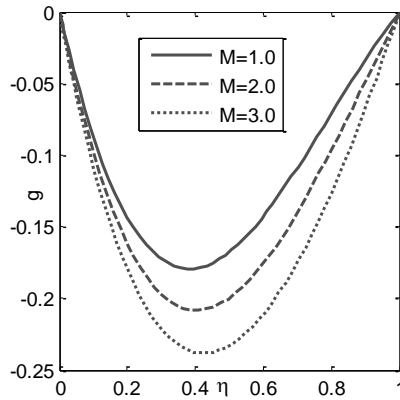


Fig.10 Secondary velocity profile for various values of M and $m = 0.2$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

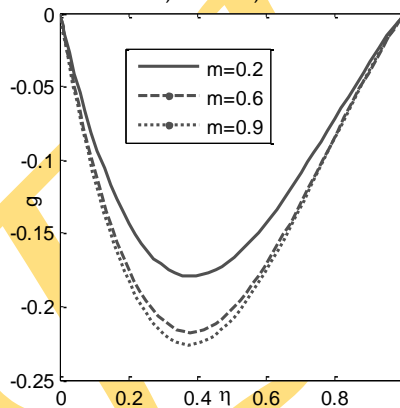


Fig.11 Secondary velocity profile for various values of m and $M = 1.0$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

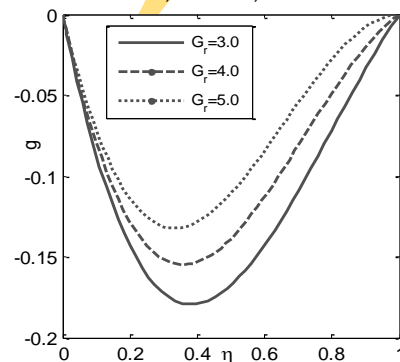


Fig.12 Secondary velocity profile for various values of G_r and $m = 0.2$, $\gamma = 30^\circ$, $M = 1.0$, $P_r = G_c = E_c = 3.0$, $S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

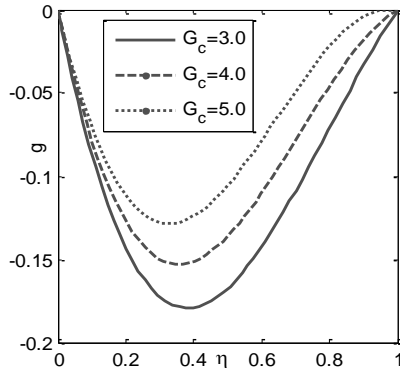


Fig.13 Secondary velocity profile for various values of G_c and $m = 0.2, \gamma = 30^\circ, M = 1.0, P_r = G_r = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

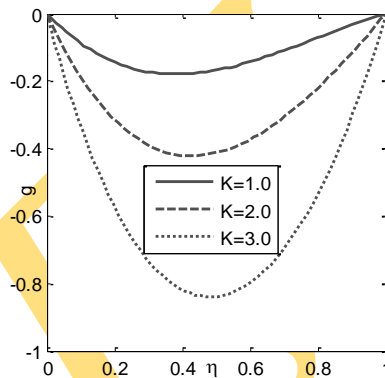


Fig.14 Secondary velocity profile for various values of K and $M = 1.0, m = 0.2, P_r = 0.71, G_r = G_c = E_c = 3.0, S_c = 0.22, \gamma = 30^\circ, f_w = 1.0$

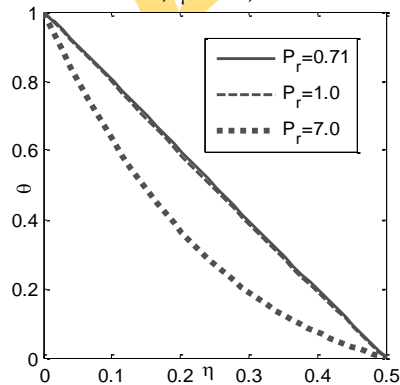


Fig.15 Temperature profile for various values of P_r and $m = 0.2, \gamma = 30^\circ, M = 1.0, G_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

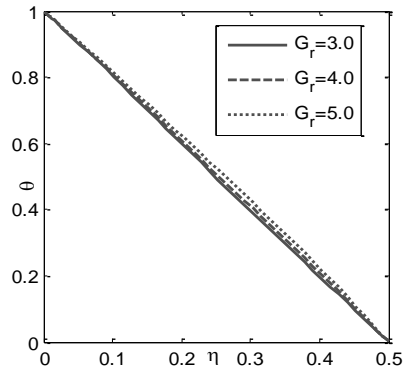


Fig.16 Temperature profile for various values of G_r and $m = 0.2$, $\gamma = 30^\circ$, $M = 1.0$, $P_r = G_c = E_c = 3.0$,

$S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

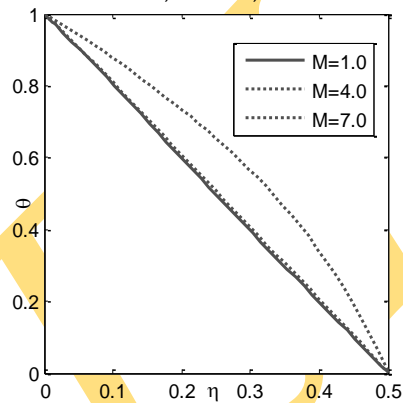


Fig.17 Temperature profile for various values of M and $m = 0.2$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$,

$S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

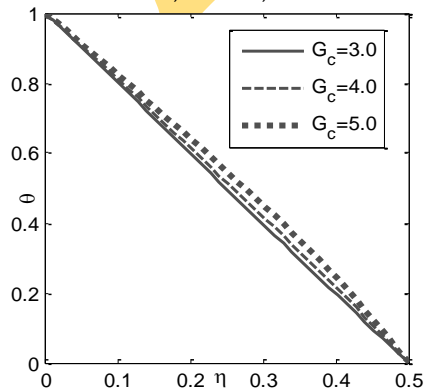


Fig.18 Temperature profile for various values of G_c and $m = 0.2$, $\gamma = 30^\circ$, $M = 1.0$, $P_r = G_r = E_c = 3.0$,

$S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

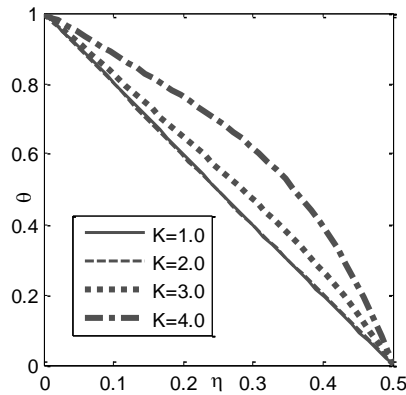


Fig.19 Temperature profile for various values of K and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$,

$S_c = 0.22$, $\gamma = 30^\circ$, $f_w = 1.0$

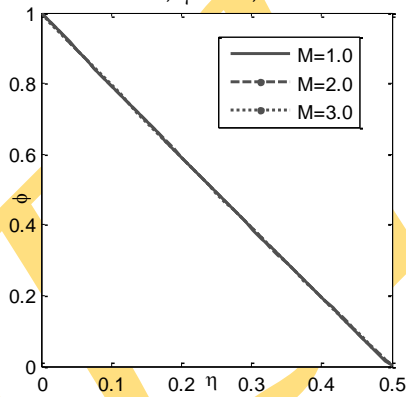


Fig.20 Concentration profile for various values of M and $m = 0.2$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$,

$S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

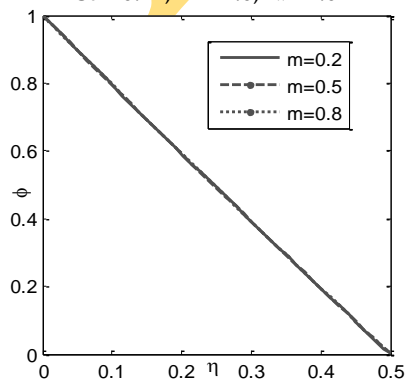


Fig.21 Concentration profile for various values of m and $M = 1.0$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$,

$S_c = 0.22$, $K = 1.0$, $f_w = 1.0$

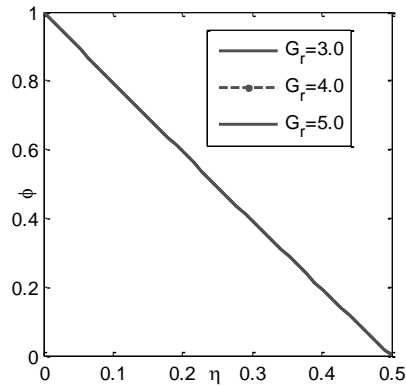


Fig.22 Concentration profile for various values of G_r and $m = 0.2, \gamma = 30^\circ, M = 1.0, P_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

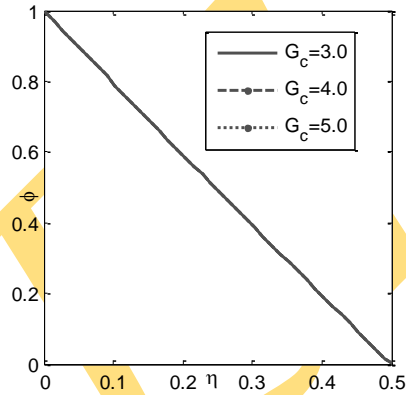


Fig.23 Concentration profile for various values of G_c and $m = 0.2, \gamma = 30^\circ, M = 1.0, P_r = G_r = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

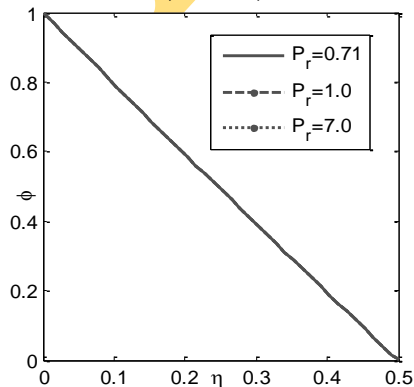


Fig.24 Concentration profile for various values of P_r and $m = 0.2, \gamma = 30^\circ, M = 1.0, G_r = G_c = E_c = 3.0, S_c = 0.22, K = 1.0, f_w = 1.0$

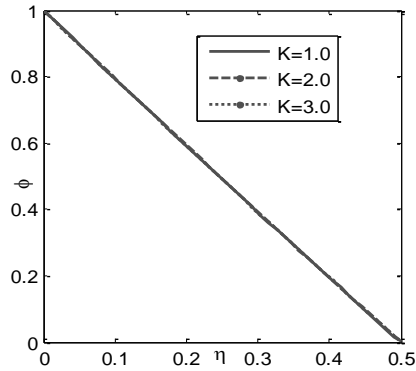


Fig.25 Concentration profile for various values of K and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $\gamma = 30^\circ$, $f_w = 1.0$

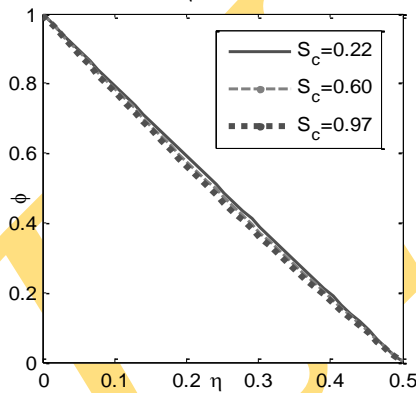


Fig.26 Concentration profile for various values of S_c and $m = 0.2$, $\gamma = 30^\circ$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $M = 1.0$, $K = 1.0$, $f_w = 1.0$

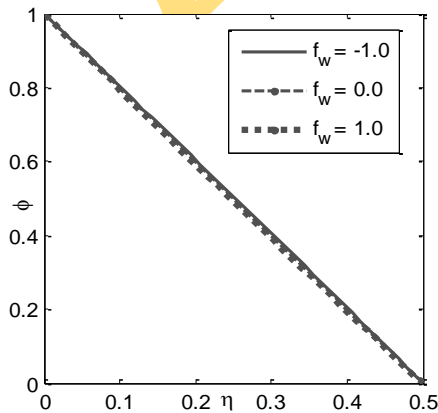


Fig.27 Concentration profile for various values of f_w and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $\gamma = 30^\circ$, $K = 1.0$

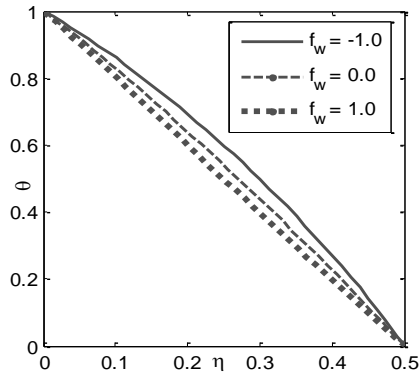


Fig.28 Temperature profile for various values of f_w and $M = 1.0$, $m = 0.2$, $P_r = 0.71$, $G_r = G_c = E_c = 3.0$, $S_c = 0.22$, $\gamma = 30^\circ$, $K = 1.0$

CONCLUSIONS

The present numerical study has been investigated steady MHD boundary layer flow of an incompressible fluid of combined heat and mass transfer over a moving inclined plate in a porous media with suction and viscous dissipation in presence of Hall current. The shooting method with RK-45 iteration scheme has been implemented to solve the dimensionless velocity, thermal and mass boundary layer equations. From the present study, we arrive at the following significant observations.

- The magnitude of velocity decreases with increasing magnetic parameter causing of Lorentz force. Similar results are found for permeability parameter, angle of inclination and suction parameter, also reverse results arise for remaining parameters.
- Increase in magnetic parameter, thermal Grashof number and modified Grashof number, the temperature is increased. Reverse trend arises for remaining entering parameters.
- Increase in magnetic parameter, Hall parameter Schmidt number and suction/injection the concentration decreases and there is no effect for other parameters.

It is interesting to note that the temperature profile is decreased for $K \leq 2$ but when $K \geq 3$ then it is increased

Nomenclature:

MHD	Magnetohydrodynamics
c_p	Specific heat of with constant pressure
g	Gravitational acceleration
g_0	Secondary Velocity
f'	Velocity Profile
M	Magnetic parameter, $M = \frac{\sigma B_0^2 x}{\rho A}$
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
D	Thermal molecular diffusivity
F_w	Dimensionless suction velocity
C	Concentration
C_∞	Concentration of the fluid outside the boundary layer
P_r	Prandtl number,
	$P_r = \frac{\mu c_p}{\rho}$
G_r	Local thermal Grashof number,
	$G_r = \frac{g\beta(T_w - T_\infty)x}{A^2}$
G_c	Local solutal Grashof number
	$G_c = \frac{g\beta^*(C_w - C_\infty)x}{A^2}$
	Eckert number,
E_c	$E_c = \frac{\mu A^2}{kx(T_w - T_\infty)}$
S_c	Schmidt number,
	$S_c = \frac{\nu}{D}$
k^*	Permeability of the porous medium
K	Permeability parameter
B_0	Constant magnetic field intensity
T_w	Temperature at the Plate
T_∞	Temperature of the fluid outside the boundary layer
k	Thermal conductivity
W	Quantities at wall
∞	Quantities at the free stream

Table-1: The skin friction coefficient at the wall, for various values of $M, m, \gamma, P_r, G_r, G_c, F_w, K$ and taking $S_c = 0.22, E_c = 3.0$

M	m	K	γ	P_r	G_c	G_r	F_w	$f''(0)$
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.548509
2.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.037127
3.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	-0.486827
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.548509
1.0	0.6	1.0	30°	0.71	3.0	3.0	1.0	0.5921997
1.0	0.9	1.0	30°	0.71	3.0	3.0	1.0	0.655833
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.548509
1.0	0.2	2.0	30°	0.71	3.0	3.0	1.0	-0.325895
1.0	0.2	3.0	30°	0.71	3.0	3.0	1.0	-1.210374
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.548509
1.0	0.2	1.0	45°	0.71	3.0	3.0	1.0	0.128442
1.0	0.2	1.0	60°	0.71	3.0	3.0	1.0	-0.0472449
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	0.548509
1.0	0.2	1.0	30°	1.0	3.0	3.0	1.0	0.553417
1.0	0.2	1.0	30°	7.0	3.0	3.0	1.0	0.615444
1.0	0.2	1.0	30°	1.0	3.0	3.0	1.0	0.548509
1.0	0.2	1.0	30°	1.0	4.0	3.0	1.0	0.921111
1.0	0.2	1.0	30°	1.0	5.0	3.0	1.0	1.267379
1.0	0.2	1.0	30°	1.0	3.0	3.0	1.0	0.548509
1.0	0.2	1.0	30°	1.0	3.0	4.0	1.0	0.858208
1.0	0.2	1.0	30°	1.0	3.0	5.0	1.0	1.1217915
1.0	0.2	1.0	30°	1.0	3.0	3.0	-1.0	0.849388
1.0	0.2	1.0	30°	1.0	3.0	3.0	0.0	0.725358
1.0	0.2	1.0	30°	1.0	3.0	3.0	1.0	0.548509

Table-2: The rate of heat transfer at the wall, for various values of $M, m, \gamma, P_r, G_r, G_c, F_w, K$ and taking $S_c = 0.22, E_c = 3.0$

M	m	K	γ	P_r	G_c	G_r	F_w	$-\theta'(0)$
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.834366
4.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.771562
7.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.073092
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.834366
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	-
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	-
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.834366
1.0	0.2	2.0	30°	0.71	3.0	3.0	1.0	1.897262
1.0	0.2	3.0	30°	0.71	3.0	3.0	1.0	1.634461
1.0	0.2	4.0	30°	0.71	3.0	3.0	1.0	1.0485202
1.0	0.2	1.0	30°	0.71	3.0	3.0	1.0	1.834366

1.0	0.2	1.0	30 ⁰	0.71	3.0	3.0	1.0	-
1.0	0.2	1.0	30 ⁰	0.71	3.0	3.0	1.0	1.834366
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	1.0	1.924583
1.0	0.2	1.0	30 ⁰	7.0	3.0	3.0	1.0	4.221751
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	1.0	1.834366
1.0	0.2	1.0	30 ⁰	1.0	4.0	3.0	1.0	1.786807
1.0	0.2	1.0	30 ⁰	1.0	5.0	3.0	1.0	1.621447
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	1.0	1.834366
1.0	0.2	1.0	30 ⁰	1.0	3.0	4.0	1.0	1.789751
1.0	0.2	1.0	30 ⁰	1.0	3.0	5.0	1.0	1.713647
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	-1.0	1.192054
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	0.0	1.541049
1.0	0.2	1.0	30 ⁰	1.0	3.0	3.0	1.0	1.834366

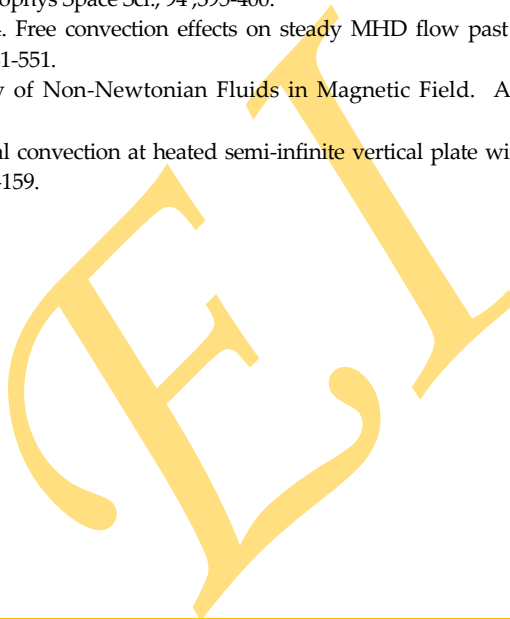
Table-3: The rate of concentration at the wall, for various values of M, m, S_c, P_r, G_r, G_c, F_w, K and taking $\gamma = 30^0, E_c = 3.0$

M	m	K	S _c	P _r	G _c	G _r	F _w	$-\phi'(0)$
1.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06509
2.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.065207
3.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06531
1.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.6	1.0	0.22	0.71	3.0	3.0	1.0	2.06508
1.0	0.9	1.0	0.22	0.71	3.0	3.0	1.0	2.06505
1.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.2	2.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.2	3.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.60	0.71	3.0	3.0	1.0	2.18052
1.0	0.2	1.0	0.97	0.71	3.0	3.0	1.0	2.29651
1.0	0.2	1.0	0.22	0.71	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	1.0	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	7.0	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	1.0	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	1.0	4.0	3.0	1.0	2.06499
1.0	0.2	1.0	0.22	1.0	5.0	3.0	1.0	2.06493
1.0	0.2	1.0	0.22	1.0	3.0	3.0	1.0	2.06509
1.0	0.2	1.0	0.22	1.0	3.0	4.0	1.0	2.06501
1.0	0.2	1.0	0.22	1.0	3.0	5.0	1.0	2.06493
1.0	0.2	1.0	0.22	1.0	3.0	3.0	-1.0	1.95473
1.0	0.2	1.0	0.22	1.0	3.0	3.0	0.0	2.00941
1.0	0.2	1.0	0.22	1.0	3.0	3.0	1.0	2.06509

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