Effect of Hall Current, Thermal Radiation, Dissipation and Chemical Reaction on Hydromagnetic Non-Darcy Mixed Convective Heat and Mass Transfer Flow Past a Stretching Sheet in the Presence of Heat Sources

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Abstract

We study the combined influence of Hall current, radiation and dissipation on convective heat and mass transfer flow of a viscous electrically conducting g fluid past a stretching sheet. The equations governing the flow , heat and mass transfer have been solved by Galerkin finite element analysis with three nodded line segments. The velocity, temperature and concentration have been analysed for different values of m, N, F, γ, Ec and Q. The rate of heat and mass transfer on the plate has been evaluated numerically for different variations.

1. INTRODUCTION

Laminar boundary layer behavior over a moving continuous and linearly stretching surface is a significant type of flow has considerable practical applications in engineering, electrochemistry (Chin [13], Gorla [19]) and polymer processing, (Erickson et. al. [17]). For example, materials manufactured by extrusion process and heat treated materials traveling between a feed roll and a windup roll or on a conveyor belt possesses the characteristics of a moving continuous surface. The hydromagnetic flow and heat transfer problems have become important industrially. To be more specific, it may be pointed out that many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are sometimes stretched. Mention may be made of drawing, annealing and tinning of copper wires. In all the cases the properties of the final product depend to a great extent on the rate of cooling. By drawing such strips in an electrically conducting fluid subjected to magnetic fluid, the rate of cooling can be controlled and a final product of desired characteristics can be achieved. Another interesting application of hydromagnetics to metallurgy lies in the purification of molten metals from nonmetallic inclusions by the application of a magnetic field. The study of heat and mass transfer is necessary for the determining the quantity of the final product. However, there are fluids, which react chemically with some other ingredients present in them. The effect of a chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux was studied by Anderson et. al. [7], have studied the diffusion of a chemical reactive species from a linearly stretching sheet. Raptis et. al. [31], have studied the viscous flow over a non-linearly stretched sheet in the presence of a chemical reaction and magnetic field.

Due to entertainment of ambient fluid, this boundary layer flow situation is quite different from the classical blasius problem over a semi-infinite flat plate. Suction or injection of a stretched surface was studied by Erickson et.al. [17], and Fox et.al. [18] for uniform velocity and temperature and investigates its effects on the heat and mass transfer in the boundary layer. Chen and Char [12] have studied the suction and injection on a linearly moving plate subject to uniform wall temperature and heat flux and the more general case using a power law velocity and temperature distribution at the surface was studied by Ali [6]. Magyari et.al. [25] have reported analytical and computational solution when the surface moves with rapidly decreasing velocities using the self-similar method. In all the papers mentioned above the effect of buoyancy force was relaxed. The above investigations having a definite bearing on the problem of a Polymer sheet extruded continuously from a dye. It is usually assumed that the sheet is in extensible, but situations may arise in the polymer industry in which it is necessary to deal with a stretching plastic sheet, as noted by Crane [15]. The study of heat generation or absorption in moving fluids is important in the problems dealing with chemical reactions and these concerned with dissociating distribution. Consequently, the practice deposition rate in nuclear reactors, electronic chips and semi conductor waves. Vajravelu and Hadjinicolaou [39] have studied the heat characteristics in the laminar boundary layer of a viscous fluid over a stretching sheet with viscous dissipation or frictional heating and internal heat generation. Mohebujjaman et.al. [27] have studied the MHD heat transfer mixed convection flow along a vertical stretching sheet in presence of magnetic field with heat generation. Sajid et.al. [32] have discussed the non-similar analytic solution for MHD flow and heat transfer in a third-order fluid over a stretching sheet. Biliana et.al. [9] have analyzed the numerical solution of the boundary layer flow over an exponentially stretching sheet with thermal radiation. Jat et.al. [23] have studied the MHD flow and heat transfer over a stretching sheet.

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 [5] in the presence of a transverse magnetic field. In all these investigations the electrical conductivity of the fluid was assumed to be uniform. However, in an ionized fluid where the density is low and/or magnetic field is very strong, the conductivity normal to the magnetic field is reduced due to the spiraling of electrons and ions about the magnetic lines of force before collisions take place and a current induced in a direction normal to both the electric and magnetic fields. This phenomenon available in the literature is known as Hall Effect. Thus the study of MHD viscous flows, heat and mass transfer with Hall currents has important bearing in the engineering applications. Hall effect 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 [41]. Abo-Eldahab [3] have investigated free convective flows past a semi-infinite vertical plate with mass transfer. The effect of Hall current on the study MHD flow of an electrically conducting, incompressible Burger's fluid between two parallel electrically insulating infinite plane was studied by Rana et. al. [30].

Samadh et. al. [33] have studied MHD heat and mass transfer free convection flow along a vertical stretching sheet in the presence of magnetic field with heat generation. Seddeek [36] have studied the heat and mass transfer on a stretching sheet with a magnetic field in a visco-elastic fluid flow through a porous medium with heat source or sink. Veena et.al. [40] have discussed the non-similar solutions for heat and mass transfer flow in an electrically conducting visco-elastic fluid over a stretching sheet embedded in a porous medium. Hsiao [22] has analysed the heat and mass transfer for electrical conducting mixed convection with radiation effect for visco-elastic fluid past a stretching sheet. Shit [37] has studied Hall effects on MHD free convective flow on mass transfer over a stretching sheet. Raghavendra Rao [29] has discussed the effect of chemical reaction, Hall effects on the convective heat and mass transfer flow past a stretching sheet. Recently, Sreerangavani et al [38] has discussed the effect of Hall currents, thermal radiation and radiation absorption on mixed convective heat and mass transfer flow past a stretching sheet. Sarojamma et al [35] have discussed the influence of hall currents on cross diffusive convection in a MHD boundary layer flow on stretching sheet in porous medium with heat generation.

The study of heat source/sink effects on heat transfer is very important in view of several physical problems. Aforementioned studies include only the effect of uniform heat source/sink (i.e. temperature dependent heat source/sink) on heat transfer. Abo-Eldahab and El-Aziz [4] have included the effect of non uniform heat source with suction/blowing, but confined to the case of viscous fluid only. Abel et al. [1] investigated on non-Newtonian boundary layer flow past a stretching sheet taking into account of non-uniform heat source and frictional heating. Abel and Mahesha [2] studied the magnetohydrodynamic boundary layer flow and heat transfer characteristic of a non-Newtonian viscoelastic fluid over a flat sheet with variable thermal conductivity in the presence of thermal radiation and non-uniform heat source. They have reported that the combined effect of variable thermal conductivity, radiation and non-uniform heat source have significant impact in controlling the rate of heat transfer in the boundary layer region. Dulal Pal et al [16] studied the effect of variable viscosity on MHD non-Darcy mixed convective heat transfer over a stretching sheet embedded in a porous medium with non-uniform heat source/sink.

The motion of rotation fluids enclosed with in a body or vice versa, was given by Green span, discussed these problems relating to the boundary layers and their interaction in rotating flows and gave so many examples relating to such interaction. The rotating viscous flow equation yields a layer known as Eckman boundary layer after the Swedish oceanographer Eckman who discovered it. Attempts to observe the structure of the Eckman layer in the surface layers of the sea have been successful. Eckman layers are easy to produce and observe in the laboratory. Such boundary layers or similar ones are required to connect principally geotropic flow in the interior of the fluid to the horizontal boundaries where conditions like a prescribed horizontal stress or no slip on a solid bottom are given. In a similar way other kinds of various boundaries have been studies so as to connect geotropic flow to vertical boundaries (for example a vertical well along which the depth varies) on which boundary conditions consistent with geotropic flow are given. Mahendra Mohan [26] has discussed the free and forced convections in rotating Hydromagnetic viscous fluid between two finitely conduction parallel plates maintained at constant temperature gradients. In view of many scientific and engineering applications of fluids flow through porous media. Rao et.al. [28] made an investigation of the combined free and forced convective effects on an unsteady Hydro magnetic viscous incompressible flow in a rotating porous channel. This analysis has been extended to porous boundaries by Sarojamma and Krishna [34]. An initial value investigation of the hydro magnetic and convective flow of a viscous electrically conducting fluid through a porous medium in a rotating channel has been made by Krishna et.al. [24]. The fluid was subjected to an external uniform magnetic field perpendicular to the plane of the disk. The effects of uniform suction or injection through the disk on the unsteady MHD flow were also considered. Circar and Mukherjee [14] have analyzed the effect of mass transfer and rotation on flow past a porous plate in a porous medium with variable suction in a slip flow regime. Balasubramanyam [8] has investigated convective heat and mass transfer flow in horizontal rotating fluid under different conditions. Stanford Sateyi et al(38a) investigated the effect of Hall currents with Soret and Dufour effects on the flow on a vertical surface.

In this paper, we study the combined influence of Hall current,radiation and dissipation on convective heat and mass transfer flow of a viscous electrically conducting g fluid past a stretching sheet. The equations governing the flow , heat and mass transfer have been solved by Galerkin finite element analysis with three nodded line segments. The velocity, temperature and concentration have been analysed for different values of M, m, D^{-1}, N, F,γ, Sc,Ec ,Pr and Q. The rate of heat and mass transfer on the plate has been evaluated numerically for different variations.

2. FORMULATION OF THE PROBLEM:

We consider the steady flow of an incompressible, viscous ,electrically conducting fluid past a flat surface which is assuming from a horizontal slit on a vertical surface and is stretched with a velocity proportional to distance from a fixed origin O. We choose a stationary frame of reference O(x,y,z) such that x-axis is along the direction of motion of the stretching surface, y-axis is normal to this surface and z-axis is transverse to the xy-plane. The governing equations with Hall effects and Thermal Radiation are

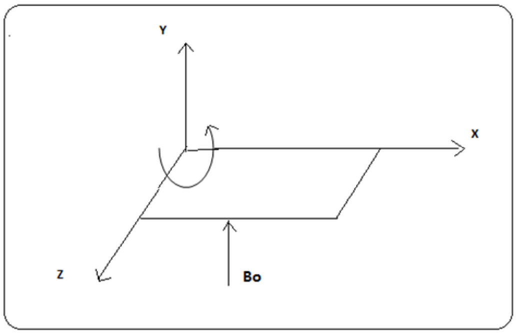

Fig.1 : Physical Configuration of the Problem

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma\mu_e H_0^2}{1+m^2}(u+mw)+ -(\frac{\nu}{k})\quad u\quad+\beta g(T-T_\infty)+\beta^{\bullet}g(C-C_\infty) \tag{1}$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}=\nu\frac{\partial^2 w}{\partial y^2})+\frac{\sigma\mu_e^2 H_0^2}{1+m^2}(m_0u-w)-(\frac{\nu}{k})\quad w \tag{2}$$

$$\rho C_p\left(u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}\right)=k_f\frac{\partial^2 T}{\partial y^2}-Q_H(T-T_\infty)+\frac{16\sigma^* T_\infty^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2}++\frac{\sigma\mu_e^2 H_o^2}{(1+m^2)}(u^2+w^2) \tag{3}$$

$$\left(u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial z}\right)=D\frac{\partial^2 C}{\partial y^2}-k_c(C-C_\infty) \tag{4}$$

where T is the temperature and C is the concentration in the fluid. k_f is the thermal conductivity, Cp is the specific heat at constant pressure, β is the coefficient of thermal expansion, $\beta^{\bullet}$ is the volumetric expansion with concentration, Q_H is the is the strength of the heat source, q_r is the radiative heat flux, kc is the chemical reaction coefficient, D is the molecular viscosity, k is the porous permeability parameter.
The boundary conditions for this problem can be written as

$$u=U_S=bx, v=-v_w, w=0, T=T_w, C=C_w \qquad at\ \ y=0 \tag{5}$$

$$u=w=0, T=T_\infty, C=C_\infty \qquad as\ \ y\to\infty \tag{6}$$

Where b>0.The boundary conditions on the velocity in(4) are the no-slip conditions at the surface at y=0,while the boundary conditions on the velocity as $y\to\infty$ follow from the fact that there is no flow far away from the stretching surface. The temperature and species concentration are maintained at a prescribed constant values T_w

and C_w at the sheet and are assumed to vanish far away from the sheet.
On introducing the similarity variables

$$\eta = \sqrt{\frac{b}{\nu}}\,y$$
$$u = bx\,f'(\eta)$$
$$v = -\sqrt{b\,\nu}\,f(\eta)$$
$$w = bx\,g(\eta)$$
$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}$$
$$\phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \tag{7}$$

the equations (1), (2) & (3) reduces to

$$f''' + f\,f'' - f'^2 + G(\theta + N\varphi) - D^{-1} f' - \frac{M^2}{1+m^2}(f' + mg) = 0 \tag{8}$$

$$g'' + fg' - (f' + \frac{M^2}{1+m^2})g - D^{-1}g + + \frac{mM^2}{1+m^2} f' = 0 \tag{9}$$

$$\theta'' + P_1 f\,\theta^1 - Q_1\theta + \frac{\Pr Ec M^2}{1+m^2}(f'^2 + g^2) = \tag{10}$$

$$\phi'' + Sc(\phi' f - \gamma\,\phi) = 0 \tag{11}$$

It is pertinent to mention that $\gamma > 0$ corresponds to a degenerating chemical reaction while $\gamma < 0$ indicates a generation chemical reaction.
The boundary conditions (5)&(6) are now obtained from (7) as

$$f'(0) = 1,\ \ f(0) = fw\ ,\quad \theta(0) = \phi(0) = 0 \tag{12}$$

$$f'(\infty) = g(\infty) = \theta(\infty) = 0 \tag{13}$$

Where $fw = \frac{v_w}{\sqrt{b\nu}}$ is the mass transfer coefficient such that fw>0 represents suction and fw<0 represents injection at the surface.
where

$G = \frac{\beta g(T_w - T_\infty)}{b^2 x}$ (Grashof number), $M^2 = \frac{\sigma\mu_e^2 H_0^2}{bx}$ (Hartmann number)

$D^{-1} = \frac{L^2}{k}$ (Inverse Darcy parameter), $N = \frac{\beta^*(C_w - C_\infty)}{\beta(T_w - T_\infty)}$ (Buoyancy ratio)

$Sc = \frac{\nu}{D}$ (Schmidt number), $\gamma = \frac{k_0}{b}$ (Chemical reaction parameter)

$\Pr = \frac{\mu C_p}{k_f}$ (Prandtl number), $fw = \frac{v_w}{\sqrt{b\nu}}$ (Mass transfer coefficient)

$Ec = \frac{U_s^2}{C_p \Delta T}$ (Eckert Number), $F = \frac{3\beta_R}{4\sigma^* T_\infty^3}$ (Radiation parameter)

$Q = \frac{Q_H \nu}{bk_f}$ (Heat source parameter)

$$N_2 = \frac{3F}{3F+4}, P_1 = \Pr N_2 \quad Q_1 = QN_2$$

For the computational purpose and without loss of generality ∞ has been fixed as 8.The whole domain is divided into 11 line elements of equal width, each element being three nodded.

3. THE METHOD OF SOLUTION

The Galerkinfinite element method has been implemented to obtain numerical solutions of coupled non-linear equations (8) to (11) of third-order in f and second order in h,θ, φ under boundary conditions (12) and (13). This technique is extremely efficient and allows robust solutions of complex coupled, nonlinear multiple degree differential equation systems. The fundamental steps comprising the method are [1996].

1]Discretization of the domain into elements
2] Derivation of element equations
3] Assembly of Element Equations
4] Imposition of boundary conditions
5] Solution of assembled equations

COMPARISON

The values of Skin friction on $\eta=0$ with M=1,m=G=N=Q==0,Ec=1,Pr=0.71 Sc=1 and fw= -0.7 are in good agreement with those of Stanford Sateyi et al(38a) and Elgazery (16a)

$1/D^{-1}$	Stanford Sateyi et al(38a)	Elgazert(16a)	**Preset results**
1	1.4170597047	1.417059047	**1.4169597042**
2	1.269413474	1.269413474	**1.2693994735**
5	1.173975065	1.173975965	**1.1729950674**
10	1.140805151	1.140805152	**1.1399051556**
15	1.129583275	1.125832753	**1.1288832798**

4. DISCUSSION OF THE NUMERICAL RESULTS

To obtain a physical insight of the problem, the profiles of velocity, temperature and concentration are graphically presented. The values of the parameters are fixed throughout the computations as M=m=G=1,N=1, D-1=0.2,Pr=0.71,F=0.5,Ec=0.1,γ=0.5,Sc=1.3 unless otherwise stated.

Figs.1a-1d represents the velocity components, temperature and concentration wit Hall parameter (m).It can be seen from the fig.4a that the primary velocity increases with increase in the Hall parameter(m).The secondary velocity decreases as the Hall parameter increases. The effect of Hall parameter on temperature and concentration is to increase them as a consequence of enhancing the thermal and solutal boundary layers(figs.1c&1d).

Figs. 2a-2d shows the variation of the velocity components, temperature and concentration with buoyancy ration(N). It can be seen from the profiles that when the molecular buoyancy force dominates over the thermal buoyancy force both the velocity components and concentration experience a enhancement when the buoyancy forces are in the same direction while fore the forces acting in opposite directions they reduces in the boundary layer. The temperature reduces with increase in N irrespective of the directions of the buoyancy forces.

The effect of chemical reaction parameter (γ) on the velocity, temperature and concentration can be seen from figs.8a-8d.It can be observed from the figures the primary velocity component and temperature increases in both degenerating and generating chemical reaction cases. The secondary velocity reduces in the degenerating chemical reaction and enhances in the generating case. The temperature reduces in both the degenerating/ generating chemical reaction cases. This is due to the fact that the thickness of the momentum boundary layer increases with increase in the chemical reaction parameter γ.An increase in $\gamma>0$,reduces the thermal boundary layer and reduces the solutal boundary layer while a reversed effect is noticed in the thickness of the thermal and solutal boundary layer thickness (figs. 3a-3d).

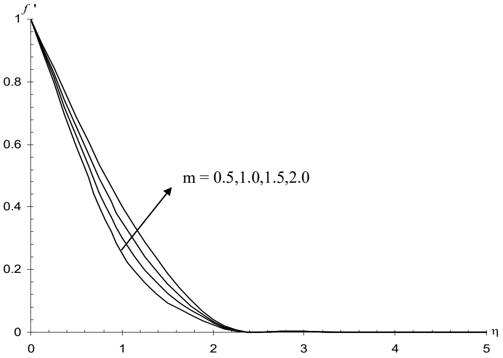

Fig. 1a : Variation of f' with m
G=2, M=0.5, D^{-1}=0.2,N=1,Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

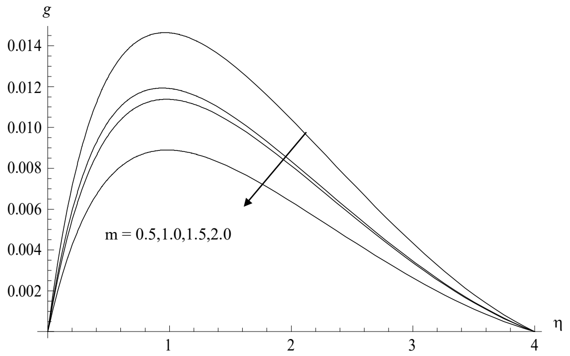

Fig. 1b : Variation of g with m
G=2, M=0.5, D^{-1}=0.2,N=1,Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

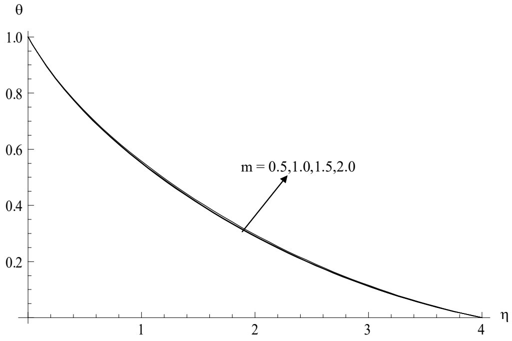

Fig. 1c : Variation of θ with m
G=2, M=0,D^{-1}=0.2,N=1,Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

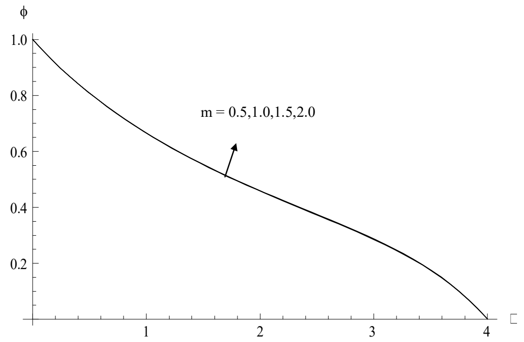

Fig. 1d : Variation of ϕ with m
G=2, M=0.5, D^{-1}=0.2,N=1,Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

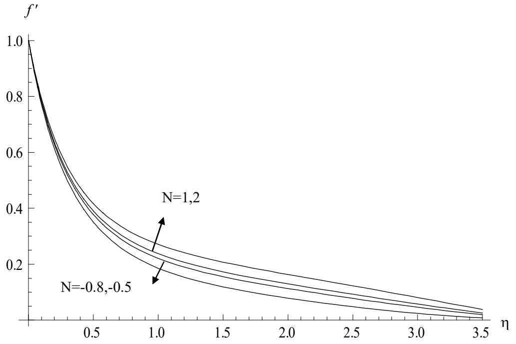

Fig. 2a : Variation of f' with N
G=2, M=0.5,m=0.5,D^{-1}=0.2,Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

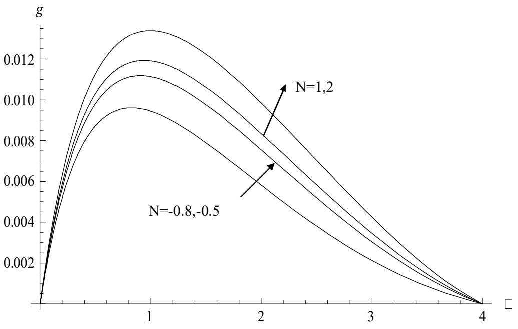

Fig. 2b : Variation of g with N
G=2, M=0.5,m=0.5,D^{-1}=0.2, Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

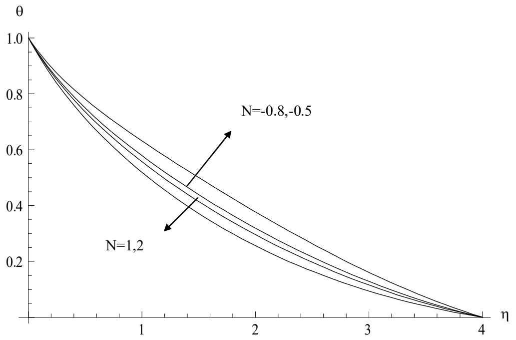

Fig. 2c : Variation of θ with N
G=2, M=0.5,m=0.5,D^{-1}=0.2, Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

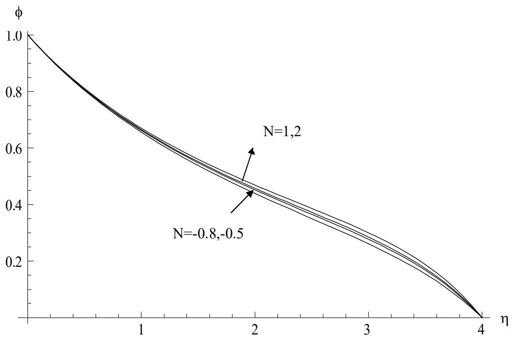

Fig. 2d : Variation of ϕ with N
G=2, M=0.5,m=0.5,D^{-1}=0.2, Sc=1.3, γ=0.5,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

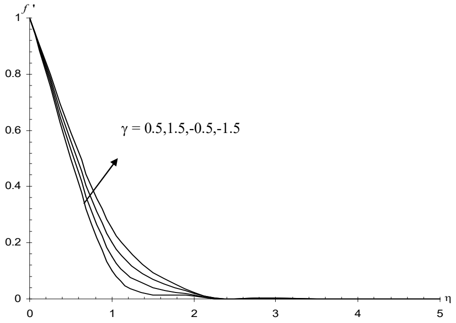

Fig. 3a : Variation of f' with γ
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

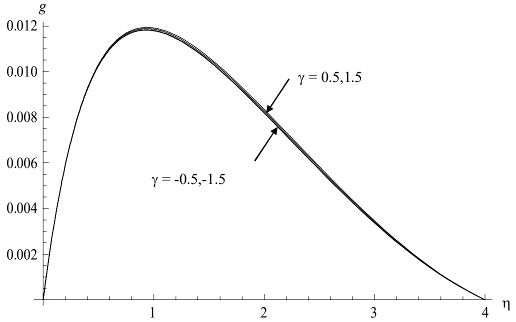

Fig. 3b : Variation of g with γ
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

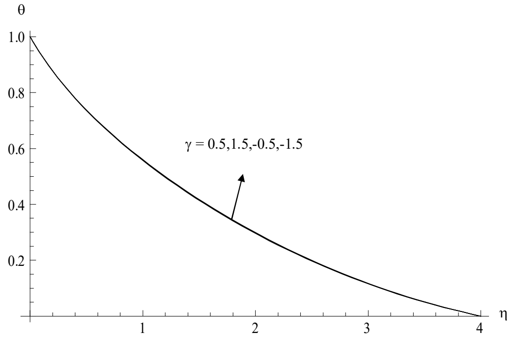

Fig. 3c : Variation of θ with γ
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

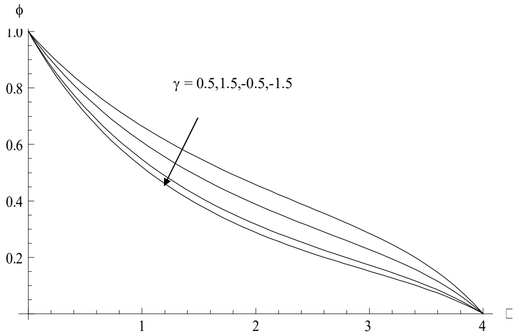

Fig. 3d : Variation of ϕ with γ
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
Q=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

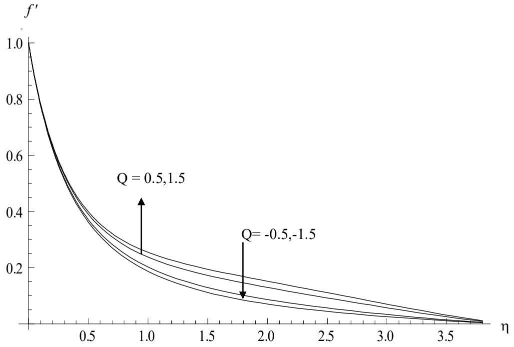

Fig. 4a : Variation of f' with Q
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

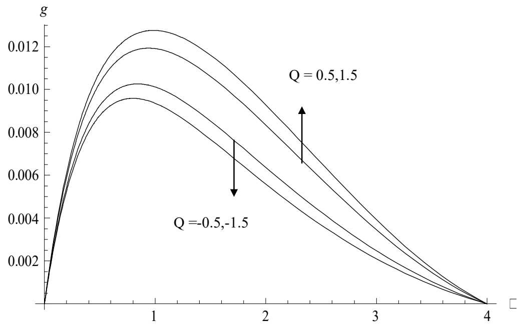

Fig. 4b : Variation of g with Q
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

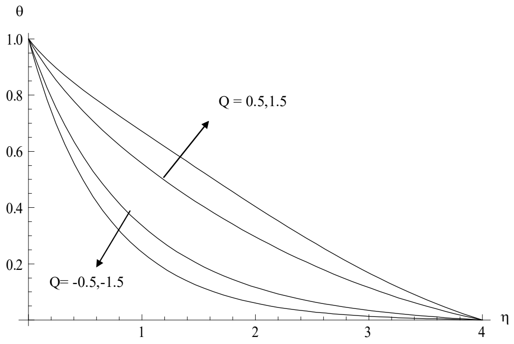

Fig. 4c : Variation of θ with Q
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

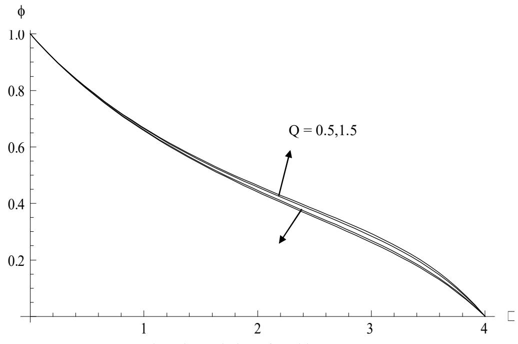

Fig. 4d : Variation of ϕ with Q
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Ec=0.01, f_w=0.2, F=2, Pr=0.71

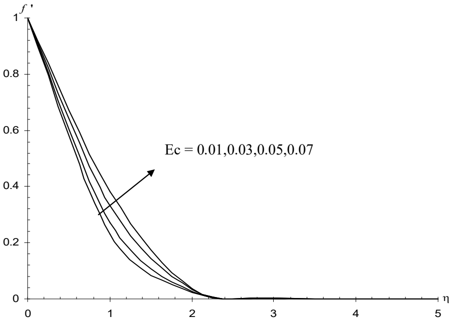

Fig. 5a : Variation of f' with Ec
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, f_w=0.2, F=2, Pr=0.71

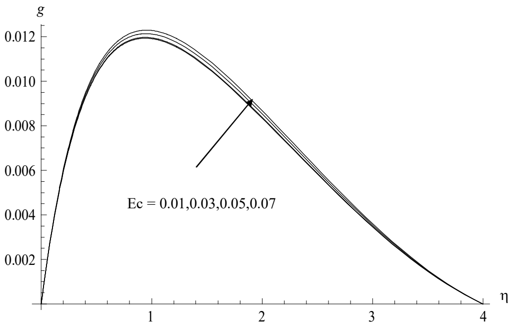

Fig. 5b : Variation of g with Ec
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, f_w=0.2, F=2, Pr=0.71

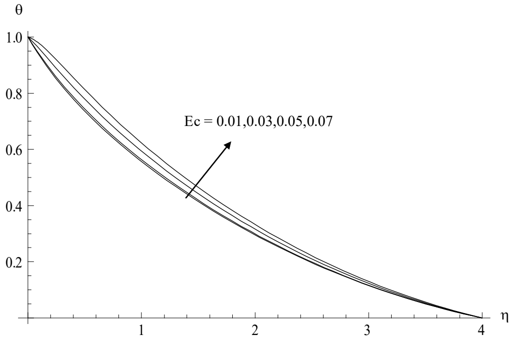

Fig. 5c : Variation of θ with Ec
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, f_w=0.2, F=2, Pr=0.71

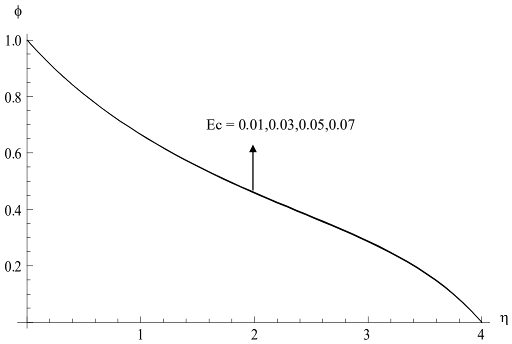

Fig. 5d : Variation of ϕ with Ec
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, f_w=0.2, F=2, Pr=0.71

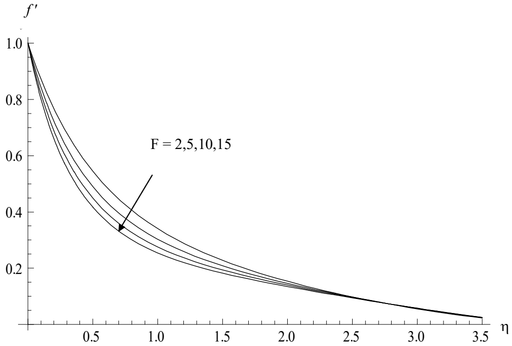

Fig. 6a : Variation of f' with F
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, Ec=0.01, f_w=0.2, Pr=0.71

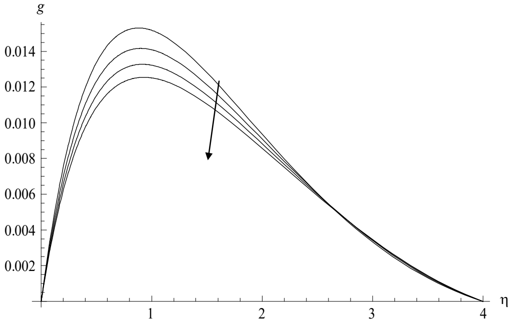

Fig. 6b : Variation of g with F
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, Ec=0.01, f_w=0.2, Pr=0.71

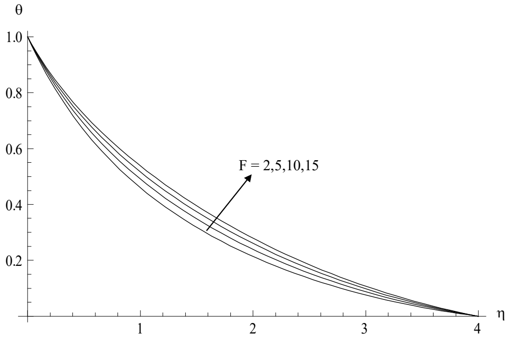

Fig. 6c : Variation of θ with F
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, Ec=0.01, f_w=0.2, Pr=0.71

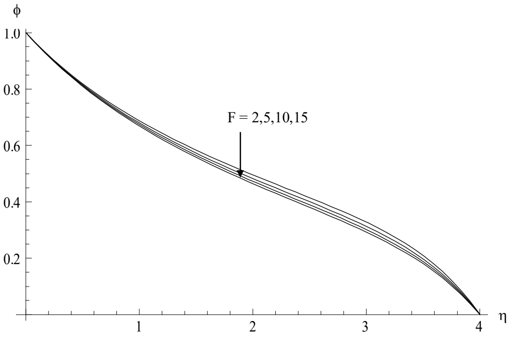

Fig. 6d : Variation of ϕ with F
G=2, M=0.5,m=0.5,D^{-1}=0.2,N=1,Sc=1.3,
γ=0.5, Q=0.5, Ec=0.01, f_w=0.2, Pr=0.71

Figs.4a-4d represent the velocity components, temperature and mass concentration with heat generating/absorption source. An increase in the temperature dependent source enhances the primary and secondary velocities owing to the generation of energy in the boundary layer while in the case of heat absorption source, they reduces in the boundary layer owing to the absorption in the boundary layer. The temperature and mass concentration increases with strength of heat degenerating source and an opposite effect is observed in the case of heat absorption.

Figs.5a-5d show the variation of velocity,tempertature and concentration with Eckert number(Ec).It is pointed out that the presence of Eckert number reduces the velocity components. This is due to the fact that the energy is absorbed in the fluid .An increase in Ec increases the temperature .This is owing to the fact that the thermal energy is reserved in the fluid on account of frictional heating .Hence, the temperature distribution rises in the entire thermal boundary layer. Also an increase in Ec results in an enhancement in the mass concentration(10d).

Figs.6a-6d represents the effect of radiation parameter(F) on velocity, temperature and concentration. It is found that there is a significant fall in the primary and secondary velocity components in the presence of thermal radiation throughout the boundary layer. The presence of thermal radiation is very significant on the variation of temperature. It is seen that the temperature increases rapidly in the presence of thermal radiation parameter(F) throughout the thermal boundary layer. This may be attributed to the fact that as the Rosseland radiative absorption parameter R diminishes the corresponding heat flux diverges and thus rising the rate of radiative heat transfer to the fluid causing a rise in the temperature of the fluid. The thickness of the boundary layer also increases in the presence of F. The effect of F on mass concentration is to reduce it in the solutal boundary layer(fig.12d).

The skin friction coefficients (τ_x) and (τ_z) are exhibited in table.1 for different values of m,N,γ,Ec,Q and F. An increase in Hall parameter $m \leq 1.0$, reduces (τ_x) and enhances (τ_z) on the wall. While for higher $m \geq 1.5$,we observe an opposite effect in their behaviour. With respect to buoyancy ratio N,we find that when the molecular buoyancy force dominates over the thermal buoyancy force the stress component (τ_x) reduces and (τ_z) enhances when the buoyancy forces are in the same direction and for the forces acting in opposite directions an reversed effect is noticed. The variation of stress with chemical reaction parameter γ shows that τ_x increases and τ_z reduces in the degenerating chemical reaction case while in the generating chemical reaction case both the stress components increase on the wall. Higher the dissipation lesser the stress component (τ_x) and larger (τ_z) s on the wall. An increase in the radiation parameter F reduces increases the (τ_x) and reduces (τ_z) on the wall. An increase in Q>0 decreases τ_x and τ_z on the wall while for Q<0,we notice an enhancement in (τ_x) and reduction in (τ_z) on the wall fixing the other parameters.

The rate of heat transfer (Nulsselt number) at the wall $\eta=0$ is exhibited in table.1.for different parametric variations. The rate of heat transfer increases with increase in N when the buoyancy forces are in the same direction and reduces when they act in opposite directions. Lesser the molecular diffusivity larger the rate of heat transfer .It decreases in the degenerating chemical reaction case and increases in the generating case. Higher the radiation parameter or dissipation smaller the Nusselt number. The variation of Nu with heat source parameter Q shows that the rate of heat transfer reduce with increase in the strength of the heat generating source and enhances with that of heat absorption.

The rate of mass transfer (Sherwood Number) at the wall $\eta=0$ is shown in table.1 for different variations. It is found that the rate of mass transfer at the wall reduces with hall parameter (m).Thus higher the Lorentz force/lesser the permeability of the porous medium larger the Sherwood number at the wall. The rate of mass transfer at the wall reduces with increase in the buoyancy ratio(N) when the buoyancy forces are in the same direction and for the forces acting in opposite directions, it increases on the wall. The rate of mass transfer increases in the degenerating chemical reaction case and reduces in the generating chemical reaction case. The rate of mass transfer decreases with increase in Q>0 and enhances with for Prandtl number Q<0.

Table.1
Values of Skin friction components, Nusselt number, Sherwood number at $\eta=0$

	$\tau_x(0)$	$\tau_z(0)$	Nu(0)	Sh(0)
m 0.5	-2.58529	0.0384736	0.706831	0.458223
1.0	-2.56273	0.0458714	0.713731	0.457565
1.5	-2.55808	0.0407987	0.715223	0.457424
2.0	-2.55476	0.0349737	0.7163	0.457323
N 1.0	-2.58529	0.0384736	0.706831	0.458223
2.0	-2.48359	0.0407265	0.759617	0.453661
-0.5	-2.63538	0.0373088	0.677272	0.460578
-1.5	-2.73897	0.0347905	0.60691	0.465668
Gm 0.5	-2.58529	0.0384736	0.706831	0.458223
1.5	-2.58866	0.0382192	0.700644	0.980856
-0.5	-2.48004	0.0224172	-0.232779	-0.925687
-1.5	-2.58422	0.0356775	0.639381	-0.123309
Ec 0.01	-2.58529	0.0384736	0.706831	0.458223
0.03	-2.58354	0.0385311	0.645849	0.458104
0.05	-2.57589	0.0387823	0.376777	0.457585
0.07	-2.56842	0.039025	0.112517	0.457082
Q 0.5	-2.58529	0.0384736	0.706831	0.458223
1.5	-0.86027	0.00906248	0.0250418	0.129374
-0.5	-2.62176	0.036137	1.1957	0.462301
-1.5	-2.64053	0.035115	1.50689	0.464186
F 2	-1.40993	0.0471684	0.887249	0.436374
4	-1.76923	0.0442288	0.828533	0.443626
6	-2.07404	0.0419333	0.781128	0.449379
10	-2.58529	0.0384736	0.706831	0.458223

5. CONCLUSIONS:

The coupled equations governing the flow, heat and mass transfer have been solved by using Galerkin finite element technique. The important conclusions of this analysis are

- An increase in the Grashof number enhances the velocity, temperature and concentration. The stress component τx and Sherwood number reduces on the walls while τy and Nusselt number enhances on the walls.
- Higher the Lorentz force/lesser the permeability of the porous permeability reduces the velocity and enhances the concentration while the temperature increases with M and reduces with D-1.The stress components and Sherwood number increase and the Nusselt number reduces on the walls.
- An increase in Hall parameter (m) enhances the velocity components, temperature and concentration, τz, Nu and reduces τx, Sh on the walls.
- 4)Irrespective of the directions of the buoyancy forces the velocity, and concentration enhances and the temperature reduces in the flow region The Nusselt number increases and Sherwood number reduces with N>0 and a reversed effect is noticed with N<0.
- The velocity and temperature enhances in both degenerating and generating chemical reaction cases. The concentration reduces with $\gamma>0$ and increases with $\gamma<0$.The rate of heat transfer reduces and mass transfer increases with $\gamma>0$ and a reversed effect is noticed with increase in $\gamma<0$.
- Higher the dissipation smaller the velocity, larger the temperature and concentration. The rate of heat and mass transfer reduces on the walls with increase in Ec.
- Higher the radiative heat flux smaller the velocity, larger the temperature and concentration. The rate of heat transfer reduces and mass transfer enhances on the walls with F.
- Higher the thermal diffusivity larger the velocity, temperature and concentration .The rate of heat transfer reduces and mass transfer enhances on the walls.

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