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Influence of Radiation on Heat and Mass Transfer in MHD Fluid Flow Over an Infinite Vertical Porous Surface with Chemical Reaction

Research Article

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Abstract: An examination is completed to think about the nonlinear MHD stream with heat and mass transfer attributes of an incompressible, viscous, electrically directing and Boussinesq fluid over a vertical moving permeable porous plate in presence of homogeneous chemical reaction of first request and heat radiation impacts. The problem is explained numerically utilizing the perturbation technique for the velocity, the temperature, and the concentration field. The impacts of different thermo-physical parameters on the velocity, temperature and concentration has been processed numerically and discussed about subjectively.

Keywords: Radiation, heat exchange, MHD, vertical plate, chemical reaction.

1. Introduction

Magnetohydrodynamics (MHD) is the branch of continuum mechanics which manages the flow of electrically conducting fluids in electric and magnetic fields. Numerous characteristic wonders and designing problems merit being subjected to a MHD investigation. Magneto-hydrodynamic conditions are normal electromagnetic and hydrodynamic conditions altered to check the association between the movement of the fluid and the electromagnetic field. The plan of the electromagnetic hypothesis in a scientific structure is known as Maxwell's equation. The impact of the gravity field is constantly present in constrained stream heat transfer as a result of the buoyancy forces associated with the temperature contrasts. Generally they are of a little request of size so that the external forces might be dismissed. There has as of late been an extensive enthusiasm for the impact of body strengths on constrained convection phenomena. In certain engineering problems, be that as it may, they can't be let well enough alone for thought. Realize that the heat transfer in blended convection can be fundamentally not quite the same as that both in unadulterated regular convection and in pure forced convection. The investigation of constrained and free convection stream and heat transfer for electrically leading liquids past a semi-interminable permeable plate affected by an attractive field has pulled in light of a legitimate concern for some specialists in perspective of its applications in numerous building issues, for example, geophysics, astronomy, limit layer control in the field of streamlined features. Engineers utilize MHD rule, in the configuration of heat transfer pumps and stream meters, in space vehicle impetus, warm security, braking, control and reentry, in making novel force creating frameworks and so on.

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The radiation impacts have wonderful applications in material science and engineering, especially in space innovation and high temperature forms. Be that as it may, next to no is thought about the impacts of radiation on the limit layer. Thermal radiation consequences for the limit layer may assume vital part in controlling heat transfer in polymer handling industry where the nature of the last item relies on upon the heat controlling components to some degree. High temperature plasmas, cooling of atomic reactors, fluid metal liquids, power era frameworks are some imperative uses of radiative heat transfer. Really, numerous procedures in new building zones happen at high temperatures and learning of radiation heat transfer adjacent to the convective heat transfer turns out to be imperative for the outline of the applicable hardware. Atomic force plants, gas turbines and the different drive gadgets for flying machine, rockets, satellites and space vehicles are case of such designing zones. In addition, when radiative heat transfer happens, the fluid included can be electrically leading since it is ionized because of the high working temperature. As needs be, it is important to inspect the impact of the attractive field on the stream. Concentrate such impact has incredible significance in the application fields where thermal radiation and MHD are correlative. In every one of these applications understanding the conduct of MHD free and constrained convective stream and the different issue parameters that impact is a vital resource for originators creating applications that plan to control this stream. For instance, the way toward melding of metals in an electrical heater by applying an attractive field and the way toward cooling of the principal divider inside an atomic reactor regulation vessel where the hot plasma is confined from the divider by applying an attractive field.

Over the past years, this problem attracted the attention of several researchers. However, none of them included all relevant aspects that influence the flow behavior. Watanabe [1] presented a laminar forced and free mixed convection flow on a flat plate with uniform suction or injection was theoretically investigated. Non-similar partial differential equations are transformed into non-similar ordinary ones by means of difference-differential method. Also, Ahmed and Liu [2] analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Hussain et al. [3] considered the problem of natural convection boundary layer flow, induced by the combined buoyancy forces from mass and thermal diffusion from a permeable vertical flat surface with non-uniform surface temperature and concentration but a uniform rate of suction of fluid through the permeable surface. Alom et al. [4] investigated the steady MHD heat and mass transfer by mixed convection flow from a moving vertical porous plate with induced magnetic, thermal diffusion, constant heat and mass fluxes and the non-linear coupled equations are solved by shooting iteration technique. Orhan and Kaya [5] investigated the mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects using the Keller box scheme, an efficient and accurate finite-difference scheme. They concluded that, an increase in the radiation parameter decreases the local skin friction parameter and increases the local heat transfer parameter. Ghosh et al. [6] considered an exact solution for the hydromagnetic natural convection boundary layer flow past an infinite vertical flat plate under the influence of a transverse magnetic field with magnetic induction effects and the transformed ordinary differential equations are solved exactly. G.Dharmaiah et al.,[7] analysed MHD Free Convection Flow Through A Porous Medium Along A Vertical Wall. Dharmaiah Gurram et al., [8] expalined Effcts Of Radiation, Chemical Reaction And Soret On Unsteady Mhd Free Convective Flow Over A Vertical Porous Plate Ch. Baby Rani et al., [9] examined Synthetic Response And Radiation Impacts. K.S.Balamurugan et al., [10] studied MHD Free Convective Flow Past a Semi-Infinite Vertical Permeable Moving Plate with Heat Absorption.

As the importance of radiation in the fields of aerodynamics as well as space science technology, the present study is motivated towards this direction.

The main objective of the present investigation will, therefore, be to study the effects of radiation and magnetic Prandtl number on the steady mixed convective heat and mass transfer flow of an optically thin gray gas over an infinite vertical porous plate with constant suction in presence of transverse magnetic field, by means of analytical solutions. These analytical approximate solutions under perturbation technique give a wider applicability in understanding the basic physics and chemistry of the problem, which are particularly important in industrial and technological fields. In this article, it is considered the effects of chemical reaction as well as magnetic field on the heat and mass transfer of Newtonian fluids over an infinite vertical oscillating permeable plate with variable mass diffusion. The magnetic field is imposed transversely to the plate. The temperature and concentration of the plate is oscillating with time about a constant nonzero mean value. The dimensionless governing equations involved in the present analysis are solved using a closed analytical method and discussed.

2. Mathematical Analysis

Thermal radiation and mass transfer effects on unsteady MHD flow of a viscous incompressible fluid past along a vertical oscillating plate with variable temperature and also with variable mass diffusion in the presence of transverse applied magnetic field has been discussed.

- The $x'-$axis is taken along the plate in the vertical upward direction and the $y'-$axis is taken normal to the plate.
- It is assumed that the plate and fluid are at the same temperatureT'_∞ in the stationary condition with concentration level C'_∞ at all the points.
- At time $t > 0$, the plate is given an oscillatory motion in its own plane with velocity $U_0 \cos(\omega' t')$.
- At the same time the plate temperature is raised linearly with time and also mass is diffused from the plate linearly with time.
- A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate.
- The induced magnetic field and viscous dissipation is assumed to be negligible as the magnetic Reynolds number of the flow is taken to be very small.
- The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium.

Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

$$\frac{\partial u'}{\partial t'} = \frac{\partial^2 u'}{\partial y^2} + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \frac{u'}{K'} - \frac{\sigma}{\rho}B_0^2 u' \tag{1}$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q'_r}{\partial y'} \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_r\left(C' - C'_\infty\right) \tag{3}$$

The boundary conditions for the velocity, temperature and concentration fields are:

$$t' \le 0 : u' = 0,\, T' = T'_\infty,\, C' = C'_\infty \;\forall\, y$$

$$t' > 0 \begin{cases} u' = U_0 \cos(\omega' t')\,,\; T' = T'_\infty + \varepsilon\,(T'_w + T'_\infty)\,e^{n' t'},\; C' = C'_\infty + \varepsilon\,(C'_w - C'_\infty)\,e^{n' t'} \text{ at } y' = 0 \\ u' \to 0,\;\; T' \to T'_\infty,\;\; C' \to C'_\infty \;\;\text{ as } y' \to \infty \end{cases} \tag{4}$$

where u' is the velocity in the x'-direction, K' is the permeability parameter, β is the volumetric coefficient of thermal expansion, β^* is the volumetric coefficient of expansion for concentration, ρ is the density, σ is the electrical conductivity,

$k-$the thermal conductivity, $g-$the acceleration due to gravity, T' is the temperature, $T'_w-$the fluid temperature at the plate, $T'_\infty-$ the fluid temperature in the free stream, C' is the species concentration, C_p is the specific heat at constant pressure, $C'_\infty-$Species concentration in the free stream, C'_w-Species concentration at the surface,D is the chemical molecular diffusivity, q_r is the radiative flux. The local radiant absorption for the case of an optically thin gray gas is expressed as

$$\frac{\partial q_r}{\partial y'} = -4a'\sigma'\left(T'^4_\infty - T'^4\right) \tag{5}$$

where σ' and a' are the Stefan-Boltzmann constant and the Mean absorption coefficient, respectively. we assume that the temperature differences within the flow are sufficiently small so that T'^4 can be expressed as a linear function of T' after using Taylor's series to expand T'^4 about the free stream temperature T'_∞ and neglecting higher-order terms. This results in the following approximation:

$$T'^4 \cong 4T'^3_\infty T' - 3T'^4_\infty \tag{6}$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{16a'\sigma'}{\rho C_p}T'^3_\infty\left(T' - T'_\infty\right) \tag{7}$$

In order to write the governing equations and the boundary conditions in dimensionless from, the following non-dimensional quantities are introduced.

$$\left.\begin{array}{l} u = \frac{u'}{u_0}, y = \frac{u_0 y'}{v}, t = \frac{t' u_0^2}{v}, \theta = \frac{T'-T'_\infty}{T'_w-T'_\infty}, \phi = \frac{C'-C'_\infty}{C'_w-C'_\infty}, \omega = \frac{\omega'\nu}{u_0^2} \\ K = \frac{K' u_0^2}{v^2}, \Pr = \frac{v\rho C_p}{k},\ Sc = \frac{v}{D}, M = \frac{\sigma B_0^2 v}{\rho u_0^2}, Gr = \frac{v\beta g\left(T'_w-T'_\infty\right)}{u_0^3}, \\ Gm = \frac{v\beta^* g\left(C'_w-C'_\infty\right)}{u_0^3}, K_r = \frac{K'_r v}{u_0^2}, R = \frac{16a'\nu\sigma' T'^3_\infty}{k u_0^2}, A = \frac{u_0^2}{\nu} \end{array}\right\} \tag{8}$$

Using the transformations (8), the non-dimensional forms of (1), (3) and (7) are

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - \left(M + \frac{1}{K}\right)u \tag{9}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{\Pr}\theta \tag{10}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - Kr\phi \tag{11}$$

The corresponding boundary conditions are

$$\begin{array}{llll} u = \cos(\omega t), & \theta = t, & \phi = t & \text{at} \quad y = 0 \\ U \to 0, & \theta \to 0, & \phi \to 0 & \text{as} \quad y \to \infty \end{array} \tag{12}$$

where $M, K, Gr, Gm, \Pr, Kr, Sc, R$ are the magnetic parameter, permeability parameter, Grashof number for heat transfer, Grashof number for mass transfer, Prandtl number, Chemical reaction parameter, Schmidt number and radiation parameter respectively.

3. Method of Solution

In order to reduce the above system of partial differential equations to a system of ordinary differential equations in dimensionless form, we assume the trial solution for the velocity, temperature and concentration as:

$$u(y,t) = u_0(y)e^{i\omega t} \tag{13}$$

$$\theta(y,t) = \theta_0(y)e^{i\omega t} \tag{14}$$

$$\phi(y,t) = \phi_0(y)e^{i\omega t} \tag{15}$$

Substituting Equations (13), (14) and (15) in Equations (9), (10) and (11), we obtain:

$$u_0'' - A_3^2 u_0 = -\left[Gr\theta_0 + Gm\phi_0\right] \tag{16}$$

$$\theta_0'' - A_2^2\theta_0 = 0 \tag{17}$$

$$\phi_0'' - A_1^2\phi_0 = 0 \tag{18}$$

Here the primes denote the differentiation with respect to y. The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = e^{-i\omega t}\cos(\omega t), \quad \theta_0 = te^{-i\omega t}, \quad \phi_0 = te^{-i\omega t} \quad \text{at} \quad y = 0 \\ &u_0 \to 0, \qquad \theta_0 \to 0, \quad \phi_0 \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{19}$$

The analytical solutions of equations (16)-(18) with satisfying the boundary conditions (19) are given by

$$u_0(y) = \left\{\left[\cos(\omega t) - A_4 - A_5\right]e^{-A_3 y} + \left(A_4 e^{-A_1 y} + A_5 e^{-A_2 y}\right)\right\}e^{-i\omega t} \tag{20}$$

$$\theta_0(y) = \left(te^{-A_2 y}\right)e^{-i\omega t} \tag{21}$$

$$\phi_0(y) = \left(te^{-A_1 y}\right)e^{-i\omega t} \tag{22}$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$u(y,t) = \left\{\left[\cos(\omega t) - A_4 - A_5\right]e^{-A_3 y} + \left(A_4 e^{-A_1 y} + A_5 e^{-A_2 y}\right)\right\} \tag{23}$$

$$\theta(y,t) = \left(te^{-A_2 y}\right) \tag{24}$$

$$\phi(y,t) = \left(te^{-A_1 y}\right) \tag{25}$$

4. Results and Discussion

In order to get a physical insight in to the problem the effects of various governing parameters on the physical quantities are computed and represented in Figures below and discussed in detail. The effect of magnetic field on velocity profiles in the boundary layer is depicted in Figure 1. From this figure it is seen that the velocity starts from minimum value at the surface and increase till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is to decrease the value of the velocity profiles throughout the boundary layer. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. This type of resisting force slows down the fluid velocity as shown in this figure. For the case of different values of thermal Grashof number the velocity profiles on the boundary layer are shown in Figure 2. As expected, it is observed that an increase in Grashof number leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of Grashof number correspond to cooling of the surface. Figure 3 shows the velocity profiles for different values of the radiation parameter, clearly as radiation parameter increases the peak values of the velocity tends to increases. Figure 4 represents typical velocity profiles in the boundary layer for various values of the modified Grashof number, while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value more distinctive due to increase in the concentration buoyancy effects represented by modified Grashof number. This is evident in the increase in the value of velocity as modified Grashof number increases. For different values of the Schmidt number the velocity profiles are plotted in Figure 5. It is obvious that an increase in the Schmidt number results in decrease in the velocity within the boundary layer. Figure 6 illustrates the behavior velocity for different values of chemical reaction parameter Kr. It is observed that an increase in leads to a decrease in the values of velocity. Figure 7 shows the velocity profiles for different values of the permeability parameter, clearly as permeability parameter increases the peak values of the velocity tends to increase. For different values of time t on the velocity profiles are shown in Figure 8. It is noticed that an increase in the velocity with an increasing time t. Figure 9 illustrates the temperature profiles for different values of Prandtl number. It is observed that the temperature decrease as an increasing the Prandtl number. The reason is that smaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence in the case of smaller Prandtl number the thermal boundary layer is thicker and the rate of heat transfer is reduced. Figure 10 has been plotted to depict the variation of temperature profiles for different values of radiation parameter R by fixing other physical parameters. From this Graph we observe that temperature decrease with increase in the radiation parameter. Figure 11 displays the effect of Schmidt number Sc on the concentration profiles respectively. As the Schmidt number increases the concentration decreases. Figure 12 displays the effect of the chemical reaction on concentration profiles. We observe that concentration profiles decreases with increasing chemical reaction parameter.

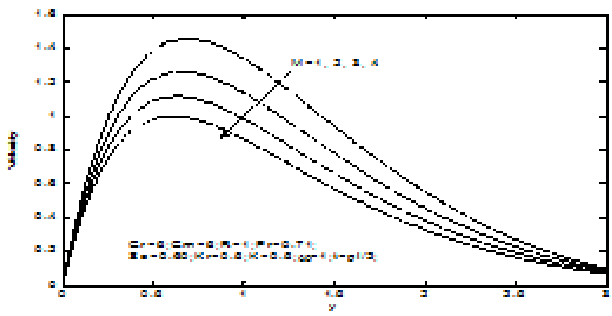

Figure 1: Velocity profiles for different values of magnetic parameter.

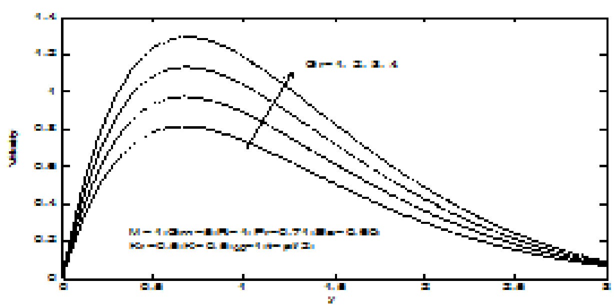

Figure 2: Velocity profiles for different values of Grashof number.

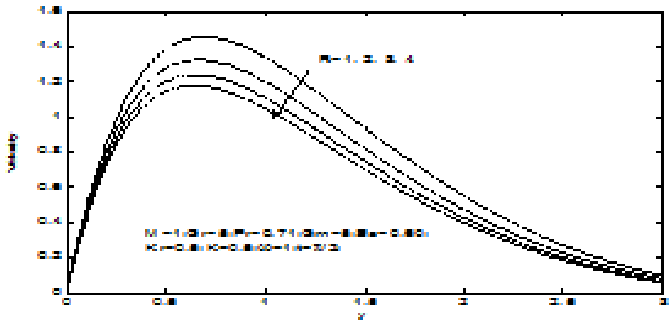

Figure 3: Velocity profiles for different values of radiation parameter.

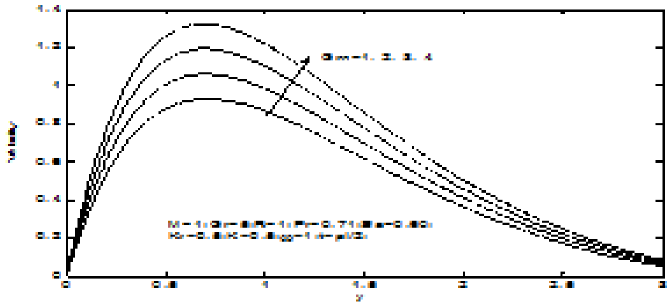

Figure 4: Velocity profiles for different values of modified Grashof number.

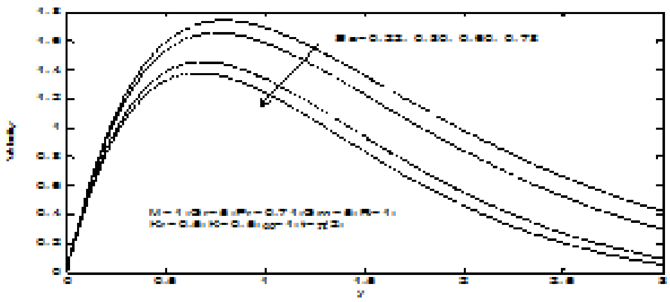

Figure 5: Velocity profiles for different values of Schmidt number.

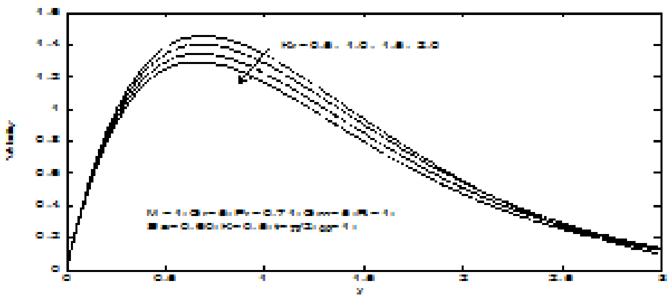

Figure 6: Velocity profiles for different values of chemical reaction parameter.

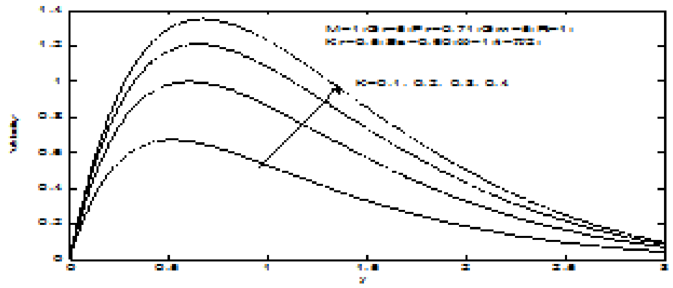

Figure 7: Velocity profiles for different values of permeability parameter.

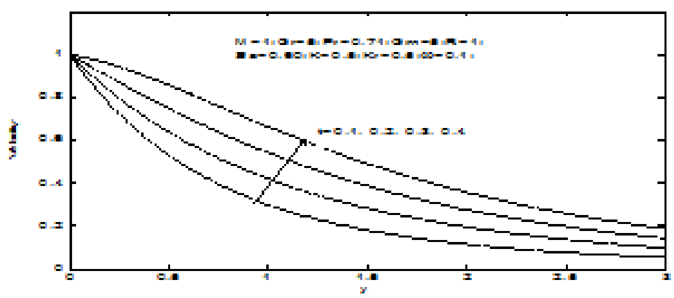

Figure 8: Velocity profiles for different values of time.

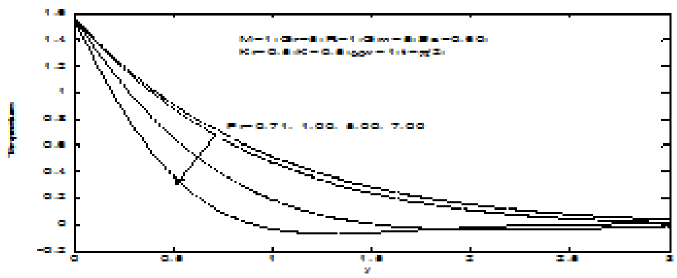

Figure 9: Temperature profiles for different values of Prandtl number.

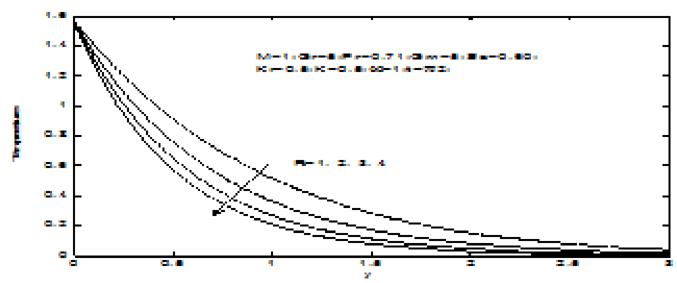

Figure 10: Temperature profiles for different values of radiation parameter.

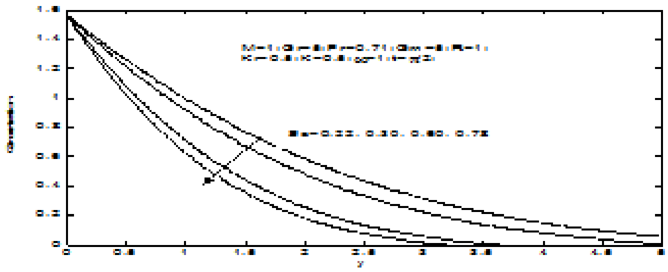

Figure 11: Concentration profiles for different values of Schmidt number.

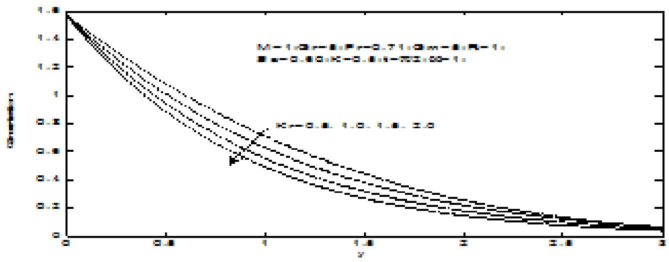

Figure 12: Concentration profiles for different values of chemical reaction.

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