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UNSTEADY MHD FREE CONVECTIVE FLOW OVER AN EXPONENTIALLY MOVING VERTICAL POROUS PLATE IN THE PRESENCE OF RADIATION AND CHEMICAL REACTION

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Abstract

A study has been carried out on unsteady, magnetohydrodynamic free convection, viscous, incompressible fluid flow past an accelerated, vertical porous plate in the presence of radiation, heat absorption and variable surface temperature and concentration. The dimensionless governing coupled, non-linear boundary layer partial differential equations are solved by a closed analytical method. Numerical results for the velocity, temperature and concentration profiles as well as for the skin-friction coefficient, wall heat transfer and mass transfer rate are obtained and reported graphically and discussed qualitatively.

Keywords: MHD, radiation, chemical reaction, skin-friction, heat transfer and mass transfer.

1. Introduction

The study of unsteady MHD free convection flow with mass transfer along a vertical porous plate is receiving considerable attention of many researchers because of its various applications. 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 insulation of the surface more effective. Sometimes along with the free convection currents caused by difference in temperature the flow is also affected by the differences in concentration or material constitution. This type of flow has applications in many branches of science and engineering. The study of such flow under the influence of magnetic field has attracted the investigators in view of its various applications in MHD generators, plasma studies, nuclear reactors, geothermal energy extractions and boundary layer control in the field of aerodynamics. Moreover, considerable interest has been shown in radiation interaction with convection for heat and mass transfer in fluids. This is due to the significant role of thermal radiation in the surface heat transfer when convection heat transfer is small, particularly in free convection problems involving absorbing-emitting fluids. Several workers have studied the problem of free convection flow with mass transfer. Singh et al. [1] have studied MHD free convective flow past an accelerated vertical porous plate by finite difference method. Free convection and mass transfer flow through porous medium bounded by an infinite vertical limiting surface with constant suction have been analyzed by Raptis et al [2]. Unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate has been discussed by Sattar et al [3]. Das et al [4] have studied numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Das et al [5] have studied Mass transfer effects on MHD flow and heat transfer past a vertical porous plate through porous medium under oscillatory suction and heat source. Applied magnetic field on transient convective flow in a vertical channel has been discussed by Jah [6].Kim [7] has investigated the problem of unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Soundalgekar et al. [8] have analyzed the transient free convection flow of a viscous dissipative fluid past a semi-infinite vertical plate. Mohameda et al [9] have analyzed finite element analysis of hydromagnetic flow and heat transfer of a heat generation fluid over a surface embedded in a non-Darcian porous medium in the presence of chemical reaction. The Soret effect on free convective unsteady MHD flow over a vertical plate with heat source has been analyzed by Bhavana et al. [10]. Abd EL–Naby et al [11] employed implicit finite finite-difference methods to study the effect of radiation on MHD unsteady free convection flow semi-infinite vertical porous plate but did not take into account the viscous dissipation. Recently, Alam and Rahman [12] have examined Dufour and Soret effects on mixed convection flow past a vertical porous flat plate with variable suction embedd medium for a hydrogen-air mixture as the nonchemical reacting fluid pair. Anwa et al. [13] examined the combined effects of Soret and Dufour diffusion and porous on laminar magneto-hydrodynamic mixed convection heat and mass transfer of an electrically-conducting, Newtonian, Boussinesq fluid from a vertical stretching surface in a Darcian porous medium under uniform transverse magnetic field. Hady et al. [14] studied the problem of free convection flow along a vertical wavy surface embedded in electrically conducting fluid saturated porous media in the presence of internal heat generation or absorption effect. have discussed Free-convection flow with thermal radiation and mass transfer past a moving vertical porous From the previous literature survey about unsteady fluid flow, we observe that a few papers have medium. The effect of radiation on MHD flow and heat transfer must be considered when high temperatures are reached. The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluid undergoing exothermic or endothermic chemical reactions. When the mass flux contains a term that depends on the temperature gradient then the Soret effect arises focus of our study is the effect on free convection of the addition of a second fluid. Convection in binary fluids is considerably more complicated than that in pure fluids. Both temperature and concentration gradients contribute initiation of convection and each may be stabilizing or destabilizing. Even when a concentration gradient is not externally imposed (the thermosolutal problem) it can be created by the applied thermal gradient via the Soret effect. Mbeledogu et.al [16] have discussed the unsteady MHD free convection flow of a compressible fluid past a moving vertical plate in the presence of radioactive heat transfer Ahmmed et al. [17] have discussed Numerical Study on MHD free convection and mass transfer flow flat plate.

In our present paper the unsteady MHD free convection heat and mass transfer flow past a vertical porous plate has been investigated analytically by using a closed form method. The effects of the flow parameters on the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number distribution of the flow field have been studied with the help of graphs.

2. Formulation of The Problem

We consider the unsteady magnetohydromagnetic flow of viscous incompressible fluid past an exponentially accelerated isothermal infinite vertical porous plate with variable temperature with variable mass diffusion in the presence of heat absorption and variable temperature. Initially, the plate and the fluid are ate same temperature $T_\infty^{'}$ in the stationary condition with concentration level $C_\infty^{'}$ at all the points .At time $t^{'} > 0$, the plate is exponentially accelerated with velocity $u = u_0 e^{a't'}$ in its own plane and temperature of the plate is raised linearly with time and species concentration level near the plate is also raised linearly with time $t^{'}$. The temperature of the plate and the concentration level are also raised or lowered to $T_\infty^{'} + (T_w^{'} - T_\infty^{'})At^{'}$ and $c_\infty^{'} + (c_w^{'} - c_\infty^{'})At^{'}$ respectively. All the fluid physical properties are considered to be constant except the influence of the body force term. Applied transverse magnetic field of uniform strength B_0 is normal to the plate. The fluid’s conducting property is supposed to be slight and hence the magnetic Reynolds number is lesser than unity and the included magnetic field is small in comparison with the transverse magnetic field. It is further supposed that there is no applied voltage as the electric field is absent. Viscous dissipation and joule heating in energy equation are neglected. Electric field is neglected. According to Boussinesq’s approximation the unsteady flow is governed following set of equations:

Momentum equation

$$\left[\frac{\partial u^{'}}{\partial t^{'}}\right]=\vartheta\left[\frac{\partial^2 u^{'}}{\partial y^{'2}}\right]-\left[\frac{\sigma B_0^2}{\rho}\right]u^{'}+\left[g\beta(T^{'}-T_\infty^{'})\right]+\left[g\beta^{*}(C^{'}-C_\infty^{'})\right]-\frac{\vartheta}{K^{'}}u^{'} \quad (1)$$

Energy Equation

$$\frac{\partial T^{'}}{\partial t}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^{'2}}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^{'}}-Q_0(T_\infty^{'}-T^{'}) \quad (2)$$

Species Diffusion equation

$$\left[\frac{\partial C^{'}}{\partial t^{'}}\right]=D\left[\frac{\partial^2 C^{'}}{\partial y^{'2}}\right]-D\left[K_r^{'}(C^{'}-C_\infty^{'})\right] \quad (3)$$

The corresponding initial and boundary conditions are

$$t^{'}\le 0 \quad u^{'}=0, T^{'}=T_\infty^{'}, C^{'}=C_\infty^{'} \; for\,all \;\; y^{'}$$

$$\begin{aligned}
&t^{'}>0: u^{'}=u_0\exp(a^{'}t^{'}),\; T^{'}=T_\infty^{'}+(T_w^{'}=T_\infty^{'})At^{'}, and\\
&\qquad C^{'}=C_\infty^{'}+(C_w^{'}=C_\infty^{'})At^{'} \;\; at \;\; y^{'}=0\\
&\qquad u^{'}=0,\, T^{'}\to T_\infty^{'},\;\, C^{'}\to C_\infty^{'} \; as \; y^{'}\to\infty
\end{aligned} \quad (4)$$

On introducing the following non dimensional quantities into the equations (1)-(3)

$$\begin{aligned}
&u=\frac{u^{'}}{u_0}, t=\frac{t^{'}u_0^2}{\vartheta}, y=\frac{y^{'}u_0}{\vartheta}, \theta=\frac{T^{'}-T_\infty^{'}}{T_w^{'}-T_\infty^{'}}, \phi=\frac{C^{'}-C_\infty^{'}}{C_w^{'}-C_\infty^{'}},\\
&M=\frac{\sigma B_0^2\vartheta}{\rho u_0^2}, G_r=\frac{g\beta\vartheta(T_w^{'}-T_\infty^{'})}{u_0^3}, G_c=\frac{g\beta^{*}\vartheta(C_w^{'}-C_\infty^{'})}{u_0^3},\\
&P_r=\frac{\rho C_p}{K}, S_c=\frac{\vartheta}{D}, S=\frac{Q_0\vartheta^2}{Ku_0^2}, a=\frac{a^{'}\vartheta}{u_0^2}, \lambda=\frac{\vartheta K_r^{'}}{u_0^2},\\
&\mathrm{Re}_x=\frac{u_0 x}{\vartheta}, A=\frac{u_0^2}{\vartheta}
\end{aligned} \quad (5)$$

We obtain the following governing equations in dimensionless form

$$\frac{\partial u}{\partial t}=G_r\theta+G_c\phi+\frac{\partial^2 u}{\partial y^2}-(M+\frac{1}{K})u \quad (6)$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{P_r}\frac{\partial^2\theta}{\partial y^2}-\frac{(Q+R)}{P_r}\theta \tag{7}$$

$$\frac{\partial\phi}{\partial t}=\frac{1}{S_c}\frac{\partial^2\phi}{\partial y^2}-\frac{\lambda}{S_c}\phi \tag{8}$$

The initial and boundary conditions in dimensionless form are as follows

$$\begin{aligned} &t>0: u=\exp(at),\ \theta=t, \phi=t,\ at\ y=0\\ &\quad u=0,\ \theta\to 0,\ \phi\to 0\ as\ y\to\infty \end{aligned} \tag{9}$$

3. Solution of The Problem

Equations (6) – (8) are coupled, non – linear partial differential Equations and these Equations can be reduced to a set of ordinary differential Equations, which can be solved closed analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} u(y,t)&=u_0(y)e^{iwt}\\ \theta(y,t)&=\theta_0(y)e^{iwt}\\ \phi(y,t)&=\phi_0(y)e^{iwt} \end{aligned} \tag{10}$$

The corresponding boundary conditions are

$$\begin{aligned} &t>0: u_0=e^{at-iwt},\ \theta_0=te^{-iwt}, \phi_0=te^{-iwt},\ at\ y=0\\ &\quad u_0\to 0,\ \theta_0\to 0,\ \phi_0\to 0\ as\ y\to\infty \end{aligned} \tag{11}$$

Substituting Equations (10) and (11) in Equations (5-9), and solving for the velocity, temperature and concentration in the boundary layer as

$$\begin{aligned} u(y,t)&=A_1e^{-k_2y}+A_2e^{-k_1y}+A_3e^{-k_3y}\\ \theta(y,t)&=te^{-k_1y}\\ \phi(y,t)&=te^{-k_2y} \end{aligned}$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –dimensional form is given by

$$C_f=\left(\frac{\partial u}{\partial y}\right)_{y=0}=\left(k_2A_1+k_1A_2+k_3A_3\right)$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non –dimensional form is given, in terms of the Nusselt number, is given by

$$N_u = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = tk_2$$

where $\mathrm{Re}_x = \frac{v_0 x}{\nu}$ is the local Reynolds number.

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non –dimensional form, in terms of the Sherwood number, is given by

$$S_h = \left(\frac{\partial \phi}{\partial y}\right)_{y=0} = tk_1$$

Here the constants are not given due to shake of brevity.

4. Results and Discussion

The analysis of the graphical representation of the flow, heat and mass transfer phenomena brings out the effects of various parameters governing of the flow.

Velocity Profiles for different parameters

In Fig. 1 the effect of the magnetic field strength on the momentum boundary layer thickness is demonstrated. It is now a well established fact that the magnetic field presents a damping effect on the velocity field by creating drag force that opposes the fluid motion, causing the velocity to decrease. However, in this case an increase in the M only slightly slows down the motion of the fluid away from the moving vertical plate surface towards the free stream velocity, while the fluid velocity near the moving vertical plate surface decreases. This phenomenon is in excellent agreement with the physical fact that the Lorentz force generated in the present flow model due to interaction of the transverse magnetic field and the fluid velocity acts as a resistive force to the fluid flow which serves to decelerate the flow. Figure 2 evince the velocity for different values of the permeability parameter (K) .It is clear that the peak value of the velocity tends to increases as permeability (K) increases. At y =1.85 (approximately) the velocity is highest. Figure 3 exhibit the velocity profiles across the boundary layer for different values of Prandtl number (Pr). It is obvious that the effect of increasing values of Prandtl number (*Pr*) results in decreasing the velocity. From Figure 4 it is observed that with an increasing in the thermal radiation parameter results a decrease in the velocity field. The effect of increasing the value of the heat absorption parameter is to decrease the boundary layer as shown in Fig. 5, which is as expected due to the fact that when heat is absorbed the buoyancy force decreases which retards the flow rate and thereby giving rise to decrease in the velocity profiles. The velocity profile for different values of Grashof number (*Gr*) are described in Figure 6. From this figure it is observed that an increasing in *Gr* leads to increase in the values of velocity. Here the Grashof number leads free convection currents. If *Gr*=0 then it represents the absence of free convection currents. *G*r>0 means heating of the fluid of cooling of the boundary surface and *Gr*<0 means cooling of the fluid of heating of the boundary surface. For the case of different values of the solutal Grashof number (Gc), the velocity profiles in the boundary layer are shown in Figure 7.The velocity distribution attains a distinctive maximum value in the vicinity of the plate and then decreases properly to approach a free stream value. As expected, the fluid velocity increases and the peak value becomes more distinctive due to increase in the buoyancy force represented by the modified Grashof number. For different values of the Schmidt number (*Sc*), the velocity profiles are plotted in Figure 8. It is obvious that the effect of increasing values of *Sc* parameters results in decreasing velocity distribution across the boundary layer. The effects of the chemical reaction parameter *Kr* on the velocity is shown in Figure 9. It is noticed that an increase in the chemical reaction parameter results a decrease in the velocity within the boundary layer.

Temperature profiles for different parameters

Figures 10 & 11 represent the temperature profiles due to the variations in R and Q respectively. The temperature decreases with an increase in R or Q. Typical variations of the temperature profiles along the span wise coordinate *y* are shown in Figure 12 for different values of Prandtl number (*Pr*). The result shows that for an increasing value of Prandtl number leads an increasing the temperature profiles of thermal boundary layer thickness and constant temperature distribution across the boundary layer.

Concentration profiles for different parameters

The concentrations profiles are plotted in Figure 13 for different values of the Schmidt number (*Sc*). It is observed that the effect for increasing values of *Sc* results in decreasing concentrations distribution across the boundary layer and all curves meet the *y* axis. The effects of the chemical reaction parameter *Kr* on the concentration is shown in Figure 14. It is noticed that an increase in the chemical reaction parameter results a decrease in the concentration within the boundary layer.

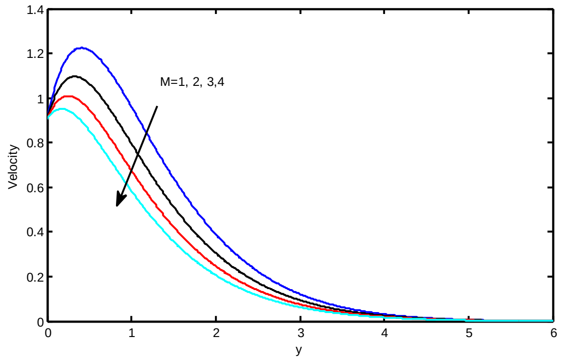

Fig.1 Velocity profiles for different values magnetic parameter (M)

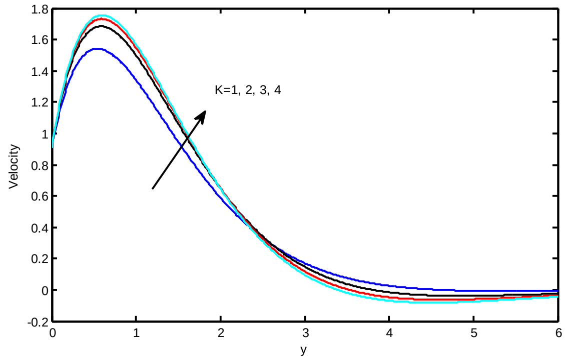

Fig.2 Velocity profiles for different values permeability parameter (K)

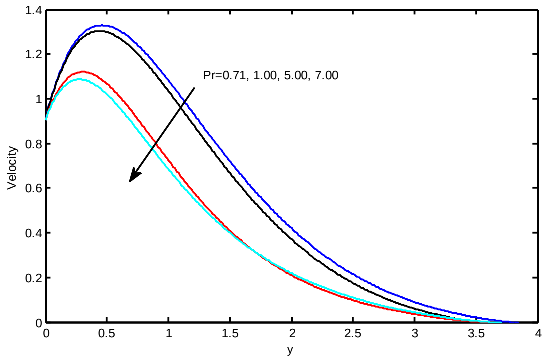

Fig.3 Velocity profiles for different values Prandtl number (Pr)

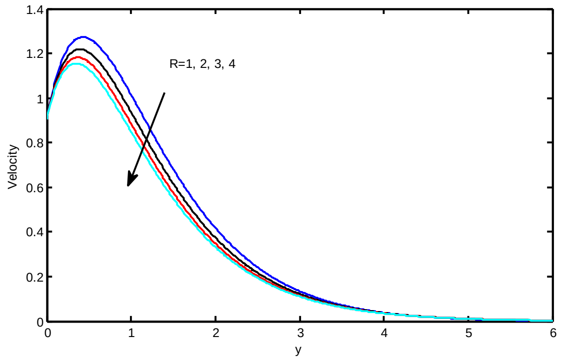

Fig.4 Velocity profiles for different values radiation parameter (R)

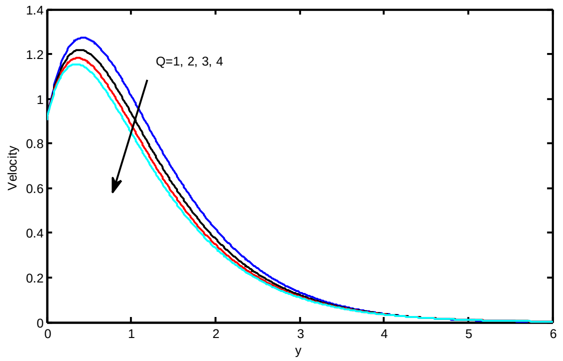

Fig.5 Velocity profiles for different values heat absorption parameter (Q)

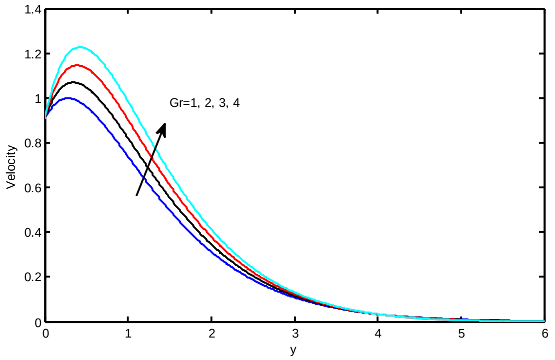

Fig.6 Velocity profiles for different values Grashof number (Gr)

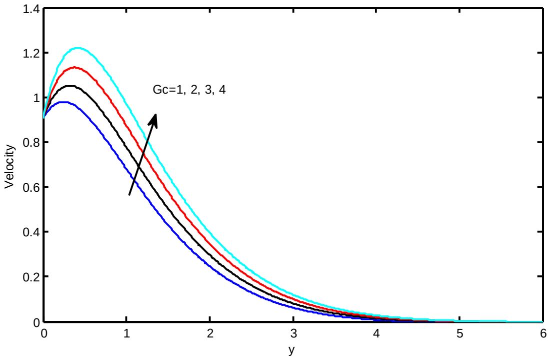

Fig.7 Velocity profiles for different values modified Grashof number (Gc)

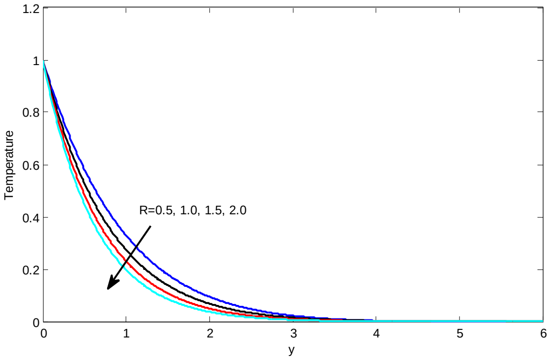

Fig.10 Temperature profiles for different values radiation parameter (R)

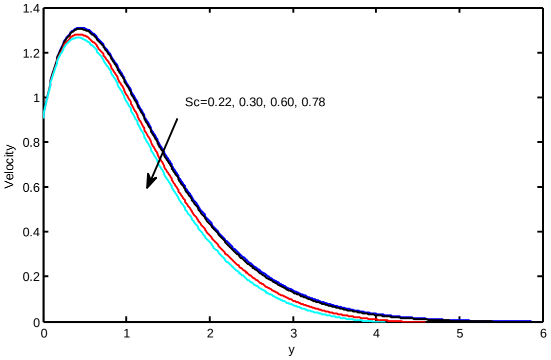

Fig.8 Velocity profiles for different values Schmidt number (Sc)

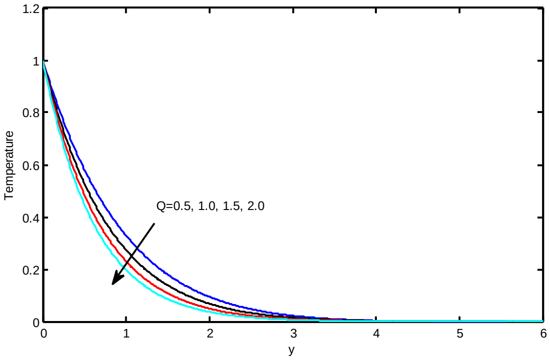

Fig.11 Temperature profiles for different values heat absorption parameter (Q)

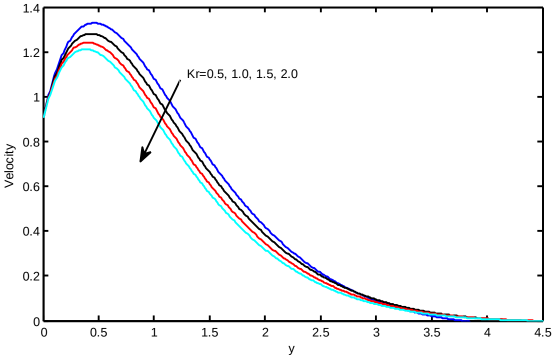

Fig.9 Velocity profiles for different values chemical reaction parameter (Kr).

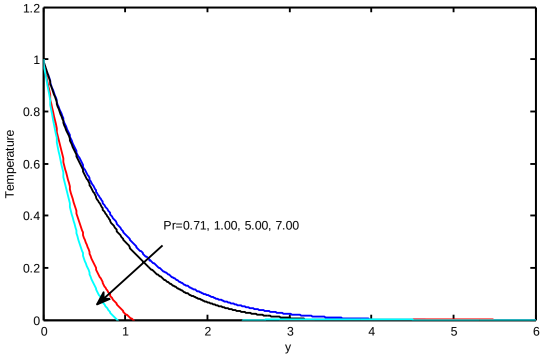

Fig.12 Temperature profiles for different values Prandtl number (Pr)

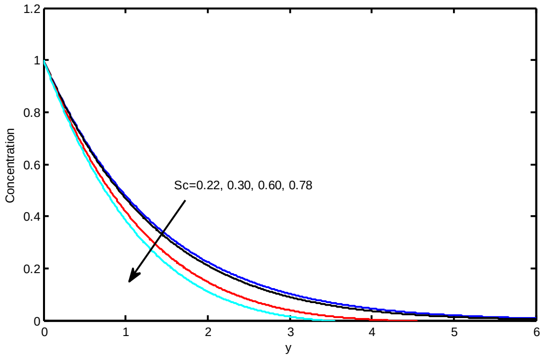

Fig.13 Concentration profiles for different values Schmidt number (Sc)

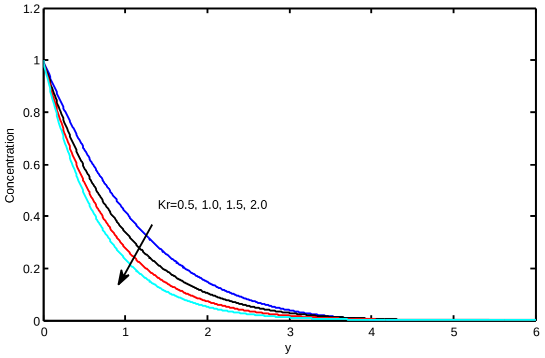

Fig.14 Concentration profiles for different values chemical reaction parameter (Kr)

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