International Journal of Mathematical Archive-8(11), 2017, 92-99
IJMA Available online through www.ijma.info ISSN 2229 – 5046

RADIATION EFFECT ON CONVECTIVE HEAT AND MASS TRANSFER FLOW FROM A VERTICAL SURFACE WITH CHEMICAL REACTION AND HEAT SOURCE/ABSORPTION

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(Received On: 24-10-17; Revised & Accepted On: 14-11-17)

ABSTRACT

We have studied the radiation and chemical reaction effects of heat and mass transfer on MHD mixed convection flow of a vertical surface with heat source/absorption and has been is discussed. The resulting set of coupled non-linear ordinary differential equations is solved using the MATLAB in-built numerical solver bvp4c. Approximate solutions have been derived for the velocity, temperature, concentration profiles, skin friction and Nusselt number. The obtained results are discussed with the help of the graphs to observe the effect of various flow parameters.

***Keywords**: MHD, Mass transfer, Radiation, Chemical reaction, Heat source and Radiation absorption.*

I. INTRODUCTION

Convective flows with coincident heat and mass transfer under the influence of a magnetic field and chemical reaction arise in many transport processes both naturally and artificially in many branches of science and engineering problems. This process plays an important role in the chemical industry, cooling of nuclear reactors and petroleum industries, cooling of an infinite metallic plate in a cooling path, chemical vapour deposition on surfaces. The study of heat and mass transfer with chemical reaction is a practical importance in many branches of science and engineering. P.A Lakshmi Narayana and P.Sibanda [1] considered the influence of the Soret effect and double dispersion on MHD mixed convection along a vertical plate in non – Darcy porous medium. G Palani *et al.* [2] have analyzed the effect of viscous dissipation on an MHD free convective flow past a semi – infinite vertical cone with a variable surface heat flux. M.Turkyimazogulu and I.Pop [3] presented the Soret and heat source effects on the unsteady radiative MHD free convection flow from an impulsively started infinite vertical plate. A. Mahd [4] studied the effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in a porous media with variable viscosity. H. Singh, *et al.* [5] analyzed a study of the effect of chemical reaction and radiation absorption on MHD convective heat and mass transfer flow past a semi-infinite vertical moving plate with time dependent suction. Kinyanjui *et al.* [6] presented magnetohydrodynamic free convection heat and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with hall current and radiation absorption. R. Muthucumaraswamy [7] discussed the effect of a chemical reaction on a moving isothermal vertical surface with suction. Pal and Talukdar [8] analyzed the combined effect of mixed convection with thermal radiation and chemical reaction on MHD flow of viscous and electrically conducting fluid past a vertical permeable surface embedded in a porous medium is analyzed. Muthuraj and Srinivas [9] studied the fully developed MHD flow of a micro polar and viscous fluid in a vertical porous space using HAM. Ramana Reddy *et al.* [10] have studied the mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption. O. D. Makinde and P. Sibanda [11] presented Magnetohydrodynamic mixed convective flow and heat and mass transfer past a vertical plate in a porous medium with constant wall suction. The unsteady free convective MHD flow with heat transfer past a semi-infinite vertical porous moving plate with variable suction has been studied by Kim [12]. Anand-Rao *et al.* [13] presented the finite element solution of heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity. P. M. Patil and P. S. Kulkarni [14] analyzed the effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Dessie and Kishan [15] have studied the MHD effects on heat transfer over stretching sheet embedded in porous medium with variable viscosity, viscous dissipation and heat source/sink.

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R. Kandasamy, K. Periasamy and K. K. Sivagnana Prabhu [16] presented the effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection. MHD flow and heat transfer of a viscous fluid over a radially stretching power - law sheet with suction/ injection in a porous medium has been studied by M.Khan *et al.* [17]. R.N. Barik and G.C. Dash [18] discussed thermal radiation effect on an unsteady magnetohydrodynamic flow past inclined porous heated plate in the presence of chemical reaction and viscous dissipation. S.S. Tak [19] analyzed MHD mixed convection boundary layer flow with double diffusion and thermal radiation adjacent to a vertical permeable surface embedded in a porous medium. A. O. Beg *et al.* [20] discussed Magnetohydrodynamic convection flow from a sphere to a non-Darcian porous medium with heat generation or absorption effects: network simulation.

All the above studies, we discuss the radiation effects on convective heat and mass transfer flow past a vertical surface with chemical reaction and heat source/absorption. The governing equations are transformed into a system of non-linear ordinary differential equations and are solved by using the MATLAB with in-built numerical solver bvp4c. Graphical results for the velocity, temperature, concentration and skin-friction coefficient has been presented.

II. FORMULATION OF THE PROBLEM

We consider the mixed convection flow of an incompressible, electrically conducting, radiating, heat source/absorbing and chemically reacting fluid. The x' - axis is taken along the plate in upwards direction and η'-axis is normal to it. A transverse constant magnetic field is applied i.e. in the direction of η'- axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x'. Let u' and v' be the components of velocity in x' and η' directions, respectively, taken along and perpendicular to the plate. The governing equations of continuity, momentum and energy for a flow of an electrically conducting fluid along a hot, non-conducting porous vertical plate in the presence of concentration and radiation is given by

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

$$v' = -v_0 \text{ (Constant)} \tag{2}$$

$$\frac{\partial p'}{\partial \eta'} = 0 \Rightarrow p' \text{ is independent of } \eta' \tag{3}$$

$$\rho\left(v'\frac{\partial u'}{\partial \eta'}\right) = \mu\frac{\partial^2 u'}{\partial \eta'^2} + \rho g\,\beta(T' - T_\infty) + \rho g\beta'(C' - C_\infty) - \sigma B_0^2 u' \tag{4}$$

$$\left(v'\frac{\partial T'}{\partial \eta'}\right) = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial \eta'^2} - \frac{1}{\rho C_p}\frac{\partial q_r'}{\partial \eta'} - \frac{Q_0}{\rho C_p}\left(T' - T_\infty\right) + \frac{Q_l'}{\rho C_p}\left(C' - C_\infty\right) \tag{5}$$

$$v'\frac{\partial C'}{\partial \eta'} = D\frac{\partial^2 C'}{\partial \eta'^2} - Kr'\left(C' - C_\infty\right) \tag{6}$$

Here, g is the acceleration due to gravity, T' the temperature of the fluid near the plate, T_∞ the free stream temperature, C' concentration, β the coefficient of thermal expansion, k the thermal conductivity, P' the pressure, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ viscosity of the fluid, q' the radiative heat flux, ρ the density, σ the magnetic permeability of fluid V_0 constant suction velocity, ν the kinematic viscosity and D molecular diffusivity.

The radiative heat flux q_r' is given by equation (5) in the spit of Cogly *et.al* [3]

$$\frac{\partial q_r'}{\partial \eta'} = 4(T' - T_\infty)I \tag{7}$$

where $I = \int_0^\infty K_{\lambda w}\frac{\partial e_{b\lambda}}{\partial T'}d\lambda,\ K_{\lambda w} -$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function, I is absorption coefficient

The boundary conditions are

$$\begin{aligned} &u' = 0, \quad T' = T_w,\ C' = C_w \qquad \eta' = 0 \\ &u' \to 0,\ T' \to T_\infty, C' \to C_\infty \quad \eta' \to \infty \end{aligned} \tag{8}$$

Introducing the following non-dimensional quantities

$$\begin{aligned} &u = \frac{u'}{v_0}, \eta = \frac{v_0 \eta'}{\nu},\ \theta = \frac{T' - T_\infty}{T_w - T_\infty}, C = \frac{C' - C_\infty}{C_w - C_\infty}, Q = \frac{Q_0}{\rho C_p v_0^2}, Sc = \frac{\nu}{D}, R = \frac{4\nu I}{\rho C_p v_0^2} \\ &Gm = \frac{\rho \beta' g (C - C_\infty)}{v_0^3},\ M^2 = \frac{B_0{}^2 \nu^2 \sigma}{v_0{}^2 \mu}, Kr = \frac{Kr' \nu}{v_0^2}, Gr = \frac{\rho \beta g \nu^2 (T_w - T_\infty)}{v_0^3 \mu}, \\ &Q_l = \frac{Q l' \left(C_w - C_\infty\right) \nu}{\rho C_p v_0^2 \left(T_w - T_\infty\right)}, \Pr = \frac{\mu C_p}{k}, \end{aligned} \tag{9}$$

Upon using these variables, the boundary layer governing equations reduces to

$$\frac{\partial^2 u}{\partial \eta^2} + \frac{\partial u}{\partial \eta} - M^2 u + Gr\theta + Gm C = 0 \tag{10}$$

$$\frac{\partial^2 \theta}{\partial \eta^2} + \Pr \frac{\partial \theta}{\partial \eta} - \left(R + Q\right) \Pr \theta + Q_l C = 0 \tag{11}$$

$$\frac{\partial^2 C}{\partial \eta^2} + Sc \frac{\partial C}{\partial \eta} - Sc Kr C = 0 \tag{12}$$

where Gr is Grashof number, Gm is the mass Groshof number, $\Pr$ is Prandtl number, M is magnetic parameter, R is Radiation parameter, Sc is Schmidt number, Q is heat source parameter, Kr is Chemical reaction parameter, Q_l is the heat absorption parameter.

The corresponding boundary condition in dimensionless form are reduced to

$$\begin{aligned} &u = 0, \quad \theta = 1, \quad C = 1 \qquad \eta = 0 \\ &u \to 0, \quad \theta \to 0,\ C \to 0 \qquad \eta \to \infty \end{aligned} \tag{13}$$

The physical variables $u, \theta\ and\ C$ can be expanded in the power of $\left(\varepsilon << 1\right)$.

Skin – friction: The skin-friction coefficient at the plate is given by $\tau = \left(\frac{\partial u}{\partial y}\right)_{\eta=0}$.

III. METHOD OF SOLUTION

Numerical solutions have been obtained for the governing equations (10), (11) and (12) with the associated boundary condition (13) by using the above mentioned numerical scheme for some of the governing parameters, namely: thermal Grashof number $\left(Gr\right)$, Magnetic parameter M, Permeability parameter Kl, absorption radiation parameter $\left(Ql\right)$, thermal radiation parameter $\left(R\right)$, Prandtl number $\left(\Pr\right)$, heat source parameter $\left(Q\right)$, chemical reaction parameter $\left(Kr\right)$ and Schmidt number $\left(Sc\right)$. Effects of $Gr, Gm. M, Kl, R\ Pr, Kr$ and Sc on the velocity, temperature and concentration are discussed. In computation, we have taken $\eta_\infty = 8$ and axis according to the clear figure.

IV. RESULTS AND DISCUSSION

We have studied numerically the effects of the thermal Grashof number(Gr), solutal Grashof number(Gm), Prandtl number (Pr), Schmidt number (Sc) absorption radiation parameter(Ql), the magnetic field parameter(M), thermal radiation parameter (R), heat source parameter(Q), and chemical reaction parameter(Kr) o on the velocity, temperature and concentration and are discussed with the help of graphs to observe the effect of various flow parameters.

Figures (1) and (2) depict the effect of thermal Grashof number and solutal Grashof numbers on the velocity profile with other fixed parameters. It can be seen that the velocity increases for rising values of both the numbers (Gr) and (Gm). This is due to the buoyancy which is playing on the fluid particles due to gravitational forces that enhances the fluid velocity. The effect of increasing the value of thermal radiation (R) parameter on the velocity and temperature profiles are shown in figures (3) and (4). We observe that the thermal radiation increases enhances convective flow and thermal boundary layer thickness decreases i.e., it is to enhance heat transfer as thermal boundary layer thickness decreases with increase in the thermal radiation. Figure (5) and (6) exhibit the effect of heat source parameter (Q) on the velocity and temperature profiles. Here velocity increases and temperature decreases with the increase of heat source parameter. Figures (7) & (8) depict the influence of Prandtl number (Pr) on the velocity and temperature profiles. We observe that the velocity and temperature profiles decreases with an increase in the value of Prandtl number (Pr),

Figures (9) & (10) illustrate the influence of the absorption parameter on velocity and temperature. We observe that that increasing in the value of the absorption of the radiation parameter due to increase in the buoyancy force which accelerates the flow rate in the same way the effect of absorption of radiation will increase temperature with the increase of absorption parameter. The effect of chemical reaction parameter (Kr) on the velocity, temperature and concentration are shown in figures (11) to (13). We see that the velocity, concentration profiles decreases and temperature profile increases with an increase of chemical reaction parameter. The influences of Schmidt number (Sc) on the velocity, temperature and concentration are shown in figures (14) - (16). The result shows that increasing in the values of (Sc) results in decreasing the velocity, temperature and concentration profiles distributions. Figure (17) shows the velocity profiles across the boundary layer for different values of magnetic field (M) number. The result shows that the effect of increasing values of M results in decreasing the velocity distribution across the boundary layer. Figure (18) depicts the effect of Prandtl number on the skin-friction versus M of the fluid under consideration. As the Prandtl number increases the skin-friction is found to be decreasing.

CONCLUSIONS

The governing equations for the radiation and chemical reaction effects of heat and mass transfer on MHD mixed convection flow past a vertical surface with heat source/absorption was formulated. The resulting partial differential equations were solved using the MATLAB with in-built numerical solver bvp4c. From the present study the following are the conclusions:

- In both the cases the fluid velocity increases in the presence of thermal Grashof number(Gr), solutal Grashof number(Gm), absorption radiation parameter(Ql), thermal radiation parameter (R) and heat source parameter(Q), while an increasing magnetic field parameter (M), chemical reaction parameter (Kr), Prandtl number (Pr),, Schmidt number (Sc).
- The fluid temperature iincreases with an increasing in the absorption radiation parameter (Ql) , whiledecreases with an increase in the heat source parameter(Q), Prandtl number(Pr), thermal radiationparameter(R) and Schmidt number(Sc).
- The fluid concentration decreases with an increase in the chemical reaction parameter (Kr) and Schmidt number (Sc)
- As Prandtl number increases, skin-friction decreases.

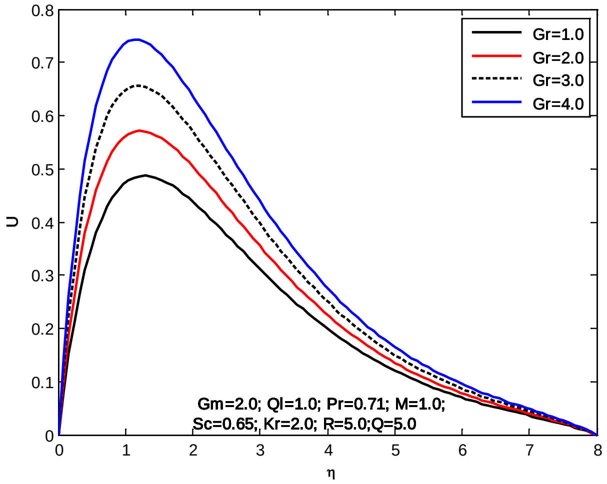

Figure-1: Velocity profile for various values of Gr

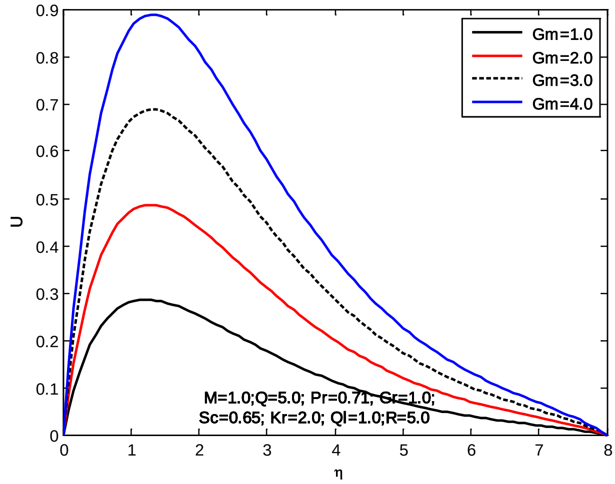

Figure-2: Velocity profile for various values of Gm

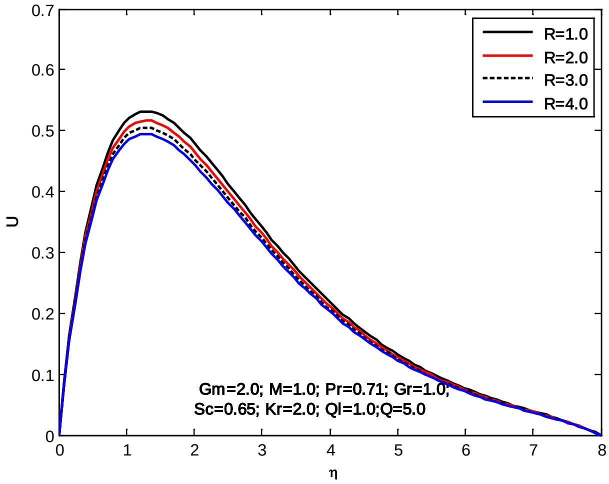

Figure-3: Velocity profile for various values of R

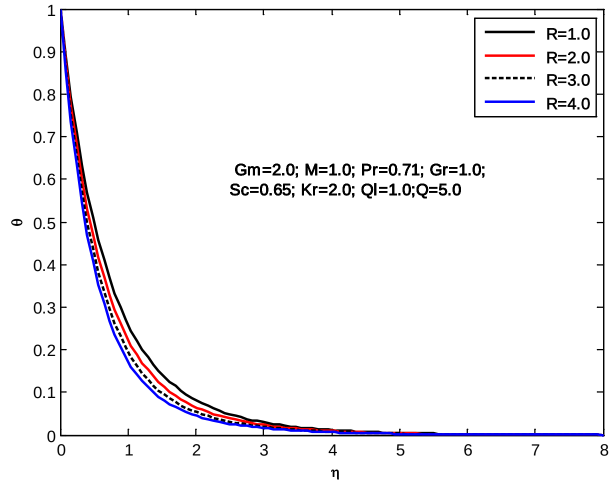

Figure-4: Temperature profile for various values of R

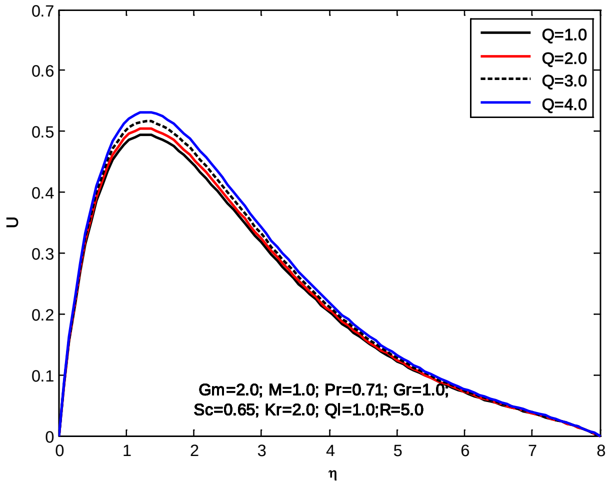

Figure-5: Velocity profile for various values of Q

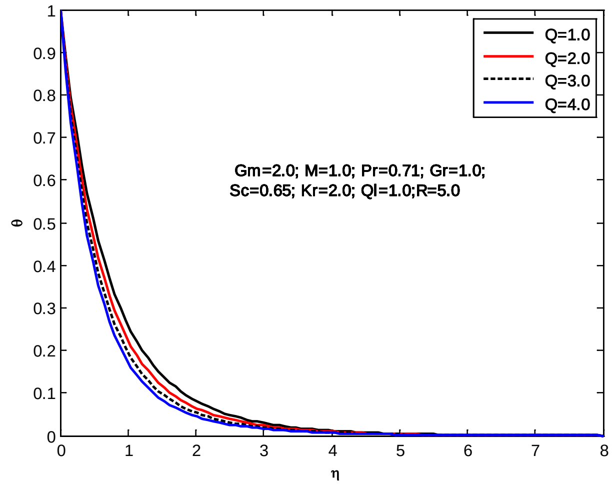

Figure-6: Temperature profile for various values of Q

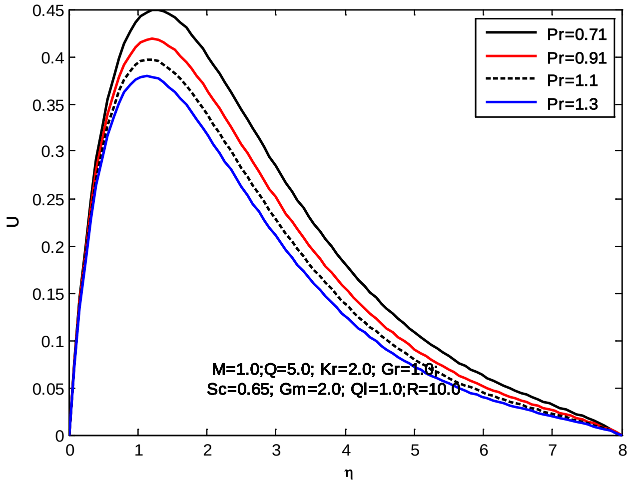

Figure-7: Velocity profile for various values of Pr

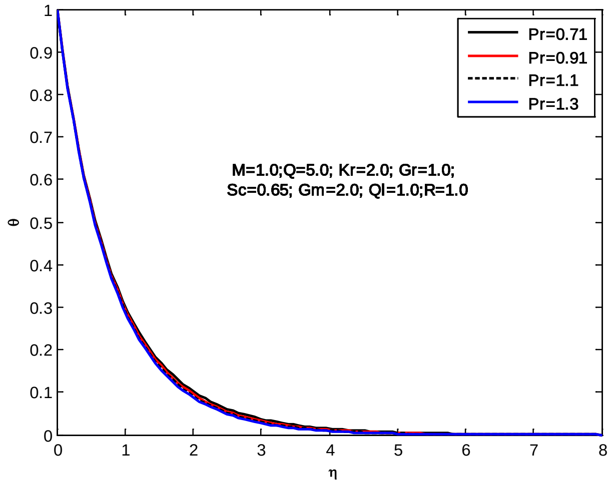

Figure-8: Temperature profile for various values of Pr

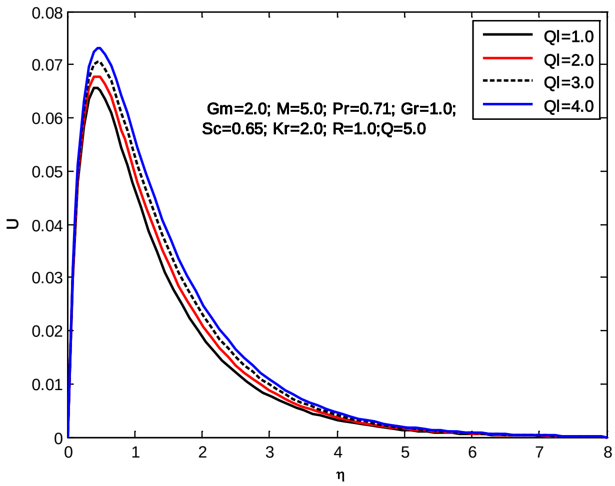

Figure-9: Velocity profile for various values of Ql

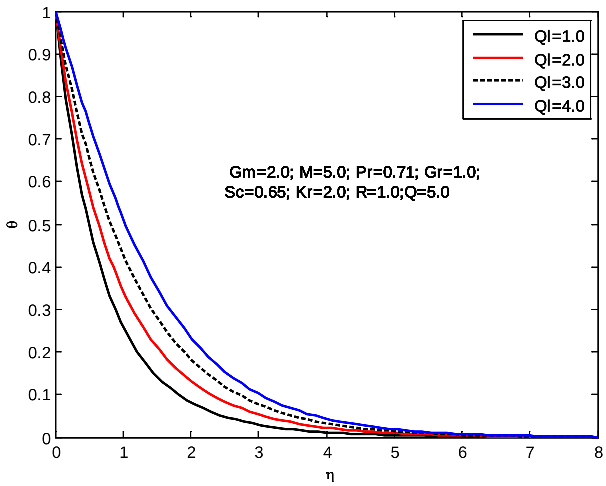

Figure-10: Temperature profile for various values of Ql

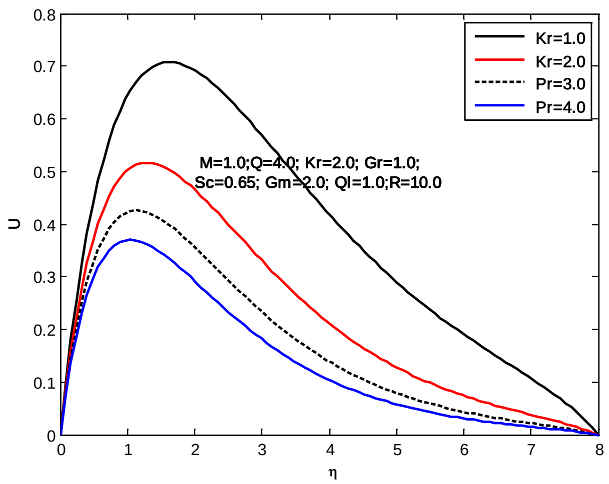

Figure-11: Velocity profile for various values of Kr

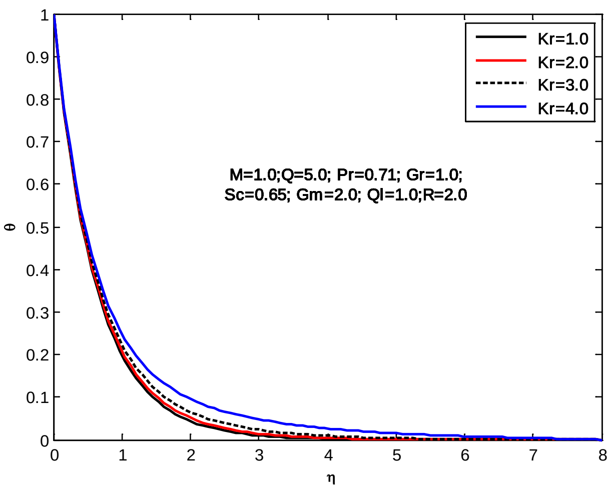

Figure-12: Temperature profile for various values of Kr

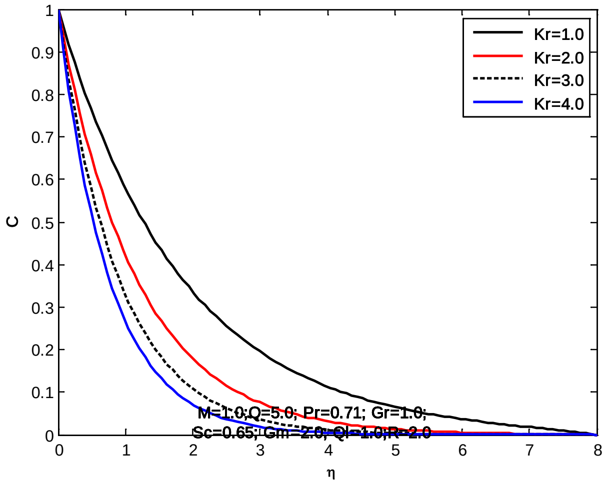

Figure-13: Concentration profile for various values of Kr

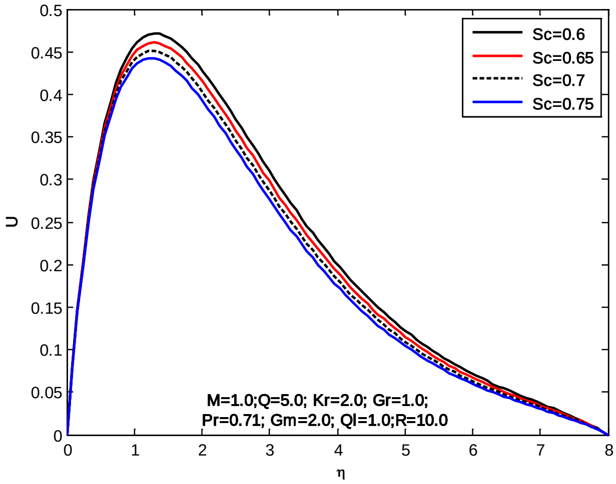

Figure-14: Velocity profile for various values of Sc

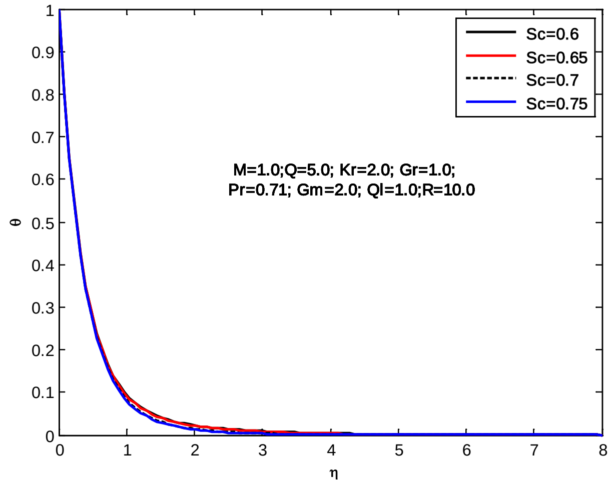

Figure-15: Temperature profile for various values of Sc

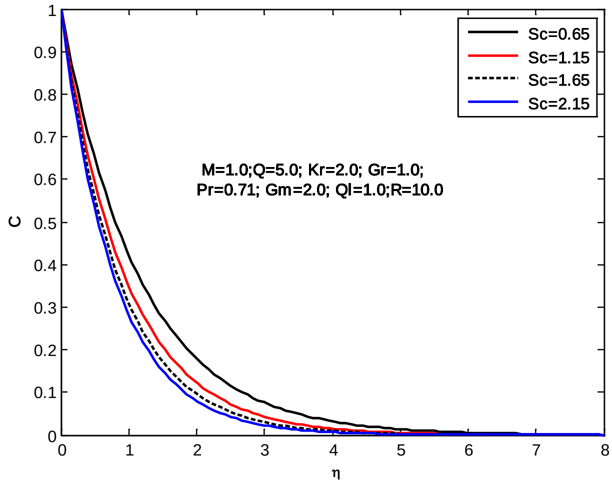

Figure-16: Concentration profile for various values of Sc

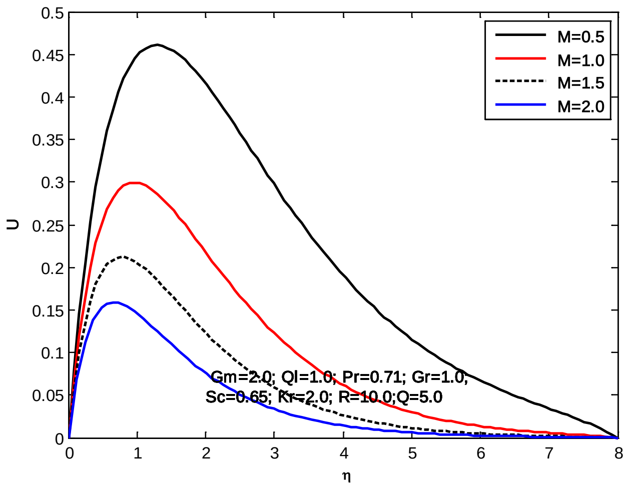

Figure-17: Velocity profile for various values of M

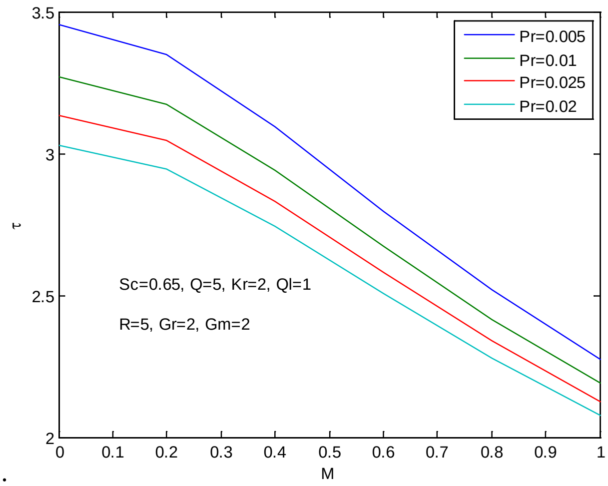

Figure-18: Skin friction number for Pr v/s M

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Source of support: Nil, Conflict of interest: None Declared.