[Volume 4 issue 07 July 2016]
PageNo.1526-1540 ISSN : 2320-7167

INTERNATIONAL JOURNAL OF MATHEMATICS AND COMPUTER RESEARCH

Chemical Reaction Effects On MHD Viscous Flow Past An Implusively Strated Infinite Vertical Plate

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Abstract:
In this chapter, we study the chemical reaction effects on the unsteady visco-elastic second order Rivin-Erickson and radiave fluid past an impulsively started infinite vertical plate in the presence of foreign mass on taking into account of viscous dissipative heat at the plate under the influence of a uniform transverse magnetic field. The dimensionless governing equations for this study are solved numerically using finite difference method. The velocity, temperature and concentration profiles are shown graphically for various material parameters such as magnetic parameter (M), Prndtl number (Pr), Schmidt number (Sc), Chemical reaction parameter (Kr), Grashof number (Gr), modified Grashof number (Gm), Sink-strength parameter (S), Permeable parameter (k).

Keywords: MHD, chemical reaction, radiation, impulsively started infinite vertical plate etc.

INTRODUCTION:

Viscoelastic fluid mechanics affords an excellent opportunity for studying many of the mathematical techniques which have been developed to analyze non-linear problems and these flows arise in various applications in chemical engineering systems. Such flows contains both viscous and elastic properties and can exhibit normal stresses and relaxation effects. Ezzat (1) discussed the magnetohydrodynamic unsteady flow of a non-Newtonian fluid past an infinite porous plate. Jyothi and Viswanatha Reddy (2) studied the free convective MHD heat and mass transfer flow of a visco-elastic fluid flow through porous medium bounded by an impulsively started infinite vertical plate. Bhagwat and Kuldeep (3) examined the mass transfer effects on MHD free convective flow of a visco-elastic dusty gas embedded in a porous medium in the presence of heat source. Rita Choudhary et al. (4) illustrated the heat and mass transfer effects on visco-elastic fluid flow in a vertical channel through porous medium.

Bansal et al. (5) examined the horizontal layer double diffusive convective flow of a viscoelastic Maxwell fluid embedded in a porous medium with internal linear heating. Noushima et al (6) investigated hydro magnetic free convective Rivin-Erickson flow through a porous medium with variable permeability. Ambethkar (7) studied numerically effect of heat and mass transfer on an oscillatory flow of a viscoelastic fluid with thermal relaxation. Saravana et al. (8) studied the flow of a viscous incompressible visco-elastic second order Rivlin-Erickson fluid past an impulsively started infinite vertical plate.

In many chemical engineering procedures contains the chemical reaction between a fluid and foreign mass. Muthucumaraswamy and Meenakshisundaram (9) investigated theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Reddy and Srihari (10) investigated the numerical solution of unsteady flow of a radiating and chemically reacting fluid with time-dependent suction.

Viscous mechanical dissipation effects are very important in geophysical flows and also in certain industrial operations and these effects are mainly considered by the Eckert number. Mohammed Ibrahim and Bhaskar Reddy (11) studied the radiation and mass transfer effects on MHD free convection flow along a stretching surface taking into the account of viscous dissipation and heat generation.
However the collaboration of radiation with mass transfer of an electrically conducting and diffusing fluid impulsively started infinite vertical plate has received little attention. Hence an attempt is made to investigate the chemical reaction and radiation effects on an unsteady visco-elastic second order Rivin-Erickson fluid past an impulsively started infinite vertical plate in the presence of foreign mass on taking into account of viscous dissipation. The equations of continuity, momentum, energy and diffusion, which governing the flow field, are numerically solved by using explicit finite difference method.

Nomenclature

u', v'	-	velocity components along the x', y' directions (m/s)
T'	-	temperature of the fluid (K)
T'_w	-	temperature of the fluid (K)
T'_∞	-	temperature of the fluid in the free stream (K)
C'	-	concentration of the species (Kgm^{-1})
C'_w	-	concentration of the species at the plate (Kgm^{-1})
C'_∞	-	concentration of the species in the free stream (Kgm^{-1})
C	-	dimensionless species concentration (Kgm^{-1})
K'_r	-	chemical reaction coefficient (K^{-1})
g	-	gravitational acceleration (m/s^2)

k - dimensionless chemical reaction (K^{-1})

v_0 - suction velocity (m/s)

C_p - specific heat at constant pressure $(J.kg^{-1}.K)$

$\Pr$ - Prandtl number

Sc - Schmidt number

D - mass diffusion coefficient $(m^2.s^{-1})$

t - dimensionless time (s)

Gr - thermal Grashof number

Gc - mass Grashof number

B_0 - magnetic field flux density

M - Magnetic parameter

Ec - Eckert number

Greek symbols

α - thermal diffusivity $(m^2.s^{-1})$

β - coefficient of thermal expansion (K^{-1})

β^* - coefficient of thermal expansion with concentration (K^{-1})

ε - small reference parameter

θ - dimensionless temperature (K)

κ - thermal conductivity $(W.m^{-1}K^{-1})$

ρ - density (Kgm^{-1})

μ - coefficient of viscosity $(kgs^{-1}m)$

υ - kinematic viscosity (m^2s^{-1})

ω - frequency parameter (s^{-1})

τ - dimensional shearing stress $(N.m^{-1})$

σ - electrical conductivity $(\Omega^{-1}m)$

Subscripts

w - evaluated at wall conditions

∞ - evaluated at free stream conditions

1.

FORMULATION OF THE PROBLEM:

Consider the flow of a viscous incompressible visco-elastic second order Rivin-Erickson radiating and chemically reacting fluid past an impulsively started infinite vertical plate. The x'-axis is taken along the plate in the vertically upward direction and the y'-axis is chosen normal to the plate. Initially the temperature of the plate and the fluid T'_∞, and the species concentration at the plate C'_w and in the fluid throughout C'_∞ are assumed to be the same. At time $t' > 0$, the plate temperature is changed to T'_w causing convection currents to flow near the plate and mass is supplied at a constant rate to the plate and the plate starts moving upward due to impulsive motion, gaining a velocity of U_0. A uniform magnetic field of intensity H_0 is applied in the y-direction. Therefore the velocity and the magnetic field are given by $\bar{q} = (u, 0, 0)$ and $\bar{H} = (0, H_0, 0)$. The flow being slightly conducting the magnetic Reynolds number is much less than unity and hence the induced magnetic field can be neglected in comparison with the applied magnetic field in the absence of any input electric field, the flow is governed by the following equations:

Continuity Equation

$$\frac{\partial u'}{\partial y'} = 0 \tag{4.1}$$

Momentum equation

$$\frac{\partial u'}{\partial t'} = g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) + v\frac{\partial^2 u'}{\partial y'^2} + K_0^* \frac{\partial^3 u'}{\partial y'^2 \partial t'} - \frac{\sigma \mu_e^2 H_0^2}{\rho} u' \tag{4.2}$$

Energy equation

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r}{\partial y'} + \mu \left(\frac{\partial u'}{\partial y'}\right)^2 \tag{4.3}$$

Diffusion equation

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K'_r(C' - C'_\infty) \tag{4.4}$$

The initial and boundary conditions are:

$$\left.\begin{array}{l} t' \leq 0: \; u' = 0,\, T' = T'_\infty,\, C' = C'_\infty \; for all \; y' \\ t' > 0: u' = U_0,\; T' = T'_w,\; C' = C'_w \; at \; y' = 0 \\ \qquad u' \to 0, T' \to T'_\infty,\; C' \to C'_\infty \; as \; y' \to \infty \end{array}\right\} \tag{4.5}$$

By using the Rosseland approximation, the radiative heat flux q_r is given by

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T'^4}{\partial y'} \tag{4.6}$$

where σ^* is the Stefan-Boltzmann constant and k^* is the mean absorption coefficient. It should be noted that by using the Rosseland approximation the present analysis is limited to optically thick fluids. Assuming that the differences in temperature within flow are such that ${T'}^4$ can be expressed as a linear combination of the temperature, we expand ${T'}^4$ in a Taylor's series about T'_∞ as follows

$${T'}^4 = {T'_\infty}^4 + 4{T'_\infty}^3(T' - T'_\infty) + 6{T'_\infty}^2(T' - T'_\infty)^2 + \ldots$$

and neglecting higher order terms beyond the first degree in $(T' - T'_\infty)$ we get

$${T'}^4 \cong 4{T'_\infty}^4 T' - 3{T'_\infty}^4 \quad (4.7)$$

From equations (4.6), (4.7) we obtain

$$\frac{\partial q_r}{\partial y'} = -\frac{16\sigma^* {T'_\infty}^4}{3k^*}\frac{\partial^2 T'}{\partial {y'}^2} \quad (4.8)$$

From (4.3) and (4.8) we have

$$\rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial {y'}^2} + \frac{16\sigma^* {T'_\infty}^4}{3k^*}\frac{\partial^2 T'}{\partial {y'}^2} + \mu\left(\frac{\partial u'}{\partial y'}\right)^2 \quad (4.9)$$

On introducing the following dimensionless variables and parameters

$$\left.\begin{aligned} u = \frac{u'}{U_0}, t = \frac{t'U_0^2}{v}, y = \frac{y'U_0}{v}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, C = \frac{C' - C'_\infty}{(j''v/DU_0)} \\ G = \frac{vg\beta(T'_w - T'_\infty)}{U_0^3}, Gc = \frac{vg\beta^*(j''v/DU_0)}{U_0^3}, \lambda = \frac{K_0^* U_0^2}{v^2}, \mathrm{Pr} = \frac{v\rho C_p}{\kappa} \\ M = \frac{\sigma\mu_e^2 H_0^2 v}{\rho U_0^2}, Ec = \frac{\mu U_0}{v\rho C_p(T'_w - T'_\infty)}, Sc = \frac{v}{D}, F = \frac{k_e k}{4\sigma_s {T'_\infty}^3}, Kr = \frac{K'_r v}{U_0^2} \end{aligned}\right\} \quad (4.10)$$

In terms of the above dimensionless quantities, Equations (4.2), (4.9) and (4.4) reduces to

$$\frac{\partial u}{\partial t} = G\theta + Gc\,C + \frac{\partial^2 u}{\partial y^2} + \lambda\frac{\partial^3 u}{\partial y^2 \partial t} - Mu \quad (4.11)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\left(1 + \frac{4}{3F}\right)\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 \quad (4.12)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC \quad (4.13)$$

With the following initial and boundary conditions:

$$\left.\begin{aligned} t \le 0: u = 0, \quad T = 0, \quad C = 0 \quad for all\ y \\ t > 0: u = 1, \ \theta = 1, \quad C = 1 \ at \quad y = 0 \\ u \to 0, T \to 0, \ C \to 0\ as \ \ y \to \infty \end{aligned}\right\} \quad (4.14)$$

METHOD OF SOLUTION:

Equations (4.11) – (4.13) are coupled non-linear partial differential equations, and are to be solved by using the initial and boundary conditions (4.14). However, exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference scheme of equations for (4.11) – (4.13) are as follows:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t} = G\theta_{i,j} + Gc.C_{i,j} + \frac{u_{i+1,j}-2u_{i,j}+u_{i-1,j}}{(\Delta y)^2}$$
$$+\lambda\left(\frac{u_{i+1,j+1}-2u_{i,j+1}+u_{i-1,j+1}-u_{i+1,j}+2u_{i,j}-u_{i-1,j}}{\Delta t.(\Delta y)^2}\right) - Mu_{i,j} \qquad (4.15)$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t} = \frac{1}{Pr}\left(1+\frac{4}{3F}\right)\left(\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{(\Delta y)^2}\right) + Ec\left(\frac{u_{i+1,j}-u_{i,j}}{\Delta y}\right)^2 \qquad (4.16)$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t} = \frac{1}{Sc}\frac{C_{i+1,j}-2C_{i,j}+C_{i-1,j}}{(\Delta y)^2} - KrC_{i,j} \qquad (4.17)$$

Where index i refers to y and j to time t, and during computation Δy = 0.1 and Δt = 0.001.

From the initial and boundary conditions in (4.14), we have the following equivalent:

$u(i,0) = 0, \theta(i,0) = 0, C(i,0) = 0 \; for \; all \; i$

$u(0,j) = 1, \theta(0,j) = 1, C(0,j) = 1 \; for \; all \; j$

$u(i_{max},j) = 0, \theta(i_{max},j) = 0, C(i_{max},j) = 0 \; for \; all \; j$

Here i_{max} was taken as 50

First the velocity at the end of time step viz, $u(i,j+1)(i=1,50)$ is computed from (4.15) in terms of velocity, temperature and concentration at points on the earlier time-step. Then $\theta(i,j+1)$ is computed from (4.16) and $C(i,j+1)$ is computed from (4.17). The procedure is repeated until $t = 0.5(i.e. j = 500)$. During computation Δt was chosen as 0.001.

To judge the accuracy of the convergence and stability of finite difference scheme, the same program was run with different values of Δt i.e., $\Delta t = 0.0009, 0.0001$ and no significant change was observed. Hence, we conclude that the finite-difference scheme is stable and convergent.

RESULTS AND DISCUSSION:

The effects of radiation and viscous dissipation on the flow of an incompressible viscous chemically reacting fluid along a infinite vertical plate in the presence of transverse magnetic field was considered and analyzed. In order to obtain the physical significance of the problem, a representative set of numerical results is shown graphically in Fig. 4.1-4.6, to illustrate the influence of physical parameters embedded in the flow system.

The effect of radiation parameter F on the transient velocity (u) and temperature (θ) variations are depicted in Figs. 4.1(a) and 4.1(b). The radiation parameter F (i.e., Stark number) defines the relative contribution of conduction heat transfer to thermal radiation transfer. As F increases, considerable reduction is observed in both velocity and temperature profiles.

The influence of chemical reaction parameter Kr on the velocity and concentration profiles are depict in Figs. 4.2(a) and 4.2(b). It is observed, that an increasing in chemical reaction parameter Kr results leads to decrease velocity distribution as well as concentration also.

In Figs. 4.3(a) and 4.3(b) we depict the effect of Prandtl number Pr, on the velocity and temperature fields. It is observed that the velocity and temperature both are decreasing with increasing Prandtl number Pr.

The effects of viscous dissipative heat (Ec) on the transient velocity (u) as well as temperature (θ) have been plotted in Figs. 4.4(a) and 4.4(b). It is noticed that an increase in viscous dissipative heat leads to increase in both the transient velocity as well as the temperature.

Fig. 4.5(a) and 4.5(b) illustrate the influence of the Schmidt number Sc on the velocity and concentration fields. It is evident that the velocity and concentration both are decreasing with increasing values of Schmidt number Sc.

The velocity profiles for different values of Grashof number Gr and solutal Grashof number Gc are described in Figs. 4.6(a) and 4.6(b). It is easily says that velocity increases with increasing values of Grashof number or solutal Grashof number. Here the positive values of Gr correspond to a cooling of the surface by natural convection.

The effect of different values of Hartmann number (magnetic parameter M) for velocity profile is shown in Fig. 4.7. It is observed that an increase in M leads to decrease in velocity.

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GRAPHS:

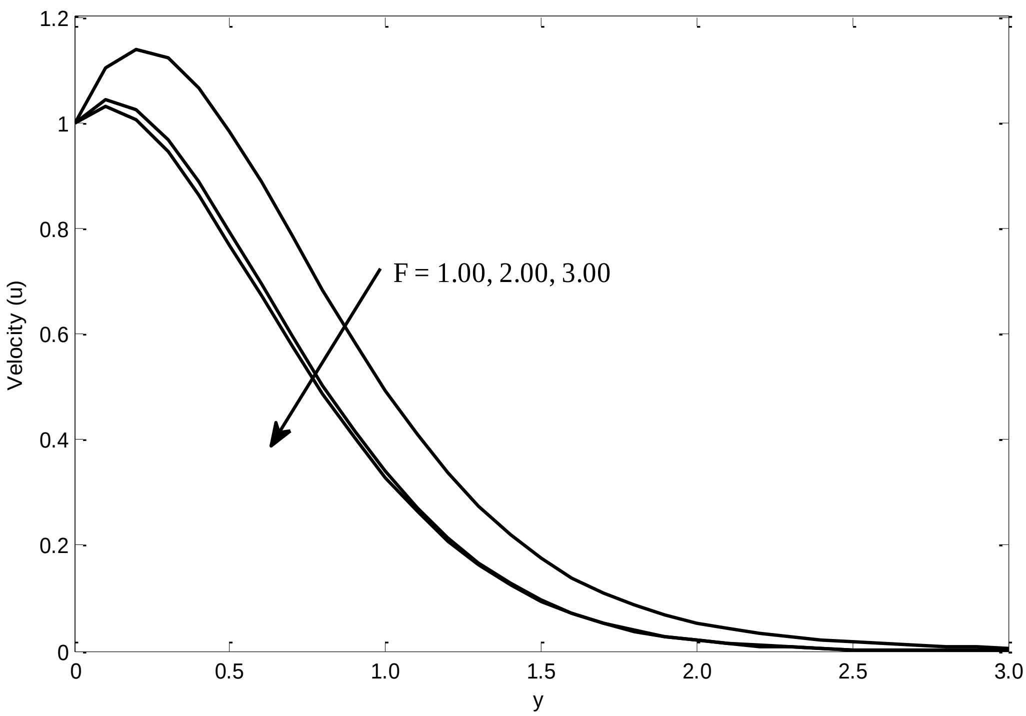

Fig. 4.1(a) – Velocity profiles for different values of Radiation parameter (R)

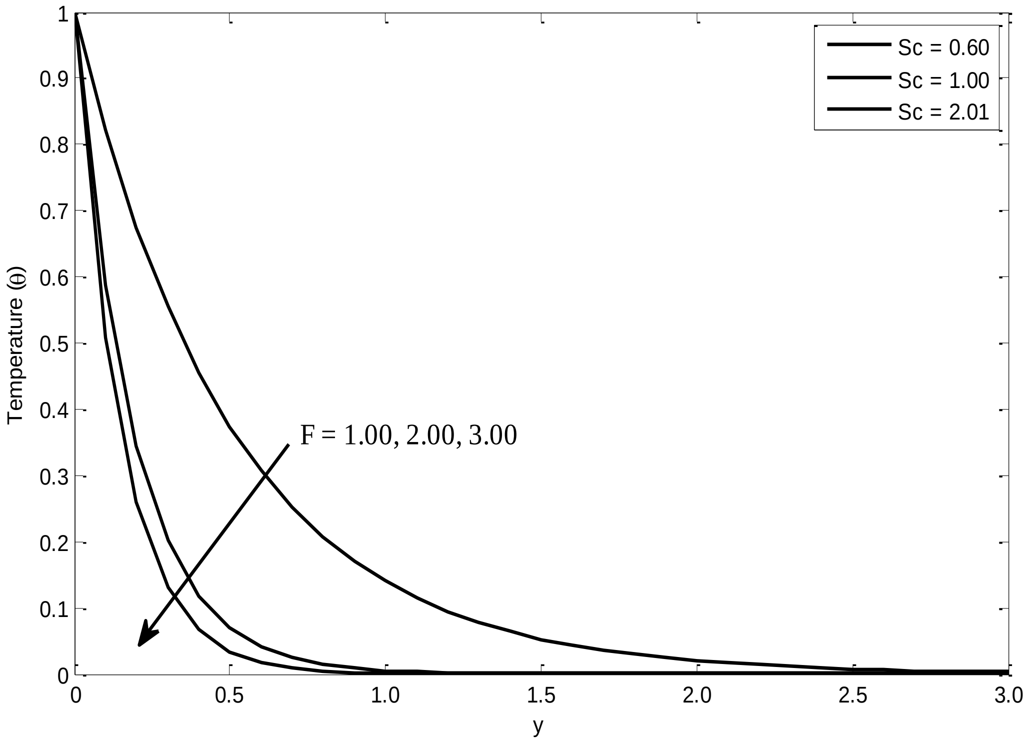

Fig. 4.1(b) – Temperature profiles for different values of Radiation parameter (R)

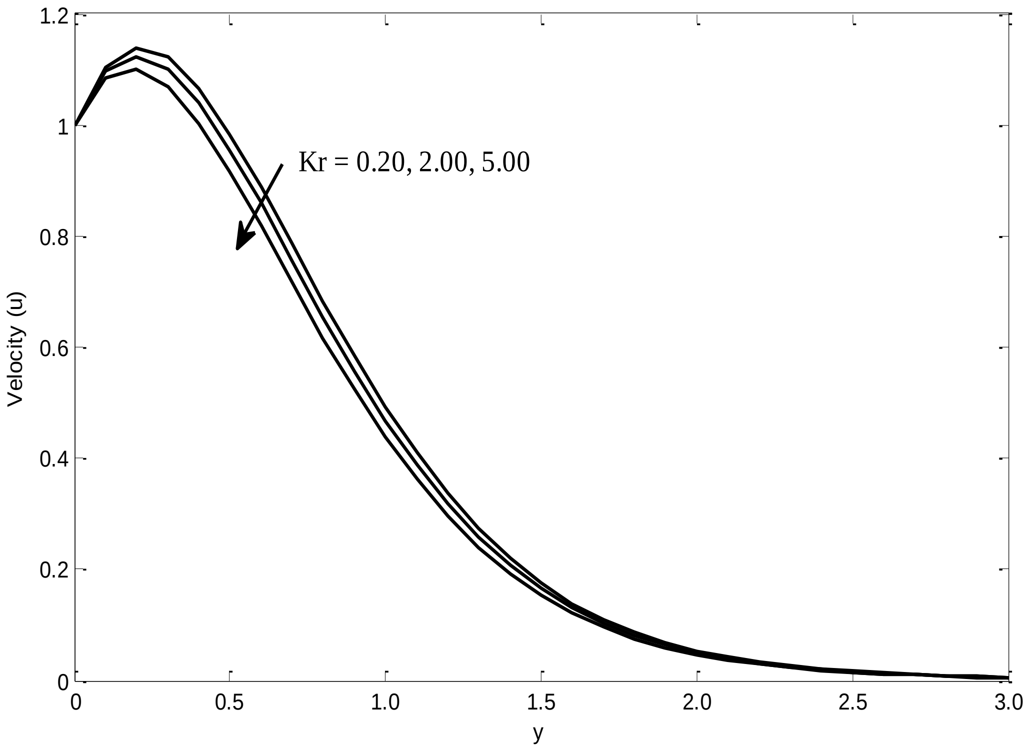

Fig. 4.2(a) – Velocity profiles for different values of chemical reaction parameter (Kr)

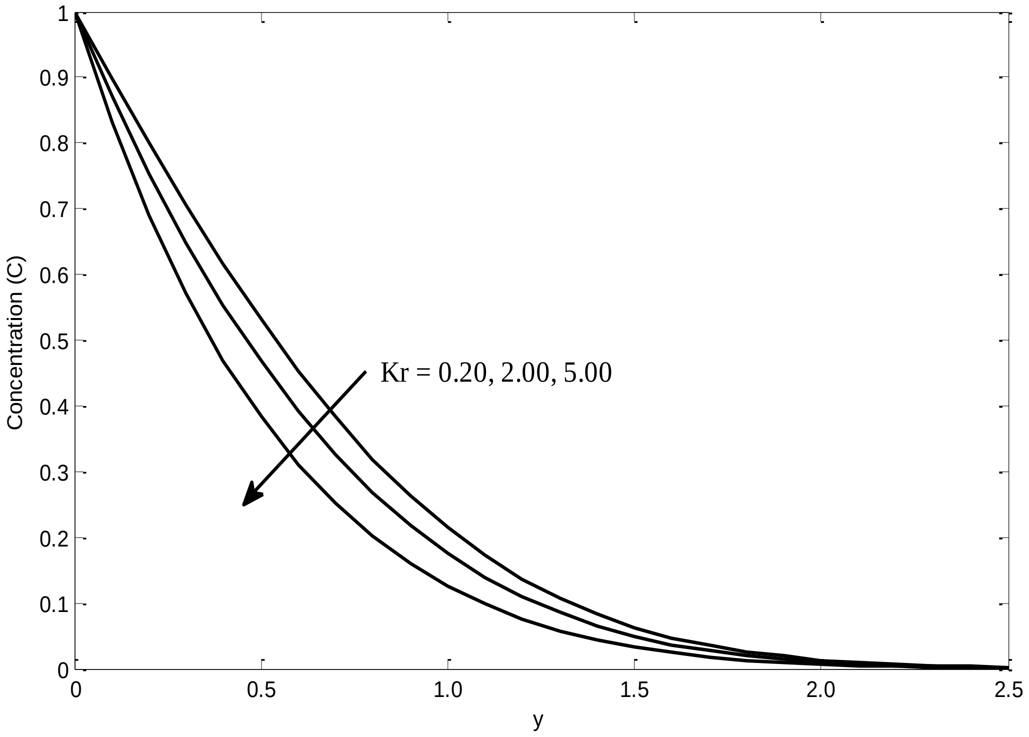

Fig. 4.2(b) – Concentration profiles for different values of chemical reaction parameter (Kr)

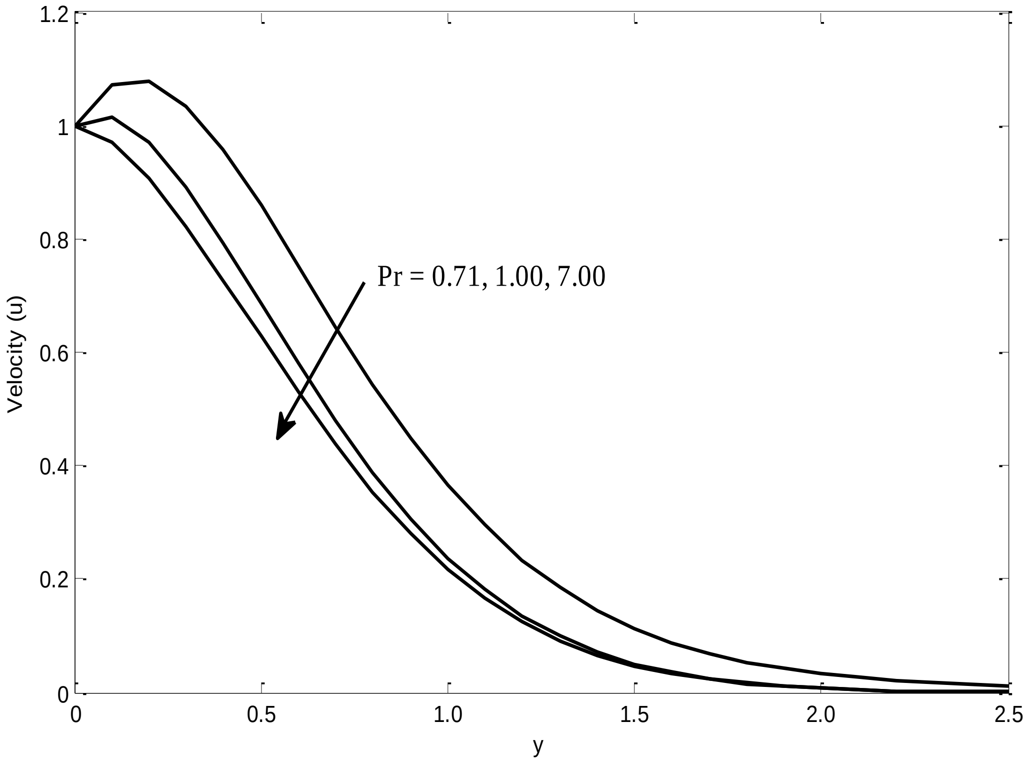

Fig. 4.3(a) – Velocity profiles for different values of Prandtl number (Pr)

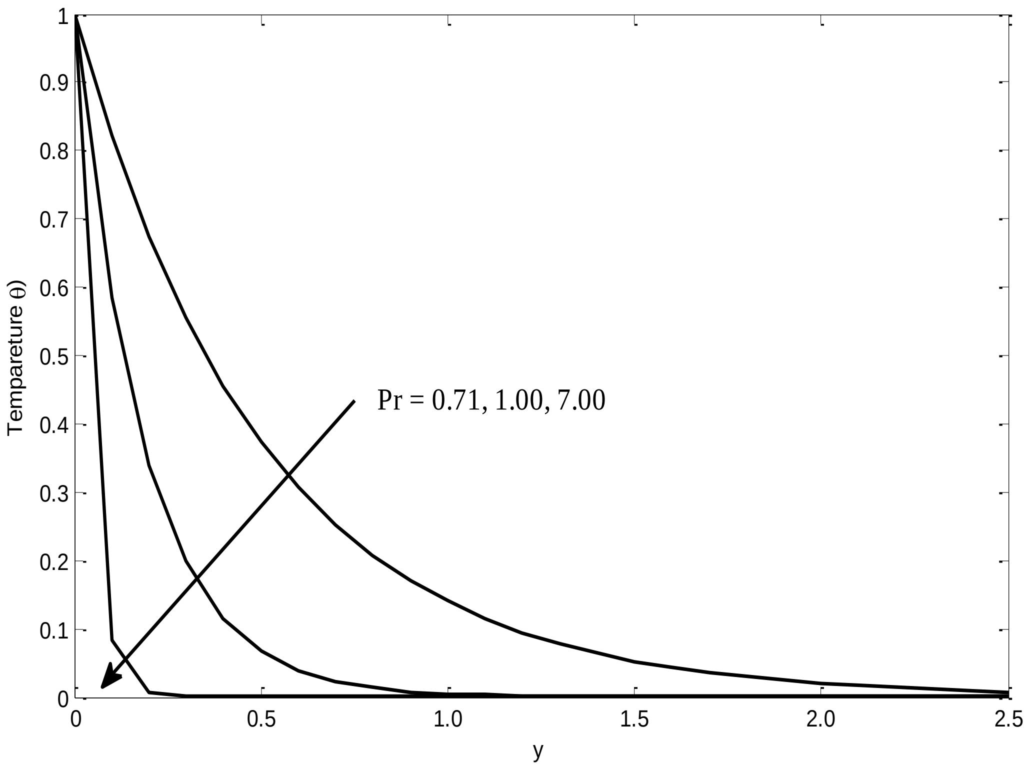

Fig. 4.3(b) – Temperature profiles for different values of Prandtl number (Pr)

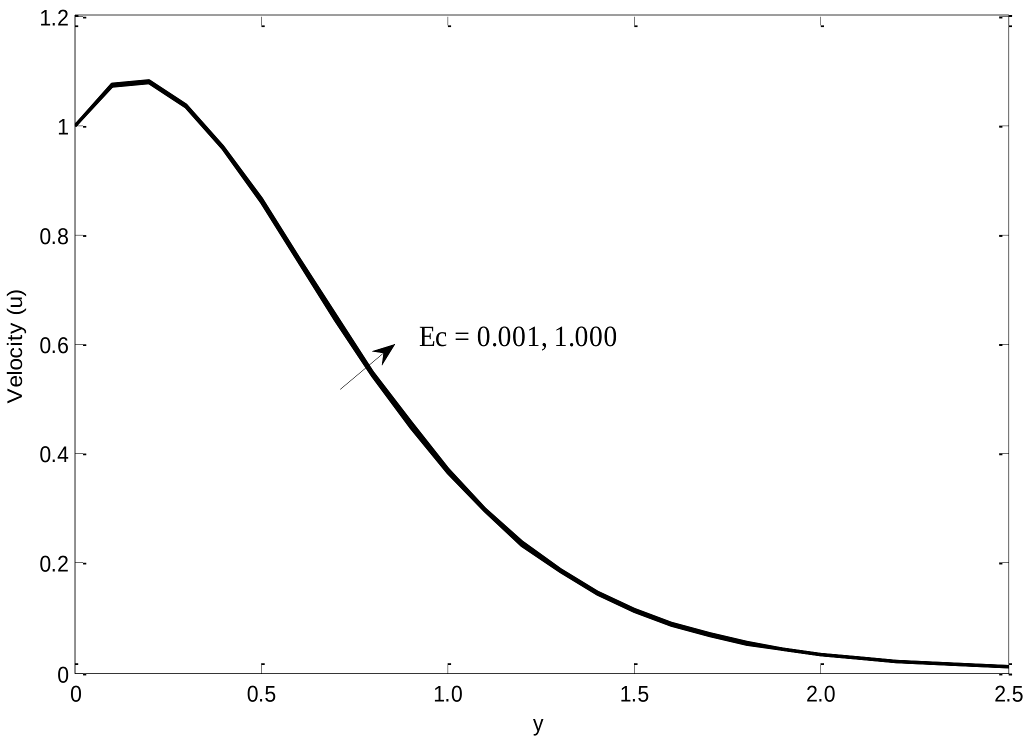

Fig. 4.4(a) – Velocity profiles for different values of Eckert number (Ec)

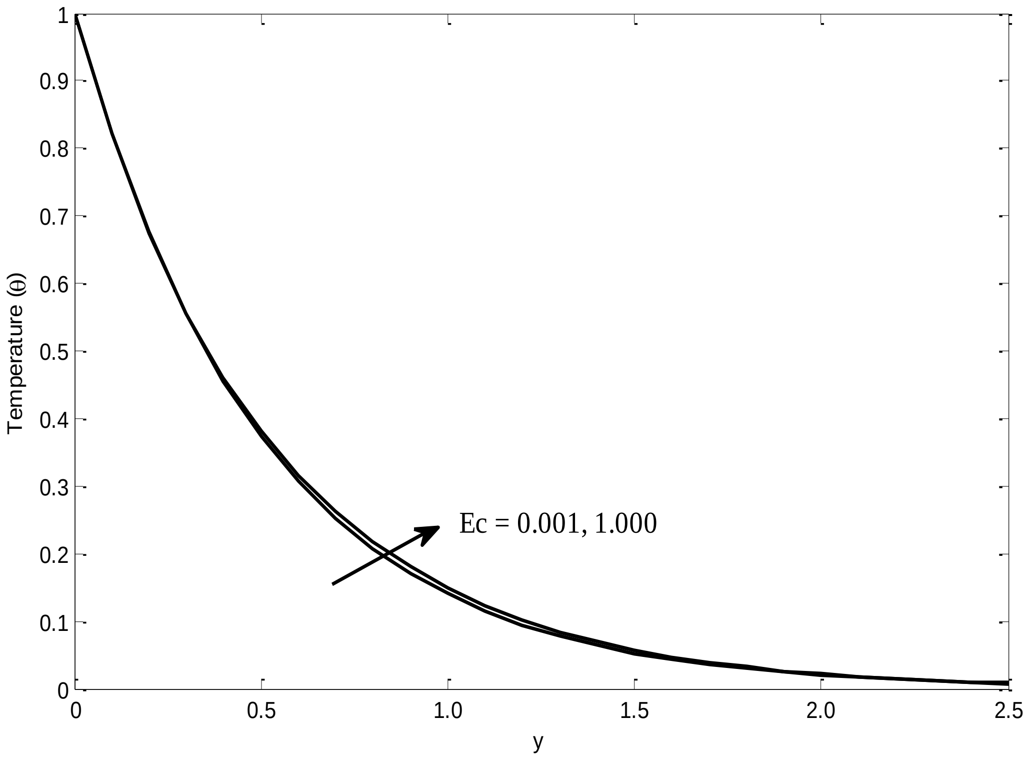

Fig. 4.4(b) – Temperature profiles for different values of Eckert number (Ec)

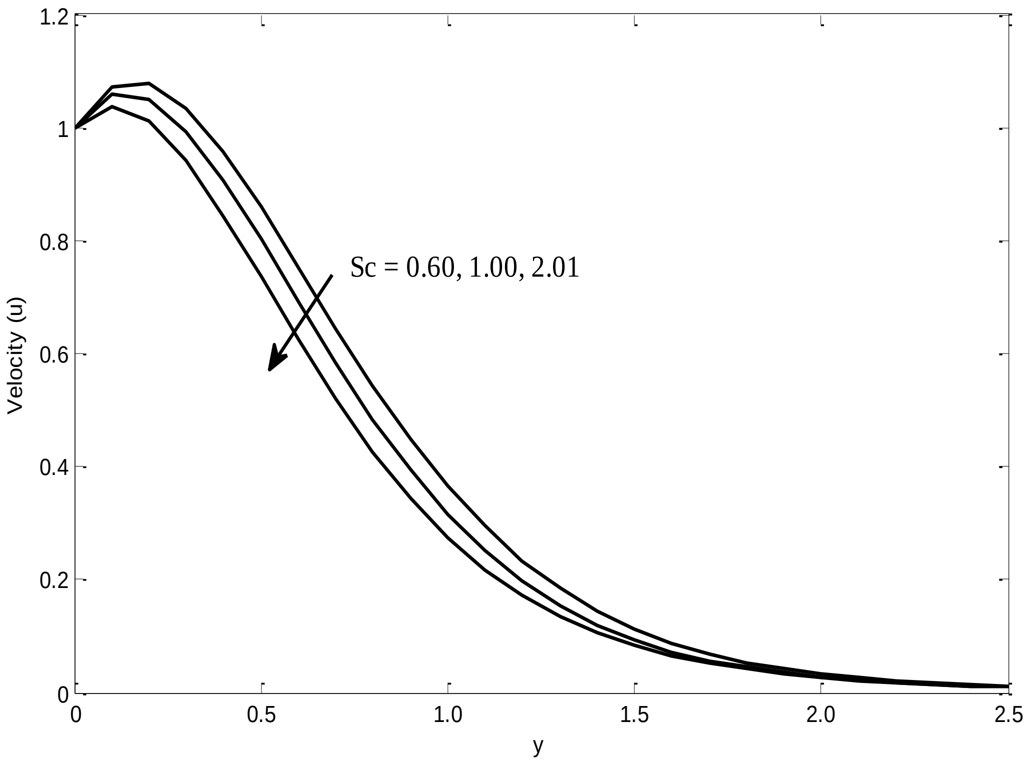

Fig. 4.5(a) – Velocity profiles for different values of Schmidt number (Sc)

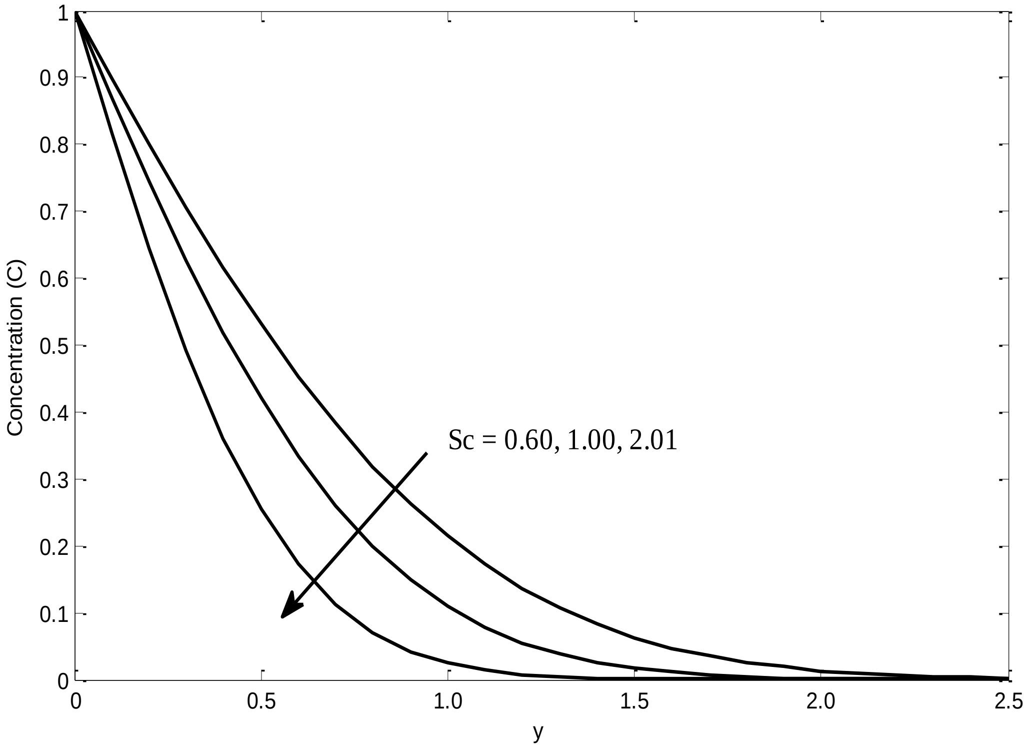

Fig. 4.5(b) – Concentration profiles for different values of Schmidt number (Sc)

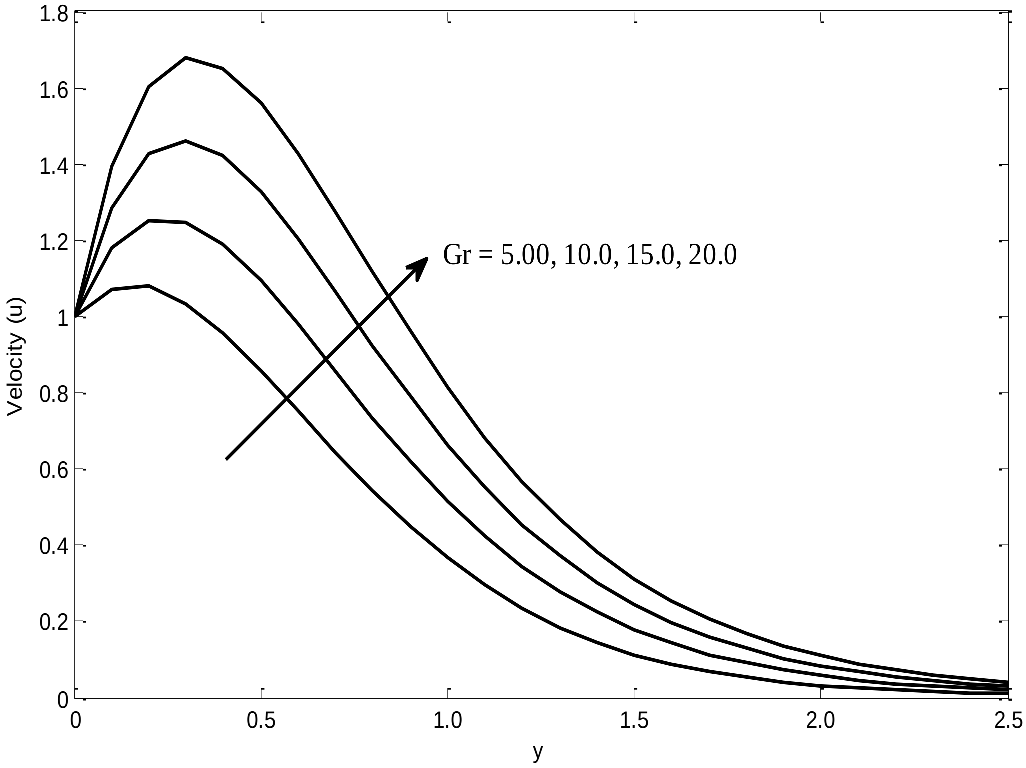

Fig. 4.6(a) – Velocity profiles for different values of Grashof number (Gr)

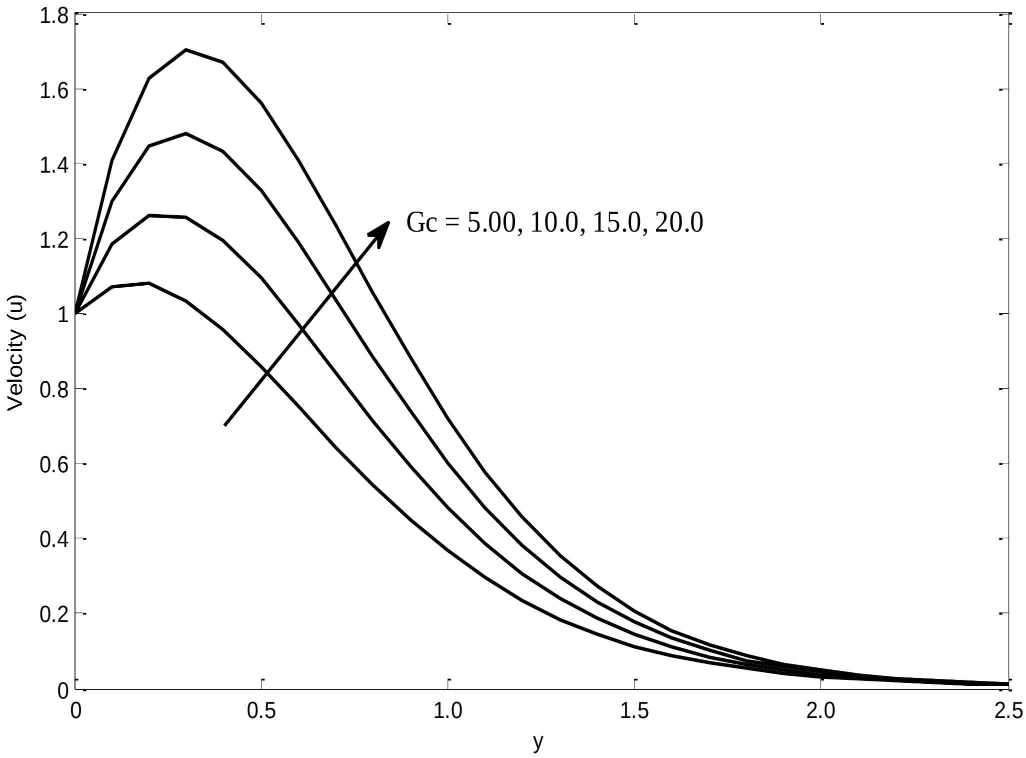

Fig. 4.6(b) – Velocity profiles for different values of solutal Grashof number (Gc)

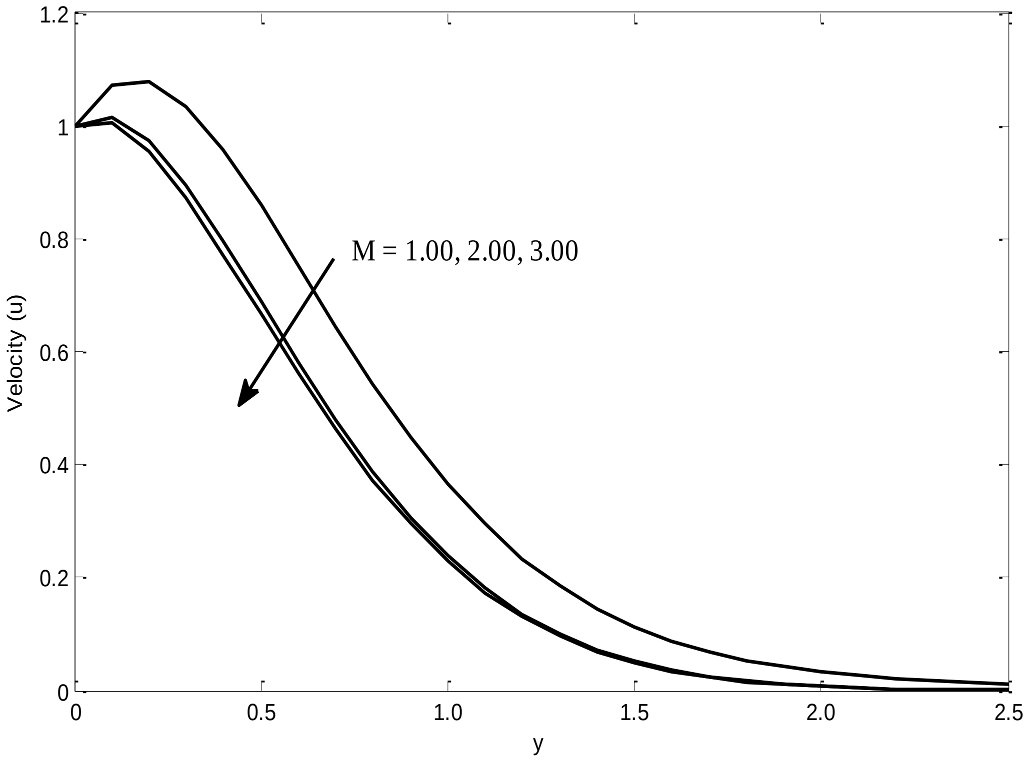

Fig. 4.7 – Velocity profiles for different values of magnetic parameter (M)