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Hydro Magnetic Heat and Mass Transfer Flow in a Porous Plate with Varying Temperature

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Abstract

Objectives: To study the unsteady hydro magnetic naturally convicting flow with heat and mass flux in the presence of chemical reaction, fluid past an infinite vertical porous plate with varying temperature and concentration. **Statistical Analysis:** An analysis is carried out to study the heat transfer in unsteady two dimensional Mass transfer flow of a magneto hydrodynamic over a porous medium. The flow is subjective in the action of uniform transverse magnetic field. With the help of dimensionless variable, the governing flow equation are reduced to a system of nonlinear Partial Differential Equation. This system has been solved analytically using Perturbation Approximation. **Findings:** The influence of the temperature distribution, concentration distribution, Skin friction coefficient, BrandtNumber, Magnetic Parameter, chemical Reaction Parameter, Gash of number, Modified Gash of Number, Schmidt Number, Heat source Parameter, Radiation Parameter are discussed in Graph. In this paper, suppression of velocity on magnetic Parameter and chemical reaction are discussed. The Gash of Number and Modified Gash of Number increase the velocity, whereas in the literature survey, the analytical or numerical solution obtained by assuming that the temperature at the interface was continuous and well defined. The highlights of the results are helpful to variety the ramped temperature and ramped concentration on the wall of the infinite vertical porous plate. **Applications:** The combined heat and mass transfer problem along with chemical reaction play a prominent role in chemical and hydrometallurgical industries. It is used by different scientific disciplines for different processes and mechanisms. In many practical situations, mass transfer is accomplished in order to bring chemical reagents together so that a reaction can take place. Thus for example reaction can be used to provide more rapid solution of a gas in to a liquid than physical solution.

Keywords: Hydro Magnetic, Heat Transfer, Mass Transfer, Chemical Reaction, Porous Medium

1. Introduction

Nowadays the laminar flow problem along the magnetic field has fascinated many researchers. Lot of study has been done on the physical problem in this field. In[1] studied two dimensional unsteady mass transfer and free convection flow in an electrically conducting incompressible viscous dissipative fluid. In[2] analyzed the steady hydro free convection flow through a porous medium bounded by two parallel plates.

In[3] also discussed unsteady natural convection flow with an electrically conducting infinite vertical viscous porous plate. In[4] investigated the exact solution of flow due to impulsive motion with infinite vertical plate. In[5] investigated the effect of an optically dense viscous incompressible fluid along a heated vertical plate. In[6] analyzed unsteady MHD free convection flow along with porous medium[7] presented two dimensional free convection laminar flow of an incompressible viscous fluid bounded by infinite vertical plate. In[8] studied the effects on a constantly moving isothermal vertical surface with unvarying suction. In[9] examined the problem of unsteady incompressible mixed flow of micro polar fluid[10] also discussed an exact solution of the flow of a viscous incompressible unsteady flow past an oscillating infinite vertical plate with varying temperature.

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In[11] focused on the study of combined effects of free convective heat and mass Transfer on the steady two dimensional, laminar flow along with a porous medium in the presence of internal heat generation and chemical reaction of first order. In[12] presented radiation effects on semi-infinite vertical permeable moving plate with MHD convective Heat and mass transfer flow. In[13] analyzed the influence of a first order homogeneous thermal radiation and chemical reaction on hydro magnetic free convective viscous fluid in the presence of heat generation and thermal diffusion. In[14] examined the effects of chemical reaction and radiation absorption in the presence of uniform magnetic field. In[15] investigated the influence of ohmic heating and magnetic field with combined heat and mass transfer flown of electrically conducting semi-infinite vertical plate in the presence of viscous dissipation. In[16] discussed the two dimensional unsteady, incompressible flow with electrically conducting fluid along with vertical permeable plate entrenched in a porous medium. In[17] discussed the influence of critical parameters on the unsteady two dimensional, laminar boundary layer flow in the presence of thermal effects under the influence of magnetic field. In[18] investigate the MHD free convective flow past a vertical porous plate in the occurrence of Soret. In[19] dealt with the effects of MHD free convectional heat and mass transfer flow on two-dimensional vertical porous plate under the influence of dufour and Soret Effects. In[20] discussed about the MHD Heat and Mass transfer flow in semi-infinite vertical moving porous medium with heat source and suction.

2. Mathematical Formulation of the Problem

Consider a viscous, incompressible, electrically conducting, fluid flow with heat and mass transfer in the existence of heat source, chemical reaction, heat source with thermo diffusion effects. Choose the coordinate system as x*- axis in the upward direction. Fluid is rotating with angular velocity Ω^* about the z^*- axis. A constant transverse magnetic field is applied in the rotation.

The flow is variant, laminar and perpendicular to the plate. It is also undertaken that there is absence of voltage which gives no electric field. Dufour effect is considered as negligible. The rate of chemical reaction, physical properties are constant through the fluid.

The following equations denotes velocity components u^*, v^*, w^* in the x^*, y^*, z^* directions respectively,

Continuity equation:

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial u}{\partial t} + w_0 \frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + v\frac{\partial^2 u}{\partial z^2} + 2\Omega V + \frac{\sigma \mu_e B_0 (mv - u)}{\rho(1+m^2)} - \frac{vu}{k} + g\beta(T - T_\infty) + g\beta(C - C_\infty) \tag{2}$$

$$\frac{\partial v}{\partial t} + w_0 \frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + v\frac{\partial^2 V}{\partial z^2} - 2\Omega u - \frac{\sigma \mu_e B_0 (mu + v)}{\rho(1+m^2)} - \frac{vV}{k} \tag{3}$$

Energy equation:

$$\frac{\partial T}{\partial t} + w_0 \frac{\partial T}{\partial z} = \frac{K}{\rho c_p}\frac{\partial^2 T}{\partial z^2} - \frac{Q_0}{\rho c_p}(T - T_\infty) + Q_1(C - C_\infty) - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial z} \tag{4}$$

Mass diffusion equation:

$$\frac{\partial C}{\partial t} + w_0 \frac{\partial C}{\partial z} = D\frac{\partial^2 C}{\partial z^2} - K_r(C - C_\infty) \tag{5}$$

The corresponding marginal conditions for the velocity, temperature and concentration are

$$\begin{aligned}
&u = u_p;\ T = T_\infty + \varepsilon(T_w - T_\infty)e^{nt};\\
&C = C_\infty + \varepsilon(C_w - C_\infty)e^{nt}\ T \to T_\infty\\
&uU_\infty = U_0 + \varepsilon(1 + e^{nt});\ T \to T_\infty;\\
&C \to C_\infty \text{ at } y \to \infty
\end{aligned} \tag{6}$$

From (1), we can get,

$$W = -W_0(1 + \varepsilon A e^{nt}) \tag{7}$$

Eliminating Modified pressure under usual Boundary condition (2) and (3) becomes,

$$\frac{\partial u}{\partial t} + w_0 \frac{\partial u}{\partial z} = v\frac{\partial^2 u}{\partial z^2} + \frac{dv}{dt} + 2\Omega V + \frac{\sigma B_0^2 (mv - u + U)}{\rho(1+m^2)} - \frac{v(u - U)}{k} + g\beta(T - T_\infty) + g\beta(C - C_\infty) \tag{8}$$

$$\frac{\partial v}{\partial t} + w_0 \frac{\partial v}{\partial z} = v\frac{\partial^2 V}{\partial z^2} - 2\Omega(u - U) - \frac{\sigma B_0^2 (mu - mU + v)}{\rho(1+m^2)} - \frac{vV}{k} \tag{9}$$

By means of the Rosseland diffusion approximation, the radiactive heat flux, q_r becomes,

$$q_r = -\frac{4\sigma^*}{3k_s}\frac{\partial T^{*4}}{\partial y^*} \tag{10}$$

T^4 is expressed as a linear function of temperature

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \tag{11}$$

By (10) and (11), last term of equation (4) becomes

$$\frac{\partial q_r}{\partial z^*} = -\frac{16\sigma^* T_\infty^3}{3k_s}\frac{\partial^2 T}{\partial z'^2} \tag{12}$$

The following non-dimensional Quantities are introduced to write the foremost equations,

$$z = \frac{w_0 z}{\gamma},\ u = \frac{u}{U_0},\ V = \frac{V}{U_0},\ t = \frac{t w_0^2}{\gamma},\ U_\infty = \frac{U_\infty}{U_0},$$

$$U_p = \frac{U_p}{U_0},\ \theta = \frac{T - T_\infty^*}{T_w^* - T_\infty^*},\ c = \frac{c^* - c_\infty^*}{c_w^* - c_\infty^*},$$

$$G_r = \frac{g\beta \mathrm{v}\left(T^* - T_\infty^*\right)}{w_0^3},\ G_m = \frac{g\beta^* \mathrm{v}\left(c_w^* - c_\infty^*\right)}{w_0^3},$$

$$S_c = \frac{\mathrm{v}}{D},\ Q = \frac{\mathrm{v}Q}{cPw},\ Q1 = \frac{\mathrm{v}Q_1\left(c_w^* - c_\infty^*\right)}{\left(T_w^* - T_\infty^*\right)w_0^2},\ n = \frac{\mathrm{v}n^*}{w_0^2}$$

$$M = \frac{\sigma B_{0\mathrm{v}}^2}{\rho w_0^2},\ K = \frac{k^* w_0^2}{v^2},\quad k_r = \frac{k_r^* \mathrm{v}}{w_0^2},\ R = \frac{4\sigma^* T_\infty^3}{k_s},$$

$$P_r = \frac{\mathrm{v}\rho c_p}{k},\ \grave{U} = \frac{\grave{U} d^2}{v} \tag{13}$$

By using equations (6) – (13), Equations (2) – (5) reduces to,

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial u}{\partial z} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial z^2} + G_r\theta + G_c C + \frac{M\left(mV - u + U\right)}{1+m^2} + 2\Omega V + N\left(U_\infty - u\right) \tag{14}$$

$$\frac{\partial V}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial V}{\partial z} = \frac{\partial^2 V}{\partial z^2} - 2\Omega\left(u - U\right) - \frac{M\left(mu - MU + V\right)}{1+m^2} - NV \tag{15}$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial z} = \frac{1}{Pr}\left[1 + \frac{4R}{3}\right]\frac{\partial^2 \theta}{\partial z^2} - Q\theta + Q_1 C \tag{16}$$

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial C}{\partial z} = \frac{1}{Sc}\frac{\partial^2 C}{\partial z^2} - K_r C \tag{17}$$

Where $N = M + \dfrac{1}{K}$,

The corresponding boundary conditions becomes,

$$u = U_p,\ \theta = 1 + \varepsilon e^{nt},\quad C = 1 + \varepsilon e^{nt}\quad at\quad y = 0$$

$$u \to U_\infty = 1 + \varepsilon e^{nt},\ \theta \to 0,\quad C \to 0\quad at\quad y \to \infty \tag{18}$$

3. Solution of the Problem

Equations (14) – (17) are coupled, non - linear partial differential Equations, so consider,

$$U\,(z, t) = u_0(z) + \varepsilon e^{nt} u_1 + o\left(\varepsilon^2\right) + \ldots$$

$$\theta\,(Z, t) = \theta_0(z) + \varepsilon e^{nt}\theta_1 + o\left(\varepsilon^2\right) + \ldots.$$

$$c\,(Z, t) = c_0(z) + \varepsilon e^{nt} c_1 + o\left(\varepsilon^2\right) + \ldots. \tag{19}$$

Substituting equation (19) in equations (14) – (17), we get

Zeroth order equation

$$u_0'' + u_0' - \left(N + \frac{M}{1+m^2}\right)u_0 = -N - G_r\theta_0 - G_m C_0 + \frac{MmV_0}{1+m^2} - \frac{MU}{1+m^2} - 2\Omega V_0 \tag{20}$$

$$V_0'' + V_0' - \left(N + \frac{M}{1+m^2}\right)V_0 = \frac{Mmu_0}{1+m^2} - \frac{MmU}{1+m^2} - 2\Omega U + 2\Omega u_0 \tag{21}$$

$$\left[1 + \frac{4R}{3}\right]\theta_0'' + Pr\theta_0' - PrQ\theta_0 = -PrQ_1 C_0 \tag{22}$$

$$\mathrm{C}_0'' + \mathrm{ScC}_0' - \mathrm{ScKrC}_0 = 0 \tag{23}$$

First Order Equation

Accumulating the co-efficient of similar powers of ε and ignoring the co-efficient of O(ε^2), the first order equations are attained as

$$u_1'' + u_1' - \left(N + n + \frac{M}{1+m^2}\right)u_1 = -G_r\theta_1 - G_m C_1 - \frac{MmV_1}{1+m^2} + \frac{Mu_1}{1+m^2} - 2\Omega V_1 - Au_0' \tag{24}$$

$$V_1'' + V_1' - \left(N + n + \frac{M}{1+m^2}\right)V_1 = \frac{Mmu_1}{1+m^2} + 2\Omega u_1 - AV_0' \tag{25}$$

$$\left[1 + \frac{4R}{3}\right]\theta_1'' + Pr\theta_1' - \Pr\left(Q + n\right)\theta_1 = -PrQ_1C_1 - APr\theta_0' \tag{26}$$

$$C_1'' + ScC_1' - Sc\left(Kr + n\right)C_1 = -ScAC_0' \tag{27}$$

The equivalent boundary conditions can be written as

$$u_0 = U_p,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1,\ C_0 = 1,\ C_1 = 1\quad at\quad y = 0$$

$$u_0 \to 1,\ u_1 \to 1,\ \theta_0 \to 0,\ \theta_1 \to 0,\ C_0 \to 0,\ C_1 \to 0\quad at\ y \to \infty \tag{28}$$

On cracking the Equations (20) - (27) under the boundary condition (28) we attain,

$$U(y,t) = A9e^{r9y} + A10e^{r10y} + m7 + m8e^{r5y} + m9e^{r1y} + m10e^{r1y} + m11 + m12 + m13 + \varepsilon e^{nt} \tag{29}$$

$$\theta(y,t) = A5e^{r5y} + m2e^{r1y} + \varepsilon e^{nt}\left(A7e^{r7y} + m3e^{r5y} + m4e^{r1y} + m5e^{r3y} + m6e^{r1y}\right) \tag{30}$$

$$\mathrm{C(y, t)} = e^{r1y} + \grave{o}e^{nt}\left(\mathrm{A3e^{r3y}} + \mathrm{m1e^{r1y}}\right) \tag{31}$$

Skin Friction

$$C_f = \frac{\tau}{\rho U_0 V_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \grave{o} e^{nt}\frac{\partial \mathrm{u}_1}{\partial \mathrm{y}}\right)_{y=0}$$

$$\begin{aligned} C_f =\, & r9A9 + r10A10 + m7 + r5m8 + r1m9 + r1m10 + m11 + m12 + m13 + \\ & \varepsilon e^{nt}(r11A11 + r12A12 + r7m14 + r5m15 + r1m16 + r3m17 + r1m18 \\ & + r3m19 + r1m20 + m21 + m22 + r9m23 + r10m24 + r5m25 + r1m26 + r1m27) \end{aligned} \quad (32)$$

Nusselt Number

$$N_u = \frac{\left(\frac{\partial t}{\partial y}\right)_{y=0}}{T_w - T_\infty} = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\frac{\partial \theta_0}{\partial y} + \grave{o} e^{nt}\frac{\partial \grave{e}_1}{\partial y}\right)_{y=0}$$

$$= r5A5 + r1m2 + \varepsilon e^{nt}\left(r7A7 + r5m3 + r1m4 + r3m5 + r1m6\right) \quad (33)$$

Sherwood Number

$$S_h = \frac{\left(\frac{\partial C}{\partial y}\right)_{y=0}}{C_w - C_\infty} = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(\frac{\partial c_0}{\partial y} + \grave{o} e^{nt}\frac{\partial \mathrm{C}_1}{\partial \mathrm{y}}\right)_{y=0}$$

$$= \mathrm{r}1 + \varepsilon e^{nt}\left(r3A3 + r1m1\right) \quad (34)$$

4. Results and Discussion

The Methodical results of the problem have been obtained in the previous section. In order to highlight the effects of non-dimensional parameters over the velocity field, temperature distribution, concentration distribution and skin friction coefficient the numerical values of the diagnostic results are obtained.

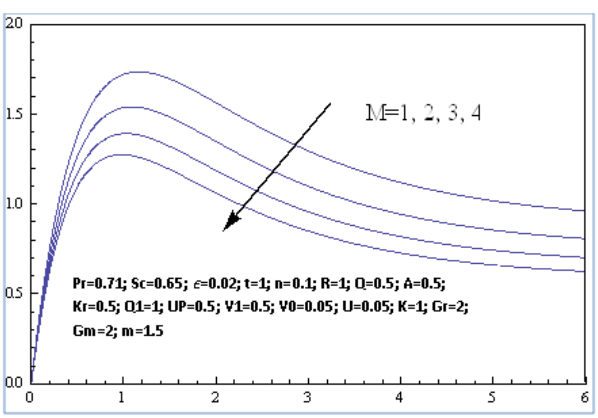

Figure 1. Velocity profiles on different M.

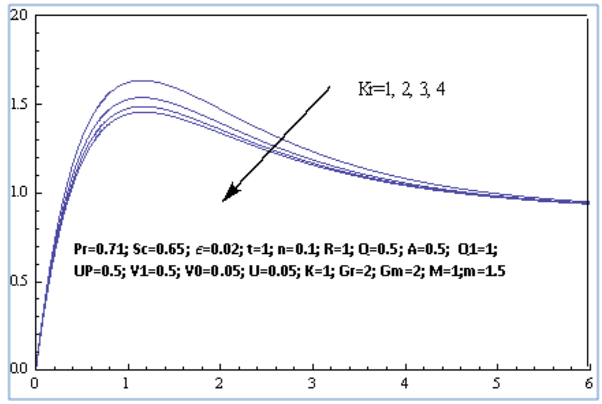

Figure 2. Velocity Profiles on different Kr.

Figure1 portrays the velocity which reduces with araise in the Magnetic Parameter because the presence of magnetic field in an electrically conducting fluid establishes Lorentz force acts against the flow if the magnetic field which is applied in the normal direction. This type of resisting slows down the fluid velocity as shown in the figure. The influence of chemical reaction parameter Kr on the velocity profile across the boundary layer is seen that the chemical reaction across the boundary layer is to reduce the velocity (Figure 2). The velocity profile across the boundary layer for different values of Prandtl number are disclosed in Figure 3. The results show that the effect of increasing value of Prandtl number suppresses the velocity. Figure 4 demonstrates the effect of Grash of number Gr over Velocity distribution. It is elucidated that the raise in Grash of number increases the velocity. Grash of number represents the effects of free convection currents.

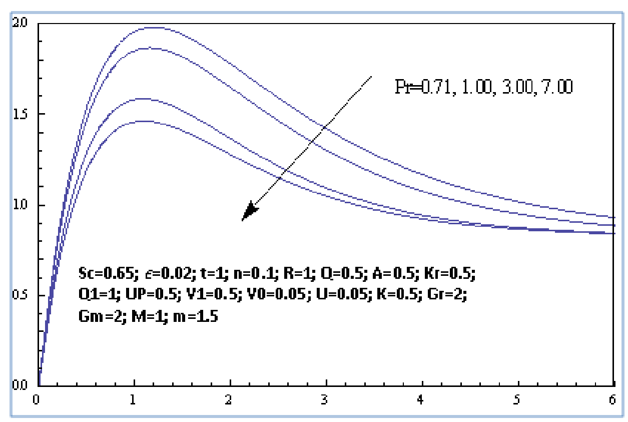

Figure 3. Velocity Profiles on different Pr.

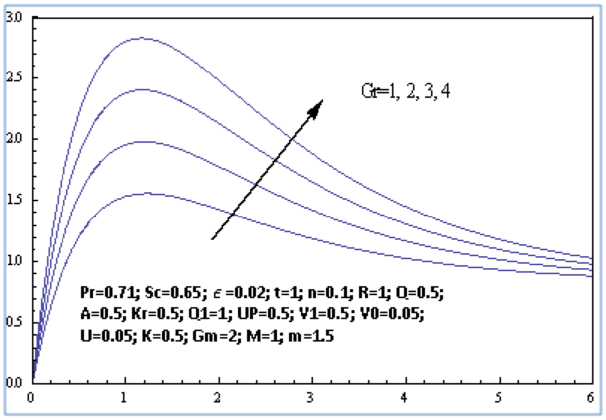

Figure 4. Velocity Profiles on different Gr.

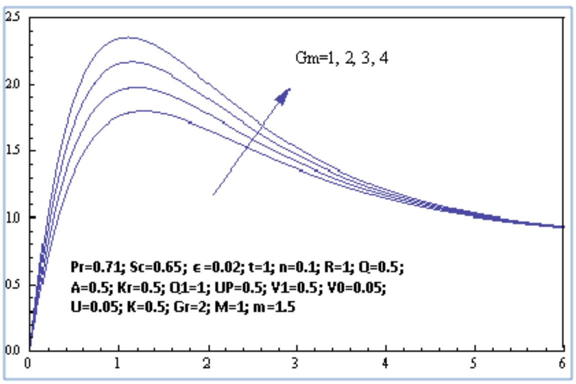

Figure 5. Velocity Profiles on different Gm.

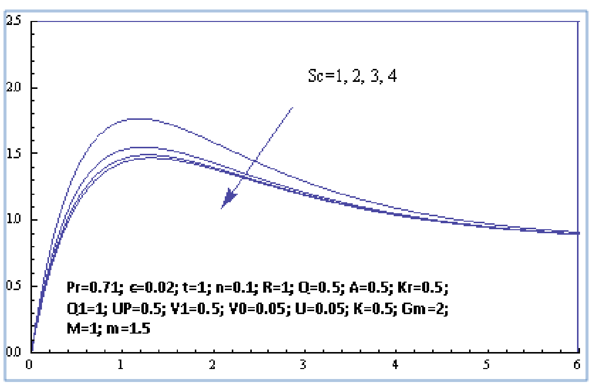

Figure 6. Velocity Profiles on different Sc.

The influence of modified Grash of number Gm over velocity profiles is disclosed through Figure 5 and Figure 6. It is noted that Schmidt number Sc increases as the velocity field reduces. The velocity distribution attains a unique maximum value in the vicinity of the plate surface and then decreases. This causes the velocity buoyancy effect yielding a reduction in the fluid velocity. Through Figure 7 we observe that the raise in Heat source parameter Q reduces the temperature because when heat is absorbed, the buoyancy force decreases the temperature profile.

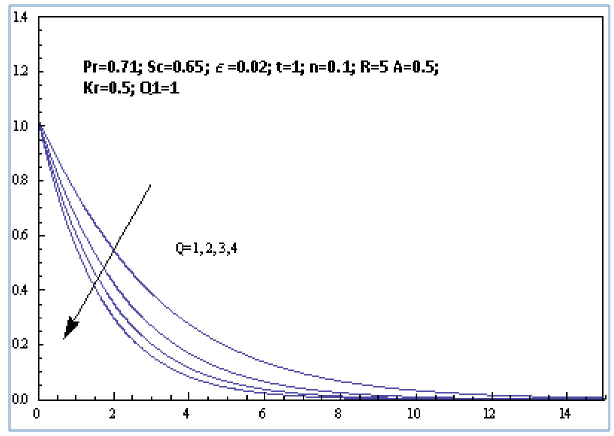

Figure 7. Temperaturte Profiles on various.

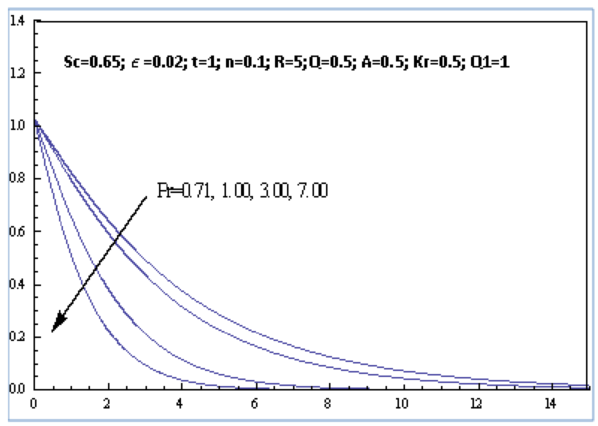

Figure 8. Temperaturte Profiles on various Pr.

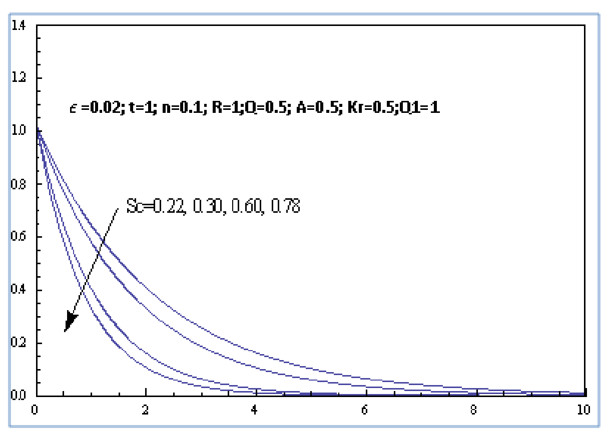

Figure 9. Concentration Profiles on various.

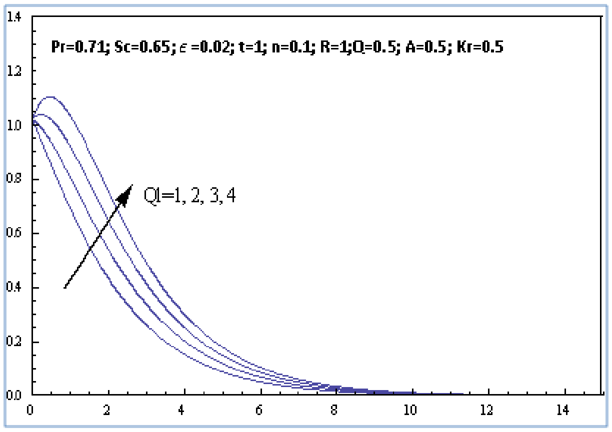

Figure 10. Temperature Profiles on various Q1.

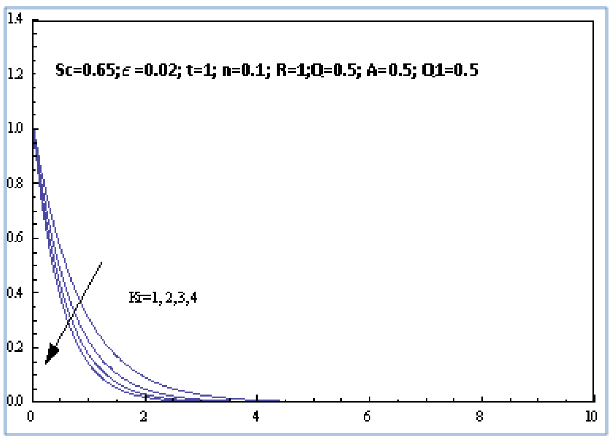

Figure 11. Concentration Profiles on various.

The effect of Prandtl number is to reduce the temperature as it increases which is portrayed through Figure 8, since the smaller value of Pr are equivalent to increase the thermal conductivity of the fluid. The influence of Schmidt number Sc is to decrease the concentration which is disclosed through Figure 9 as the lesser value of Schmidt number are equivalent to rising the chemical molecular diffusivity. Figure 10 shows the effect of radiation parameter as seem to raise the temperature profile. Figure 11 depicts the influence of chemical reaction as Kr is to decrease the concentration, this is due to fact that destructive chemical reduces the boundary layer thickness and increases the mass transfer.

5. Conclusion

In this study, a numerical analysis is presented to investigate the effect of unsteady hydro magnetic infinite vertical porous plate with electrically conducting, incompressible viscous fluid with prescribed heat and mass flux in the presence of chemical reaction, heat source and Roseland Diffusion approximation. The non-linear and coupled governing equations are solved analytically by perturbation technique. Velocity, temperature and concentration profiles are presented graphically and analyzed. The fundamental parameters found to effect the problem under consideration are the chemical reaction parameter, Grash of number, Modified Grash of number, magnetic parameter, Prandtl number and heat absorption parameter. It is found that, the velocity as well as concentration decreases with increasing the Magnetic Parameter, chemical reaction parameter, heat source parameter, thermal radiation parameter, Schmidt number and magnetic parameter. Additionally, the temperature is decreased with the effect of radiation parameter, Heat source parameter, Prandtl number.

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