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Aligned Magneticfield, Radiation and Chemical Reaction Effects on MHD Boundary Layer Flow over a Moving Vertical Porous Plate

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Abstract
In this paper we analyzed the effects of aligned magnetic field, radiation and chemical reaction on MHD boundary layer flow over a moving vertical porous plate with heat source. The governing equations of the flow are solved numerically by shooting method. The influence of various parameters on velocity, temperature and concentration profiles, as well as Nusselt number, Sherwood Number and Skin-friction coefficient are examined and presented through graphs and tables. We observed that rate of heat transfer is more influenced by aligned angle, radiation and chemical reaction parameters. Increase in aligned magnetic field angle causes the decrease in velocity profiles of the flow.
Keywords: Convection, MHD, Porous Medium, Radiation, Chemical Reaction.

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 diminishing the free convection, which would otherwise occur intensely on 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. Radiative heat and mass transfer play an important role in manufacturing industries for the design of reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications. If the temperature of surrounding fluid is rather high, radiation effects play an important role and this situation does not exist in space technology.In such cases one has to take into account the effect of thermal radiation and mass diffusion.

Influence of thermal radiation on transient magneto hydrodynamic couttee flow through porous medium by using finite difference method discussed by Baoku et al. (2012). Cramer and Pai (1973) taken transverse applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field is very negligible. Muthucumaraswamy et al. (2006a) have studied the effect of homogeneous chemical reaction of first order and free convection on the oscillating infinite vertical plate with variable temperature and mass diffusion. Chaudhary (2008) have examined the effect of chemical reaction on the flow in presence of heat transfer and magnetic field. The effect of thermal radiation on flow past an impulsively started infinite isothermal vertical plate in presence of first order chemical reaction was studied by Muthucumaraswamy et al. (2006b).Radiation and chemical reaction effects on flow over a vertical porous plate by applying transverse magnetic field was discussed by Sandeep et al. (2012). The heat and mass transfer effects on a flow along a vertical plate in the presence of transverse magnetic field was analyzed by Elbashbeshy (1997). Mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux was discussed by Jha et al. (1991). Das et al. (1999) have studied the effects of mass transfer on flow past an impulsively started vertical infinite plate with constant heat flux and chemical reaction.

The influence of magnetic field on an electrically conducting viscous incompressible fluid is extensively used in many applications. Because of its application for MHD natural convection flow in the nuclear engineering where convection aids the cooling of reactors, the natural convection boundary layer flow of an electrically fluid up a hot vertical wall in the presence of strong magnetic field has been studied Riley (1964). The flow past an impulsively started vertical plate in a porous medium by using finite difference method was discussed by Raptis and Singh (1985). Mixed convection boundary layer flow over a vertical surface in a porous medium was also investigated by Nazar et al. (2004) and Aly et al. (2003). Maleque and Alam (2004) numerically studied free convection and mass transfer characteristics for an unsteady magneto hydrodynamic flow of an electrically conducting viscous incompressible fluid past an infinite vertical porous plate with Dufour and Soret effects. Kandasamy et al. (2005) analyzed the effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. Das et al (1994) have discussed the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Inclined magnetic field and radiation on free convective flow of dissipative fluid past a vertical plate in porous medium was discussed by Sandeep and Sugunamma (2013). They used analytical method to solve the problem. Many researchers like (Mohan Krishna et.al 2013, 2014, Ramana Reddy et al. 2014, Sugunamma and Sandeep 2011) discussed the magneticfield, radiation and chemical reaction effects at different channels.

In this paper our main objective is to analyze the aligned magnetic field, radiation and chemical reaction effects on MHD boundary layer flow over a moving vertical porous plate with heat source. It is pertinent to mention here that some researchers have pursued their investigation with transverse magnetic field only. The influence of various parameters on velocity, temperature and concentration profiles, as well as Nusselt number and Skin-friction coefficient are examined and presented graphically and through tables. We observed that the rate of heat transfer is more influenced by radiation and chemical reaction parameters. Increase in aligned magnetic field angle causes the decrease in velocity profiles of the flow.

2. Mathematics Formulation

Consider two-dimensional steady incompressible laminar MHD flow over a linearly started porous vertical plate. The flow is along the direction of x and y is normal to it. The velocity of the fluid which is assumed to be zero far away from the plate surface. For a quiescent state fluid, the surface temperature and concentration are taken to be linear. Aligned magnetic field is applied to the flow. All the fluid properties are assumed to be constant except for the density variations in the buoyancy force term. With these assumptions, along with Boussinesq approximations, the boundary layer equations are described as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta'(C-C_\infty)-\frac{\upsilon}{k'}u-\frac{\sigma B_0^2}{\rho}\sin^2\theta u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{Q}{\rho C_p}(T-T_\infty)-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}+K_l'(C-C_\infty) \tag{4}$$

The corresponding boundary conditions are

$$\begin{aligned} &u=Bx,\ v=V,\ T=T_w=T_\infty+ax,\ C=C_w=C_\infty+bx\ \text{at}\quad y=0\\ &u\to 0,\ T\to T_\infty,\quad C\to C_\infty\quad as\quad y\to\infty \end{aligned} \tag{5}$$

Here x and y represents the coordinate axes along the continuous moving vertical surface in the direction of motion and normal to it respectively, u and v are the velocity components along the x and y axes respectively, υ is the kinematic viscosity, β,β' are the thermal and concentration expansion coefficients respectively, σ is the electric conductivity, B_0 is the uniform magnetic field, θ is the aligned angle, ρ is the density, k' is the permeability of the porous medium, T is the temperature inside the boundary layer, T_∞ is the temperature far away from the plate, C is the species concentration in the boundary layer, C_∞ Species concentration of the ambient fluid, D is the is the molecular diffusivity of the species concentration, K_l' is the chemical reaction parameter, K_l is the dimensionless chemical reaction parameter, B is a constant, a and b denotes the stratification rate of the gradient of ambient temperature and concentration profiles.

By using Roseland approximation, the Radiative heat flux q_r is given by

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

where σ^* is the Steffen Boltzmann constant and k^* is the mean absorption coefficient. Considering the temperature differences within the flow sufficiently small such that T^4 may be expressed as the linear function of temperature. Then expanding T^4 in Taylor series about T_∞ and neglecting higher-order terms takes the form

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{7}$$

In view of equations (6) & (7), equation (3) reduces to

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{1}{\rho C_p}\frac{16T_\infty^3\sigma^*}{3kk^*}\frac{\partial^2 T}{\partial y^2}-\frac{Q}{\rho C_p}(T-T_\infty) \tag{8}$$

We introduce the following non-dimensional quantities as

$$\left.\begin{aligned} &M=M'\sin^2\theta, M'=\frac{\sigma B_0^2}{\rho B}, H=\frac{Q}{B\rho C_p}, \Pr=\frac{\mu C_p}{k},\\ &Gr=\frac{g\beta(T_w-T_\infty)}{xB^2}, Gc=\frac{g\beta'(C_w-C_\infty)}{xB^2}, \theta=\frac{T-T_\infty}{T_w-T_\infty},\\ &\phi=\frac{C-C_\infty}{C_w-C_\infty}, R=\frac{16T_\infty^3\sigma^*}{3kk^*}, K_l=\frac{K_l'}{B}, K=\frac{\upsilon}{k'B}, Sc=\frac{\upsilon}{D}\end{aligned}\right\} \tag{9}$$

$$\eta=\sqrt{\frac{B}{v}}y,\ f(\eta)=\frac{\psi}{x\sqrt{Bv}} \tag{10}$$

where $f(\eta)$ is a dimensionless stream function, $\theta(\eta)$ is a dimensionless temperature of the fluid in the boundary layer region, $\phi(\eta)$ is a dimensionless species concentration of the fluid in the boundary layer region and η is the similarity variable. The velocity components u and v are defined as follows

$$u=\frac{\partial\psi}{\partial y}=xBf', v=-\frac{\partial\psi}{\partial x}=-\sqrt{B\upsilon}f_w \tag{11}$$

where $f_w=\frac{V}{\sqrt{\upsilon B}}$ is the suction parameter.

In view of the equations (9), (10) and (11) the equations (2), (4) and (8) takes the form as below

$$f'''+ff''-(f')^2+Gr\theta+Gc\phi-(M+K)f'=0 \tag{12}$$

$$(1+R)\theta''-\Pr\left[\left(f'+H\right)\theta-f\theta'\right]=0 \tag{13}$$

$$\phi''-Sc\left[\left(f'-K_l\right)\phi-f\phi'\right]=0 \tag{14}$$

where the primes denote the differentiation with respect to η, M is the aligned magnetic parameter , M' is the magnetic parameter, K is the permeability parameter, Gr is the local temperature (thermal Grashof number), Gc is the local concentration (mass Grashof number), $\Pr$ is the Prandtl number, R is the Radiative parameter and Sc is the Schmidt number.

The corresponding boundary conditions are

$$\begin{aligned} &f'=1, f=-f_w,\ \theta=1,\ \phi=1 \quad \text{at} \quad \eta=0\\ &f'=0,\ \theta=0,\ \phi=0 \quad \text{as} \quad \eta\to\infty \end{aligned} \tag{15}$$

3. Numerical Solution

The governing boundary layer equations (12) to (14) subject to boundary conditions (15) are solved numerically by using shooting method. First we converted the higher order non-linear differential equations (12) to (14) into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique. The calculations are carried out by the program using MATLAB. From the process of numerical computation, the Skin-friction coefficient, the Nusselt number and Sherwood number which are respectively proportional to $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ are also sorted out and their numerical values are presented in a tabular form.

The Skin-Friction and the rate of heat and mass transfer are the most important characteristics of the flow which are defined as

The coefficient of Skin-friction

$$C_f = \frac{\tau_w}{\mu B x \sqrt{\frac{B}{\upsilon}}} = f''(0) \tag{16}$$

where $\tau_w = \mu(\partial u/\partial y)_{y=0} = \mu B x \sqrt{\frac{B}{\upsilon}} f''(0)$

The coefficient of rate of heat transfer

$$Nu = -\frac{q_w}{k\sqrt{\frac{B}{\upsilon}}(T_w - T_\infty)} = -\theta'(0) \tag{17}$$

where $q_w = -k(\partial T/\partial y)_{y=0} = -k\sqrt{\frac{B}{\upsilon}}(T_w - T_\infty)\theta'(0)$

The coefficient of rate of mass transfer

$$Sh = -\frac{m_w}{D\sqrt{\frac{B}{\upsilon}}(C_w - C_\infty)} = -\phi'(0) \tag{18}$$

where $m_w = -D(\partial C/\partial y)_{y=0} = -D\sqrt{\frac{B}{\upsilon}}(C_w - C_\infty)\phi'(0)$.

4. Results and Discussion

The results obtained show the influences of the non dimensional governing parameters, namely Radiation parameter R, Permeability parameter K, Schmidt number Sc , Heat source parameter H, Aligned angle θ, and Chemical reaction parameter K_l on the velocity, temperature and concentration profiles as well as the Skin-friction, Nusselt number, Sherwood number. Here we restricted our discussion to the aiding of favorable case only, for fluids with Prandtl number Pr=0.71 which represent air at 20 °C at 1 atmosphere and for fluids Pr=6.2 which represent 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 has Schmidt number is taken as Sc = 0.22.

Figs. 1, 2 and 3 illustrates the effect of aligned angle θ on velocity, temperature and concentration profiles of the fluid. It is evident that the velocity profiles decreases with increase in aligned angle. The increases in aligned angle strengthen the magneticfield. As a result of this electrically conducting fluid give rises a resistive type force called Lorentz force. This force have tendency to slow down the motion of the fluid in the boundary layer. In addition, it observed that the effect of θ is helps to improve the temperature and concentration profiles of the fluid. These may happen due to increase in conductivity of the fluid for variation in magneticfield. Figs. 4 and 5 show the effect of heat source parameter on velocity and temperature profiles respectively. It is clear that there is a decrease in fluid velocity and temperature profiles with an increasing in H. The cause behind this is the buoyancy forces decreases if heat absorption dominates the generation, which retard the flow rate and thereby give raise to a decrease in velocity and temperature profiles. Figs. 6 and 7 represents velocity and temperature profiles for different values of radiation parameter R. It is observed that the increase in thermal radiation causes the increase in velocity and temperature profiles of the fluid. The increase in radiation parameter releases the heat energy from the flow region and so the fluid temperature increases as the thermal boundary layer thickness become thinner.

Figs. 8 and 9 exhibits velocity and concentration profiles for different values of permeability parameter K. It is evident that increase in K causes the decrease in velocity profiles of the fluid but it takes reverse action in concentration profiles. The reason for this is the porous medium impact on boundary layer growth is significant due to increase in thickness of the thermal boundary layer. As the increase in permeability causes the holes of the porous medium become large and hence the external force is reduces on the flow field, it causes to decrease the boundary layer velocity. Figs. 10 and 11 demonstrate the effect of chemical reaction parameter on velocity and concentration profiles of the fluid. From figures, it is clear that the increase in chemical reaction parameter causes the increase in fluid velocity and concentration profiles respectively. It is important to mention that the effect of chemical reaction on the velocity and concentration profiles has less dominant at mentioned values in the figures. . It is observed that, the chemical reaction parameter has a retarding effect on the velocity of flow field as well as concentration distributions. Figs. 12 and 13 present effect of Schmidt number on velocity and concentration profiles respectively. It is clear that increase in Schmidt number causes the decrease in velocity and concentration profiles. It is the fact that the effect of higher Schmidt number results into the thinner concentration boundary layer. That is for higher Schmidt number fluid has lower concentration diffusivity.

Figs. 14, 15 and 16 present typical profiles of velocity, temperature and concentration respectively. It is clear that increase in Prandtl Number causes the decrease in velocity and temperature profiles but it is reverse in concentration profiles. It is due to the fact that the increase in Prandtl number causes the increase the density of the fluid. Increase in fluid density supports to strengthen the concentration profiles. Table 1 shows the effects of non dimensional parameters on Skin-friction coefficient, Nusselt number and Sherwood number. It is clear that The variations of Skin-friction coefficient, Nusselt number and Sherwood number are more influenced by aligned magneticfield, radiation and chemical reaction parameters. Increase in radiation and chemical reaction parameter causes the slight increase in Skin-friction coefficient, Nusselt number and Sherwood number. Increase in aligned angle helps to strengthen the magnetic field, which effect the other physical parameters to reduces the coefficient of skin friction. It was found that the magnetic parameter M has a retarding effect on transient velocity. This is a result of magnetic pull of Lorentz force acting on the velocity field. However, this same effect was found to decrease both the amplitude as well as phase of skin-fraction. Increase in Prandtl number helps to decrease in Skin-friction coefficient.

Table 1 Numerical values of the Skin-friction coefficient, Nusselt number and Sherwood number for different values of $\mathrm{Pr}, \mathrm{Sc}, \mathrm{Gr}, \mathrm{Gc}, f_w, \theta, \mathrm{R}, \mathrm{K}, \mathrm{K}_l, M \ and \ H$

θ	M	Gr	Gc	R	K	f_w	K_l	Pr	Sc	H	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
$\pi/2$	1	5	3	2	0.1	0.1	1	0.71	0.22	0.5	0.7834	0.6235	1.2431
$\pi/2$	1	5	3	2	0.1	0.1	1	0.71	0.22	0.5	0.4213	0.6062	1.1913
$\pi/2$	1	5	3	2	0.1	0.1	1	0.71	0.22	0.5	1.9234	0.8001	1.3117
$\pi/3$	2	3	5	2	0.1	0.1	1	0.71	0.22	0.5	1.8932	0.6784	1.3214
$\pi/3$	2	3	5	2	0.1	0.1	1	0.71	0.22	0.5	1.0010	0.5971	1.2842
$\pi/3$	2	3	5	2	0.2	0.1	0.5	7.0	0.60	0.1	1.0031	0.7812	1.4321
$\pi/2$	1	5	5	1	0.2	0.1	0.5	7.0	0.60	0.1	1.2312	0.8031	1.3214
$\pi/2$	1	5	5	1	0.2	0.1	0.5	7.0	0.60	0.1	0.9012	1.0213	1.5321
$\pi/2$	1	5	5	1	0.2	0.1	0.5	7.0	0.60	0.1	1.0234	0.6171	1.7821
$\pi/2$	1	2	2	1	0.2	0.1	0.5	7.0	0.60	0.1	1.4521	0.7123	1.2891

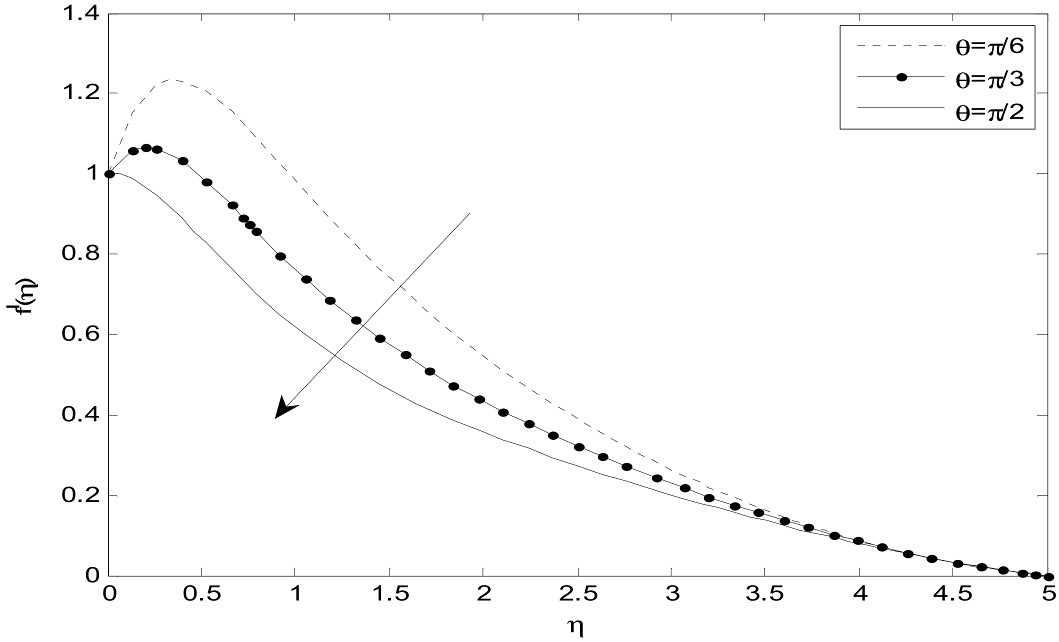

Fig. 1 Velocity profiles for different values of θ when

$Pr = 6.2, Gr = 5, Gc = 5, R = 2, K = 0.1, Sc = 0.22, H = 0.5, f_w = 0.1, K_l = 0.5.$

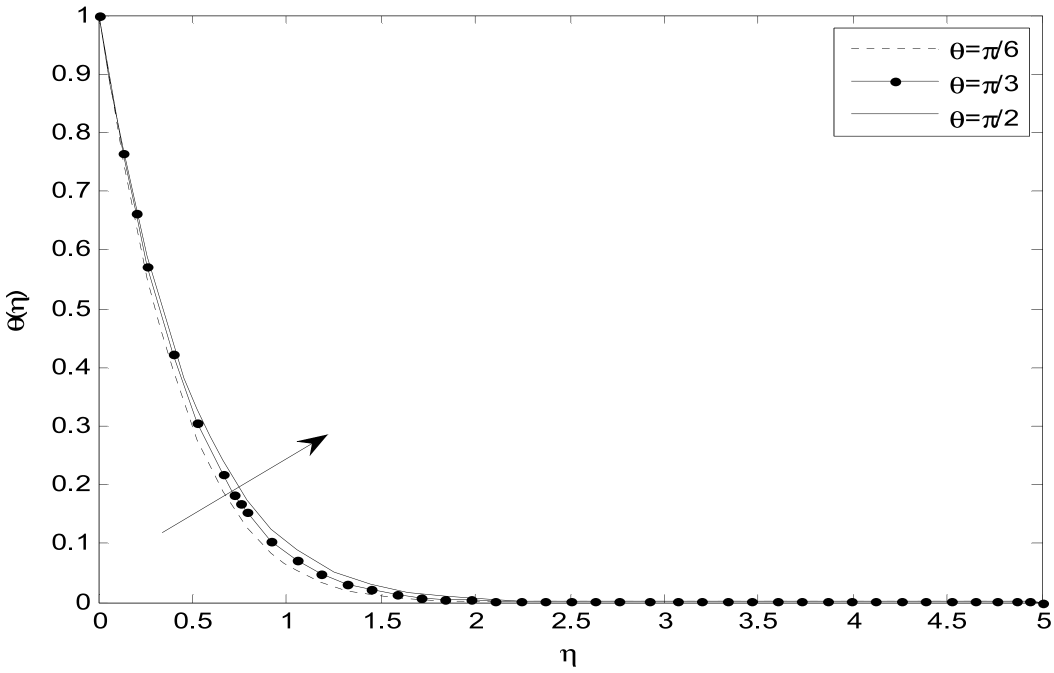

Fig. 2 Temperature profiles for different values of θ when

$Pr = 6.2, Gr = 5, Gc = 5, R = 2, f_w = 0.1, Sc = 0.22, H = 0.5, S = 0.1, K_l = 0.5.$

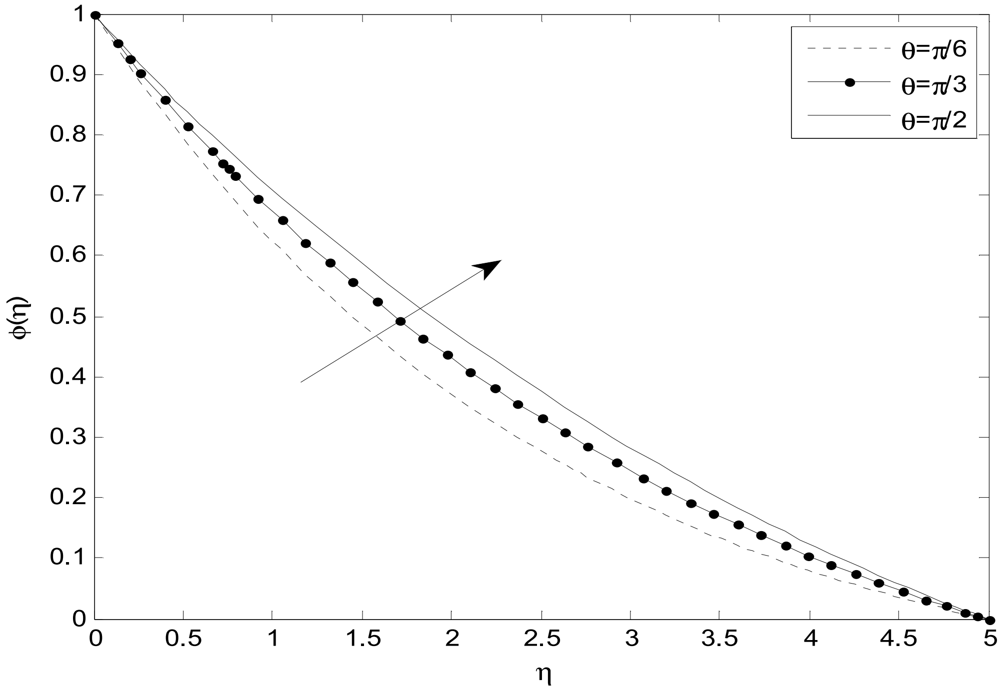

Fig. 3 Concentration Profiles for different values of θ when
$\Pr=6.2, Gr=5, \; Gc=5, \; R=2, \; K=0.1, \; Sc=0.22, H=0.5, f_w=0.1, K_l=0.5.$

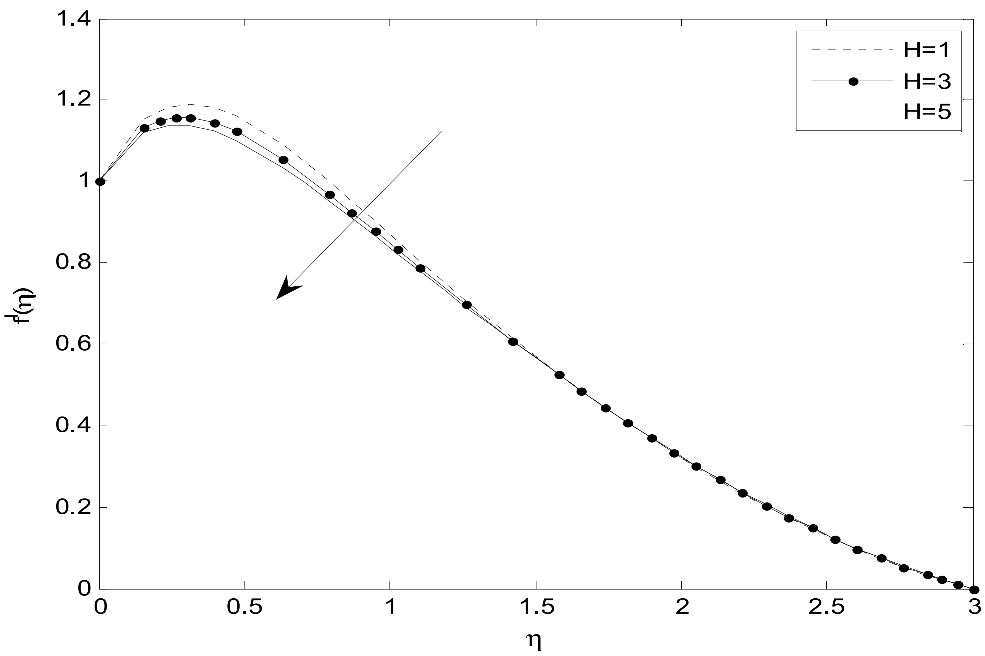

Fig. 4 Velocity profiles for different values of H when
$\Pr=6.2, Gr=5, \; Gc=5, \; R=2, \; K=0.1, \; Sc=0.22, \; \theta=\pi/3, \; f_w=0.1, K_l=0.5.$

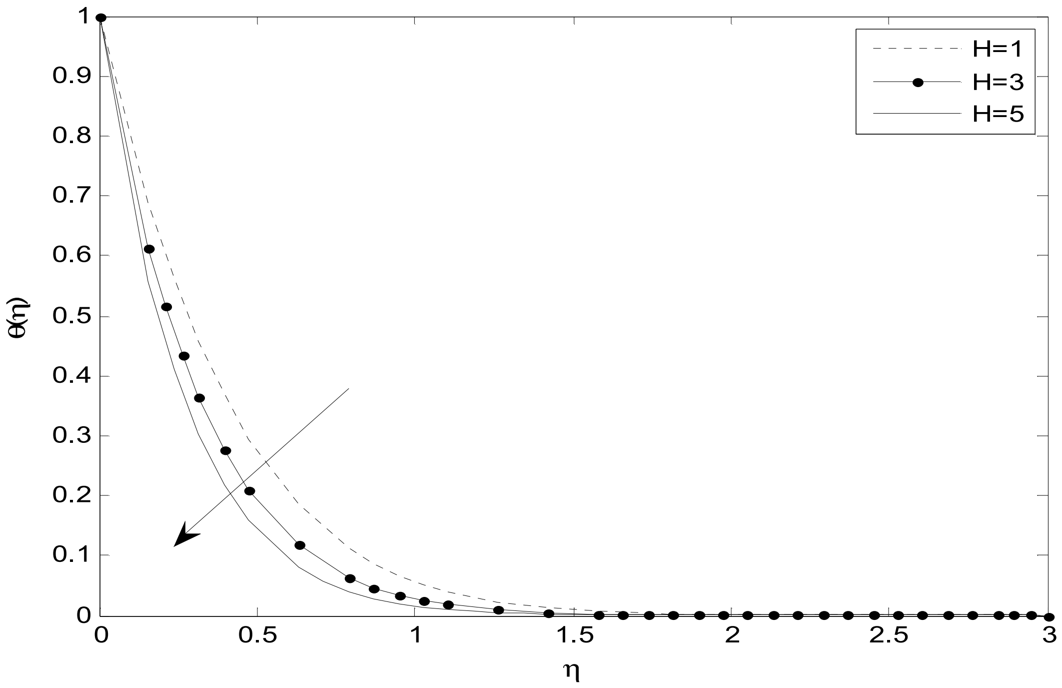

Fig. 5 Temperature profiles for different values of H when
Pr =6.2, Gr =5, Gc =5, R =2, f_w =0.1, Sc =0.22, $\theta = \pi/3$, S =0.1, K_l =0.5.

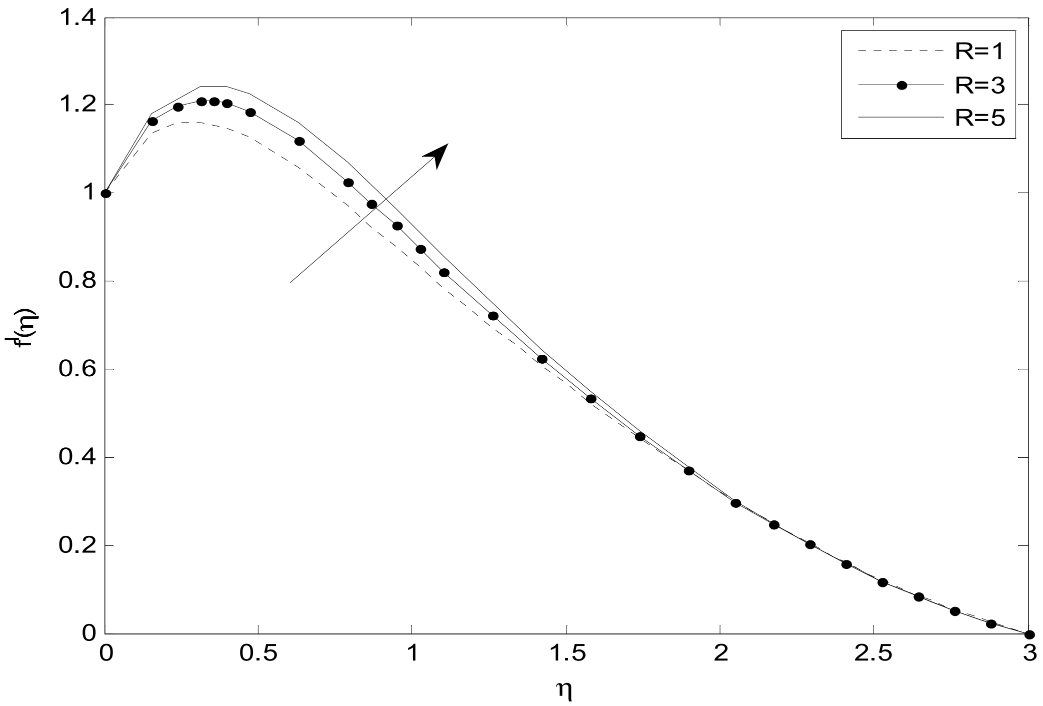

Fig. 6 Velocity profiles for different values of R when
Pr =6.2, Gr =5, Gc =5, H =0.5, K =0.1, Sc =0.22, $\theta = \pi/3$, f_w =0.1, K_l =0.5.

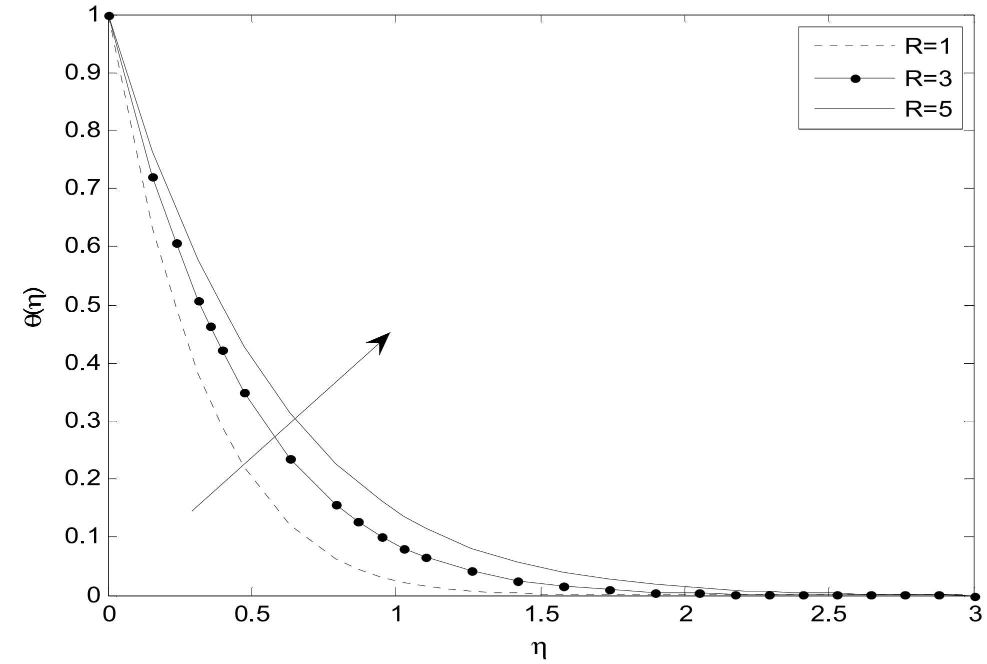

Fig. 7 Temperature profiles for different values of R when
$\Pr$ =6.2, Gr =5, Gc =5, H =0.5, f_w =0.1, Sc =0.22, $\theta = \pi/3$, S =0.1, K_l =0.5.

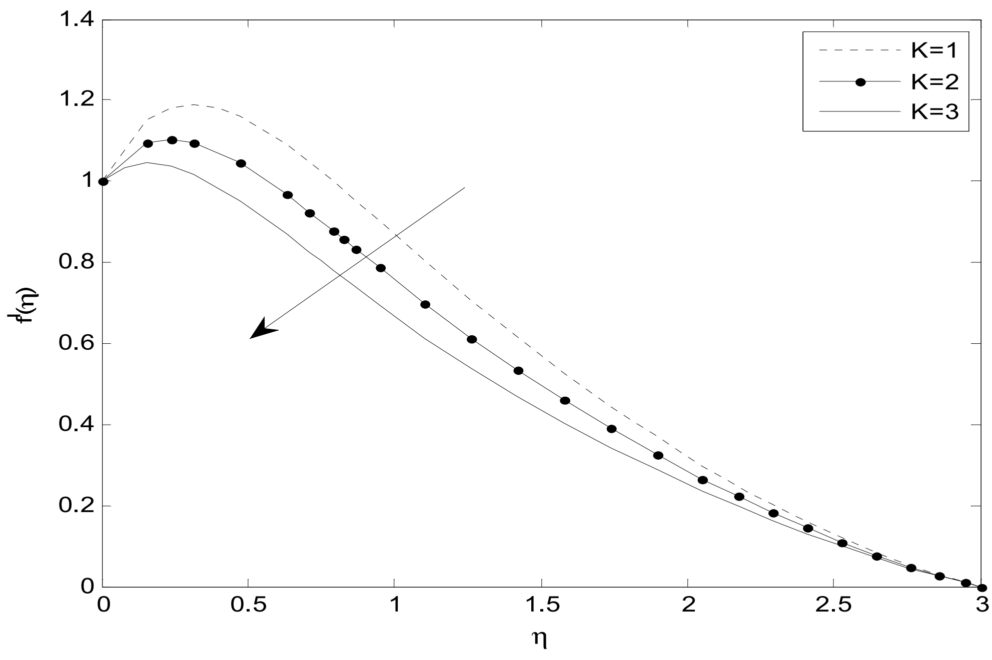

Fig. 8 Velocity profiles for different values of K when
$\Pr$ =6.2, Gr =5, Gc =5, H =0.5, R =2, Sc =0.22, $\theta = \pi/3$, f_w =0.1, K_l =0.5.

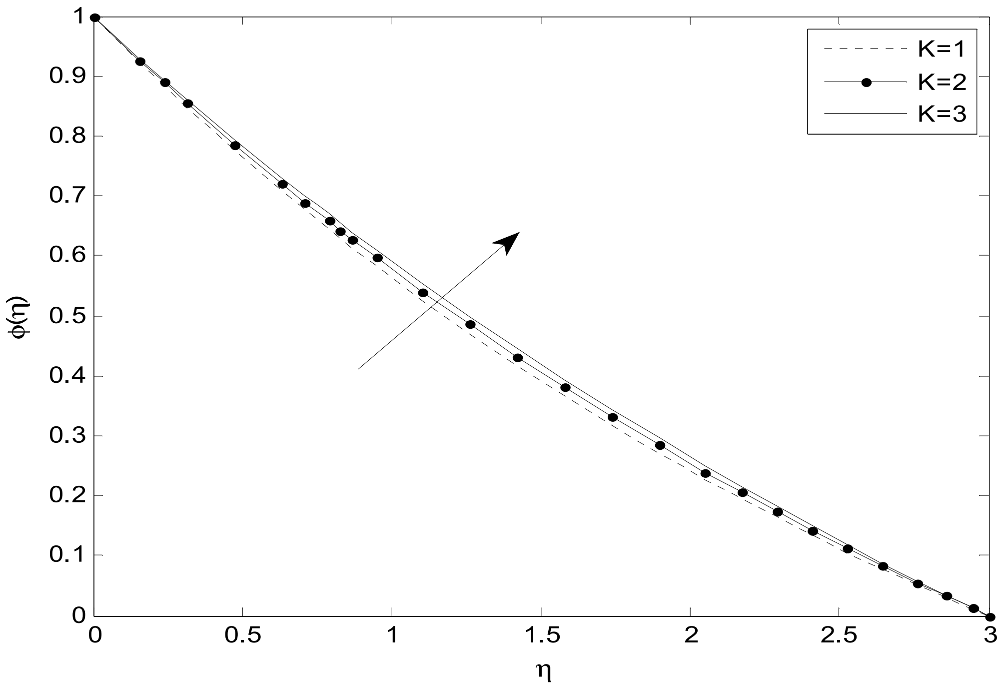

Fig. 9 Concentration profiles for different values of K when
$\Pr=6.2, Gr=5, Gc=5, H=0.5, R=2, Sc=0.22, \theta=\pi/3, f_w=0.1, K_l=0.5$.

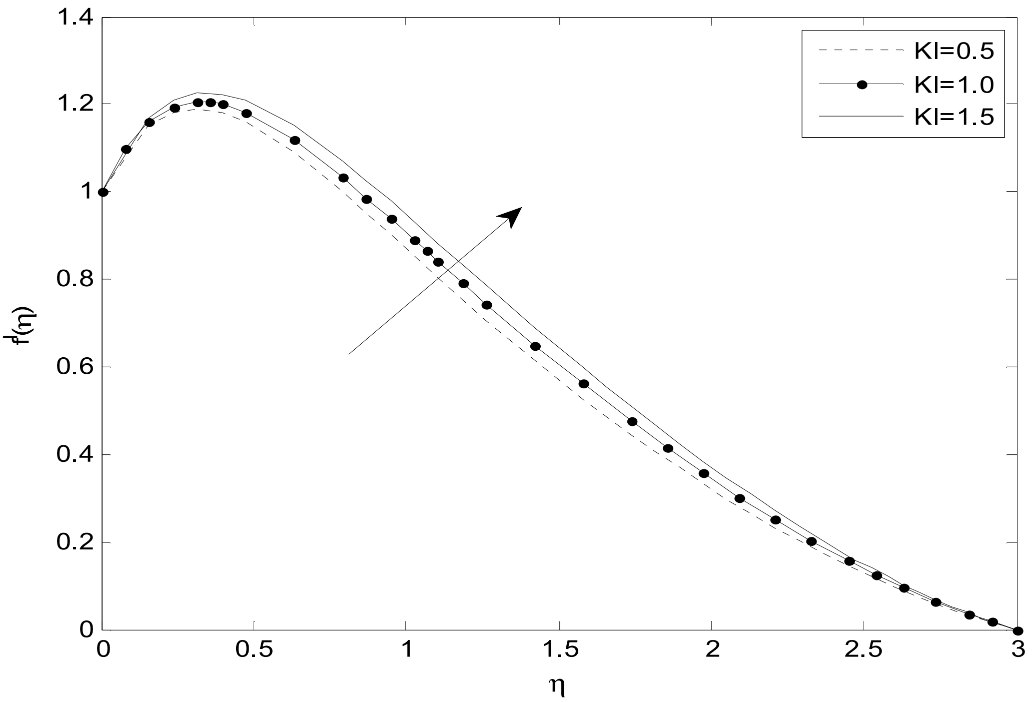

Fig. 10 Velocity profiles for different values of K_l when
$\Pr=6.2, Gr=5, Gc=5, H=0.5, R=2, Sc=0.22, \theta=\pi/3, f_w=0.1, K=0.1$.

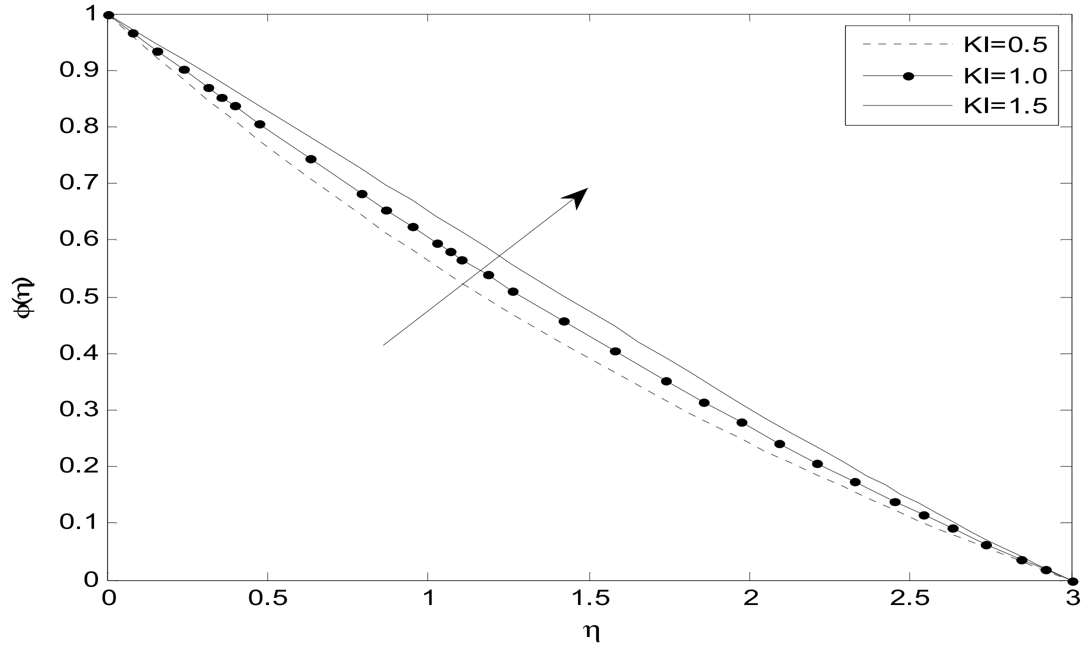

Fig. 11 Concentration profiles for different values of K_l when
$\Pr$ =6.2, Gr =5, Gc =5, H =0.5, R =2, Sc =0.22, $\theta = \pi/3$, f_w =0.1, K =0.1.

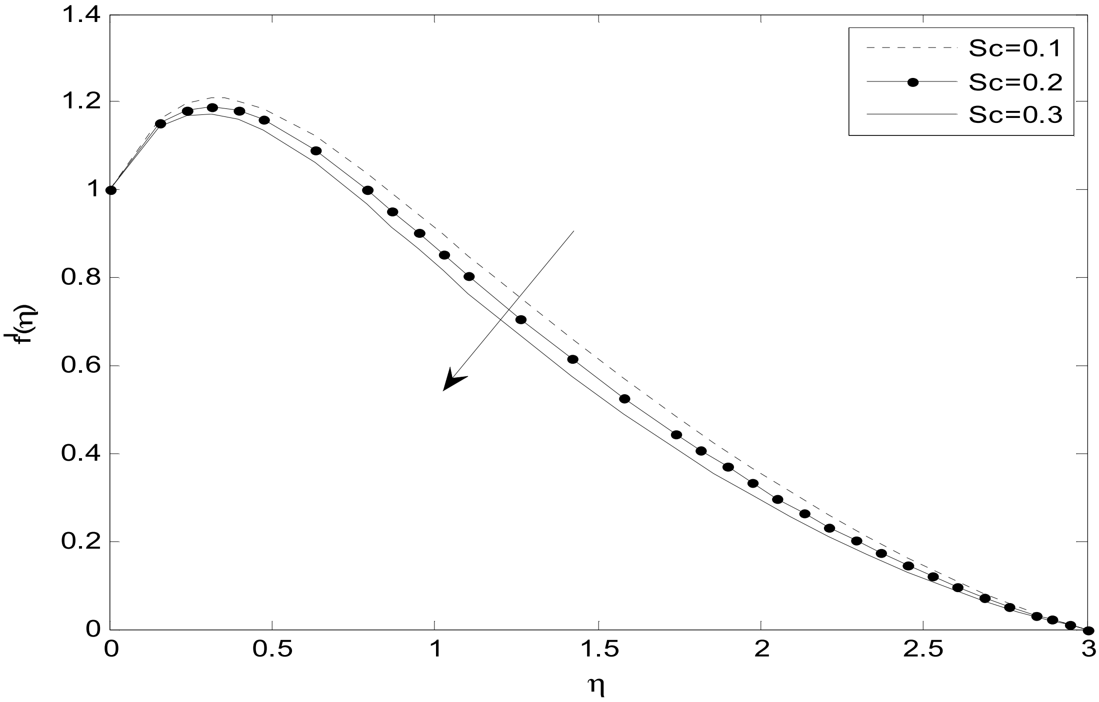

Fig. 12 Velocity profiles for different values of Sc when
$\Pr$ =6.2, Gr =5, Gc =5, H =0.5, R =2, K_l =0.1, $\theta = \pi/3$, f_w =0.1, K =0.1.

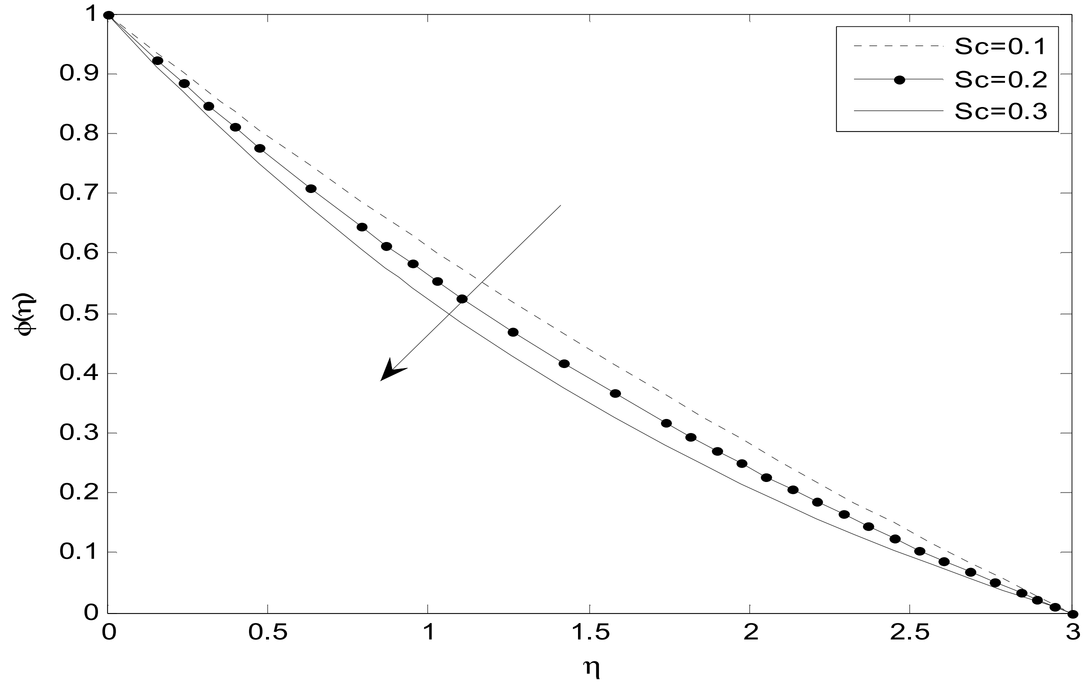

Fig. 13 Concentration profiles for different values of Sc when
$\Pr$ =6.2, Gr =5, Gc =5, H =0.5, R =2, K_l =0.1, $\theta = \pi/3$, f_w =0.1, K =0.1.

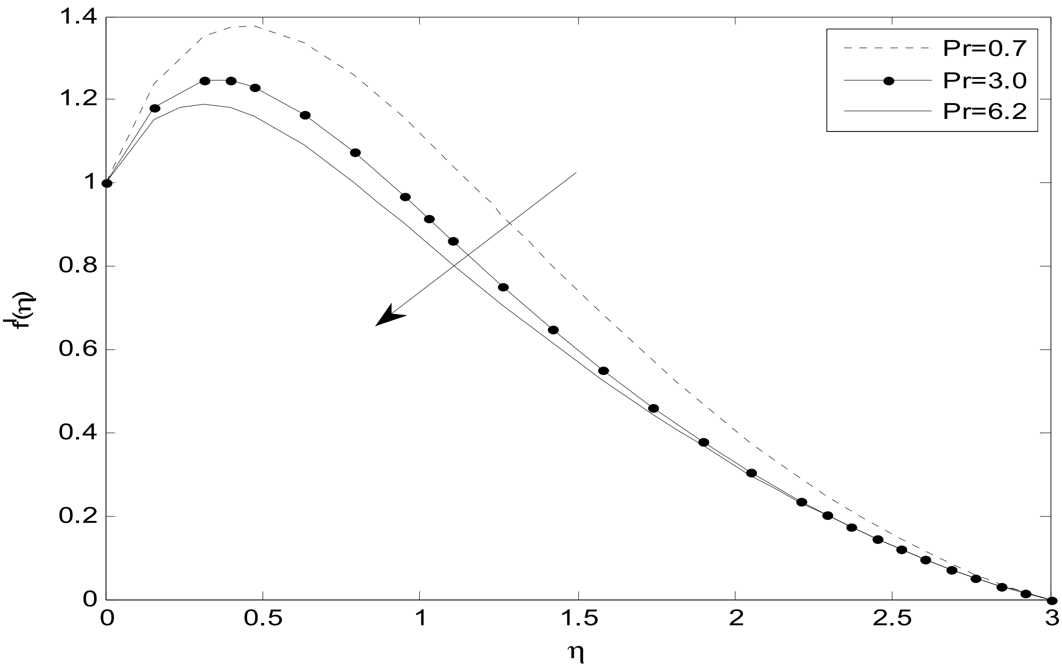

Fig. 14 Velocity profiles for different values of $\Pr$ when
Sc =0.22, Gr =5, Gc =5, H =0.5, R =2, K_l =0.1, $\theta = \pi/3$, f_w =0.1, K =0.1.

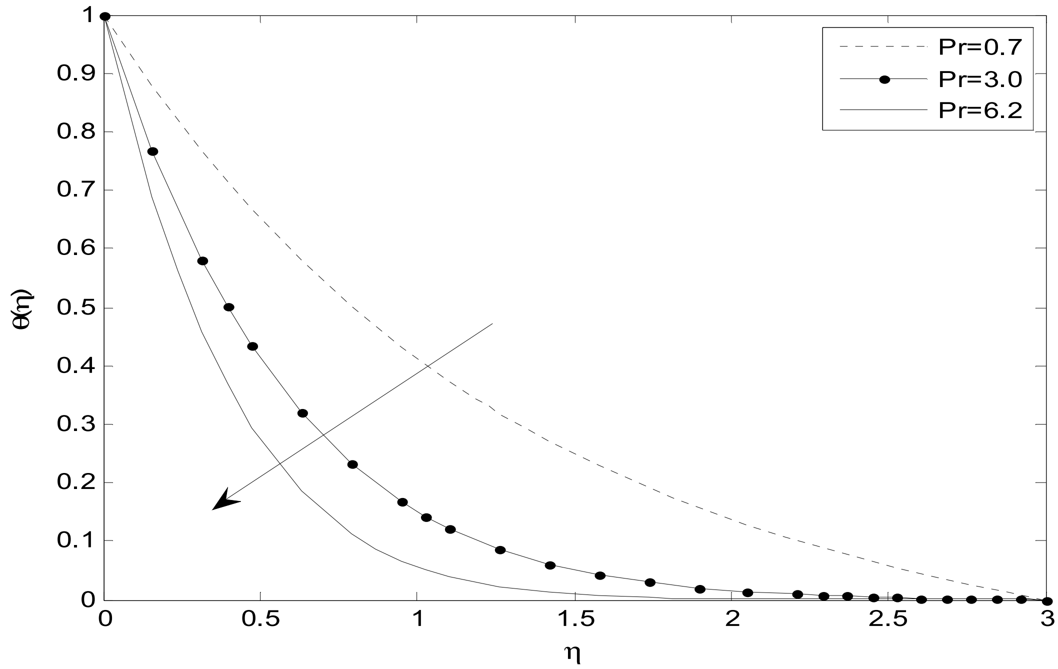

Fig. 15 Temperature profiles for different values of Pr when
$\theta = \pi/3$, Gr =5, Gc =5, R =2, f_w =0.1, Sc =0.22, H =0.5, S =0.1, K_l =0.5.

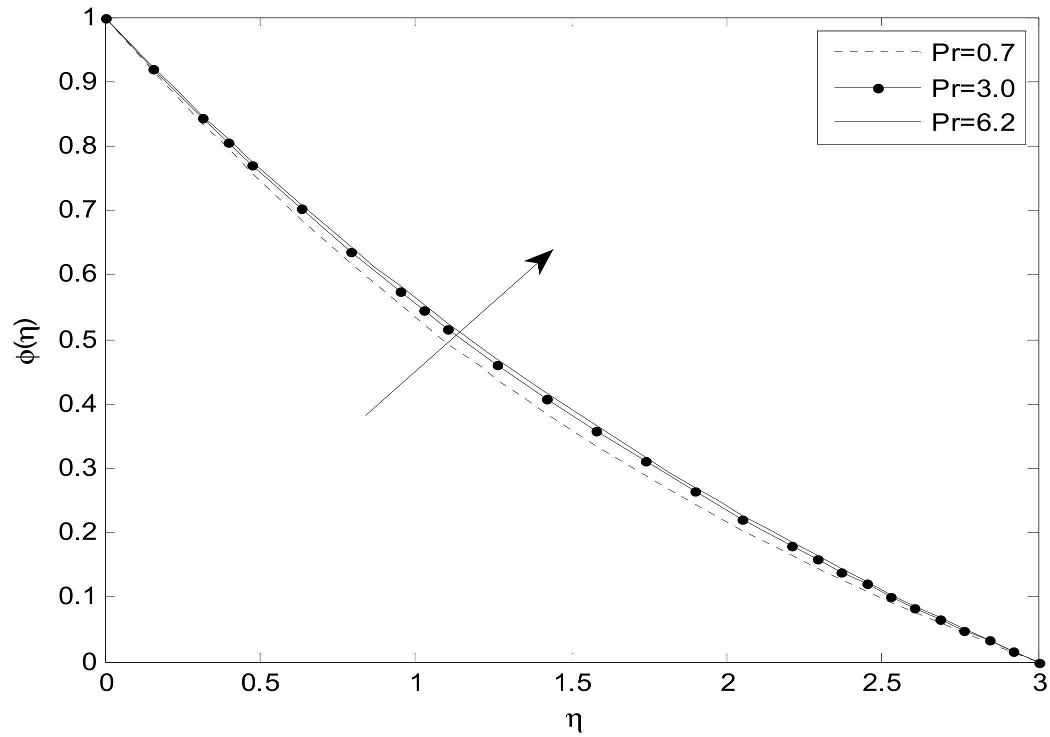

Fig. 16 Concentration profiles for different values of Pr when
Sc =0.22, Gr =5, Gc =5, H =0.5, R =2, K_l =0.1, $\theta = \pi/3$, f_w =0.1, K =0.1.

5. Conclusions

The effects of aligned magnetic field, radiation and chemical reaction on MHD boundary layer flow over a moving vertical porous plate with heat source were analyzed. The partial differential equations governing the flow are solved numerically using the shooting technique. The influence of various parameters on velocity, temperature and concentration profiles, as well as Skin-friction coefficient Nusselt number and Sherwood number are examined.

The conclusions are as follows:

1. Increase in aligned magneticfield angle helps to strengthen the magnetic field .It helps to control the velocity of the fluid at different levels and at different angles.
2. The velocity, temperature and concentration profiles of the fluid are more influenced by Aligned angle, radiation and chemical reaction parameters.
3. The variations of Skin-friction coefficient, Nusselt number and Sherwood number are more influenced by radiation and chemical reaction parameter, which is increase in radiation and chemical reaction parameter, causes the slight increase in Skin-friction coefficient, Nusselt number and Sherwood number.
4. The dimensionless surface velocity of the flow is decreases by increase in aligned magnetic field angle.
5. The velocity and concentration profile increases with an increase of chemical reaction parameter but it is reverse in case of temperature profiles.

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