CHEMICAL REACTION AND THERMO DIFFUSION EFFECTS ON MHD FREE CONVECTION FLOW PAST A MOVING VERTICAL PLATE IN A SLIP FLOW REGIME

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Abstract: The objective of this study is to investigate chemical reaction and thermodiffusion effects on unsteady hydromagnetic free convection flow of a viscous, incompressible, electricallyconducting fluid with heat and mass transfer past a moving porous vertical plate of infinite length with time dependent suction in the presence of heat source in a slip flow regime. Slip flow conditions for the velocity and jump in temperature are taken into account in theboundary conditions. A uniform transverse magnetic field is applied. The free stream velocity is considered to follow an exponentially small perturbation law. The dimensionless governing equations are solved analytically using the perturbation method and solutions for velocity, temperature and concentration are obtained. Further, the results of the skin friction coefficient and dimensionless rate of heat and mass transfer at the plate are also presented. The effects of various physical parameters over the velocity, temperature and concentration distribution as well as on skin friction coefficient, dimensionless rate of heat transfer and dimensionless rate of mass transfer at the plate are shown through graphs.

Keywords: Free convection, Slip flow, Thermodiffusion, Chemical reaction

Introduction : The problem of free convection flow of an electrically conducting fluid past a vertical plate under the influence of magnetic field has attracted the attention of many scientists in recent years in view of its applications in Aerodynamics, Astrophysics, Geophysics and Engineering. It has many important technological applications as in cooling of nuclear reactors, providing heat sinks in turbine blades etc., The structure of stars and planets are also greatly influenced by thermal convection in their interior.

The phenomenon of free convection arises in the fluid when the temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. This can be seen in our everyday life in the atmospheric flow, which is driven by temperature differences. There are many transport processes occurring in nature due to temperature and chemical differences. The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is a working medium. Several authors have analyzed physical problems in this field. Nandha and Sharma (Nandha and Sharma1962) analyzed the unsteady free convection flow with suction along an infinite permeable plate. Pop (Pop 1969) studied an unsteady flow past an infinite porous plate with variable suction for hydromagnetic case. Soundalgekar (Soundalgekar 1972) analyzed the effects of variable suction and the horizontal magnetic field on the free convection flow past an infinite vertical porous plate and made a comparative discussion of different parameters and the free convection flow of mercury and ionized air. A study on steady laminar free convection flow in an electrically conducting fluid along a porous vertical plate in the presence of heat source was carried out by Sharma and Pankaj Mathur (Sharma and Pankaj Mathur 1995). The effect of thermal diffusion on steady laminar free convective flow along a moving porous hot vertical plate in the presence of heat source with mass transfer was studied by Varshney and Shilendra Kumar (Varshney and Shilendra Kumar2004). Heat transfer in MHD free convection flow over an infinite vertical plate with time-dependent suction was investigated in detail by Basant Kumar Mishra (Basant Kumar Mishra 2005).

Rarefaction effects must be considered in gases in which the molecular mean free path is comparable to the plate's characteristic domain. The continuum assumption is no longer valid and the gas exhibits non-continuum gas flows such as velocity slip and temperature jump. Traditional examples of non-continuum gas flows such as high altitude aircraft are vacuum technology. A study of vorticity of fluctuating flow of a visco-elastic fluid past an infinite plate with variable suction in slip flow regime was made by Mittal and Mukesh Bijalwan (Mittal and Mukesh Bijalwan 2005). Rajesh Johari et al.(Rajesh Johari et al.2008) analyzed unsteady MHD flow through porous medium and heat transfer past a porous vertical moving plate with heat source.

The combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore received a considerable amount of attention in recent years. The effect of chemical reaction depend whether the reaction is homogeneous or heterogeneous. This depends on whether they occur at an interface or a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of the order n, if the reaction rate is proportional to the n power of concentration. In particular, a reaction is said to be first order, if the rate of reaction is directly proportional to concentration itself. Chambre and Young (Chambre and Young 1958) have analyzed a first order chemical reaction in the neighbourhood of a horizontal plate. Apelblat (Apelblat 1980) studied analytical solution for mass with a chemical reaction of first order. Das et al. (Das et al. 1994) have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer.

Unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical porous plate with variable viscosity and thermal conductivity was investigated by Reddy et al. (Reddy et al. 2009). Dulal Pal and Babulal Talukdar (Dulal Pal and Babulal Talukdar 2010) reported perturbation analysis of unsteady magneto hydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction neglecting the Soret, Chemical reaction and Slip due to jump in temperature. Recently, Anjali Devi and Wilfred Samuel Raj (Anjali Devi and Wilfred Samuel Raj 2011) investigated the thermodiffusion effects on unsteady hydromagnetic free convection flow with heat and mass transfer past a moving vertical plate with time dependent suction and heat source in a slip flow regime.

The main objective of the present investigation is to study the effects of chemical reaction and thermo diffusion on unsteady hydromagnetic free convection flow of a viscous, incompressible, electrically conducting fluid with heat and mass transfer past a moving porous vertical plate of infinite length with time dependent suction in the presence of heat source in a slip flow regime.Slip flow conditions for the velocity and jump in temperature are taken into account in the boundary conditions. The dimensionless governing equations are solved using perturbation method. The analytical expressions for the velocity, temperature and mass concentration are obtained. Also the expressions for skin friction and rate of heat and mass transfer coefficients are derived.The effects of various physical parameters such as velocity ratio parameter, magnetic field parameter, Prandtl number, heat source parameter, Schmidt number, thermodiffusion parameter, chemical reaction parameter and slip parameters due to velocity and jump in temperature over the velocity, temperature and concentration distribution are depicted graphically. Moreover the effect of skin friction coefficient, dimensionless rate of heat transfer and mass transfer at the plate are also plotted which is of much practical importance.

Mathematical Formulation: The unsteady hydromagnetic free convection flow of a viscous, incompressible, electrically conducting fluid with heat and mass transfer past a moving porous vertical plate of infinite length with time dependent suction in slip flow regime is considered in the presence of heat source, chemical and thermo diffusion effects. The x^* axis is taken along the plate in the upward direction and y^* axis is normal to it. Due to semi-infinite plane surface assumptions, all the flow variables except pressure are functions of y^* and t^* only. A constant transverse magnetic field is applied in the direction of y^* axis.

In the present work, the following assumptions are made:

- The flow is unsteady and laminar, and the magnetic field is applied perpendicularly to the plate.
- Boussinesq approximation is applied.
- The fluid under consideration is viscous, incompressible and electrically conducting with constant physical properties.
- The magnetic Reynolds number is assumed to be small enough so that the induced magnetic field can be neglected.
- The effect of viscous and Joule's dissipation is assumed to be negligible in the energy equation.
- It is also assumed that there is no applied voltage, which implies the absence of an electric field.
- Slip flow regime is considered.

Under, these assumptions, the governing boundary layer equations of the problem are given by

Continuity Equation

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Momentum Equation

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = \frac{dU_\infty^*}{dt^*} - \frac{\sigma B_o^2}{\rho}(u^* - U_\infty^*) + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_f (T^* - T_\infty^*) + g\beta_c (C^* - C_\infty^*) \qquad (2)$$

Energy equation $$\rho C_p \left(\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} \right) = K \frac{\partial^2 T^*}{\partial y^{*2}} + S^*(T^* - T_\infty^*) \qquad (3)$$

Species Concentration equation

$$\frac{\partial C^*}{\partial t^*}+v^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}+D_1\frac{\partial^2 T^*}{\partial y^{*2}}+D_2(C^*-C^*_\infty) \quad (4)$$

Where u^* and v^* are components of velocities along and perpendicular to the plate x^* and y^* are distance along and perpendicular to the plate respectively, ρ is the density of the fluid, g is the acceleration due to gravity, σ is the electrical conductivity, B_o is Magnetic flux density, β_f is the coefficient of volume expansion of the working fluid, β_c is the coefficient of volumetric expansion with concentration, U^*_∞ is the velocity of the fluid in the free stream, υ is the kinematic viscosity, T^* is the temperature of the fluid, T^*_∞ is the temperature of the fluid in the free stream, K is thermal conductivity, S^* is coefficient of heat source, C^* is the concentration of the fluid, C^*_∞ is concentration at infinity, D is chemical molecular diffusivity, $D_1$is thermal diffusivity, D_2 the chemical reaction rate constant, C_p is the specific heat at constant pressure.
The slip flow boundary conditions are given by

$$u^*=u^*_w+h^*_1\frac{\partial u^*}{\partial y^*};\quad T^*=T^*_w+h^*_2\frac{\partial T^*}{\partial y^*};\quad C^*=C^*_w \qquad at\ y^*=0$$
$$u^*\to U^*_\infty=U_0(1+\varepsilon e^{\delta^* t^*});\quad T^*\to T^*_\infty;\quad C^*\to C^*_\infty \quad as\ y^*\to\infty \quad (5)$$

Where u^*_w the velocity at the wall, T^*_w is temperature at the wall, C^*_w is the concentration at the wall, ε and δ^* are scalar constants which are less than unity and $\varepsilon << 1$ and U_o is the scale of stream velocity.
The plate is subjected to variable suction and from the equation of continuity, it can be written as

$$v^*=-V_0(1+\varepsilon\alpha e^{\delta^* t^*}) \quad (6)$$

Where α is a real positive constant and $\varepsilon\ \alpha$ is less than unity, V_o is the scale of the suction velocity which has a non-zero positive constant.

and $$h^*_1=\left(\frac{2-f_1}{f_1}\right)\xi_1,\quad \xi_1=\left(\frac{\pi}{2p\rho}\right)^{\frac{1}{2}},\quad h^*_2=\left(\frac{2-a}{a}\right)\xi_2,\quad \xi_2=\left(\frac{2\gamma}{\gamma+1}\right)\frac{\xi_1}{\Pr} \quad (7)$$

Where ξ_1 Mean free path and constant, f_1 Maxwell's reflection coefficient
γ Ratio of specific heats, a Thermal accommodation coefficient
Introducing the following non dimensional scheme

$$u=\frac{u^*}{U_0},\quad v=\frac{v^*}{V_0},\quad t=\frac{t^*V_0^2}{\upsilon},\quad y=\frac{V_0 y^*}{\upsilon},\quad \delta=\frac{\delta^*\upsilon}{V_0^2},\quad u_w=\frac{u^*_w}{U_0},\quad U=\frac{U^*_\infty}{U_0},$$
$$\theta=\frac{T^*-T^*_\infty}{T^*_w-T^*_\infty},\quad \phi=\frac{C^*-C^*_\infty}{C^\infty_w-C^*_\infty},\quad K=\frac{K^*V_0^2}{\upsilon^2},\quad Gr=\frac{\upsilon g\beta_f}{U_0V_0^2}(T^*_w-T^*_\infty),\quad \Pr=\frac{\mu C_p}{k},$$
$$Gm=\frac{\upsilon g\beta_c}{U_0V_0^2}(C^*_w-C^*_\infty),\quad M=\frac{\sigma B_0^2\upsilon}{\rho V_0^2},\quad S=\frac{S^*\upsilon^2}{KV_0^2},\quad Sc=\frac{\upsilon}{D},\quad So=\frac{D_1(T^\infty_w-T^*_\infty)}{\upsilon(C^*_w-C^*_\infty)},$$
$$Kr=\frac{D_2\upsilon}{V_0^2}$$

The governing equations of the problem in non dimensional form are given by

$$\frac{\partial u}{\partial t}-(1+\varepsilon\alpha e^{\delta t})\frac{\partial u}{\partial y}=\frac{dU}{dt}+\frac{\partial^2 u}{\partial y^2}+Gr\theta+Gm\phi-M[u-U(t)] \quad (8)$$

$$\frac{\partial\theta}{\partial t}-(1+\varepsilon\alpha e^{\delta t})\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}+\frac{S}{\Pr}\theta \quad (9)$$

$$\frac{\partial\phi}{\partial t}-(1+\varepsilon\,\alpha\,e^{\delta t})\frac{\partial\phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}+So\frac{\partial^2\theta}{\partial y^2}+Kr\phi \quad (10)$$

The corresponding boundary conditions in non dimensional form are

$$u=u_w+h_1\frac{\partial u}{\partial y};\quad \theta=1+h_2\frac{\partial\theta}{\partial y};\quad \phi=1 \quad at \quad y=0$$
$$u\to U(t);\quad \theta\to 0;\quad \phi\to 0 \qquad as \quad y\to\infty \quad (11)$$

Where U (t) = 1+ε $e^{\delta t}$, $u_w=\frac{u_w^*}{U_0}$ Velocity ratio parameter

$h_1=\frac{h_1^* V_0}{\upsilon}$ Slip parameter due to velocity

$h_2=\frac{h_2^* V_0}{\upsilon}$ Slip parameter due to jump in temperature

Solution Of The Problem: In order to solve the nonlinear partial differential equations, the above systems of partial differential equations are reduced to a system of ordinary differential equations in a dimensionless form. The velocity, temperature and concentration are assumed in the following form:

$F(y)=F_o(y)+\varepsilon\, e^{\delta t}\, F_1(y)+O(\varepsilon^2)$ (12)

Where F stands for any value of u, θ and ϕ

By substituting (12) in equations (8) to (10), the following equations are obtained. The corresponding boundary conditions are also calculated by substituting in equation (11).

$$u_0''+u_0'-Mu_0=-Gr\theta_0-Gm\phi_0-M \quad (13)$$

$$u_1''+u_1'-(M+\delta)u_1=-Gr\theta_1-Gm\phi_1-\alpha\,u_0'-(M+\delta) \quad (14)$$

$$\theta_0''+\Pr\theta_0'+S\theta_0=0 \quad (15)$$

$$\theta_1''+\Pr\theta_1'+(S-\Pr\delta)\theta_1=-\alpha\Pr\theta_0^1 \quad (16)$$

$$\phi_0''+Sc\phi_0'+KrSc\phi_0=-ScSo\theta_0'' \quad (17)$$

$$\phi_1''+Sc\phi_1'+(Kr-\delta)Sc\phi_1=-ScSo\theta_1''-\alpha\,Sc\phi_o' \quad (18)$$

With the corresponding boundary conditions

$$u_0=u_w+h_1\frac{\partial u_0}{\partial y};\, u_1=h_1\frac{\partial u_1}{\partial y};\, \theta_0=1+h_2\frac{\partial\theta_0}{\partial y};\, \theta_1=h_2\frac{\partial\theta_1}{\partial y};\, \phi_0=1;\, \phi_1=0 \;at\; y=0$$
$$u_0\to 1;\, u_1\to 1;\, \theta_0\to 0;\, \theta_1\to 0;\, \phi_0\to 0;\, \phi_1\to 0 \qquad as\; y\to\infty \quad (19)$$

On solving (13) to (18) subject to boundary conditions in (19) the solutions are given by

$$u_0=1+C_4e^{-m_3 y}-C_5e^{-m_1 y}-C_6e^{-m_2 y} \quad (20)$$

$$u_1=C_{13}e^{-m_6 y}+C_{14}e^{-m_1 y}-C_{15}e^{-m_2 y}+C_{16}e^{-m_3 y}+C_{17}e^{-m_4 y}-C_{18}e^{-m_5 y}+1 \quad (21)$$

$$\theta_0=C_1e^{-m_1 y} \quad (22)$$

$$\theta_1=C_8e^{-m_1 y}-C_7e^{-m_4 y} \quad (23)$$

$$\phi_0=C_2e^{-m_2 y}+C_3e^{-m_1 y} \quad (24)$$

$$\phi_1=C_9e^{-m_5 y}+C_{10}e^{-m_1 y}+C_{11}e^{-m_2 y}+C_{12}e^{-m_4 y} \quad (25)$$

Where C_1, C_2............ C_{18}, m_1......m_6 are the constants which are not mentioned because of brevity.

Skin Friction

The skin friction coefficient at the plate is given by

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_1 C_5 + m_2 C_6 - m_3 C_4 + \varepsilon\, e^{\delta t}[-m_6 C_{13} - m_1 C_{14} + m_2 C_{15} - m_3 C_{16} + m_4 C_{17} - m_5 C_{18}] \quad (26)$$

Nusselt Number

The rate of heat transfer in terms of the Nusselt number Nu is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -m_1 C_1 + \varepsilon\, e^{\delta t}[-m_1 C_8 + m_4 C_7] \quad (27)$$

Sherwood Number

The rate of mass transfer in non dimensional form is given by

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -m_2 C_2 - m_1 C_3 + \varepsilon\, e^{\delta t}[-m_5 C_9 - m_1 C_{10} - m_2 C_{11} - m_4 C_{12}] \quad (28)$$

Results And Discussion: In the present work, we have chosen t = 1, δ = 0.1, ε = 0.01, α = 1 while the other non dimensional parameters take various values. The results obtained show that the dimensionless velocity is affected by physical parameters such as Velocity ratio parameter u_w,Magnetic field parameter M, Thermo diffusion parameter So and Chemical reaction parameter Kr respectively.

Figures 1-4 show the effects of Velocity ratio parameter, Magnetic field parameter, Thermodiffsuion parameter, Chemical reaction parameter over the dimensionless velocity profiles. Figure 1 depicts the effect of velocity ratio parameter over the dimensionless velocity profiles. The effect of velocity ratio parameter is to accelerate the velocity and its influence is highly dominant near the plate whereas it remains uniform as we move far away from the plate. Figure 2 elucidates the influence of magnetic field parameter on the fluid velocity distribution, and we observed that an increase in magnetic field parameter, the velocity of the flow field decreases, it is due to the presence of magnetic field normal to the flow in an electrically conducting fluid introduces a Lorentz force which acts against the flow. Figure 3 portrays the dimensionless velocity profiles for different values of chemical reaction parameter. Due to the effect of chemical reaction parameter the velocity of the flow field gets decelerated. Figure 4 displays the influence of thermo diffusion parameter over the dimensionless velocity. It is evident that the thermo diffusion parameter accelerates the velocity of the flow field.

Figure 5 plots the temperature distribution for various values of slip parameter h_2. It is observed that slip parameter due to jump in temperature decreases the thermal boundary layer thickness. Figure 6 deals with the effect of chemical reaction parameter over the concentration profiles. Due to increase in Kr the concentration of the flow decreases. The concentration of the flow field is increased by increase in thermo diffusion parameter which is displayed through figure 7.

Variation of Skin friction coefficient against M for various values of slip parameter $h_1$and h_2, Chemical reaction parameter Kr is plotted through figures 8 to 10. The slip parameter $h_1$decreases the skin friction coefficient which is seen in figure 8. The same trend is noted for slip parameter $h_2$due to jump in temperature which is vivid through figure 9. Figure 10 demonstrates the variation of skin friction coefficient due to variation of chemical reaction parameter Kr. It is clear that the effect of chemical reaction decreases the skin friction coefficient.

In the absence of chemical reaction effect these results are in good agreement with the results of Anjali Devi and Wilfred Samuel Raj (2011).

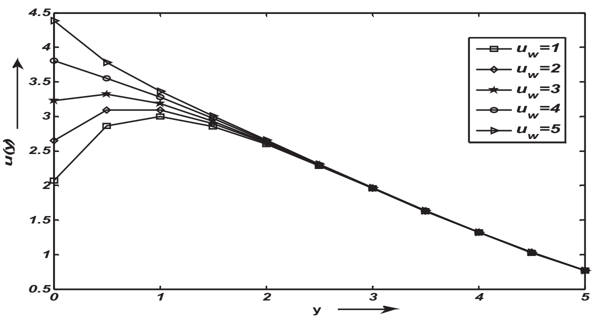


Fig.1. Velocity profile against spanwise coordinate y for different values of the velocity ratio parameter u_w with Gr = 0.9, Gm = 4, Pr = 0.71, Sc = 0.22, S = 0.1, So = 1.5, M = 5, h_1 = 0.4, h_2= 0.5, Kr = 0.5.

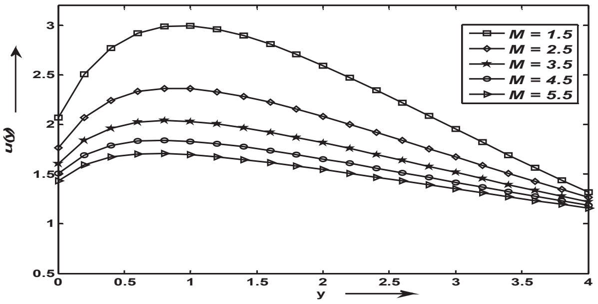


Fig.2. Velocity profile against spanwise coordinate y for different values of Magnetic parameter M with Gr = 0.9, Gm = 4, Pr = 0.71, Sc = 0.22, S = 0.1, So = 1.5, u_w =1, h_1 = 0.4, h_2 = 0.5, Kr = 0.5.

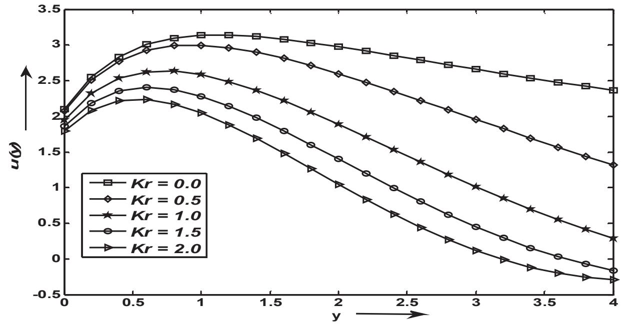
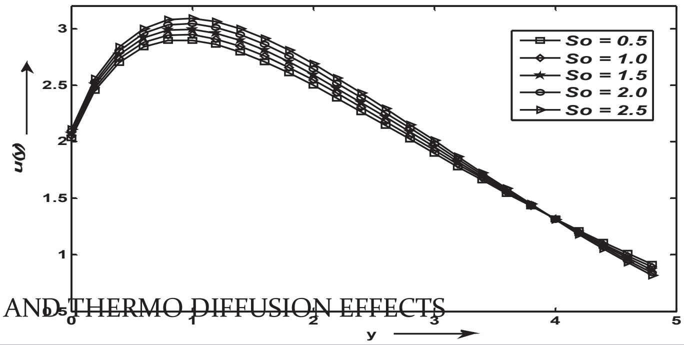


Fig.3. Velocity profile against spanwise coordinate y for different values of the Chemical reaction parameter Kr with Gr = 0.9, Gm = 4, M = 5, Pr = 0.71, So = 1.5, Sc = 0.22, u_w =1,
S = 0.1, h_1 = 0.4, h_2= 0.5.



CHEMICAL REACTION AND THERMO DIFFUSION EFFECTS

Fig.4. Velocity profile against spanwise coordinate y for different values of the Thermodiffusion parameter So with Gr = 0.9, Gm = 4, M = 5, Pr = 0.71, S = 0.1, Sc = 0.22, u_w =1, h_1 = 0.4, h_2 = 0.5, Kr = 0.5.

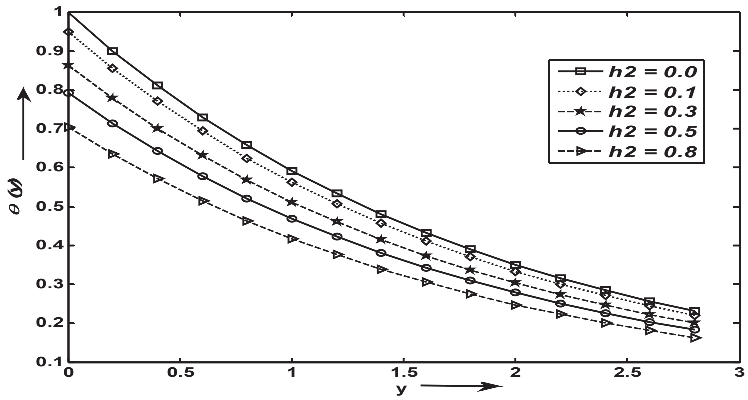


Fig.5. Temperature profile against spanwise coordinate y for different values of slip parameter h_2 with Sc = 0.22, Pr = 0.71, S = 0.1.

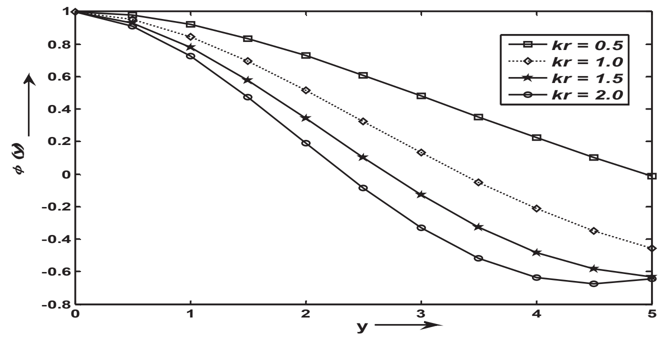


Fig.6. Concentration profile against spanwise coordinate y for different values of the chemical reaction parameter *Kr* with S = 0.1, Pr = 0.71, Sc = 0.22, So = 1.5, h_2 = 0.5.

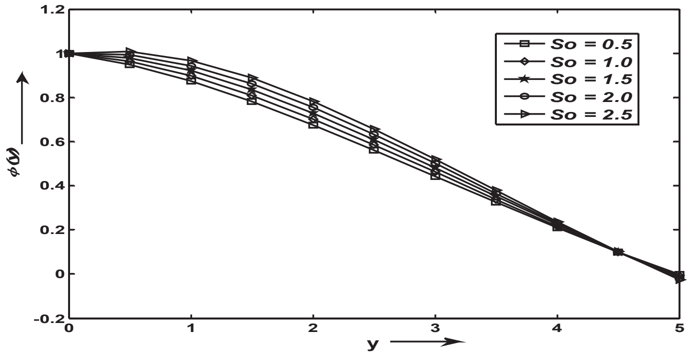


Fig.7. Concentration profile against spanwise coordinate y for different values of the thermodiffusion parameter *So* with h_2 = 0.5, Pr = 0.71, Sc = 0.22, S = 0.1, Kr = 0.5.

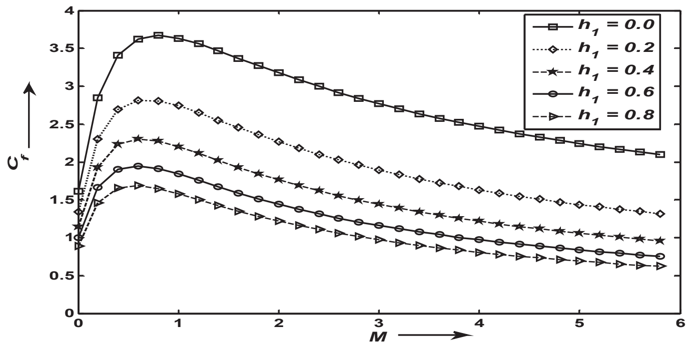


Fig.8. Skin Friction coefficient against *M* for different values of slip parameter h_1 with Gr = 0.9, Gm = 4, Pr = 0.71, So = 1.5, Sc = 0.22, u_w =1, S = 0.5, h_2 = 0.5, Kr = 0.5.

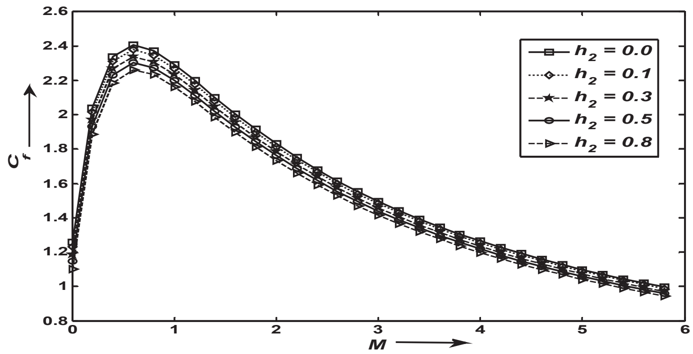


Fig.9. Skin Friction coefficient against *M* for different values of slip parameter $h_2$with Gr = 0.9, Gm = 4, Pr = 0.71, So = 1.5, Sc = 0.22, u_w =1, S = 0.5, h_1= 0.4, Kr = 0.5.

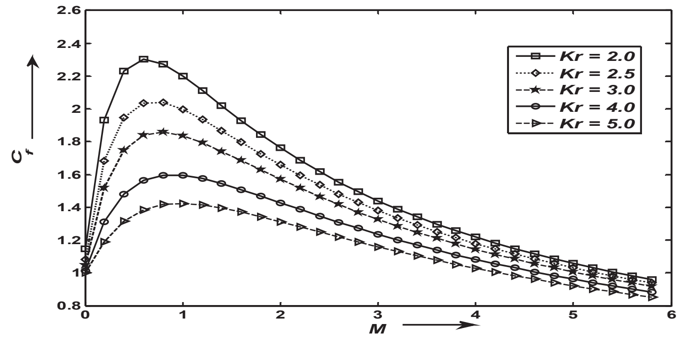


Fig.10. Skin Friction coefficient against *M* for different values of the chemical reaction parameter *Kr* with h_1= 0.4, *So* = 1.5, *Gr* = 0.9, *Gm* = 4, h_2= 0.5, *Pr* = 0.71, *S* =0.1, *Sc* = 0.22, u_w=1.

Conclusions: In this paper, Chemical reaction and Thermodifussion effects on unsteady hydromagnetic free convection flow of a viscous, incompressible, electrically conducting fluid with heat and mass transfer past a moving porous vertical plate of infinite length with time dependent suction in the presence of heat source in a slip flow regime has been studied. The dimensionless governing equations are solved using Perturbation method. From this investigation, it was found that the velocity profiles increased due to increase in velocity ratio parameter u_w andthermodiffusion parameter *So* while it decreased due to increases in magnetic parameter *M*andChemical reaction parameter *Kr*. The significant effect of slip parameter due to velocity $h_1$decreases the skin friction coefficient effectively. The temperature profiles and skin friction coefficient decreases with the increasing values of slip parameter due to jump in temperature h_2. The concentration profiles increase with the increasing values of thermodiffusion *So*, but decreases with chemical reaction parameter *Kr*. Also, it was found that the skin friction coefficient decreases due to increase in the chemical reaction parameter *Kr*.

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