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SORET AND HALL EFFECT ON MHD FLOW, HEAT AND MASS TRANSFER OVER A VERTICAL STRETCHING SHEET IN A POROUS MEDIUM DUE TO HEAT GENERATION

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ABSTRACT

The present study is considered by the effect of Soret and Hall current due to heat generation on coupled heat and mass transfer by megnetohydrodynamic (MHD) free convection over a permeable vertical stretching sheet. The governing boundary layer equations are formulated and transformed into a set of similarity equations using dimensionless similarity variables. The governing fundamental set of a system of non-linear locally similar ordinary differential equations are solved numerically by Runge-Kutta fourth-fifth order integration scheme along with shooting technique. Numerical results for dimensionless velocity, Temperature and concentration profiles displayed graphically for pertinent parameters to show interesting aspects of the solutions. Also the skin friction coefficient, the rate of heat transfer and rate of concentration are presented in Table 1.

Keywords: heat generation, MHD, porous medium, Soret and Hall effects, stretching sheet.

1. INTRODUCTION

The heat source/sink effects in thermal convection, are significant where there may exist a high temperature differences between the surface (e.g. space craft body) and the ambient fluid. Heat generation is also important in the context of exothermic or endothermic chemical reaction. In recent years MHD flow problems have become in view of its significant applications in industrial manufacturing processes such as plasma studies, petroleum industries Magneto hydrodynamics power generator cooling of clear reactors, boundary layer control in aerodynamics. Many authors have studied the effects of magnetic field on mixed, natural and force convection heat and mass transfer problems. The effect of free convection on the accelerated flow of a viscous incompressible fluid past an infinite vertical plate with suction has many important technological applications in the astrophysical, geophysical and engineering problems. The heating of rooms and buildings by the use of radiators is a familiar example of heat transfer by free convection. Heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion devices for aircraft, combustion and furnace design, materials processing, energy utilization, temperature measurements. Such application includes the flow of exotic lubricants colloidal suspensions, solidification of liquid crystals, extrusion of polymer fluids, cooling of metallic plate hipbath, animal blood, body fluids and many other situations. The study of effects of porous media is a topic of rapidly growing interest on heat and mass transfer due to of its many engineering applications in the field of chemical, geophysical sciences, geothermal reservoirs, thermal insulation engineering, exploration of petroleum and gas fields, water movements in geothermal reservoirs, etc. 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 in solution of the surface more effective. Previous studies deals 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, where the magnetic field is applied in the visco-elastic fluid flow. The study of convective heat transfer mechanisms through porous media in relation to the applications to the above areas has been made by Nield and Bejan (1998). Many researchers are investigated to the unsteady free convective flow past infinite or semi-vertical plates due to its important technological applications. The presence of suction being more important and appropriate from the technological point of view, recently, the study of free convective mass transfer flow has become the object of extensive research as the effects of heat transfer along with mass transfer effects are dominant features in many engineering applications such as rocket nozzles, cooling of nuclear reactors, high sinks in turbine blades, high speed aircrafts and their atmospheric re-entry, chemical devices and process equipments. Sharma (2004) studied unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system. But in these papers thermal diffusion effects have been neglected, whereas in a convective fluid when the flow of mass is caused by a temperature difference, thermal diffusion effects cannot be neglected. In view of the importance of this diffusion-thermo effect, Jha and Singh (1990) presented an analytical study for free convection and mass transfer flow past an infinite vertical plate moving impulsively in its own plane taking Soret effects into account. The unsteady free convection flow of a viscous incompressible fluid past an infinite vertical plate with constant heat flux is considered on taking into account viscous dissipative heat, under the influence of a transverse magnetic field studied by Srihari K *et al*. (2006). Ramana, Kumari and Bhaskar Reddy (1994) have studied a two-dimensional unsteady MHD free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous plate with variable suction. Suneetha (2009) examined the problem of radiation and mass transfer effects on MHD free convection flow past an impulsively started isothermal vertical plate with dissipation. Seddek and Salama (2007) studied the effect of temperature dependent viscosity and thermal conductivity on unsteady MHD convective heat transfer past a semi-infinite vertical porous plate. In recent years, progress has been considerably made in the study of heat and mass transfer in magneto hydrodynamic flows due to its application in many devices, like the MHD power generator and Hall accelerator. The influence of magnetic field on the flow of an electrically conducting viscous fluid with mass transfer and radiation absorption is also useful in planetary atmosphere research. Kinyanjui *et al*. (2001) presented simultaneous heat and mass transfer in unsteady free convection flow with radiation absorption past an impulsively started infinite vertical porous plate subjected to a strong magnetic field. Yih (1997) numerically analyzed the effect of transpiration velocity on the heat and mass transfer characteristics of mixed convection about a permeable vertical plate embedded in a saturated porous medium under the coupled effects of thermal and mass diffusion. Elbashbeshy (2003) studied the effect of surface mass flux on mixed convection along a vertical plate embedded in porous medium. Chin *et al.* (2007) obtained numerical results for the steady mixed convection boundary layer flow over a vertical impermeable surface embedded in a porous medium when the viscosity of the fluid varies inversely as a linear function of the temperature. Pal and Talukdar (2010) analyzed the combined effect of mixed convection with thermal radiation and chemical reaction on MHD flow of viscous and electrically conducting fluid past a vertical permeable surface embedded in a porous medium is analyzed. Mukhopadhyay (2009) performed an analysis to investigate the effects of thermal radiation on unsteady mixed convection flow and heat transfer over a porous stretching surface in porous medium. Hayat *et al*. (2010) analyzed a mathematical model in order to study the heat and mass transfer characteristics in mixed convection boundary layer flow about a linearly stretching vertical surface in a porous medium filled with a visco-elastic fluid, by taking into account the diffusion thermo (Dufour) and thermal-diffusion (Soret) effects. G. V. Ramana Reddy *et al*. (2011) studied unsteady MHD free convective mass transfer flow past an infinite vertical porous plate with variable suction and Soret effect. Soundalgekar *et al.* (1977) analyzed the problem of free convection effects on Stokes problem for a vertical plate under the action of transversely applied magnetic field. Helmy (1998) presented an unsteady two-dimensional laminar free convection flow of an incompressible, electrically conducting (Newtonian or polar) fluid through a porous medium bounded by an infinite vertical plane surface of a constant temperature. Zueco (2006) analyzed the hydromagnetic convection past a flat plate. Sparrow and Cess (1961) provided one of the earliest studies using a similarity approach for stagnation point flow with heat source/sink which vary in time. Pop and Soundalgekar (1962) studied unsteady free convection flow past an infinite plate with constant suction and heat source. Hossain *et al.* (2004) studied problem of the natural convection flow along a vertical wavy surface with uniform surface temperature in the presence of heat generation/absorption. Chamkha and Khaled (2001) obtained similarity solution of natural convection on an inclined plate with internal heat generation/absorption in presence of transverse magnetic field. Molla *et al*. (2004) observed the effect of heat generation/absorption on natural convection along a wavy surface. Shrama and Singh (2010) have studied the Steady MHD Natural Convection Flow with Variable Electrical Conductivity and Heat Generation along an Isothermal Vertical Plate. Tania *et al*. (2010) considered the effects of Radiation, Heat Generation and Viscous Dissipation on MHD Free Convection Flow along a Stretching Sheet. In all these studies Soret / Dufour effects are assumed to be negligible. Such effects are significant when density differences exist in the flow regime. For example when species are introduced at a surface in fluid domain, with different (lower) density than the surrounding fluid, both Soret and Dufour effects can be significant. Also, when heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of more complex nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The thermal-diffusion (Soret) effect, for instance, has been utilized for isotope separation, and in mixture between gases with very light molecular weight (H2, He) and of medium molecular weight (N_2, air), the diffusion-thermo (Dufour) effect was found to be of a considerable magnitude such that it cannot be ignored (Eckert and Drake (1972)). In view of the importance of these above mentioned effects, Dursunkaya and Worek (1992) studied diffusion-thermo and thermal-diffusion effects in transient and steady natural convection from a vertical surface, whereas Kafoussias and Williams (1995) presented the same effects on mixed free-forced convective and mass transfer boundary layer flow with temperature dependent viscosity. Maleque (2010) was discussed by Dufour and Soret effects on unsteady MHD convective heat and mass transfer flow due to a rotating disk. Sravan *et al*. (2012) have analyze the effect of Soret parameter on the onset of double diffusive convection in a Darcy porous medium saturated with couple stress fluid. The objective of the present paper is to study the Hall and MHD effect as well as Soret effects on the steady free convective mass transfer flow over a vertical porous plate with heat generation. 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 velocities, temperature and the concentration distributions of the flow filed are discussed and shown through graphs. The results are analyzed for various physical parameters such as of the permeability, magnetic field, Local thermal Grashof number, Local solutal Grashof number, Schmidt number, Prandtl number, Soret and Dufour numbers and Hall parameter on the flow, heat and mass transfer characteristics. Also the skin friction coefficient, the rate of heat transfer and rate of concentration are presented in Table 1.

2. FORMULATION OF THE PROBLEM AND SIMILARITY ANALYSIS

Let us consider steady two dimensional MHD free convection heat and mass transfer in an incompressible electrically conducting fluid flow with Soret and Dufour effects. The flow is subjected to a transverse magnetic field of strength B_0 which is assumed to be applied in the positive y -direction, normal to the surface. The pressure gradient, body force, viscous dissipation and joule heating effects are neglected compared with effects of with internal heat source/sink. 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 with the presence of Hall current are:

Equation of continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

Momentum equation:

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

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

Energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{\sigma B_0^2}{\rho c_p(1+m^2)}(u^2+w^2)-\frac{Q}{\rho c_p}(T-T\infty)+\frac{DK}{c_s c_p}\frac{\partial^2 c}{\partial y^2} \tag{4}$$

Concentration equation:

$$u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D\frac{\partial^2 c}{\partial y^2}-k_0(C-C_\infty)+\frac{DK}{T_m}\frac{\partial^2 T}{\partial y^2} \tag{5}$$

Boundary conditions are:

$$u=Ax,\ v=w=0,\ T=T_w,\ C=C_w \quad \text{at} \quad y=0$$

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

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

$$w=Axg_0(\eta),\ \eta=y\sqrt{\frac{A}{\nu}},\ \psi=x\sqrt{\nu A}f(\eta),\ \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\ \varphi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}$$

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

$$f'''+ff''+G_r\theta+G_c\varphi-\frac{M}{1+m^2}f'-\frac{Mm}{1+m^2}g_0-f'=0 \tag{6}$$

$$g_0''+fg_0'-f'g_0-\frac{M}{1+m^2}g_0+\frac{Mm}{1+m^2}f'-K'g_0=0 \tag{7}$$

$$\theta''+f\theta'+E_c MP_r\frac{f'^2+g_0^2}{1+m^2}-P_rQ^*\theta+D_f\varphi''=0 \tag{8}$$

$$\varphi''+S_c f\varphi'-\zeta\varphi+S_0\theta''=0 \tag{9}$$

The transform boundary conditions:

$$f=0,\ g_0=0,\ g_0'=0,\ f'=1,\ \theta=\varphi=1 \ \text{at} \ \eta=0$$

$$f=f'=g_0=\theta=\varphi=0 \ \text{as} \ \eta\to\infty$$

3. RESULTS AND DISCUSSIONS

The system of ordinary differential equations (6)-(9) subject to the boundary conditions is solved numerically by Runge- Kutta fourth-fifth order method using symbolic software. First of all, higher order non-linear differential equations (6) - (9) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique. The resultant initial value problem is solved by employing Runge-Kutta fourth-fifth order technique. 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), Permeability parameter (k^*), Mass Grashof number (G_m), Soret Number (S_0), Dufour number (D_f), Heat source/sink parameter (Q^*) and reaction parameter (ξ) of an incompressible fluid over a vertical stretching sheet. 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 taking Pr =0.71 and Pr =1.0 for velocity profiles and temperature, concentration profiles respectively. The effects of various parameters on primary and secondary velocity profiles in the boundary layer are shown in Fig. 1-Fig.10. In Fig.1 the effect of the magnetic field strength on the momentum boundary layer thickness is illustrated. It is now a well established fact that the magnetic field presents a damping effect on the primary velocity field by creating drag force that opposes the fluid motion, causing the primary velocity to decrease for increasing values of M whereas noticeable increasing effect on secondary velocity shown in Fig.8. In Fig.2, Fig.4, Fig.5, and Fig.7 are shown the effect of m, Gr, Sc, and k' respectively. It is noticed that in each case the primary velocity is increased but it is observed that a negligible increasing effect for Sc, and k'. Also reverse trend arises for Pr (Fig.3). From Fig.6 it is observed that, there is no effect on the velocity profile for increasing values of ξ. From Fig.9 and Fig.10 it is seen that secondary velocity decrease for increasing values of m and Gr but noticeable decreasing effects for m. In Fig.11 – Fig.19 illustrate the temperature profiles for different values of entering parameters. From Fig.11, Fig.13, Fig.15, Fig.16, Fig.17 and Fig.19 it is observed that the temperature increase for the increasing values of M, S0 $(0\le\eta\le1.3)$, Gr, Sc, ξ and Df but noticeable increasing effect for M and ξ. The reverse trend arises for m (Fig.12) and Q* (Fig.18). From Fig.14 it is interesting to note that the temperature is decreased for air and salt water but for fresh water it is decreased in the interval $(0\le\eta\le0.7)$ and then noticeable increasing effects, i.e. for fresh water the thermal boundary layer is thicker far away from the plate. Fig.20-Fig.28 give the distribution of concentration species for different values of Magnetic parameter (M), Hall Parameter (m), Prandtl number (Pr), Scmidt number (Sc), Grashof number (Gr), Permeability parameter (k'), Soret Number (S0), Dufour number (Df), Heat source/sink parameter (Q*) and reaction parameter (ξ). From these figure the concentration is increased for m, S0, Pr, Q* and decreased for M, Sc, ξ, and Df bur there is no effect of k' on concentration profile. It is observed from Fig.23 that, a negligible increasing effect on concentration for air and salt water but noticeable increasing effects arises for fresh water. Table -1 exhibits the behavior of $f''(0)$, $-\theta'(0)$, and $-\varphi'(0)$, for various values of magnetic parameter, Hall parameter, Prandtl number, and Grashof number. From Table- 1, it is observed that $f''(0)$ is decreased for various values of M, and P_r and increased for increasing values of m, and Gr. Again, it is observed that $-\theta'(0)$, is decreased with the increasing values of m, but increased for increasing values of M, Pr and G_r. Also, we see that $-\varphi'(0)$, is increased with the increase of m, and Pr and decreased for M

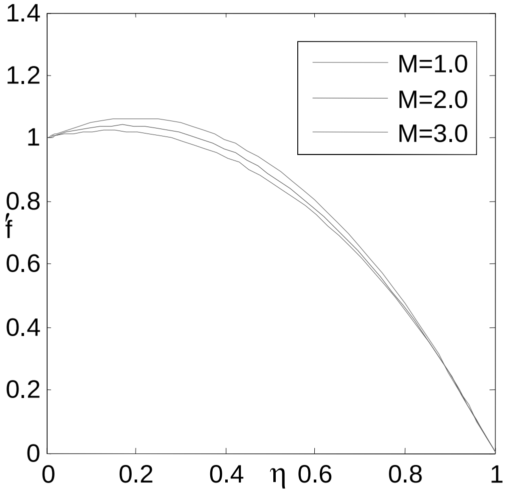

Figure-1. Primary velocity profile for various values of M and m = 1.0, S_0=1.0, P_r=0.71,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

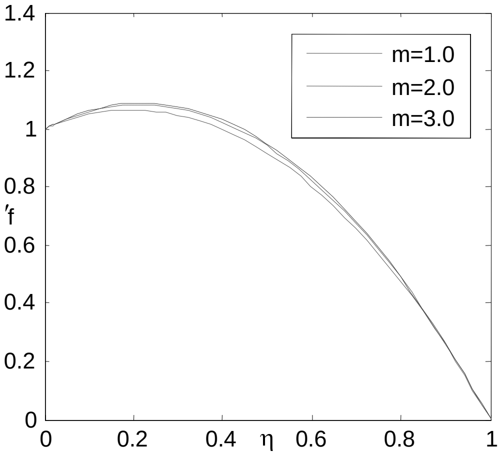

Figure-2. Primary velocity profile for various values of m and M = 1.0, S_0=1.0, P_r=0.71,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

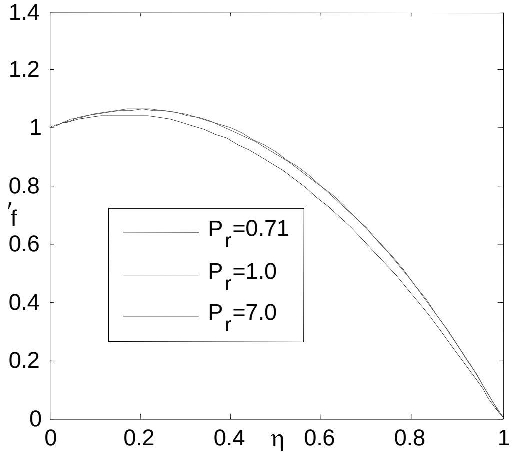

Figure-3. Primary velocity profile for various values of P_r and M = 1.0, m =1.0, S_0=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

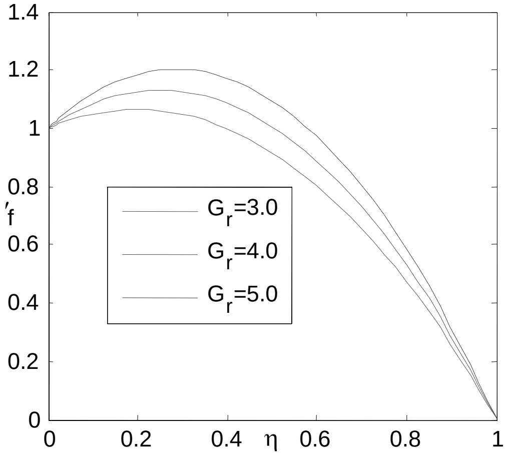

Figure-4. Primary velocity profile for various values of G_r and M = 1.0, m =1.0, P_r=0.71, S_0=1.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

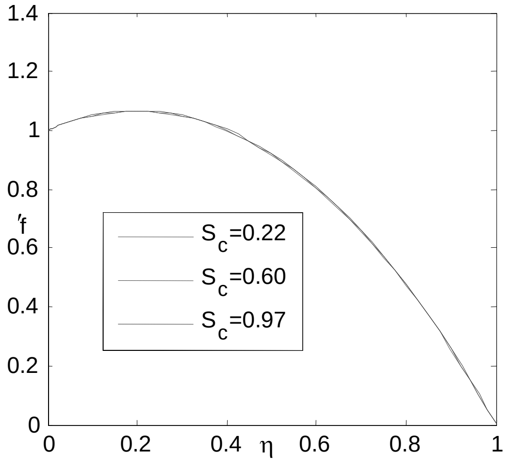

Figure-5. Primary velocity profile for various values of S_c and M = 1.0, m =1.0, P_r=0.71, S_0=1.0, G_m=3.0, G_r =3.0, E_c =1.0, ξ=1.0, Q^*=3.0, $K^'$=1.0, D_f=1.0.

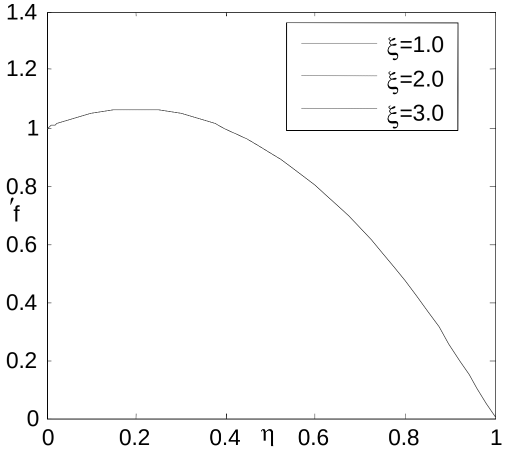

Figure-6. Primary velocity profile for various values of ξ and M = 1.0, m =1.0, P_r=0.71, S_0=1.0, G_m=3.0, G_r =3.0, S_c=0.22, E_c =1.0, Q^*=3.0, $K^'$=1.0, D_f=1.0.

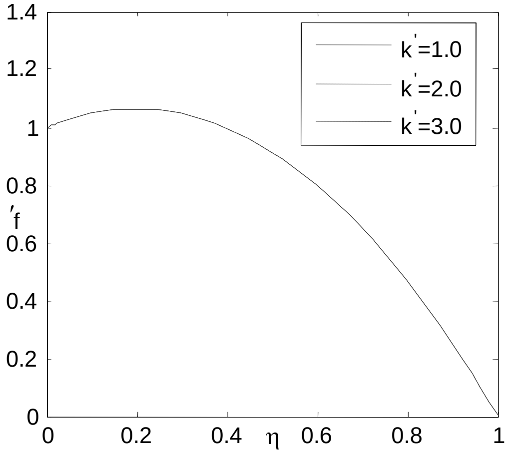

Figure-7. Primary velocity profile for various values of $K^'$ and M = 1.0, m =1.0, P_r=0.71, S_0=1.0, ξ =1.0, G_r =3.0, S_c=0.22, E_c =1.0, Q^*=3.0, G_m =3.0, D_f=1.0.

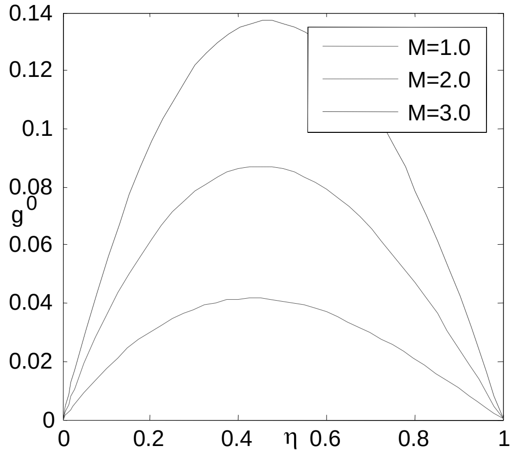

Figure-8. Secondary velocity profile for various values of M and m = 1.0, S_0=1.0, P_r=0.71,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^'$=1.0, D_f=1.0.

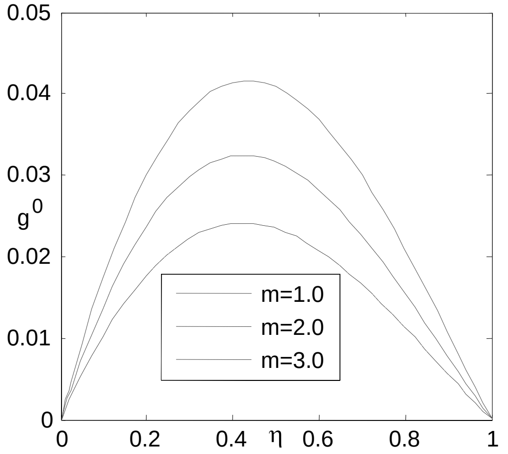

Figure-9. Secondary velocity profile for various values of m and M = 1.0, S_0=1.0, P_r=0.71,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^'$=1.0, D_f=1.0.

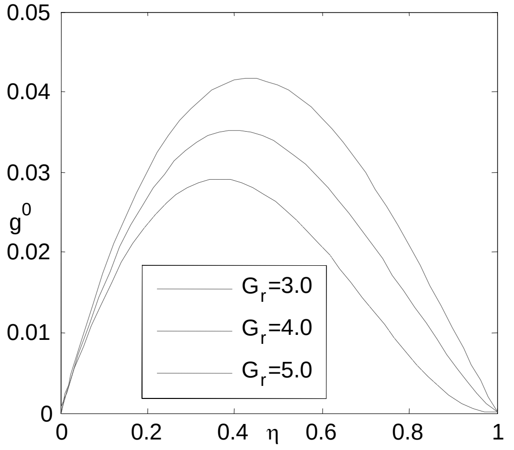

Figure-10. Secondary velocity profile for various values of G_r and M = 1.0, m =1.0, P_r=0.71, S_0=1.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^'$=1.0, D_f=1.0.

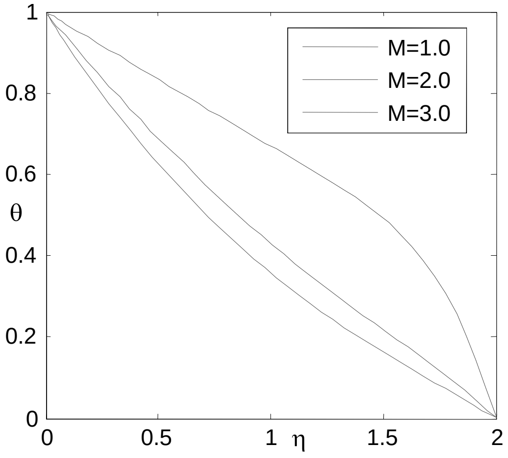

Figure-11. Temperature profile for various values of M and m = 1.0, S_0=1.0, P_r=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

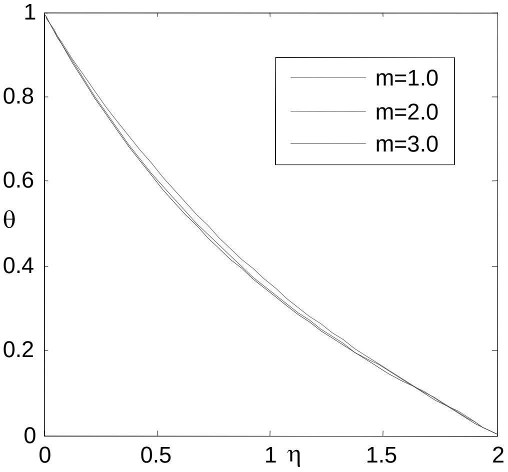

Figure-12. Temperature profile for various values of m and M = 1.0, S_0=1.0, P_r=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

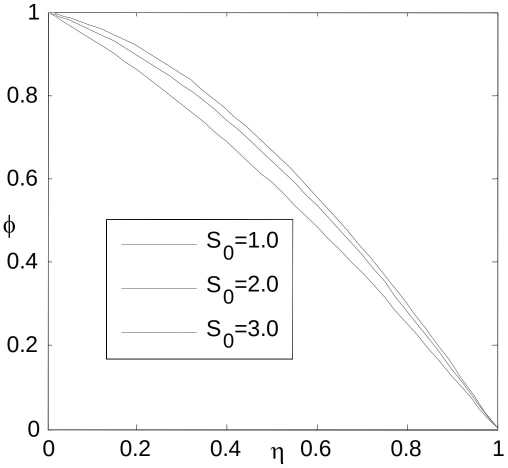

Figure-13. Temperature profile for various values of S_0 and M = 1.0, m=1.0, P_r=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

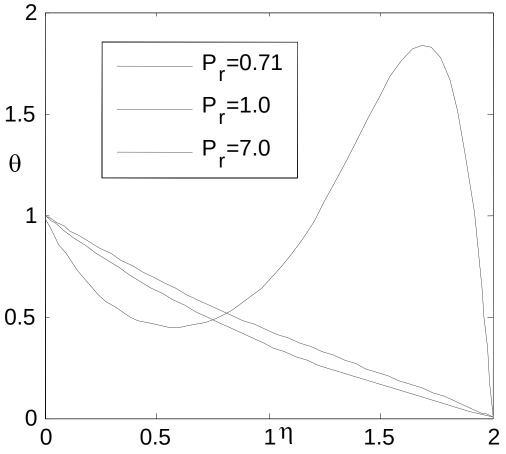

Figure-14. Temperature profile for various values of P_r and M = 1.0, m =1.0, S_0=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

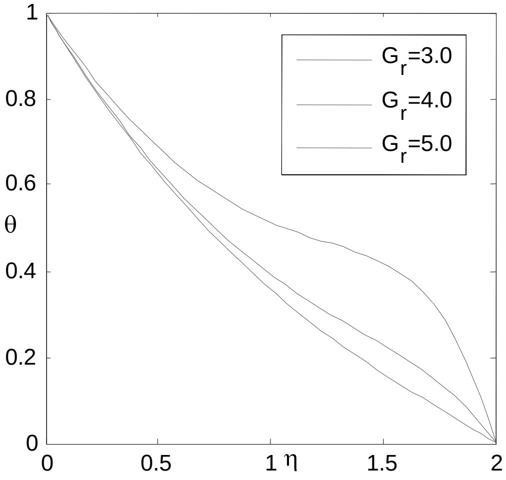

Figure-15. Temperature profile for various values of G_r and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

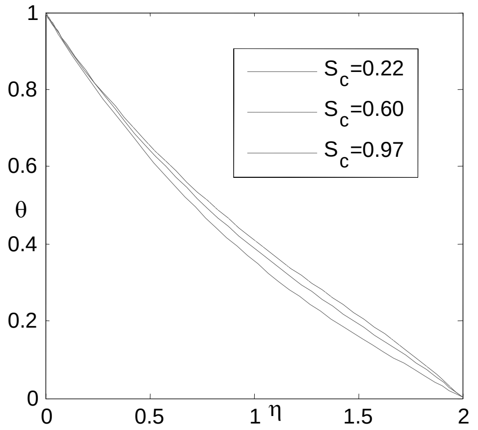

Figure-16. Temperature profile for various values of S_c and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, G_r =3.0, E_c =1.0, ξ=1.0, Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

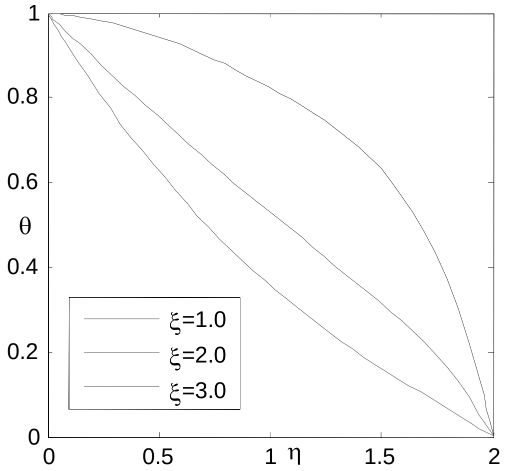

Figure-17. Temperature profile for various values of ξ and $M = 1.0$, $m = 1.0$, $P_r=1.0$, $S_0=1.0$, $G_m=3.0$, $G_r = 3.0$, $E_c = 1.0$, $S_c=0.22$, $Q^*=3.0$, $K'=1.0$, $D_f=1.0$.

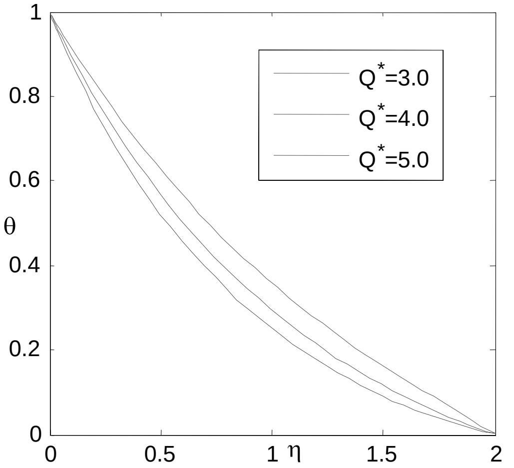

Figure-18. Temperature profile for various values of Q^* and $M = 1.0$, $m = 1.0$, $P_r=1.0$, $S_0=1.0$, $G_m=3.0$, $G_r = 3.0$, $S_c=0.22$, $E_c = 1.0$, $\xi = 1.0$, $K'=1.0$, $D_f=1.0$.

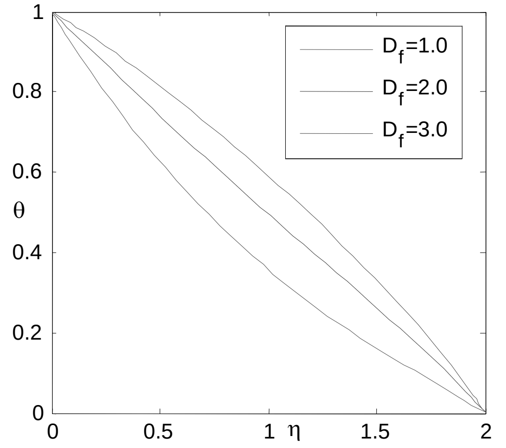

Figure-19. Temperature profile for various values of D_f and $M = 1.0$, $m = 1.0$, $P_r=1.0$, $S_0=1.0$, $G_m=3.0$, $G_r = 3.0$, $S_c=0.22$, $E_c = 1.0$, $\xi = 1.0$, $K'=1.0$, $Q^*=3.0$.

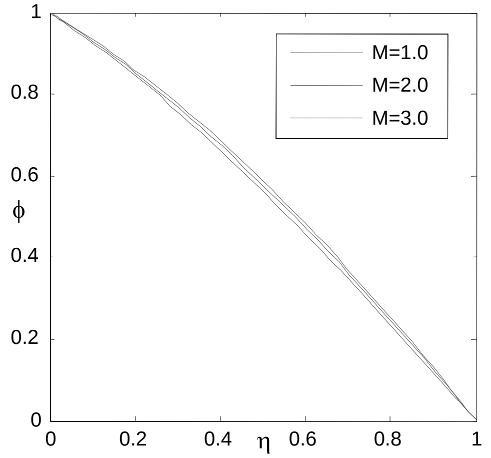

Figure-20. Concentration profile for various values of M and $m = 1.0$, $S_0=1.0$, $P_r=1.0$, $G_r=3.0$, $G_m=3.0$, $E_c=1.0$, $S_c=0.22$, $\xi=1.0$, $Q^*=3.0$, $K'=1.0$, $D_f=1.0$.

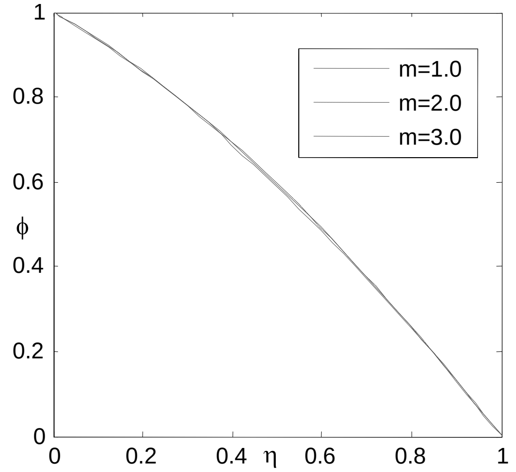

Figure-21. Concentration profile for various values of m and $M = 1.0$, $S_0=1.0$, $P_r=1.0$, $G_r=3.0$, $G_m=3.0$, $E_c=1.0$, $S_c=0.22$, $\xi=1.0$, $Q^*=3.0$, $K'=1.0$, $D_f=1.0$.

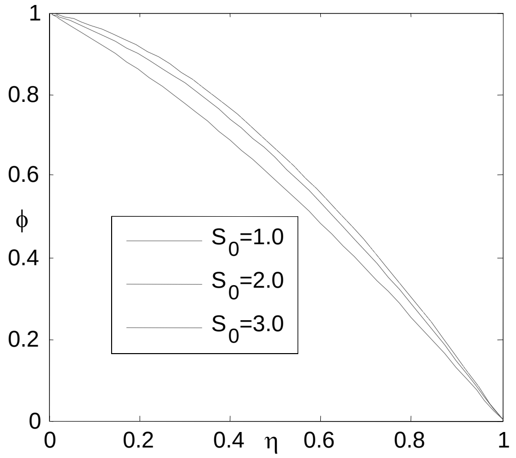

Figure-22. Concentration profile for various values of S_0 and $M = 1.0$, $m = 1.0$, $P_r=1.0$, $D_f=1.0$, $\xi = 1.0$, $G_r = 3.0$, $S_c=0.22$, $E_c = 1.0$, $Q^*=3.0$, $G_m = 3.0$, $K'=1.0$.

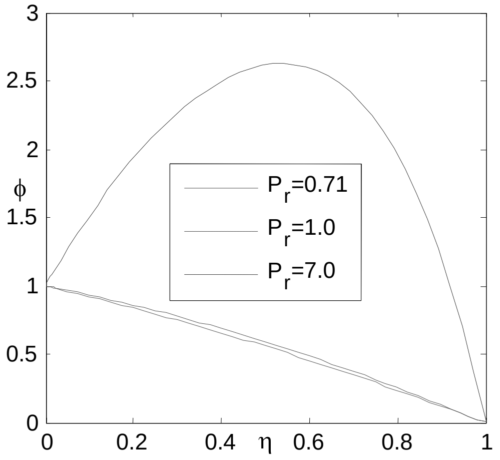

Figure-23. Concentration profile for various values of P_r and M = 1.0, m =1.0, S_0=1.0,G_r=3.0, G_m=3.0, E_c=1.0, S_c=0.22,ξ=1.0,Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

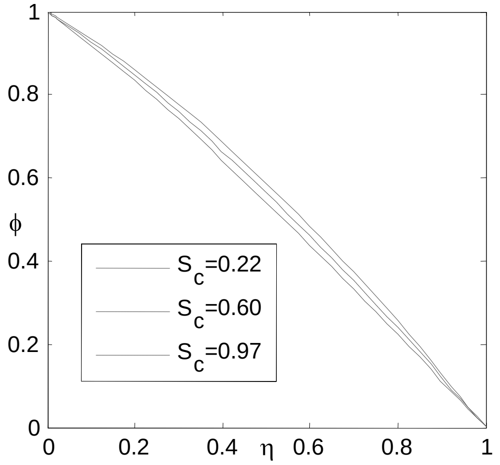

Figure-24. Concentration profile for various values of S_c and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, G_r =3.0, E_c =1.0, ξ=1.0, Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

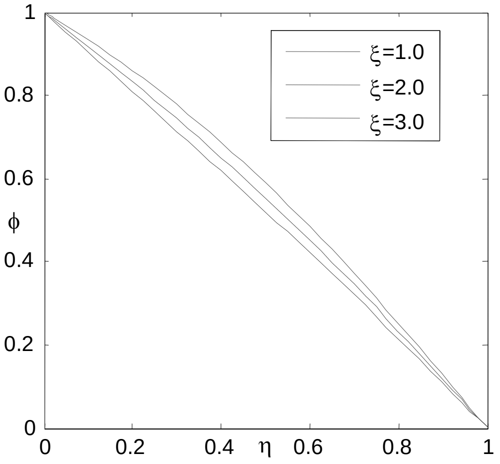

Figure-25. Concentration profile for various values of S_c and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, G_r =3.0, E_c =1.0, ξ=1.0, Q^*=3.0, $K^{'}$=1.0, D_f=1.0.

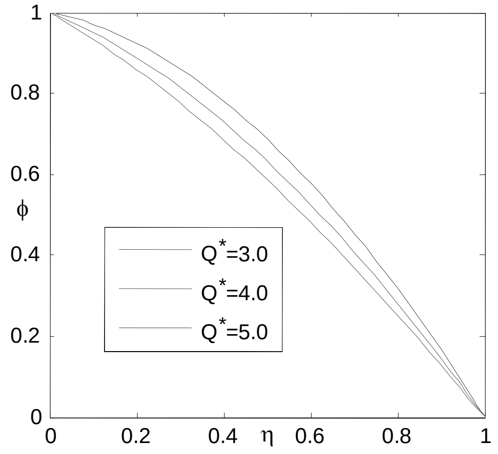

Figure-26. Concentration profile for various values of Q^* and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, G_r =3.0, S_c=0.22, E_c =1.0, ξ =1.0, $K^{'}$=1.0, D_f=1.0.

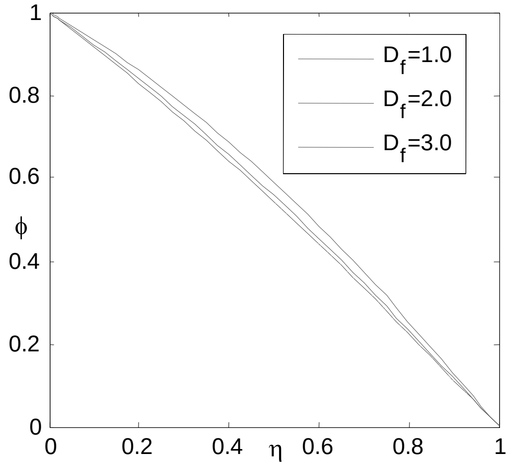

Figure-27. Concentration profile for various values of D_f and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, G_m=3.0, G_r =3.0, S_c=0.22, E_c =1.0, ξ =1.0, $K^{'}$=1.0, Q^*=3.0.

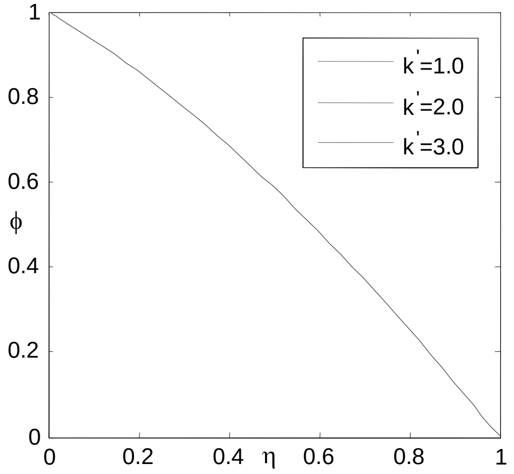

Figure-28. Concentration profile for various values of K' and M = 1.0, m =1.0, P_r=1.0, S_0=1.0, ξ =1.0, G_r =3.0, S_c=0.22, E_c =1.0, Q^*=3.0, G_m =3.0, D_f=1.0.

Table-1. The skin friction coefficient at the wall, rate of Temperature $-\theta'(0)$,(P_r= 1.0) and rate of Concentration $-\varphi'(0)$,(P_r =1.0) for various values of M, m, P_r, G_r and taking G_m = Q^*= 3.0, S_0=D_f=E_c=k'=$\zeta = 1.0$, S_c=0.22

M	m	P_r	G_r	$f''(0)$	$-\theta'(0)$	$-\varphi'(0)$
1.0	1.0	0.71	3.0	0.663409	0.894466	0.612209
2.0	1.0	0.71	3.0	0.491192	0.705523	0.649429
3.0	1.0	0.71	3.0	0.340409	0.357302	0.695896
1.0	**1.0**	0.71	3.0	0.663409	0.894466	0.612209
1.0	**2.0**	0.71	3.0	0.781813	0.975721	0.592181
1.0	**3.0**	0.71	3.0	0.820936	1.001657	0.585789
1.0	1.0	**0.71**	3.0	0.663409	0.894466	0.612209
1.0	1.0	**1.00**	3.0	0.658357	0.707656	0.763844
1.0	1.0	**7.00**	3.0	0.557341	2.4165395	5.560908
1.0	1.0	0.71	**3.0**	0.663409	0.894466	-
1.0	1.0	0.71	**4.0**	1.060712	0.875517	-
1.0	1.0	0.71	**5.0**	1.453287	0.782407	-

4. CONCLUSIONS

The objective of the present paper is to study the Hall and MHD effect as well as Soret effects on the steady free convective mass transfer flow over a vertical porous plate with heat generation. The governing equations are solved both analytically and numerically using Runge-kutta forth-fifth order method along with shooting technique. 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 Prandtl number and also reverse results arise for remaining parameters.
- Increase in magnetic parameter, Schmidt number, thermal Grashof number, Dufour number and reaction parameter, the temperature is increased. Reverse trend arises for remaining entering parameters.
- It is interesting to note that the temperature is decreased for air and salt water but for fresh water it is decreased in the interval $(0 \le \eta \le 0.7)$ and then noticeable increasing effects, i.e. for fresh water the thermal boundary layer is thicker far away from the plate.
- Increase in magnetic parameter, reaction parameter, Schmidt number and Dufour number the concentration decreases but reverse trend arise for Hall parameter and Soret number and there is no effect for permeability parameter.
- It is noticed that, a negligible increasing effect on concentration for air and salt water but noticeable increasing effects arises for fresh water.

Nomenclature

MHD	**Magnetohydrodynamics**
c_p	Specific heat of with constant pressure
g	Gravitational acceleration
g_0	Secondary velocity
f'	Velocity profile
M	Magnetic parameter, $M = \frac{\sigma B_0^2}{\rho A}$
m	Hall parameter
ν	Kinematic viscosity
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	Prandle number, $P_r = \frac{\mu c_p}{\rho}$
G_r	Local thermal Grashof number, $G_r = \frac{g\beta(T_w - T_\infty)}{A^2 x}$
G_c	Local solutal Grashof number $G_m = \frac{g\beta^*(C_w - C_\infty)}{A^2 x}$
E_c	Eckert number, $E_c = \frac{\mu A^2 x^2}{c_p(T_w - T_\infty)}$
S_c	Schmidt number, $S_c = \frac{\nu}{D}$

K'	Permeability parameter $K' = \frac{\nu}{Ak^*}$
k^*	Permeability of the porous medium
Q	Heat generation
Q^*	Heat source/ sink parameter, $Q^* = \frac{Q}{A\rho c_p}$
D_f	Dufour number, $D_f = \frac{DK(C_w - C_\infty)}{c_s c_p \alpha (T_w - T_\infty)}$
ζ	Reaction parameter, $\zeta = \frac{k_0 \nu}{AD}$
S_0	Soret number, $S_0 = \frac{K(T_w - T_\infty)}{T_m(C_w - C_\infty)}$
B_0	Constant magnetic field intensity
A	Arbitrary constant
T_w	Temperature at the plate
T_m	Mass temperature
T_∞	Temperature of the fluid outside the boundary layer
K	Thermal conductivity
W	Quantities at wall
∞	Quantities at the free stream

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