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Joule Heating and Radiation Absorption Effects on MHD Convective and Chemically Reactive Flow past a Porous Plate

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Abstract

The aim of this study is to analyze the effects of Joule heating and radiation absorption on MHD convective and chemically reactive flow past an inclined porous plate in the presence of heat source and thermal diffusion. The non-linear partial differential equations that govern the fluid flow have been transformed into a two-point boundary value problem using similarity variables and then solved numerically by fourth order Runge–Kutta method with shooting technique. Graphical results are discussed for non-dimensional velocity, temperature and concentration profiles while numerical values of the skin friction, Nusselt number and Sherwood number are presented in tabular form for various values of parameters controlling the flow system. The present study is compared with the previous literature and found to be in good agreement. The novelty of this work is the consideration of Ohmic heating, radiation absorption and thermal diffusion.

Keywords: Joule heating, Radiation absorption, MHD, Chemical reaction, Thermal diffusion, porous plate.

1. INTRODUCTION

The MHD heat and mass transfer processes over a moving surface are of interest in engineering and geophysical applications such as geothermal reservoirs, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors. Many chemical engineering processes like metallurgical and polymer extrusion processes involve cooling of a molten liquid being stretched into a cooling system; the fluid mechanical properties of the penultimate product depend mainly on the cooling liquid used and the rate of stretching. Some polymer fluids like polyethylene oxide and polyisobutylene solution in cetane, having better electromagnetic properties, are normally used as cooling liquid as their flow can be regulated by external magnetic fields in order to improve the quality of the final product.

Tripathy et al. [1] investigated about the chemical reaction effect on MHD free convective surface over a moving vertical plate through porous medium.

Makinde [2] studied MHD heat and mass transfer over a moving vertical plate with a convective surface boundary condition.

Jha et al. [3] have considered unsteady MHD free convective couette flow between vertical porous plates with thermal radiation.

Seth et al. [4] considered MHD natural convection flow past an impulsively moving vertical plate with ramped wall temperature in the presence of thermal diffusion with heat absorption.

Anjali Devi and Kandaswami [5] have analyzed the effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate.

Seddeek et al. [6] have explained effects of chemical reaction and variable viscosity on hydro magnetic convection heat and mass transfer for Hiemenz flow through porous media with radiation.

Srinivasacharya and Swamp [7] have studied chemical reaction and radiation effects on mixed convection heat and mass transfer over a vertical plate in power-law fluid saturated porous medium.

Ibrahim et al. [8] have considered effects of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with hear source and suction.

Barik [9] have explained chemical reaction and radiation effects of MHD free convective flow past an impulsively moving vertical plate with ramped wall temperature and concentration.

Raju and Varma [10] have investigated soret effects due to natural convection in a non-Newtonian fluid flow in porous medium with heat and mass transfer.

Srinivasacharya et al. [11] studied Soret and Dufour effects on mixed convection from a vertical plate in power-law fluid saturated porous medium.

Sivareddy et al. [12] analyzed Soret effect on unsteady MHD free convective flow past a semi-infinite vertical plate in the presence of viscous dissipation.

Arabawy [13] considered Soret and Dufour effects on natural convection flow past a vertical surface in a porous medium with variable surface temperature.

Alam et al. [14] investigated Dufour and Soret effects on unsteady MHD free convective and mass transfer flow past a vertical porous plate in a porous medium.

Loganathan et al. [15] analyzed Ohmic heating and viscous dissipation effects over a vertical plate in the presence of porous medium.

Chen [16] studied combined heat and mass transfer in MHD free convection from a vertical surface Ohmic heating and viscous dissipation.

Goyal and Sunitha [17] have investigated MHD free convective flow over a vertical porous surface with Ohmic heating, thermal radiation and chemical reaction.

Umamaheswar et al. [18] studied unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and ohmic heating.

Rashidi et al. [19] investigated free convective heat and mass transfer for MHD fluid flow over a permeable vertical stretching sheet in the presence of the radiation and buoyancy effect.

Venkateswarlu and Padma [20] have considered unsteady MHD free convective heat and mass transfer in a boundary layer flow past a vertical permeable plate with thermal radiation and chemical reaction.

Alam et al. [21] have analyzed heat and mass transfer in MHD free convective flow over an inclined plate with hall current.

Hemant and Chaudhary [22] have explained MHD free convection and mass transfer flow over an infinite vertical porous plate with viscous dissipation.

Anand Rao and Raju [23] have studied the effect of Hall current, Soret and Dufour on MHD flow of Heat transfer along a porous plate with mass transfer.

Krishniah et al. [24] studied, free and forced convection flow in an inclined channel.

Reddy and Raju [25] examined, the combined constant heat and mass flux effect on MHD free convective flow through a porous medium bounded by a vertical surface in presence of chemical reaction and radiation.

Reddy et al. [26] investigated recently on diffusion thermo and thermal diffusion effects on MHD free convection flow of Rivlin- Ericksen fluid past a semi-infinite vertical plate.

Keeping in view the above studies we analyze the effects of Joule heating and radiation absorption on MHD convective and chemically reactive flow past an inclined porous plate in the presence of heat source and thermal diffusion. We extend the work of Tripathy et al. [1] by taking into account the physical parameters Joule heating, radiation absorption parameter, Soret effect and we also consider the inclined plate.

2. FORMULATION OF THE PROBLEM

We consider a steady free convective flow of a viscous, incompressible, electrically conducting, chemically reactive and radiation absorption flow past an inclined porous plate in the presence of thermal diffusion and joule heating. The flow is taken to be in the x^*- direction along the inclined plate towards upward direction and y^*- axis is taken to be perpendicular to it. A magnetic field of uniform strength B_0 is assumed to be applied perpendicular to the plate. It is assumed that the induced magnetic field and electric field due to polarization of charges are negligible when compared with the applied magnetic field as the magnetic Reynolds number is very small. Therefore the presence of Hall current is also ignored. The density variations due to the buoyancy forces are considered in the momentum equation. The species concentration far away from the plate is assumed to be very small. As the fluid velocity is very slow far away from the plate, viscous dissipation influence in energy conservation is ignored. Followed by Tripathy et al. [1] and usual Boussinesq's approximation, the governing equations for this mathematical problem are as follows.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u-\frac{\upsilon u}{k_p^*}+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty) \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+S^*(T-T_\infty)+\sigma B_0^2 u^{*2}+Q^*(C-C_\infty) \quad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-Kr(C-C_\infty)+D_1\frac{\partial^2 T}{\partial y^2} \quad (4)$$

where u and v are velocity components, T and C are the temperature and concentration of chemical species in the fluid, υ is the kinematic viscosity , k_p^* is the permeability coefficient of porous medium, C_∞ is the free stream concentration, U_0 is the plate velocity , α is the thermal diffusivity and D is the mass diffusivity, β_T is the thermal expansion coefficient, β_C is the solutal expansion coefficient, ρ is the fluid density, g is the gravitational acceleration, σ is the fluid electrical conductivity, B_0 is the magnetic induction, C_p is the specific heat at constant pressure, Q^* is the dimensional heat generation / absorption coefficient, Kr is the chemical reaction parameter .
The boundary conditions at the plate surface and far into the cold fluid can be written as

$$u(x,0)=U_0\ ,\ v(x,0)=0,-k\frac{\partial T}{\partial y}(x,0)=h_f[T_f-T(x,0)],$$

$$C_w(x,0)=Ax^\lambda+C_\infty, u(x,\infty)=0, T(x,\infty)=T_\infty, C(x,\infty)=C_\infty \quad (5)$$

where species concentration at the plate surface is C_w, λ is the plate surface concentration exponent.
The continuity equation (1) is satisfied by the Cauchy-Riemann equations

$$u=\frac{\partial\psi}{\partial y}\ ,v=-\frac{\partial\psi}{\partial x} \quad (6)$$

where $\psi(x,y)$ is the stream function.

The following similarity transformations and dimensionless variables are introduced to transform equations (2) – (5) in to a set of ordinary differential equations.

$$\eta=\left(\frac{U_0}{\upsilon x}\right)^{1/2}y, \psi=\sqrt{\upsilon x U_0}\,f(\eta),$$
$$\theta(\eta)=\frac{T-T_\infty}{T_f-T_\infty}, \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty} \quad (7)$$

where $f(\eta)$ is the dimensionless stream function, θ is the dimensionless temperature, ϕ is the dimensionless concentration, η is the similarity variable.

By using the non-dimensional quantities (6) and (7), the equations (2) – (5) are transformed as follows.

$$f^{111}+\frac{1}{2}ff^{11}-(M+\frac{1}{k})f^{1}+Gr\theta+Gc\phi=0 \quad (8)$$

$$\theta^{11}+\frac{1}{2}\Pr f\theta^{1}+S\Pr\theta+Ec\Pr Mf^{1^2}+R\Pr\phi=0 \quad (9)$$

$$\phi^{11}+\frac{1}{2}Scf\phi^{1}-KcSc\phi+S_0Sc\theta^{11}=0 \quad (10)$$

Subject to boundary conditions

$$\begin{aligned} &f(0)=0,\ f^{1}(0)=1, \theta^{1}(0)=Bi[\theta(0)-1], \phi(0)=1 \\ &f^{1}(\infty)=0, \theta(\infty)=0, \phi(\infty)=0 \end{aligned} \quad (11)$$

where the primes denote differentiation with respect to η . The dimensionless variables are as follows.

$S_0=\frac{D_1(T_w-T_\infty)}{\upsilon(C_w-C_\infty)}$ (Soret number)

$Ec=\frac{\rho U_0^3}{T_w-T_\infty}$ (Eckert number)

$R=\frac{Q^*(C_w-C_\infty)x}{U_0(T_w-T_\infty)}$ (radiation absorption parameter)

$k=\frac{k_p^*U_0}{\upsilon x}$ (permeability parameter)

$P_r=\frac{\upsilon}{\alpha}$ (Prandtl number)

$Sc=\frac{\upsilon}{D}$ (Schmidt number)

$M=\frac{\sigma B_0^2x}{\rho U_0}$ (magnetic field parameter)

$S=\frac{S^*x}{U_0}$ (source parameter)

$Bi=\frac{h_f}{k}\sqrt{\frac{\upsilon x}{U_0}}$ (Convective heat transfer parameter)

$Gr=\frac{g\beta_T(T_f-T_\infty)x}{U_0^2}$ (thermal Grashof number)

$Gc=\frac{g\beta_C(C_w-C_\infty)x}{U_0^2}$ (Solutal Grashof number)

$k_c=\frac{k_rx}{U_0}$ (chemical reaction parameter)

Here the local parameters Bi , M, Gr, Gc, S, R, K, Kc, S_0 , Ec in equations (8) to (10) are chosen as functions of x . To get a similarity solution all the parameters must be constants. The physical quantities of interest are the plate surface concentration, surface temperature, surface velocity, the local skin friction coefficient, the local Nusselt number, and local Sherwood number. These are proportional to $\phi(0)$, $\theta(0)$, $f(0)$, $f^{''}(0)$, $-\theta^{'}(0)$ and $-\phi^{'}(0)$ respectively.

Method of solution: The governing boundary layer equations (8), (9) and (10) subject to boundary conditions (11) are solved numerically by using shooting method. Initially the higher order non-linear differential equations (8) to (10) are transformed into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique. From the process of numerical computation, the plate surface concentration, surface temperature, and the local Sherwood number, the local Nusselt number are presented in figures 1-25.

3. RESULTS AND DISCUSSION

In order to get a physical insight into the problem, a representative set of numerical results is shown graphically in figures1–25, to illustrate the influence of physical parameters embedded in the flow system. Figures 1 and 2 shows the effect of Gr and Gc on velocity. Here the velocity of the fluid is increased due the effect of Gr and Gc. From figure 3 and 4, it is noticed that velocity of the fluid decreases with an increase in chemical reaction parameter and magnetic field parameter. Figure 5 depicts the effect of Soret number on velocity. Velocity of the fluid decreases as the Soret number increases. The effect of porosity parameter on velocity is shown in figure 6. This figure reveals that velocity increases with raising values of porosity parameter. Figure 7 reveals the effect of Eckert number on velocity. From these figure it is observed that velocity of the fluid slightly increases for increasing values of Eckert number. Figure 8 depicts the effect of radiation absorption parameter on velocity. It is noticed from this figure that the velocity of the fluid increases for increasing values of R. The velocity of the fluid decreases for increasing values of Schmidt number Sc. It is evident from the figure 9. Figures 10 & 11 reveal the effects of Grashof number and modified Grashof number on temperature. It is evident from these two figures that temperature of the fluid falls down for increasing values of Gc and Gr. The temperature of the fluid decreases for increasing values of chemical reaction parameter and Soret number, which is presented in figures 12 & 13. The temperature of the fluid increases for increasing values of Eckert number. It is evident from the figure 14. From the figure 15, it is observed that the temperature of the fluid decreases for increasing values of Schmidt number. It noticed from the figure 16 that the temperature of the fluid increases for raising values of Prandtl number. From the figures 17, 18 & 19, it is noticed that the concentration of the fluid decreases for increasing values of chemical reaction parameter, Soret number and Schmidt number. From figures 20 & 21 it is observed that the Sherwood number increases for increasing values of Grashof number and modified Grashof number. Sherwood number increases for raising values of radiation absorption parameter. It is evident in figure 22. From figures 23 & 24 it is noticed that Sherwood number increases for increasing values Soret number and chemical reaction parameter. From figure 25 it is evident that the Nusselt number decreases for increasing values of radiation absorption parameter.

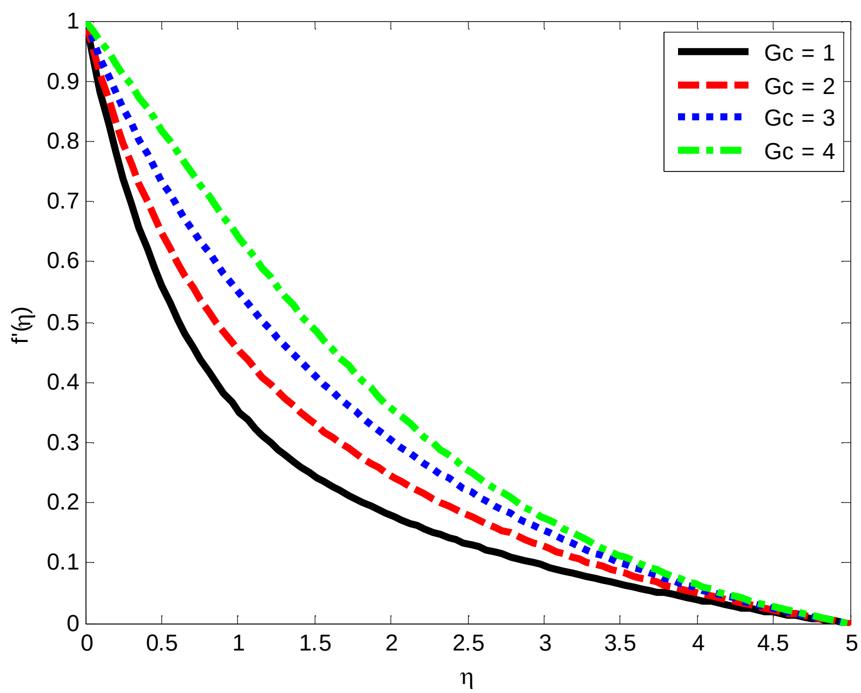

Fig. 1 : velocity profiles for different values of Gc

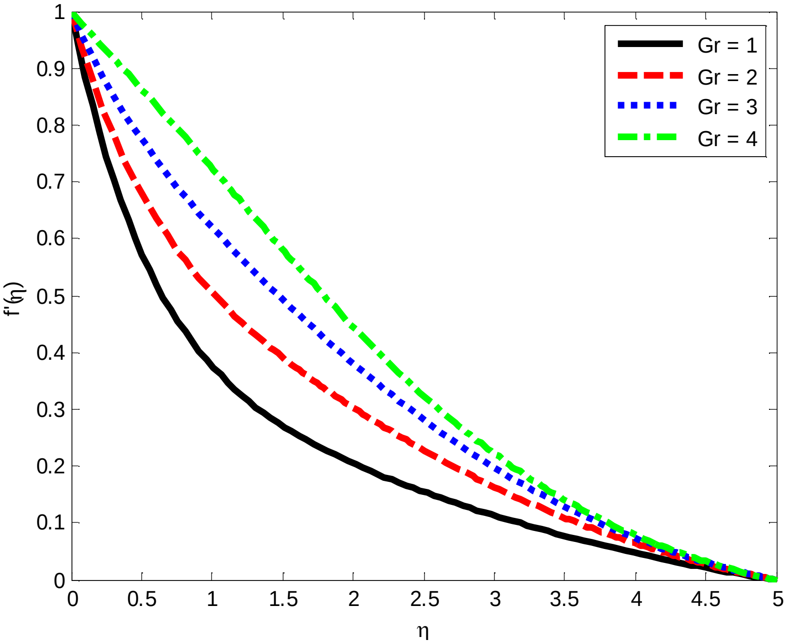

Fig. 2: velocity profiles for different values of Gr

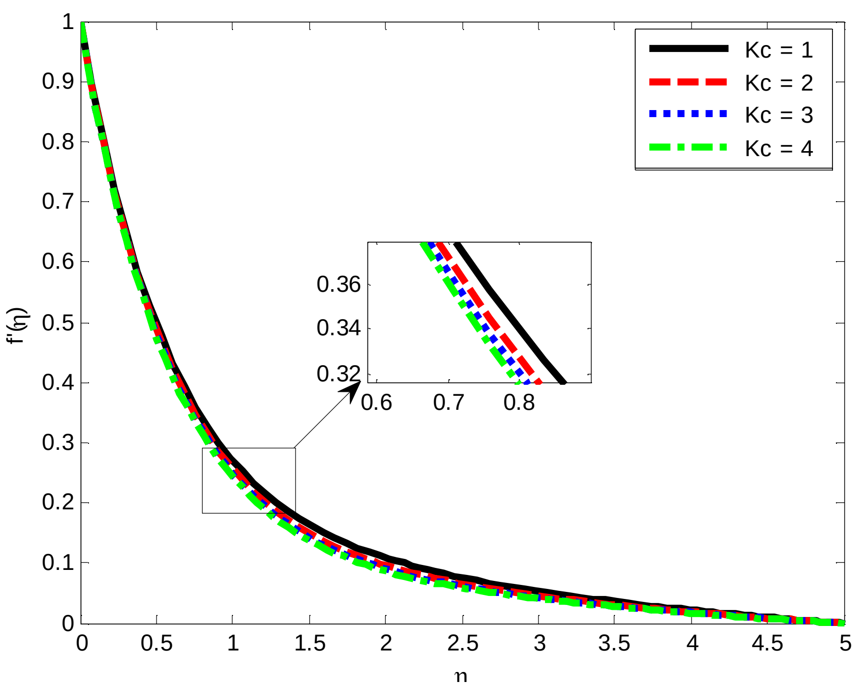

Fig. 3: velocity profiles for different values of Kc

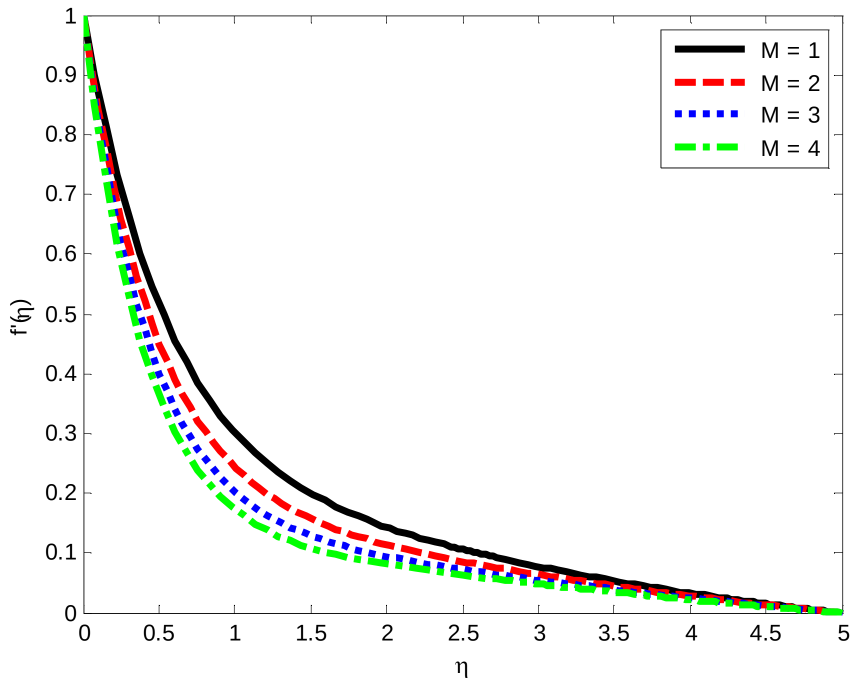

Fig. 4: velocity profiles for different values of M

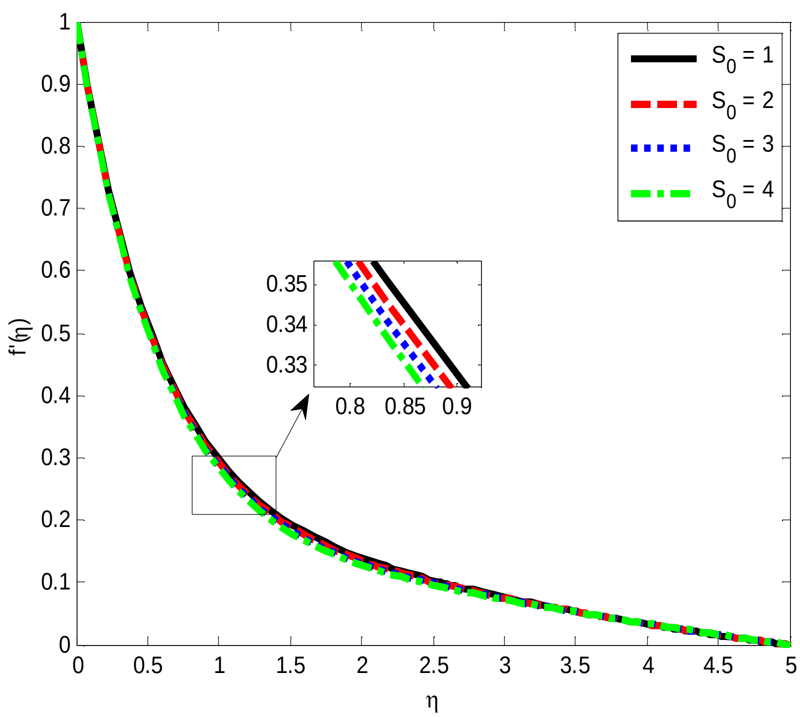

Fig. 5: velocity profiles for different values of S_0

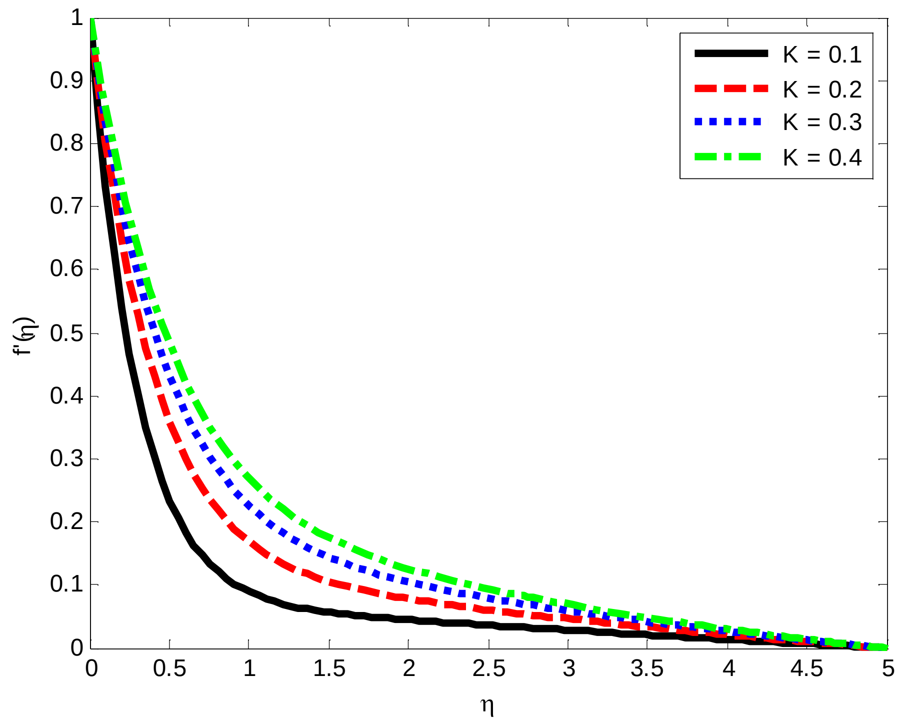

Fig. 6: velocity profiles for different values of K

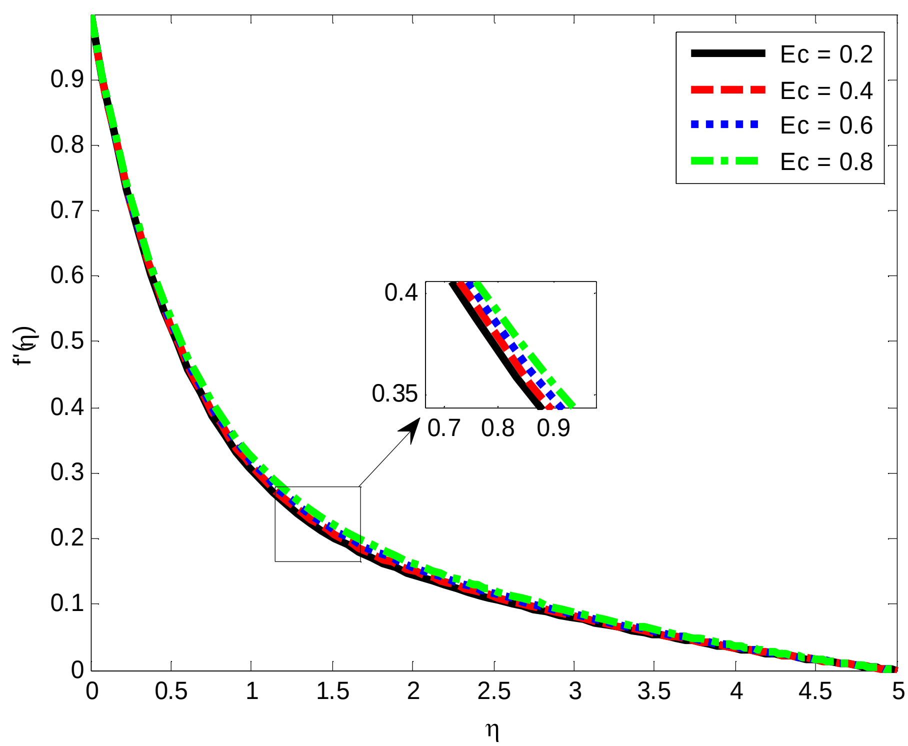

Fig. 7: velocity profiles for different values of Ec

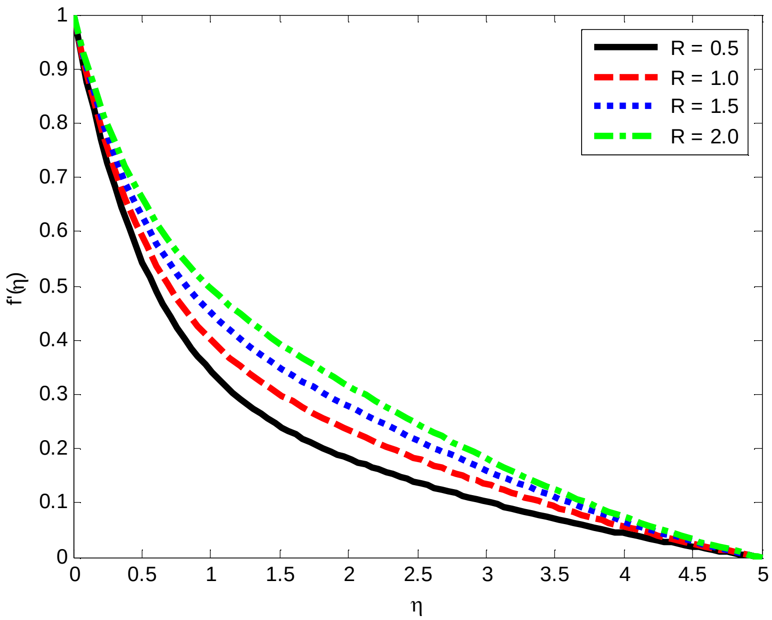

Fig. 8: velocity profiles for different values of R.

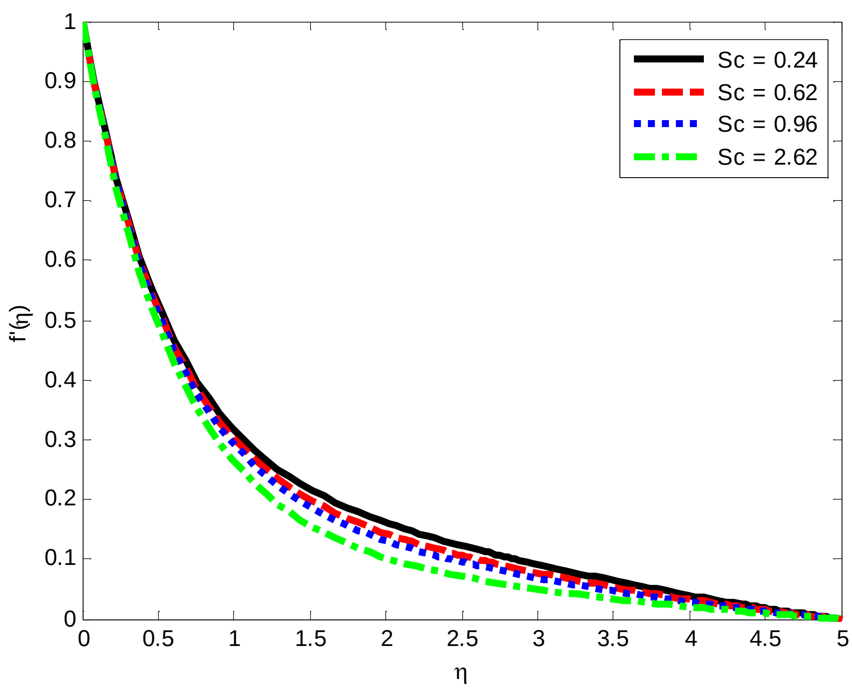

Fig. 9: velocity profiles for different values of Sc.

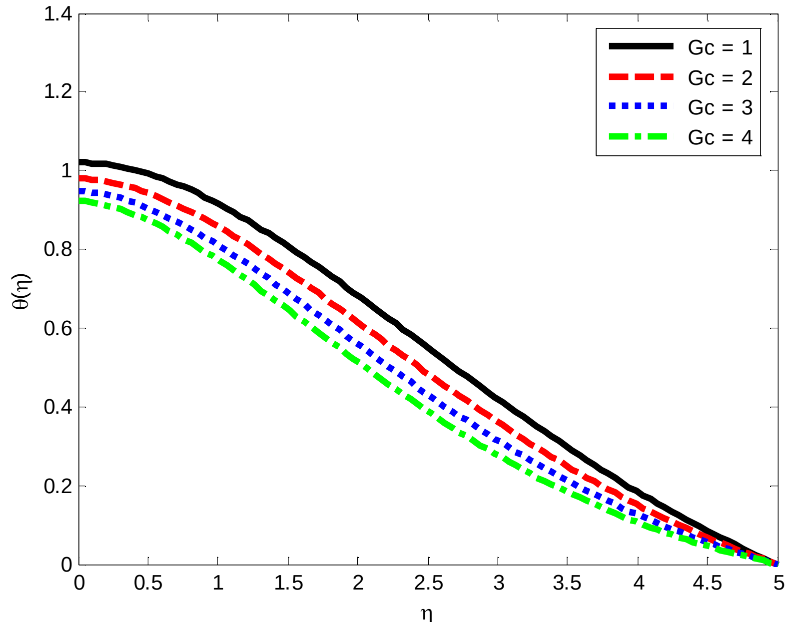

Fig. 10: Temperature profiles for different values of Gc.

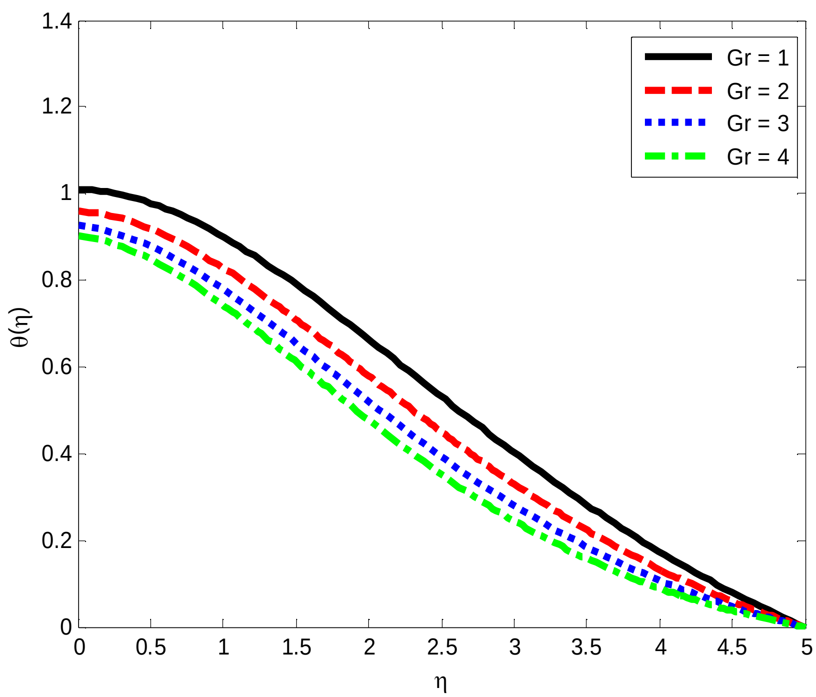

Fig. 11: Temperature profiles for different values of Gr.

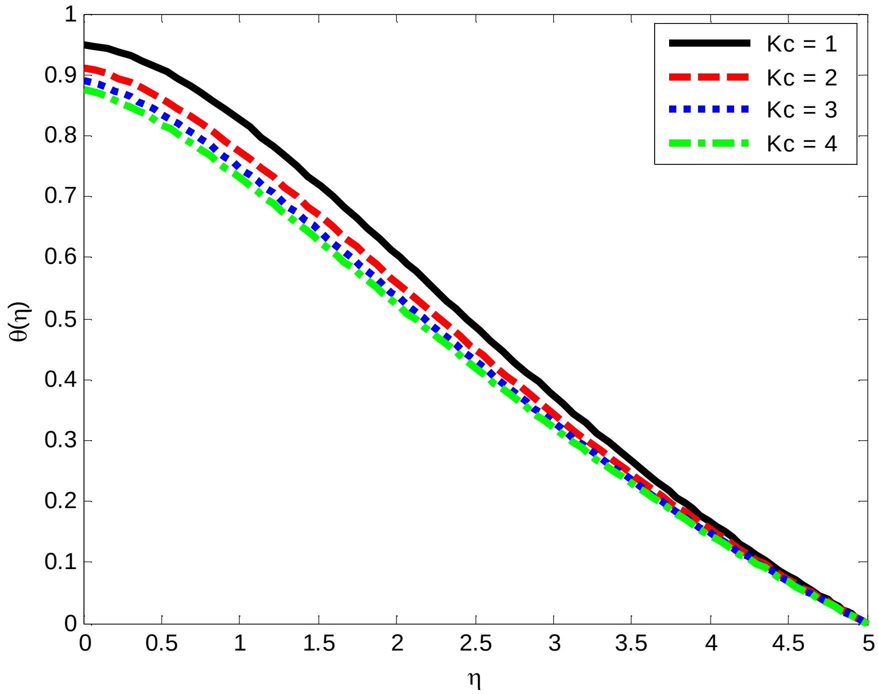

Fig. 12: Temperature profiles for different values of Kc

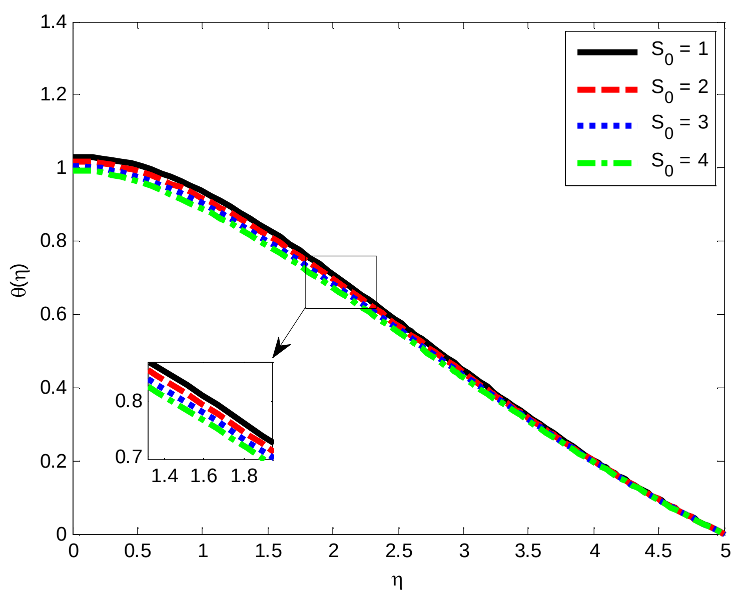

Fig. 13: Temperature profiles for different values of S

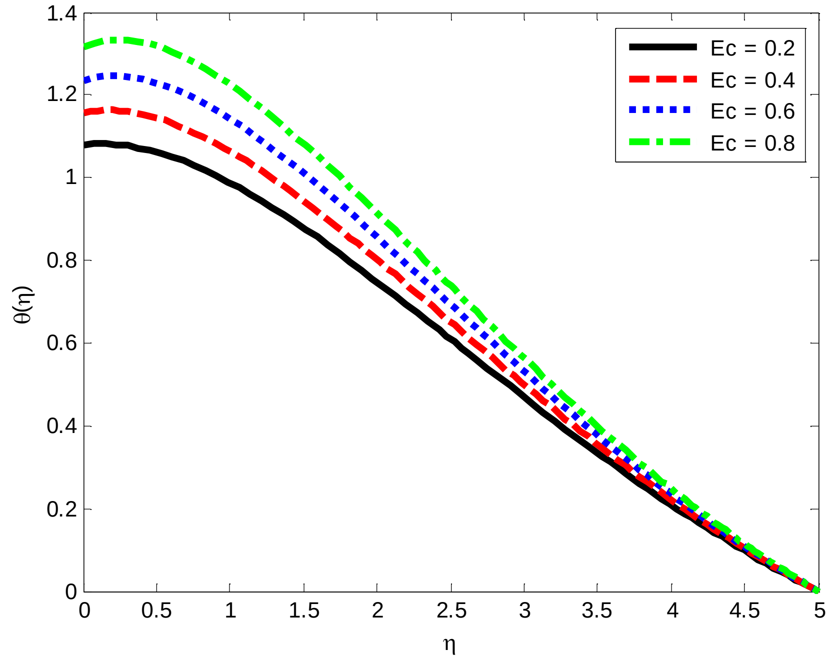

Fig. 14: Temperature profiles for different values of Ec

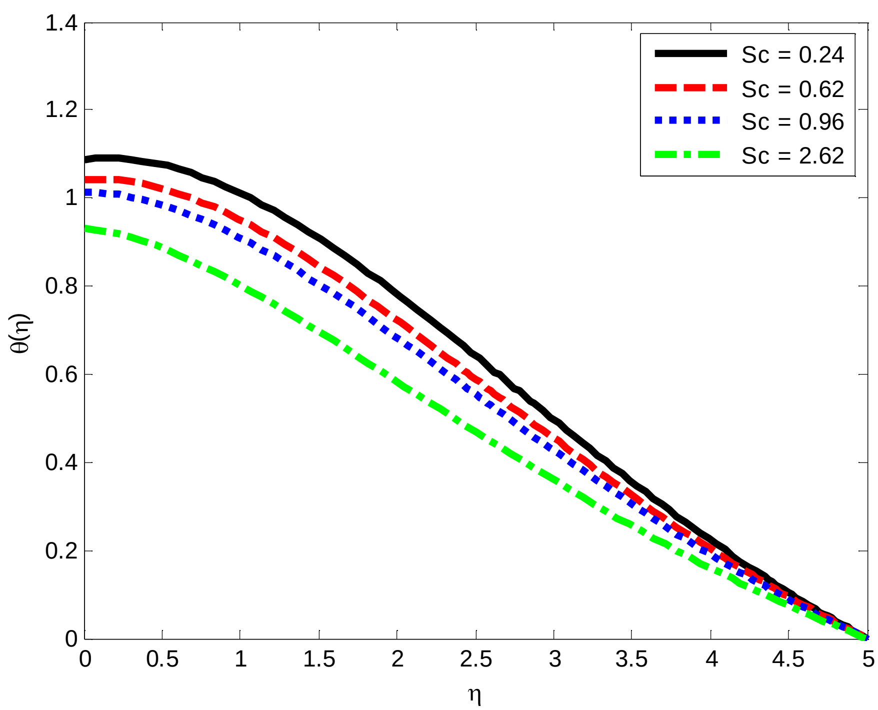

Fig. 15: Temperature profiles for different values of Sc

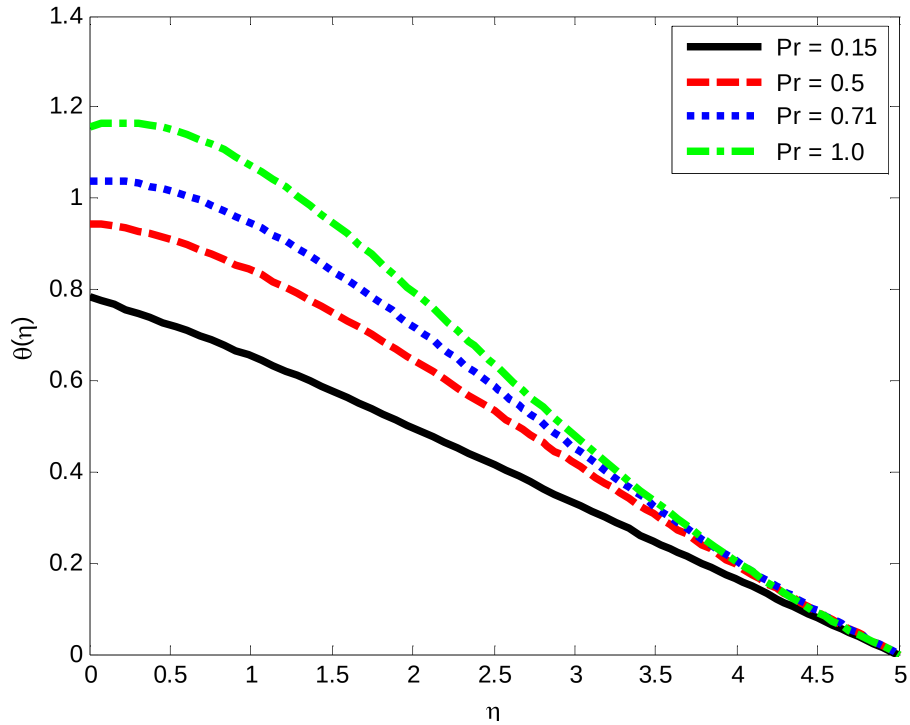

Fig. 16: Temperature profiles for different values of Pr.

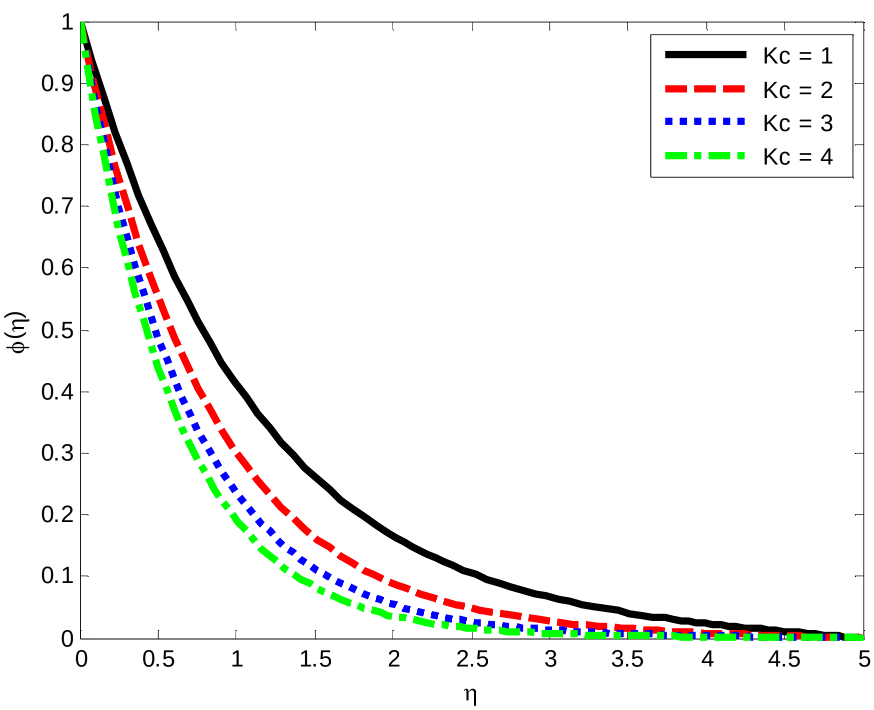

Fig. 17: Concentration profiles for different values of Kc

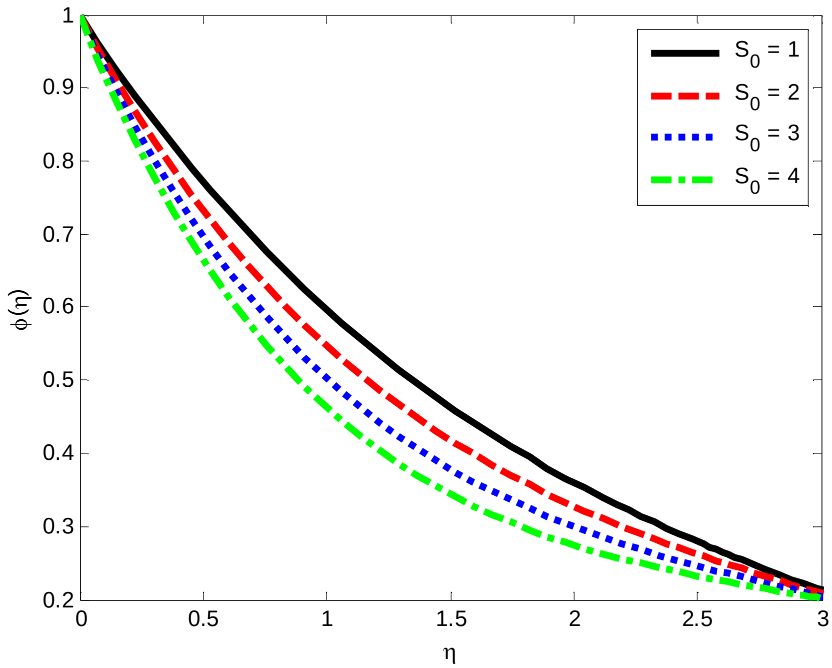

Fig. 18: Concentration profiles for different values of S_0

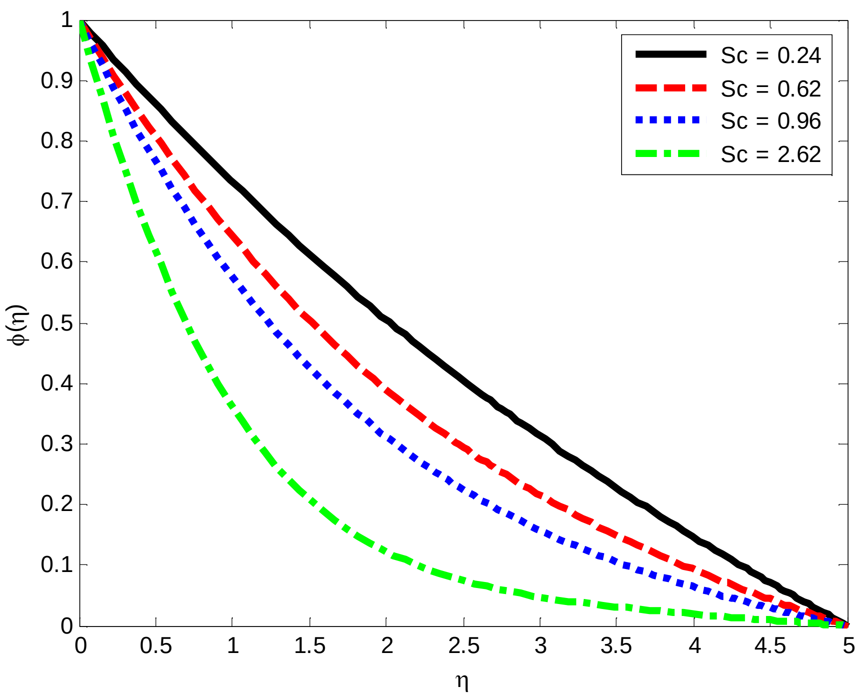

Fig. 19: Concentration profiles for different values of Sc

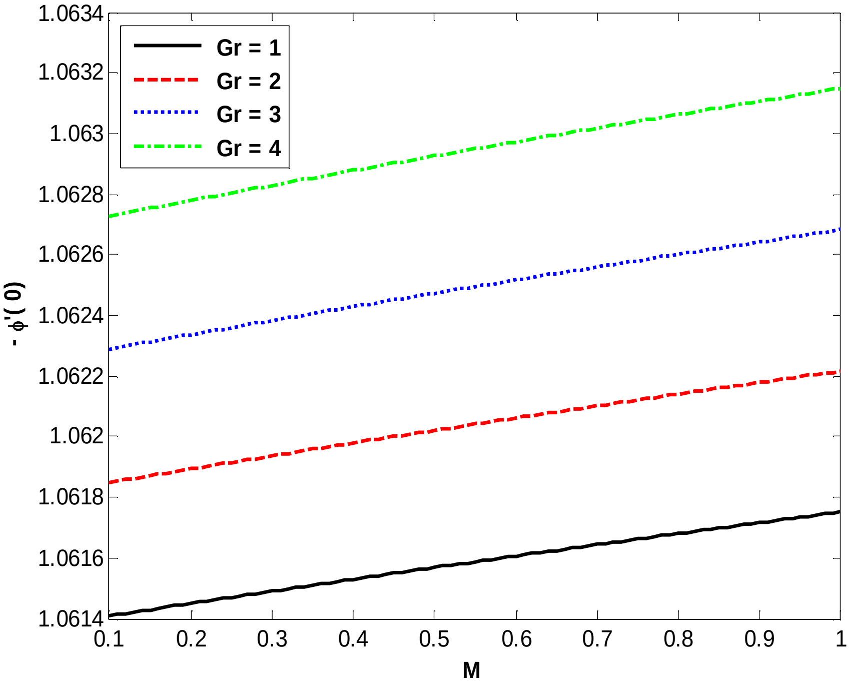

Fig. 20: Sherwood number variations

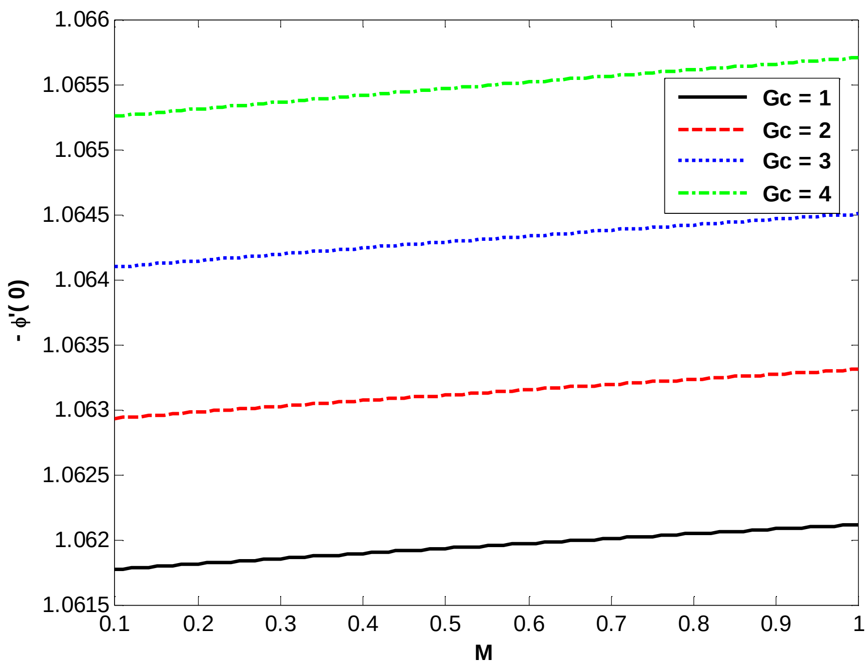

Fig. 21: Sherwood number variations

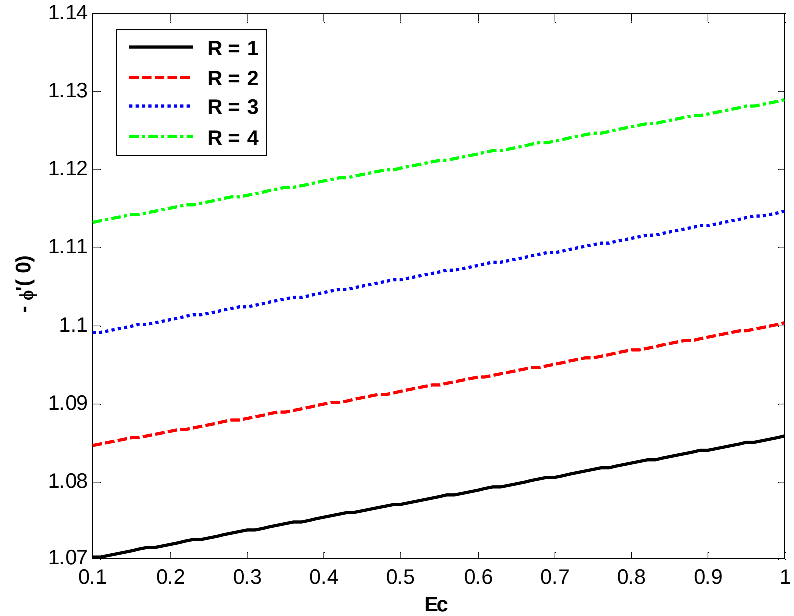

Fig. 22: Sherwood number variations under the effect of Gr and M. under the effect of Gc and M.

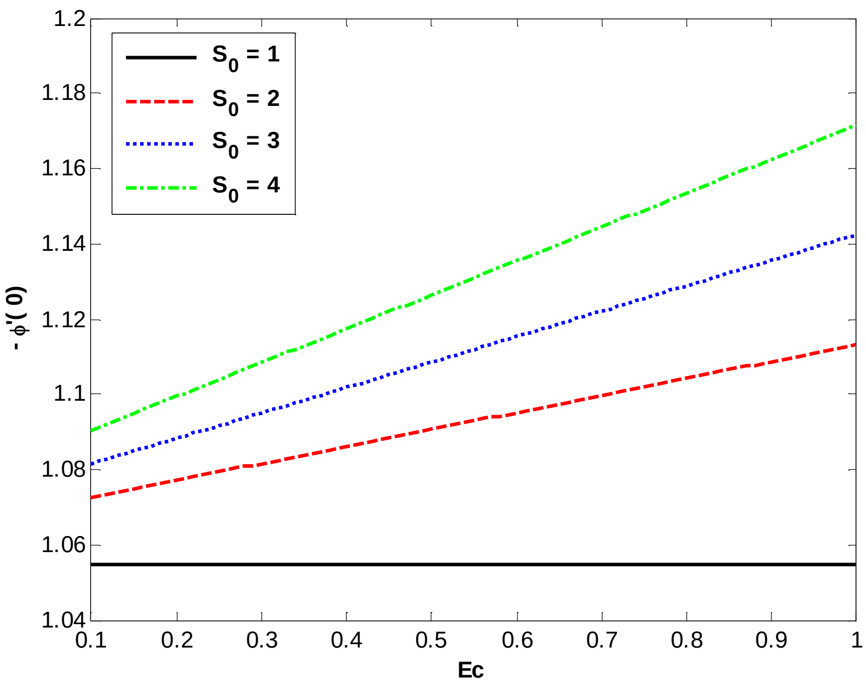

Fig. 23: Sherwood number variations

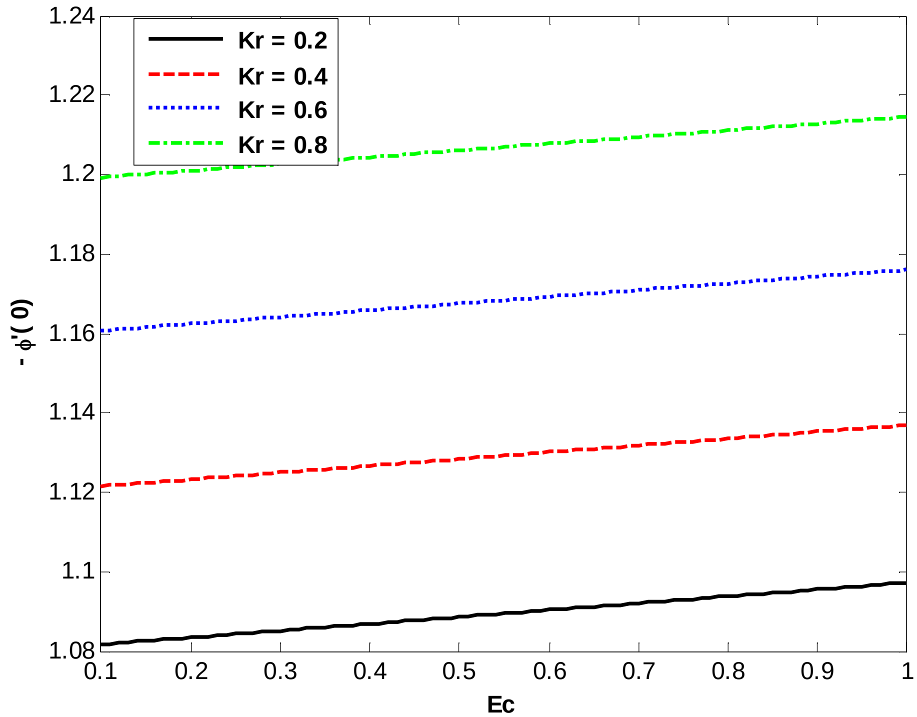

Fig. 24: Sherwood number variations under the effect of Ec and R. under the effect of Ec & S_0

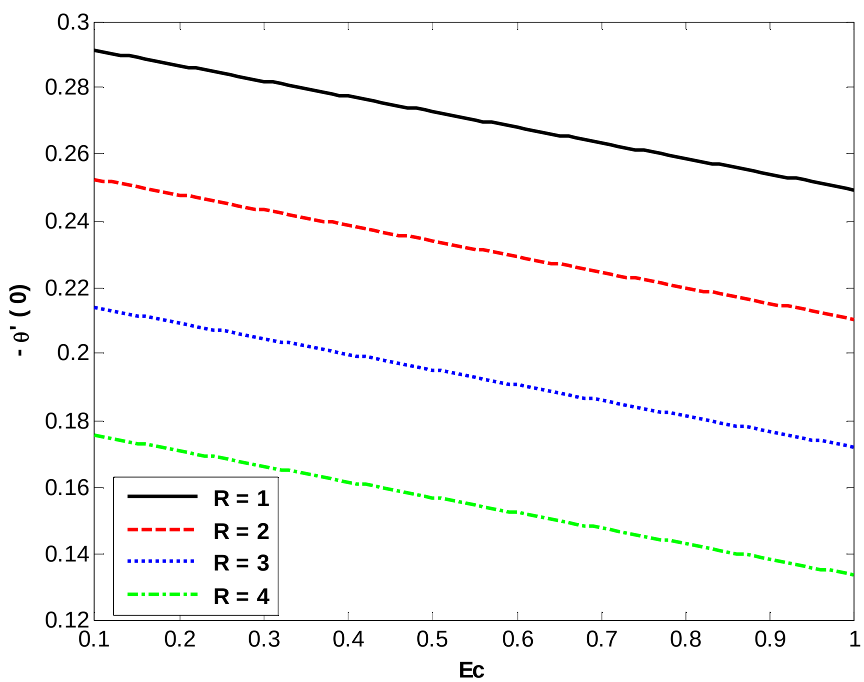

Fig. 25: Nusselt number variations under the effect of Ec and R under the effect of Kr and Ec

4. CONCLUSIONS

- Velocity of the fluid increases for increasing values of Grashof number, modified Grashof number, porosity parameter, Eckert number and radiation absorption parameter but it shows reverse tendency in the case of chemical reaction parameter, magnetic field parameter, Soret number and angle of inclination.
- Temperature of the fluid increases for increasing values of Eckert number, Prandtl number. But it shows reverse effect in the case of Grashof number, modified Grashof number, chemical reaction parameter, Soret number and Schmidt number.
- Concentration of the fluid decreases for increasing values of chemical reaction parameter, Soret number and Schmidt number.
- Rate of mass transfer increases for increasing values of Grashof number, modified Grashof number, radiation absorption parameter, Soret number and chemical reaction parameter.
- Rate of heat transfer decreases for increasing values of radiation absorption parameter.

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