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Inclined Magneticfield and Chemical Reaction Effects on Flow over a Semi Infinite Vertical Porous Plate through Porous Medium

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Abstract: We analyse the MHD, Radiation and chemical reaction effects on unsteady flow, heat and mass transfer characteristics in a viscous, incompressible and electrically conducting fluid over a semi infinite vertical porous plate through porous media in presence of inclined magnetic field. The porous plate is subjected to a transverse variable suction velocity. The transient, non-linear and coupled governing equations have been solved adopting a perturbative series expansion about a small parameter, ε. The effects of governing parameters on the flow variables are discussed graphically.

Keywords: MHD, Chemical reaction, Radiation, Inclination, Concentration

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1. INTRODUCTION

Natural convection flow over vertical surfaces immersed in porous media has paramount importance because of its potential applications in soil physics, geohydrology, and filtration of solids from liquids, chemical engineering and biological systems. Study of fluid flow in porous medium is based upon the empirically determined Darcy's law. Such flows are considered to be useful in

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diminishing the free convection, which would otherwise occur intensely on a vertical heated surface. In addition, recent developments in modern technology have intensified more interest of many researchers in studies of heat and mass transfer in fluids due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical and astrophysical studies.

Apelblat [1] studied analytical solution for mass transfer with chemical reaction of the first order. Das, et al. [2] have studied the effect of chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux. Anjalidevi et al. [3] have examined the effect of chemical reaction on the flow in the presence of heat transfer and magnetic field.Al-Odat et al. [4] have analyzed the effects of magnetic field and the chemical reaction on the velocity, temperature and concentration profiles as well as the local heat and mass transfer rates are presented. Cramer, K. R. and Pai.S.I.[5] taken transverse applied magnetic field and magnetic Reynolds number are taken very small, so that the induced magnetic field is negligible. Muthucumaraswamy et al. [6] have studied the effect of homogenous chemical reaction of first order and free convection on the oscillating infinite vertical plate with variable temperature and mass diffusion. Sharma [7] investigate the effect of periodic heat and mass transfer on the unsteady free convection flow past a vertical flat plate in slip-flow regime when suction velocity oscillates with time. Chaudhary and Jha [8] studied the effects of chemical reactions on MHD micro polar fluid flow past a vertical plate in slip-flow regime.

Ahmed [9] investigates the effects of unsteady free convective MHD flow through a porous medium bounded by an infinite vertical porous plate. Ahmed Sahin [10] studied the Magneto hydrodynamic and chemical reaction effects on unsteady flow. Atul Kumar Singh [11] analyzed the MHD free convection and mass transfer flow with heat source and thermal diffusion Processes involving the mass transfer effect have long been recognized as important principal in chemical processing equipment. Recently, Mohammad Ferdows, et.al.[12] have studied the effect of similarity solution for MHD flow through vertical porous plate with suction.

Sattar [13] studied analytical studies on the combined forced and free convection flow in a porous medium. Devi and Kandsamy [14] studied the chemical reaction, heat and mass transfer over an accelerating surface with heat source and thermal stratification in the presence of suction and injection. Seddeek et al. [15] examined the effect of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media has been studied in the presence of radiation and magnetic field. The influence of reaction rate on the transfer of chemically reactive species in the laminar visco elastic fluid flow immersed in a porous medium over a stretching sheet studied by Prasad et al. [16].

The objective of the present paper is to investigate the variation of velocity, temperature and concentration for various parameters like chemical Reaction parameter, thermal Grashof number, mass Grashof number, inclined magnetic field parameter, radiation parameter on convective heat transfer along an inclined plate embedded in porous medium. The governing non-linear partial differential equations are first transformed into a dimensionless form and thus resulting non-similar set of equations has been solved using the perturbation technique. Results are presented graphically and discussed quantitatively for parameter values of practical interest from physical point of view.

2. MATHEMATICAL FORMULATION

Consider the unsteady two dimensional MHD free convective flow of a viscous incompressible, electrically conducting and radiating fluid in an optically thin environment past an infinite heated vertical porous plate embedded in a porous medium in presence of thermal and concentration buoyancy effects . Let the x-axis be taken in vertically upward direction along the plate and y-axis is normal to the plate. It is assumed that there exist a homogeneous chemical reaction of first order with constant rate K_r between the diffusing species and the fluid .An inclined magnetic field is applied in the direction of y-axis . The viscous dissipation and the

Joule heating effects are assumed to be negligible in the energy equation. Also it is assumed that there is no applied voltage, so that the electric field is absent. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species, which are present, and hence the Soret and Dufour effects are negligible and the temperature in the fluid flowing is governed by the energy concentration equation involving radiative heat temperature. Under the above assumptions as well as Boussinesq approximation, the equations of conservation of mass, momentum, energy and concentration governing the free convection boundary layer flow over a vertical porous plate in porous medium can be expressed as

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

$$\frac{\partial u'}{\partial t'} - v_o\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial u'}{\partial y'} = g\beta\left(T' - T_\infty'\right)$$

$$+ g\beta'\left(C' - C'_\infty\right) + \upsilon\frac{\partial^2 u'}{\partial y'^2} - \frac{v}{k'}u' - Bu'Sin^2\psi \tag{2}$$

$$\rho C_p\left[\frac{\partial T'}{\partial t'} - v_0\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial T'}{\partial y'}\right] = k\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q_r'}{\partial y'} \tag{3}$$

$$\frac{\partial C'}{\partial t'} - v_0\left(1+\varepsilon A e^{i\omega t}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K'\left(C' - C_\infty'\right) \tag{4}$$

Where $g, T', C', B = \frac{\sigma\beta_o^2}{\rho}, D, \sigma, k, C_p, \upsilon, \beta, \beta_c, q'$, K' and ψ are acceleration due to gravity ,fluid temperature, species concentration, magnetic field, chemical molecular diffusivity, electrical conductivity, thermal conductivity, specific heat constant pressure, kinematic viscosity, density, coefficient of volume expansion for heat transfer, volumetric coefficient of expansion with species concentration, radiative heat flux and chemical reaction parameter and angle of inclination respectively.

The corresponding boundary conditions of the problem are

$$u' = L'\left(\frac{\partial u'}{\partial y'}\right), T' = T_w^{'} + \left(T_w^{'} - T_\infty^{'}\right)e^{i\omega' t'}$$

$$C' = C_w^{'} + \left(C_w^{'} - C_\infty^{'}\right)e^{i\omega' t'} \text{ at } y' = 0$$

$$u' \to 0, T' \to T_\infty^{'}, C' \to C_\infty^{'} \text{ at } y' \to \infty \tag{5}$$

Where $T_w^{'}$ *and* $T_\infty^{'}$ are the temperatures at the wall and at infinity

$C_w^{'}$ and $C_\infty^{'}$ are the species concentrations at the wall and at infinity respectively

By using Roseland approximation the radiative heat flux $q_r^{'}$ is given by

$q_r^{'} = -\frac{4\sigma_s}{3k_e}\frac{\partial T_w^{'4}}{\partial y'}$ Where σ_s is the Stefan Boltzmann constant and k_e is the mean absorption coefficient. By expanding $T_w^{'4}$ in to the Taylor series about $T_\infty^{'}$ which after neglecting higher order terms takes the form $T_w^{'4} \cong 4T_\infty^{'3}T_w^{'} - 3T_\infty^{'4}$.

From the equation of continuity (1), it is clear that the suction velocity at the plate is either a constant or a function of time only. Hence, the suction velocity normal to the plate is assumed to be in the form

$$v' = -v_0\left(1 + \varepsilon A e^{i\omega' t'}\right) \tag{6}$$

We now introduce the following non-dimensional quantities into the equations (3.1) to (3.5)

$$y = \frac{v_0 y'}{\upsilon}, u = \frac{u'}{v_0}, t = t' v_0^2 \big/ 4\upsilon, \omega = 4\omega' \upsilon \big/ v_0^2 \qquad \upsilon = \mu \big/ \rho, \Pr = \frac{\mu C_p}{k},$$

$$\theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, \varphi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, Gr = \frac{\upsilon g \beta \left(T'_w - T'_\infty\right)}{v_0^3}, Gc = \frac{\upsilon g \beta' \left(C'_w - C'_\infty\right)}{v_0^3},$$

$$M = \frac{\sigma \beta_0^2 \upsilon}{\rho v_0^2}, Sc = \frac{\upsilon}{D}, h = \frac{v_0 L'}{\upsilon}, K_r = \frac{\upsilon k'}{v_0^2}, \kappa = \frac{k' v_0^2}{\upsilon^2}, R = \frac{k k_e v_0^2}{4\sigma_s T_\infty'^3 \upsilon^2}. \qquad (7)$$

The governing equations (2) to (4) can be rewritten in the non-dimensional form as follows

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gc\varphi - (M Sin^2\psi + \kappa)u \qquad (8)$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1 + \frac{4}{3R}\right)\frac{\partial^2 \theta}{\partial y^2} \qquad (9)$$

$$\frac{1}{4}\frac{\partial \varphi}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial \varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial y^2} - K_r\varphi \qquad (10)$$

The transformed boundary conditions are

$$u = h\frac{\partial u}{\partial y,}\theta = 1 + \varepsilon e^{i\omega t}$$

$\phi = 1 + \varepsilon e^{i\omega t}$ at $y = 0$

$u \to 0, \theta \to 0, \phi \to 0$ at $y \to \infty$ (11)

3. SOLUTION OF THE PROBLEM

The equations (8) and (9) are coupled, non-linear partial differential equations and these cannot be solved in closed form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. So this can be done, when the amplitude of oscillations (ε <<1) is very small, we can assume the solutions of flow velocity u, temperature θ and concentration ϕ in the neighborhood of the plate as:

$$f(y,t) = f_0(y) + \varepsilon e^{i\omega t} f_1(y) + ..., \tag{12}$$

Where f is for u, θ or ϕ

$$\theta_0'' + \Pr\left(1+\frac{4}{3R}\right)\theta_0' = 0 \tag{13}$$

$$\theta_1'' + \Pr\left(1+\frac{4}{3R}\right)\theta_1' - i\omega \Pr\left(1+\frac{4}{3R}\right)\theta_1 \Big/ 4 = -2A\Pr\left(1+\frac{4}{3R}\right)\theta_0' \tag{14}$$

$$u_0'' + u_0^1 - (MSin^2\psi + \kappa)u_0 = -Gr\theta_0 - Gc\varphi_0 \tag{15}$$

$$u_1'' + u_1' - \left((MSin^2\psi + \kappa) + i\omega/4\right)u_1 = -Gr\theta_1 \tag{16}$$

$$\varphi_0'' + Sc\varphi_0' - K_r Sc\varphi_0 = 0 \tag{17}$$

$$\varphi_1'' + Sc\varphi_1' - Sc\left(K_r + i\omega/4\right)\varphi_1 = ASc\varphi_0' \tag{18}$$

Where prime denotes differentiation with respect to y. The corresponding boundary conditions are

$$u_0 = h\left(\frac{\partial u_0}{\partial y}\right), u_1 = h\left(\frac{\partial u_1}{\partial y}\right), \theta_0 = 1$$

$$\theta_1 = 1, \phi_0 = 1, \phi_1 = 1 \text{ at } y = 0$$

$$u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to 0, \phi_1 \to 0 \text{ at } y \to \infty \tag{19}$$

The solutions of the equations (13) to (18) under the boundary the conditions (19) are

$$\theta_0(y) = e^{-\Pr\left(1+\frac{4}{3R}\right)y}, \tag{20}$$

$$\phi_0(y) = e^{-ny}, \tag{21}$$

$$\theta_1(y) = B_1 e^{-\lambda y} + B_2 e^{-\Pr\left(1+\frac{4}{3R}\right)y}, \tag{22}$$

$$u_0(y) = B_5 e^{-qy} - B_3 e^{-\Pr\left(1+\frac{4}{3R}\right)y} - B_4 e^{-ny}, \tag{23}$$

$$\phi_1(y) = B_7 e^{-\mu y} - B_6 e^{-ny}, \tag{24}$$

$$u_1(y) = B_{15} e^{-\xi y} - B_{10} e^{-\lambda y} - B_{11} e^{-\mu y} + B_{12} e^{-qy} - B_{13} e^{-\Pr\left(1+\frac{4}{3R}\right)y} - B_{14} e^{-ny} \tag{25}$$

$$\theta = e^{-\Pr\left(1+\frac{4}{3R}\right)y} + \varepsilon e^{i\omega t}\left(B_1 e^{-\lambda y} + B_2 e^{-\Pr\left(1+\frac{4}{3R}\right)y} \right) \tag{26}$$

$$\phi = e^{-ny} + \varepsilon e^{i\omega t}\left(B_7 e^{-\mu y} - B_6 e^{-ny} \right) \tag{27}$$

$$u = B_5 e^{-qy} - B_3 e^{-\Pr\left(1+\frac{4}{3R}\right)y} - B_4 e^{-ny}$$

$$+\varepsilon e^{i\omega t}\left(B_{15} e^{-\xi y} - B_{10} e^{-\lambda y} - B_{11} e^{-\mu y} + B_{12} e^{-qy} - B_{13} e^{-\Pr\left(1+\frac{4}{3R}\right)y} - B_{14} e^{-ny} \right) \tag{28}$$

4. RESULTS AND DISCUSSION

The effects of governing parameters like magneticfield, chemical reaction, thermal Grashof number as well as mass Grashof number, porosity parameter and radiation parameter, angle of inclination, prandtl number, Schmidt number on the transient velocity have been presented in the respective Figures (1) to (9) . Here we restricted our discussion to the aiding of favourable case only, for fluids with Prandtl number Pr = 0.71 which represents air and for fluids Pr = 7 which represents water. The value of thermal Grashof number Gr is taken to be positive, which corresponds to the cooling of the plate. The diffusing chemical species of most common interest in air is Schmidt number (Sc) and is taken for Hydrogen (Sc = 0.22), Oxygen (Sc = 0.66), Figure (1) shows the effect of mass Grashof number on transient velocity. Here we observe that the velocity gradient at the surface increase with the increase of mass Grashof number and it is interesting to note that the velocity of fluid decreases by increase in inclined angle.

Figure (2) shows the effect of Schmidt number on transient velocity. Here we observe that the velocity gradient at the surface increase with the decrease of Schmidt number and it is very interesting to observe that the velocity of fluid is reversed when angle of inclination is at 90 degrees.

Figure (3) shows the effect of thermal Grashof number on transient velocity. Here we observe that the velocity gradient at the surface increase with the increase of thermal Grashof number and it is similar in mass Grashof number but the peack value of fluid flow at thermal Grashof number is more than mass Grashof number.

Figure (4) represents the effect of Chemical reaction parameter on transient velocity .Here we observe that the velocity is high at the surface with the decrease of Chemical reaction parameter.

Figure (5) represents the effect of inclined angle on transient velocity .Here we observe that the velocity is high at the surface with the decrease of inclined angle.

Figures (6) shows the effect of Magnetic field parameter on transient velocity .We observe that the velocity gradient at the surface increases with the decrease of Magnetic parameter.

Figure (7) shows the effect of Radiation parameter on transient velocity ,from this we observe that the velocity gradient at the surface increases with the decrease of radiation parameter but flow is together when inclined angle is 90^0

Figure (8) represents the effect of porosity parameter on transient velocity .We observe that the velocity gradient at the surface increases with the decrease of porosity Parameter.

Figure (9) shows the effect of prandtl number on transient velocity .We observe that the velocity gradient at the surface increases with the decrease of prandtl number at both angles.

Figures (10) and (11) shows the effects of radiation and prandtl number on temperature profiles. It is evident that temperature is decreases by an increase in radiation and Prandtl number.

Figures (12) and (13) shows the dimensionless concentration profiles (φ) for Schmidt number (Sc) and chemical reaction (Kr) .we observe that concentration profiles decreases by increase in Sc and Kr

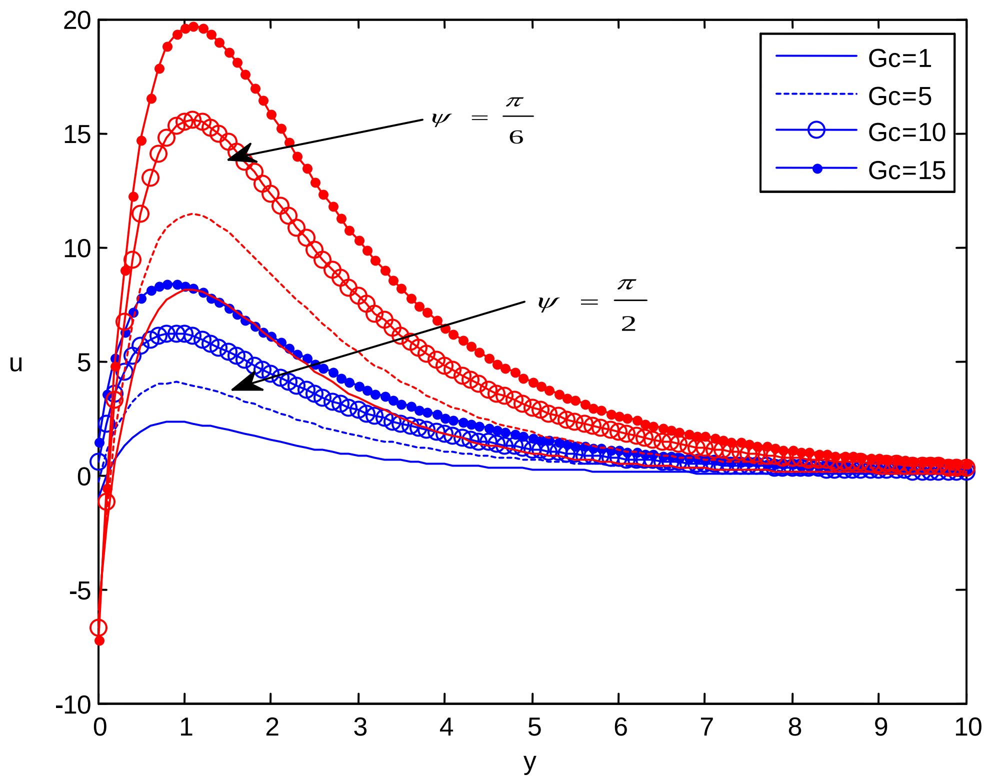

Fig (1): Velocity field for different values of Mass Grashof number (Gc)

When R=1.6, M=1, h = 0.2, Kr=0.1, Gr =5, A=0.5,k=.1

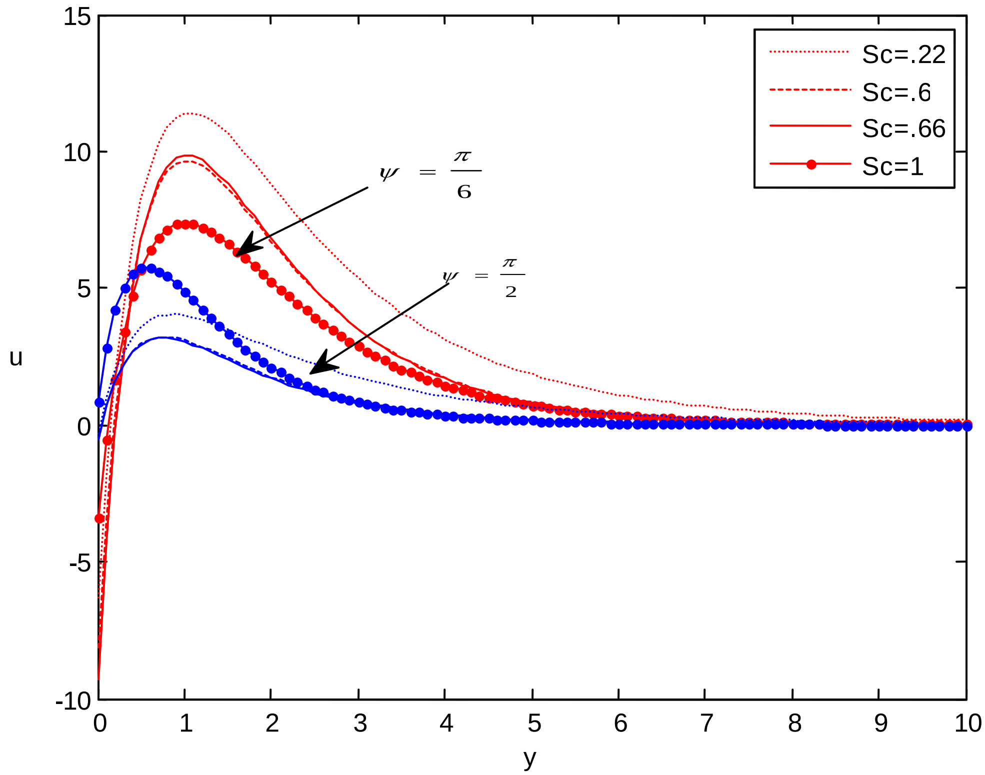

Fig (2): Velocity field for different values of Schmidt number (Sc)

When R=1.6, A=0.5, M=1, Kr=0.1, ,Gr =5, Gc=5,k=0.1

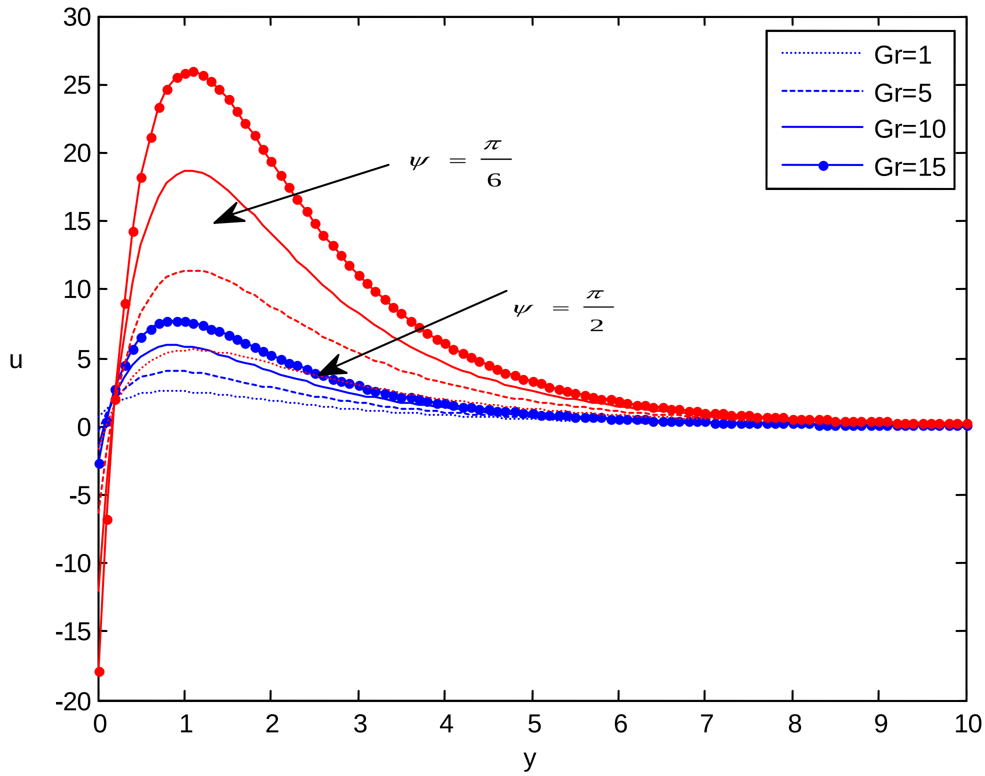

Fig (3): Velocity field for different values of Grashof number (Gr)

When Kr=0.1, R=1.6, A=0.5, h = 0.2, M=1,Gc=5,k=.1

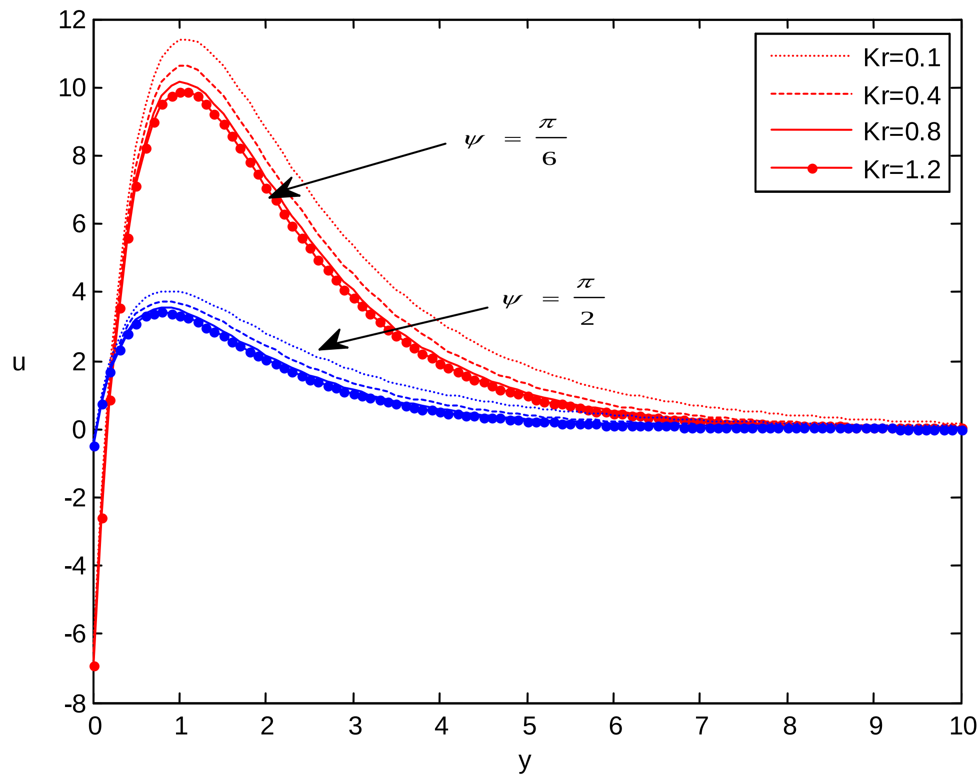

Fig (4): Velocity field for different values of Chemical reaction parameter (Kr).

When R=1.6, A=0.5, h = 0.2, M=1,Gr =5, Gc=5,k=.1

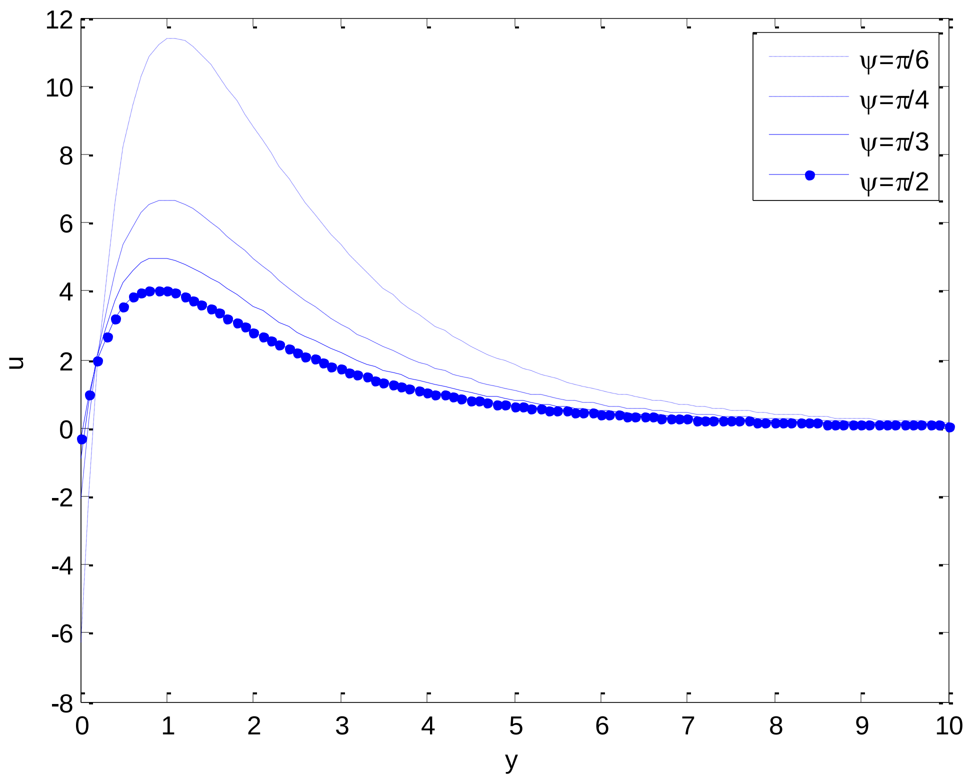

Fig (5): Velocity field for different values of inclined angle (ψ)

When R=2, A=0.5, h = 0.2, M=1, Gr =5, Gc=5,k=.1,

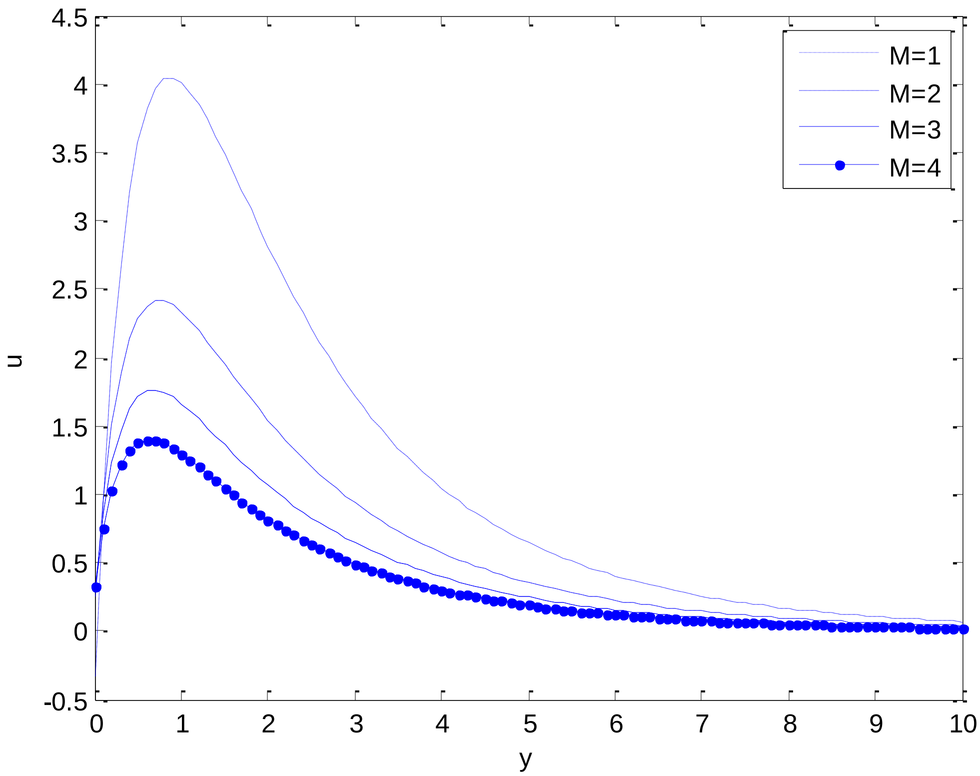

Fig (6): Velocity field for different values of Magnetic field parameter (M)

When R=2, A=0.5, h = 0.2, Kr=0.1, Gr =5, Gc=5,k=.1

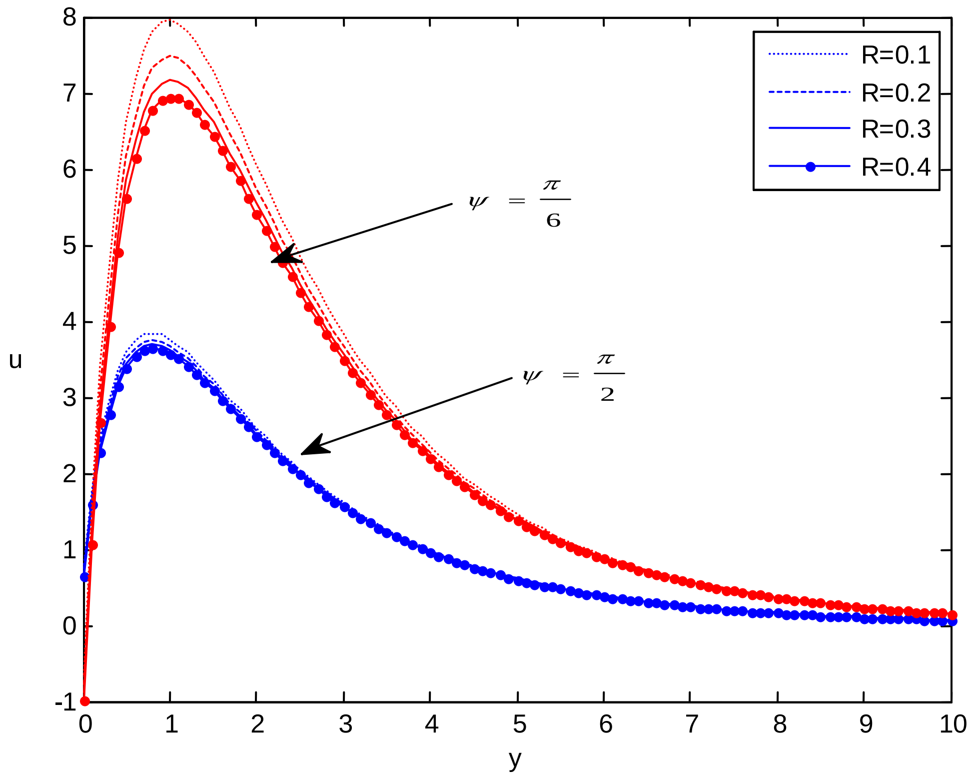

Fig (7): Velocity field for different values of Radiation parameter (R)

When Kr=0.1, A=0.5, h = 0.2, M=1, Gr =5, Gc=5,k=.1

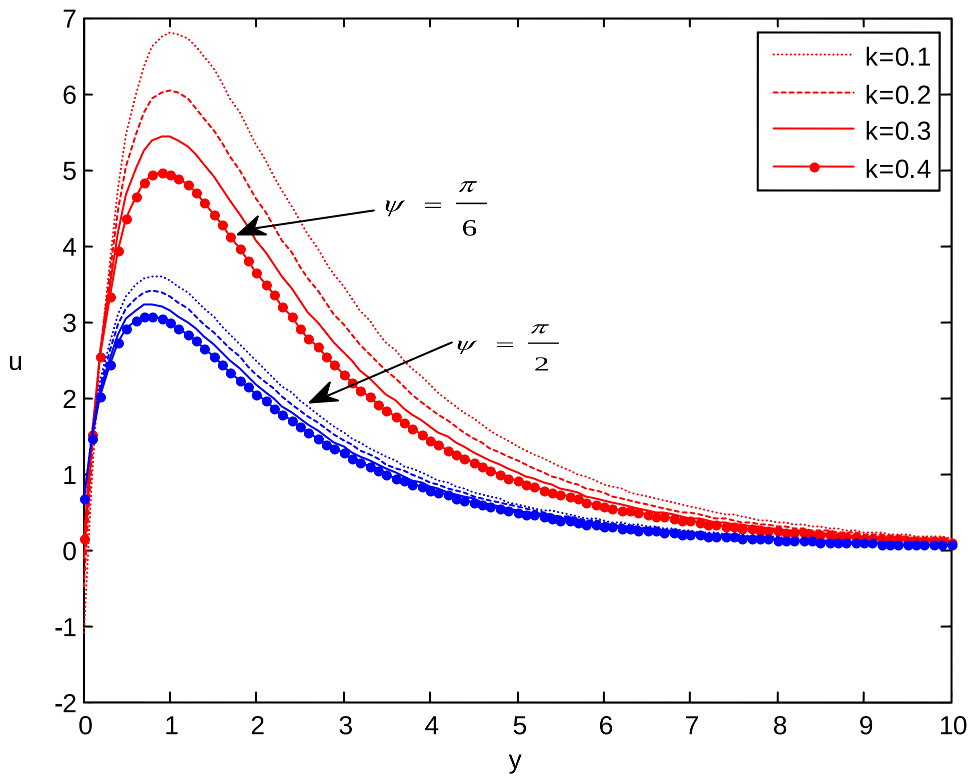

Fig (8): Velocity field for different values of porosity parameter (k)

When Kr=0.1, R=1.6, A=0.5, h = 0.2, M=1,Gr =5, Gc=5

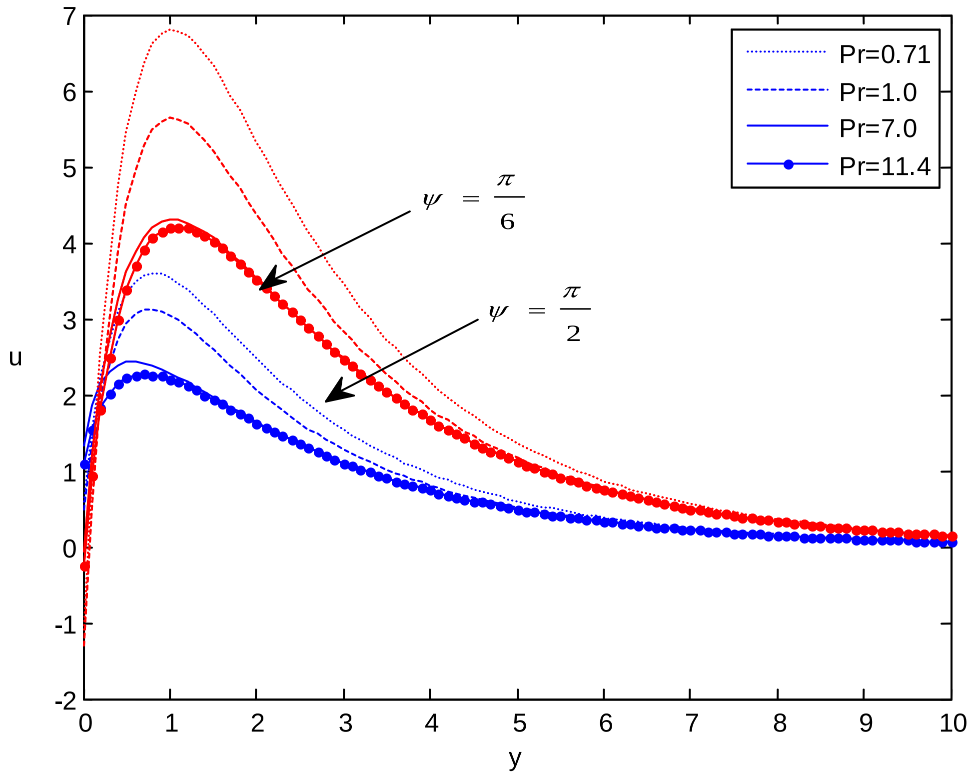

Fig (9): Velocity field for different values of Prandtl number (Pr)

When R=3, M=5, h = 0.2, Kr=0.5, Gr =5, A=0.5,k=.1.

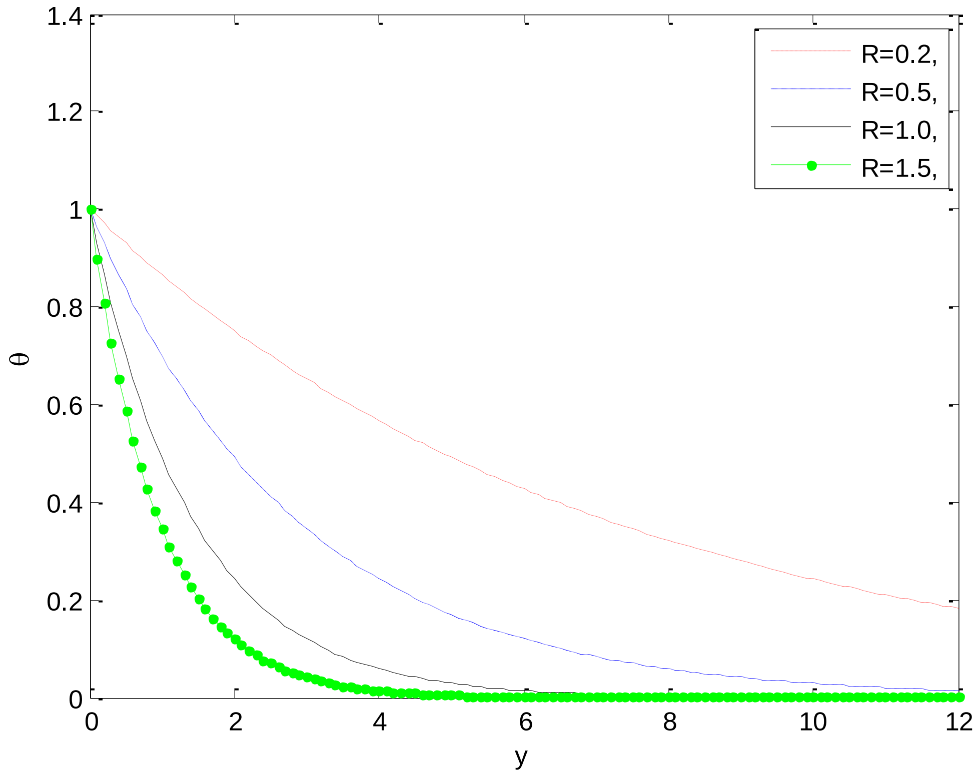

Fig (10): Temperature field for different values of Radiation parameter (R)

When R=3, M=5, h = 0.2, Kr=0.5, Gr =5, A=0.5,k=.1.

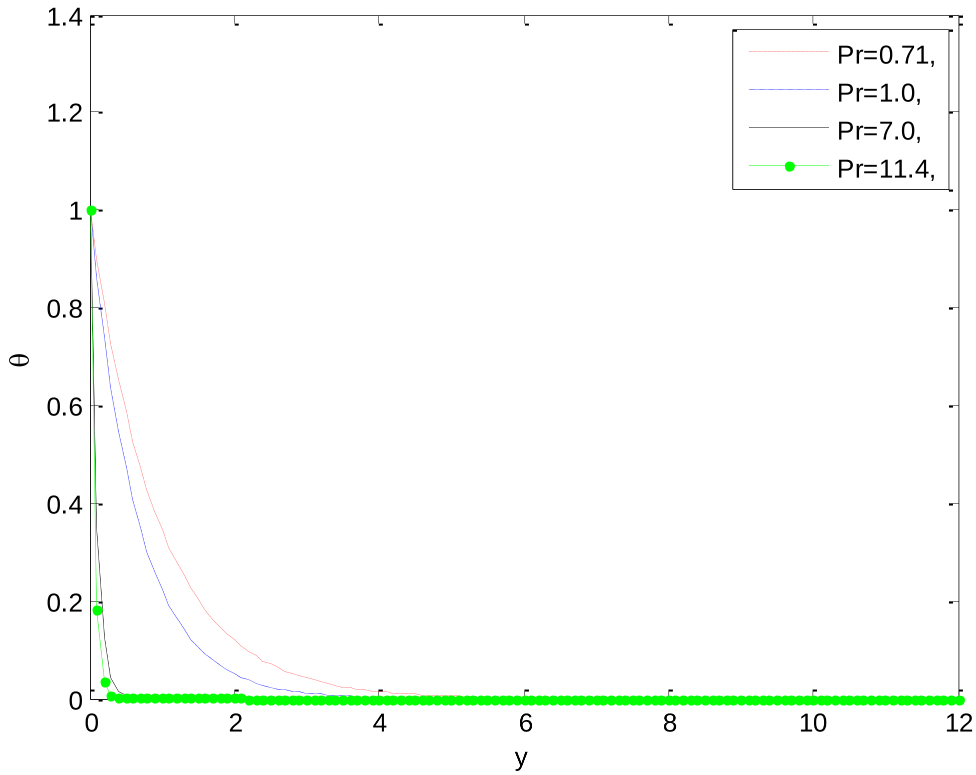

Fig (11): Temperature field for different values of Prandtl number (Pr)

When R=1.6, M=5, h = 0.2, Kr=0.5, Gr =5, A=0.5,k=.1.

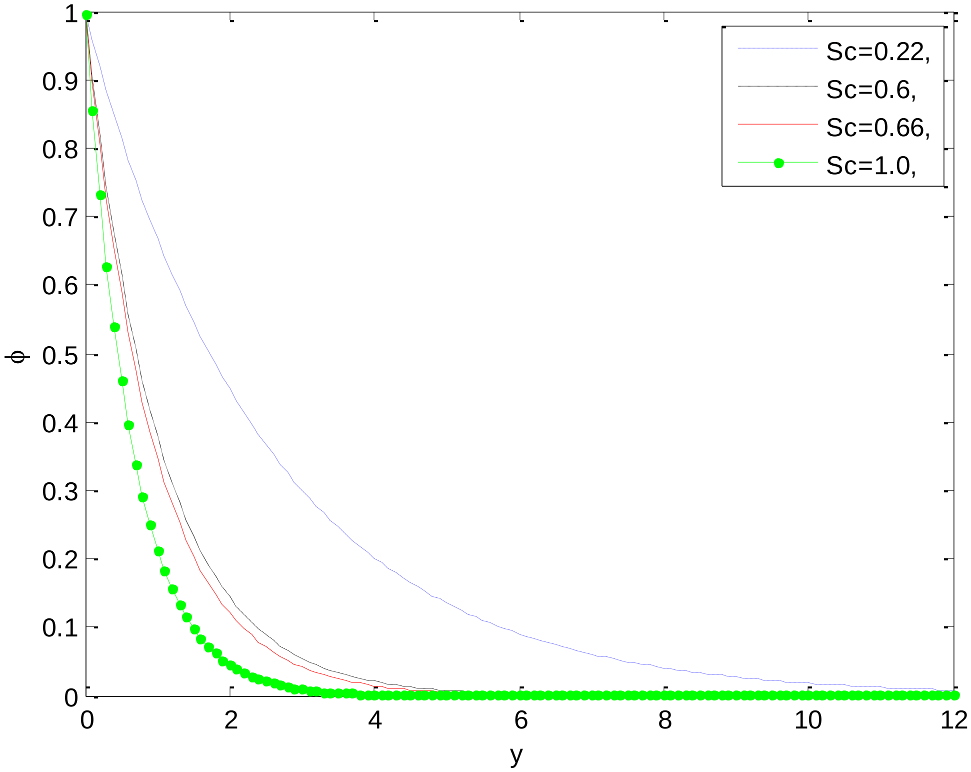

Fig (12): Concentration profiles for different values of Schmidt number (Sc)

When R=1.6, A=0.5, M=1, Kr=0.1, ,Gr =5, Gc=5,k=0.1

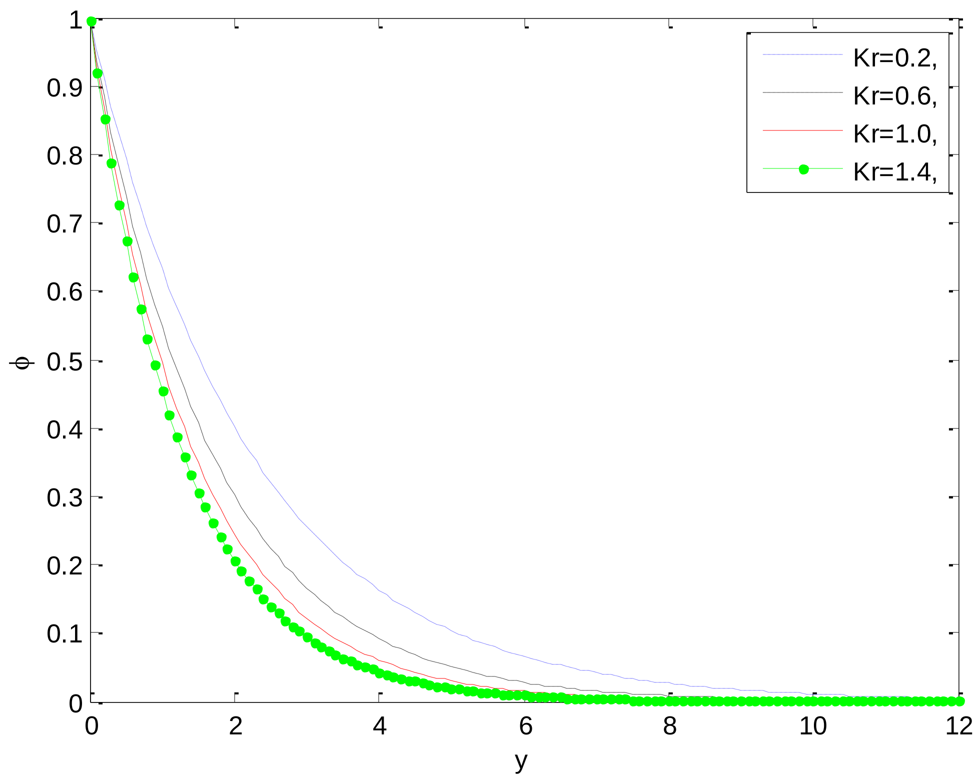

Fig (13): Concentration profiles for different values of Chemical reaction parameter(kr)

When R=1.6, A=0.5, M=1, Gr =5, Gc=5,k=0.1

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