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Unsteady MHD Free Convective Heat and Mass Transfer Flow Past a Vertical Porous Plate in the Presence of Radiation and Chemical Reaction

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Abstract:

The objective of this paper is to analyze an unsteady MHD free convective heat and mass transfer boundary flow past a semi-infinite vertical porous plate immersed in a porous medium with radiation and chemical reaction. The governing equations of the flow field are solved numerical a two term perturbation method. The effects of the various parameters on the velocity, temperature and concentration profiles are presented graphically and values of skin-frication coefficient, Nusselt number and Sherwood number for various values of physical parameters are presented through tables.

Key words: Chemical reaction, MHD, Porous plate, heat and mass transfer, Skin-friction.

I. INTRODUCTION

All industrial chemical processes are designed to transform cheaper raw materials to high value products (usually via chemical reaction). A reactor, in which such chemical transformations take place, has to carry out many functions like bringing reactants into intimate contact, providing an appropriate environment like temperature and concentration fields for adequate time and allowing for removal products. Fluid dynamics plays an important role in establishing relationship between reactor hardware and reactor performance.

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. We are particularly interested in cases in which diffusion and chemical reaction occur at roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects. The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast Growth of electronic technology, effective cooling of electronic equipment has become warranted and cooling of electronic equipment ranges from individual transistors to main frame computers and from energy suppliers to telephone switch boards and thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight.

Chambre and Young [1] have presented a first order chemical reaction in the neighborhood of a horizontal plate. Free convection and mass transfer flow through porous medium bounded by an infinite vertical limiting surface with constant suction have been analyzed by Rapits et al. [2]Muthucumaraswamy [3] presented heat and mass transfer effects on a continuously moving isothermal vertical surface with uniform suction by taking into account the homogeneous chemical reaction of first order. Meenakshisundaram et al. [4] investigated theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion.

There has been a renewed interest in studying magnetohydrodynamic (MHD) flow and heat transfer in porous and non-porous media due to the effect of magnetic fields on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. Raptis et al. [5] analyzed hydromagnetic free convection flow through a porous medium between two parallel plates. Gribben [6] presented the boundary layer flow over a semi-infinite plate with an aligned magnetic field in the presence of pressure gradient. He obtained solutions for large and small magnetic Prandtl number using the method of matched asymptotic expansion. Helmy [7] presented an unsteady two-dimensional laminar free convection flow of an incompressible, electrically conducting (Newtonian or polar) fluid through a porous medium bounded by infinite vertical plane surface of constant temperature. Gregantopoulos et al. [8] studied two-dimensional unsteady free convection and mass transfer flow of an incompressible viscous dissipative and electrically conducting fluid past an infinite vertical porous plate. For some industrial applications such as glass production and furnace design, and in space technology applications such as cosmical flight aerodynamics rocket, propulsion systems, plasma physics and spacecraft re-entry aerothermodynamics which operate at higher temperatures, radiation effects can be significant. In view of this, Hossain and Takhar [9] analyzed the effect of radiation on mixed convection along a vertical plate with uniform surface temperature. The Soret effect on free convective unsteady MHD flow over a vertical plate with heat source has been analyzed by Bhavana et al. [10].Muthuraj and Srinivas [11] studied the fully developed MHD flow of a micropolar and viscous fluid in a vertical porous space using HAM.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Possible heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electric chips and semiconductor wafers. Seddeek [12] studied the effects of chemical reaction, thermophoresis and variable viscosity on steady hydromagnetic flow with heat and mass transfer over a flat plate in the presence of heat generation/absorption. Patil and Kulkarni [13] studied the effects of chemical reaction on free convective flow of a polar fluid through porous medium in the presence of internal heat generation. Double-Diffusive Convection-Radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects was studied by Mohamed [14]. Radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium was studied by Ramachandraprasad et al. [15]. Satyanarayana et al [16] studied Hall current effect on magneto hydrodynamics free-convection flow past a semi-infinite vertical porous plate with mass transfer. Effects of the chemical reaction and radiation absorption on free convection flow through porous medium with variable suction in the presence of uniform magnetic field were studied by SudheerBabuet al. [17]. Dulal Pal et al [18] studied Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Recently, Ramana Reddy et al [19] have studied the mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption.

The objective of the present paper an unsteady MHD free convective heat and mass transfer flow past a vertical porous plate in the presence of radiation and chemical reactionby using perturbation technique. The effects of the flow parameters on the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number distribution of the flow field have been studied with the help of graphs and tables.

II. FORMULATION OF THE PROBLEM

Consider a two dimensional unsteady flow of a laminar, incompressible, viscous, electrically conducting and heat generation fluid past a semi-infinite vertical moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of a pressure gradient has been considered with free convection thermal diffusion and thermal radiation effects taking in to an account. According to the coordinate system the $x^* -$axis is taken along the porous plate in the upward direction and $y^* -$axis normal to it. The fluid is assumed to be gray, absorbing–emitting but not scattering medium. The radiative heat flux in the $x^* -$direction is considered negligible in comparison with that in the $y^* -$direction.

It is assumed that there is no applied voltage of which implies the absence of an electric field. The transversely applied magnetic field and magnetic Reynolds number are very small and the induced magnetic field is negligible. Viscous and Darcy resistance terms are taken into account the constant permeability porous medium. The MHD term is derived from an order of magnitude analysis of the Navier-Stokes equation. The fluid properties are considered to be constants except that the influence of density variation with temperature concentration has been assumed in the body-force term. Due to the semi-infinite plate surface assumption, the flow variable are functions of y*and t^* only. The homogeneous chemical reaction of first order with rate constant between the diffusing species and t the fluid assumed. The governing equation for this observation is based on the balances of mass, linear momentum, energy and concentration species. Within the frame work of delete such assumptions the equations of continuity, momentum, energy and concentration are follows, Bhavana et al.(10)

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

$$\rho\left(\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*}\right) = -\frac{\partial p^*}{\partial x^*} + \mu\frac{\partial^2 u^*}{\partial y^{*2}} - \rho\beta - \frac{\mu}{K^*}u^* - \sigma B_0^2 u^* \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\left(\frac{\partial q_r^*}{\partial y^*}\right) - \frac{Q_0}{\rho C_P}\left(T^* - T_\infty^*\right) \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + v^*\frac{\partial C^*}{\partial y^*} = D_M\frac{\partial^2 C^*}{\partial y^{*2}} + D_T\frac{\partial^2 T^*}{\partial y^{*2}} - K_r C^* \tag{4}$$

where x^*, y^* and t^* are the dimensional distances along the plate, perpendicular to the plate and dimensional time, respectively. u^* and v^* are the components of dimensional velocities along x^* and y^* directions respectively, ρ is the fluid density, Cp the specific heat at a constant pressure, σ -is the fluid electrical conductivity, B_0 is the magnetic induction, K^* is the permeability of the of the porous medium, T^* is the dimensional temperature, D_M is the coefficient of chemical molecular diffusivity, D_r is the coefficient of thermal diffusivity, K_r is the permeability parameter, C^* is the dimensional concentration is the thermal conductivity of the fluid, g is the acceleration due to gravity and q_r^* andR are the local radioactive heat flux and the reaction rate constant respectively.

The boundary conditions for the velocity, temperature and concentration fields are given as follows

$$\begin{aligned} &u^* = u_p^* T^* = T_w^* + \varepsilon\left(T_w^* - T_\infty^*\right)e^{n^*t^*}, C^* = C_w^* + \varepsilon\left(C_w^* - C_\infty^*\right)e^{n^*t^*} \quad \text{at} \quad y^* = 0 \\ &u^* \to U_\infty^* = U_0\left(1 + \varepsilon e^{n^*t^*}\right), T^* \to T_\infty^*, \quad C^* \to C_\infty^* \quad \text{as} \quad y^* \to \infty \end{aligned} \tag{5}$$

where T_w^* and C_w^* are the dimensional wall temperature and concentration respectively, C_∞^* is the free stream dimensional concentration. U_0 and n^* are constants.From the equation (1), we consider the velocity as the exponential form

$$v^* = -v_0\left(1 + \varepsilon A e^{n^*t^*}\right) \tag{6}$$

where, A is the real positive constant, εand εA are small less than unity and v_0 is a scale of suction which hasnon-zero positive constant.

In the free stream, we have

$$\rho\frac{dU_\infty^*}{dt^*} = -\frac{\partial p^*}{\partial x^*} - \rho_\infty g - \frac{\mu}{K^*}U_\infty^* - \sigma B_0^2 U_\infty^* \tag{7}$$

Eliminate $\frac{\partial p^*}{\partial x^*}$ using equation (2) and equation (7), we obtain

$$\rho\left(\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}\right)=(\rho_\infty-\rho)g+\rho\frac{dU_\infty^*}{dt^*}+\mu\frac{\partial^2 u^*}{\partial y^{*2}}-\frac{\mu}{K^*}\left(U_\infty^*-u^*\right)-\sigma B_0^2\left(U_\infty^*-u^*\right) \quad (8)$$

Also by using the equation of state, we have

$$(\rho_\infty-\rho)=\beta\left(T^*-T_\infty^*\right)+\beta^*\left(C^*-C_\infty^*\right) \quad (9)$$

Substituting equation (9) into equation (8), we have

$$\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}=\begin{bmatrix}\frac{dU_\infty^*}{dt^*}+\mu\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta\left(T^*-T_\infty^*\right)+g\beta^*\left(C^*-C_\infty^*\right)\\+\frac{\nu}{K^*}\left(U_\infty^*-u^*\right)+\frac{\sigma B_0^2}{\rho}\left(U_\infty^*-u^*\right)\end{bmatrix} \quad (10)$$

where, $\nu=\frac{\mu}{k}$ is the coefficient of the kinematic viscosity.

The radioactive heat flux term by using the Roseland approximation is given by

$$q_r^*=\frac{4\sigma^*}{3k_1^*}\frac{\partial T^{*4}}{\partial y^*} \quad (11)$$

where σ^* and k_1^* are respectively the Stefan-Boltzmann constant and the mean absorption coefficient.

We assume that the temperature difference within the flow are sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about T_∞^* and neglecting higher order terms, thus

$$T^{*4}\cong 4T_\infty^{*3}-3T_\infty^{*4} \quad (12)$$

By using equation (11) and equation (12), into equation (3) is reduced to

$$\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}=\frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{16\sigma^* T_\infty^{*3}}{3\rho C_p k_1^*}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{Q_0}{\rho C_p}\left(T^*-T_\infty^*\right) \quad (13)$$

In order to write the governing equations and the boundary condition in dimensionless form, the following non-dimensional quantities are introduced.

$$u^*=uU_0, v^*=vV_0, T^*=T_\infty^*+\theta\left(T_w^*-T_\infty^*\right), C^*=C_\infty^*+C\left(C_w^*-C_\infty^*\right), U_\infty^*=U_\infty U_0$$

$$u_p^*=U_pU_0, K^*=\frac{K\nu^2}{V_0^2}, y^*=\frac{y\upsilon}{V_0}, Gc=\frac{\nu g\beta^*\left(C_w^*-C_\infty^*\right)}{V_0^2U_0}, Gr=\frac{\nu g\beta\left(T_w^*-T_\infty^*\right)}{V_0^2U_0},$$

$$\Pr=\frac{\nu\rho C_p}{k}, M=\frac{\sigma B_0^2\nu}{\rho V_0^2}, Q=\frac{Q_0\nu}{\rho V_0^2C_p}, R=\frac{4\sigma^* T_\infty^{*3}\left(T_w^*-T_\infty^*\right)}{k_1^*k}, Sc=\frac{\nu}{D_M}, \quad (14)$$

$$t^*=\frac{t\nu}{V_0^2}, n^*=\frac{V_0^2}{\nu}, v=\left(1+A\varepsilon e^{nt}\right),$$

In view of Equations (6) – (14), Equations (1), (4),(10) and (13) reduce to the following dimensional form.

$$\frac{\partial v}{\partial y}=0 \quad (15)$$

$$\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+Gr\theta+GmC+N\left(U_\infty-u\right) \quad (16)$$

$$\frac{\partial \theta}{\partial t} + v\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1+\frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} - Q\theta \tag{17}$$

$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + S_0\frac{\partial^2 \theta}{\partial y^2} - KrC \tag{18}$$

and the boundary conditions (5) in the non-dimensional form are:

$$\begin{aligned} &u = U_p, \theta = 1+\varepsilon e^{nt}, C = 1+\varepsilon e^{nt} \quad at \quad y = 0 \\ &u \to U_\infty \to 1+\varepsilon e^{nt}, \theta \to 0, C \to 0 \quad as \quad y \to \infty \end{aligned} \tag{19}$$

III. METHOD OF SOLUTION

Equations (15) – (18) 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. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} u &= u_0(y) + \varepsilon e^{nt}u_1(y) + O(\varepsilon^2) \\ \theta &= \theta_0(y) + \varepsilon e^{nt}\theta_1(y) + O(\varepsilon^2) \\ C &= C_0(y) + \varepsilon e^{nt}C_1(y) + O(\varepsilon^2) \end{aligned} \tag{20}$$

Substituting (16) in Equations (12) – (14) and equating the harmonic and non – harmonic terms, and neglecting the higher order terms of $o\left(\varepsilon^2\right)$, we obtain

$$u_0'' + u_0' + Nu_0 = -N - Gr\theta_0 - Gc\phi_0 \tag{21}$$

$$u_1'' + u_1' - (N+n)u_1 = -(N+n) - Au_0' - Gr\theta_1 - GcC_1 \tag{22}$$

$$(3+4R)\theta_0'' + 3\Pr\theta_0' - 3Q\Pr\theta_0 = 0 \tag{23}$$

$$(3+4R)\theta_1'' + 3\Pr\theta_1' - (3n+Q)\Pr\theta_1 = -3A\Pr\theta_0' \tag{24}$$

$$\phi_0'' + Sc\phi_0' - KrSc\phi_0 = ScS_0\theta_0'' \tag{25}$$

$$\phi_1'' + Sc\phi_1' - Sc(Kr+n)\phi_1 = -ScA\phi_0' - ScS_0\theta_1'' \tag{26}$$

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \quad \text{at} \quad y = 0 \\ &u_0 \to 1, u_1 \to 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{27}$$

Solving Equations (21) – (26) under the boundary condition (27) we obtain the velocity, temperature and concentration distribution in the boundary layer as

$$u(y,t) = A_{18}e^{-k_5 y} + A_{17}e^{-k_1 y} + A_{15}e^{-k_3 y} + 1 + \varepsilon e^{nt}\begin{bmatrix} A_{32}e^{-k_6 y} + A_{29}e^{-k_1 y} + A_{30}e^{-k_2 y} \\ + A_{31}e^{-k_3 y} + A_{24}e^{-k_4 y} + A_{19}e^{-k_5 y} + 1 \end{bmatrix}$$

$$\theta(y,t) = e^{-k_1 y} + \varepsilon e^{nt}\left(A_2 e^{-k_2 y} + A_1 e^{-k_1 y}\right)$$

$$\varphi(y,t) = (A_4 e^{-k_3 y} + A_3 e^{-k_1 y}) + \varepsilon e^{nt}\left(A_{13}e^{-k_4 y} + A_9 e^{-k_3 y} + A_{10}e^{-k_1 y} + A_{11}e^{-k_2 y} + A_{12}e^{-k_1 y}\right)$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –dimensional form is given by

$$C_f = \frac{\tau'_w}{\rho U_0 v_0} = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = -\left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$C_f = \left[A_{18}k_5 + A_{17}k_1 + A_{15}k_3 + \varepsilon e^{nt}\left[A_{32}k_6 + A_{29}k_1 + A_{30}k_2 + A_{31}k_3 + A_{24}k_4 + A_{19}k_5\right]\right]$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non – dimensional form is given, in terms of the Nusselt number, is given by

$$N_u = -x\frac{\left(\frac{\partial T'}{\partial y'}\right)_{y'=0}}{\left(T'_w - T'_\infty\right)} \Rightarrow N_u \operatorname{Re}_x^{-1} = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -\left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$N_u \operatorname{Re}_x^{-1} = \left[k_1 + \varepsilon e^{nt}\left(A_2k_2 + A_1k_1\right)\right]$$

where $\operatorname{Re}_x = \frac{v_0 x}{\nu}$ is the local Reynolds number.

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non – dimensional form, in terms of the Sherwood number, is given by

$$S_h = -x\frac{\left(\frac{\partial C'}{\partial y'}\right)_{y'=0}}{\left(C'_w - C'_\infty\right)} \Rightarrow S_h \operatorname{Re}_x^{-1} = \left(\frac{\partial C}{\partial y}\right)_{y=0} = \left(\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$S_h \operatorname{Re}_x^{-1} = (A_4k_3 + A_3k_1) + \varepsilon e^{nt}\left(A_{13}k_4 + A_9k_3 + A_{10}k_1 + A_{11}k_2 + A_{12}k_1\right)$$

IV. RESULTS AND DISCUSSION

In order to get a clear insight of the physical problem, numerical results are displayed with the help of graphs. This enables us to carry out the numerical calculations for the distribution of the velocity, temperature, concentration, Nusselt number and Sherwood number across the boundary layer for various values of the flow parameters. To be realistic, the value of Schmidt number (Sc) are chosen for Sc =0.22, 0.30, 0.60 and 0.78. The value of Prandtl number (Pr) are chosen for Helium Pr=0.71 at 366 K temperature, for water Pr=7.00 at 20^0C, for stream Pr=1.00, for Ammonia Pr=3.00 at 40^0C. Grashof number for heat transfer is chosen to be Gr=2.0 Modified Grashof number for mass transfer is chosen to be Gc=2.4. The velocity, temperature and concentration profile for different values various parameters as shown in Figs (2)-(16).

Figure 2 depicts the variation of velocity profiles with magnetic field parameter (M). From this figure it is seen that the velocity starts from minimum value at the surface and increase till it attains the peak value and then starts decreasing until it reaches to the minimum value at the end of the boundary layer for all the values of magnetic field parameter. It is interesting to note that the effect of magnetic field is to decrease the value of the velocity profiles throughout the boundary layer. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem.

Fig.3 shows the velocity profiles for different values of the permeability parameter K, clearly as K increases the peak values of the velocity tends to increases. Physically, this result can be achieved when the holes of the porous medium may be neglected.For different values of the radiation parameter (R), the velocity, temperature and concentration profiles are shown in Figs. (4), (5) and (6). It is observed that an increase in the radiation parameter results, the velocity and temperature profiles are also increases and reverse trend is observed in the concentration profiles. For different values of the heat source parameter (Q) on the temperature and the concentration profiles are shown in Figs. (7) and (8) respectively. It is noticed that the heat source parameter results increases with an increasing the concentration profiles and reverse trend is observed in the temperature profiles.

For the case of different values of thermal Grashof number (Gr), the velocity profiles in the boundary layer are shown in Fig. (9). It is observed that an increase in Gr leads to increase in the values of velocity due to enhancement in buoyancy force. Here the positive values of Gr correspond to cooling of the surface. In addition the curve show that the peak values of the velocity increases rapidly near the wall of the porous plate as Grashof number increases and then decays to the free stream velocity. Fig(10) presents typical velocity profiles in the boundary layer for various values of the solutalGrashof number (Gc), while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value more distinctive due to increase in the concentration buoyancy effects represented by (Gc).

The effect of chemical reaction (Kr) on the velocity and concentration profiles is shown in Figs. (11) and (12) respectively. It is observed that an increase the chemical reaction parameter in leads to decrease the velocity and concentration profiles. A distinct velocity escalation occurs near the wall after which profiles decay smoothly to the stationary value in the free stream.

Figs (13) and (14) shows that the behavior of velocity and temperature profiles for different values of Prandtl number respectively. The numerical results show the effect of increasing values of Prandtl number, results decreasing the velocity. It is also observed that an increase the Prandtl number the results decreases as the boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller value of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence in the case of smaller Prandtl number as the thermal boundary layer is thicker and the rate of heat transfer is reduced. The effect of Schmidt number (Sc) on the concentration profiles is shown in Fig. (15). It is observed that the effect for increasing value of Schmidt number results in decreasing concentrations distribution across the boundary layer and all curves meet the y-axis. Figs (16) and (17) are illustrated the effect of Soret number on the velocity and concentration profiles. It is noticed that the Soret number increases with an increasing the velocity and concentration profiles.

Tables 1-3, show numerical values of the skin-friction coefficient (Cf) for various values of thermal Grashof number Gr, solutalGrashof number Gm, Magnetic parameter M, Permeability parameter K, Prandtl number Pr, heat source parameter Q, Schmidt number Sc and chemical reaction parameter Kr.

Table-1 observed that, an increase in the Magnetic parameter decrease in the value of the skin-friction coefficient while an increase in the thermal Grashof number, solutalGrashof number, Permeability parameter increase in the value of the skin-friction coefficient.

Table-2 show numerical values of heat transfer coefficient in terms of Nusselt number (Nu) for various values of Prandtl number Pr and heat source parameter Q. It is observed that, an increase in the Prandtl number increase in the value of heat transfer coefficient while an increase in the heat source parameter decrease in the value of heat transfer coefficient and an increase in the Prandtl number decrease in the value of the skin-friction coefficient while an increase in the heat absorption parameter increase in the value of the skin-friction coefficient.

Table-3 show numerical values of mass transfer coefficient in terms of Sherwood number (Sh) for various values of Schmidt number Scand chemical reaction parameter Kr. It is observed that, an increase in the Schmidt number or chemical reaction parameter

Table 1: Effect of Gr, Gc, M and K on the skin-friction coefficient C_f (Pr=0.71, Q=0.5, Sc=0.60, Kr=0.5, S0=0.5)

Gr	Gc	M	K	C_f
2	2	1	0.5	3.4838
4	2	1	0.5	4.4728
2	2	1	0.5	4.8249
2	4	2	0.5	3.3516
2	2	1	1.0	3.7373

Table 2: Effect of Pr, Q, M and R on the skin-friction coefficient (C_f) and Nusselt number (Nu) (Gr=2, Gc=2, M=1.0, K=0.5, Kr=0.5)

Pr	Q	R	C_f	Nu
0.71	0.5	0.5	3.7373	0.7220
7	0.5	0.5	5.3054	4.6579
0.71	1	0.5	4.4437	0.9004
0.71	0.5	1	4.1191	0.5714

Table 3: Effect of Sc, Kr, and S0 on the skin-friction coefficient (C_f) and Sherwood number (Sh) (Gr=2, Gc=2, M=1.0, K=0.5, R=0.5, Q=0.5)

Sc	S0	Kr	C_f	Sh
0.6	1	0.5	2.9741	0.6276
0.78	1	0.5	3.5189	0.7481
0.6	1	1	4.1140	1.0075
0.6	0.5	0.5	3.7373	0.7766

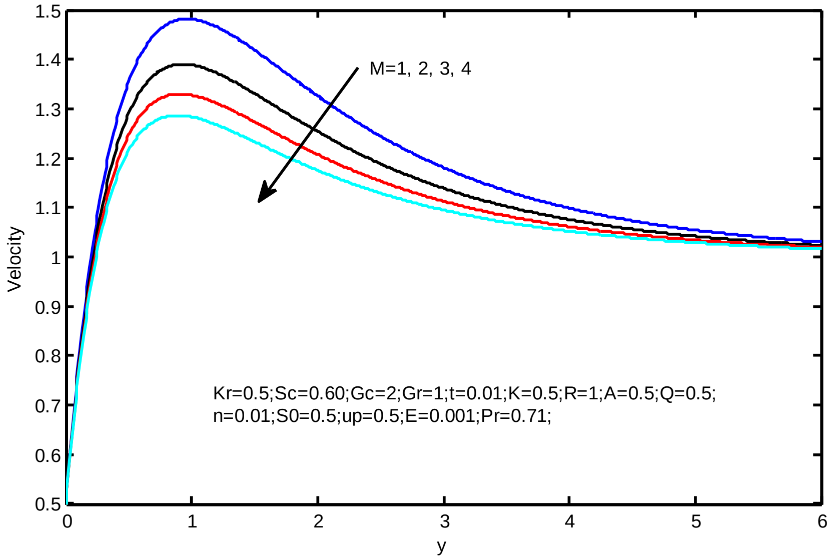

Fig.2. Velocity profiles for different values magnetic parameter (M).

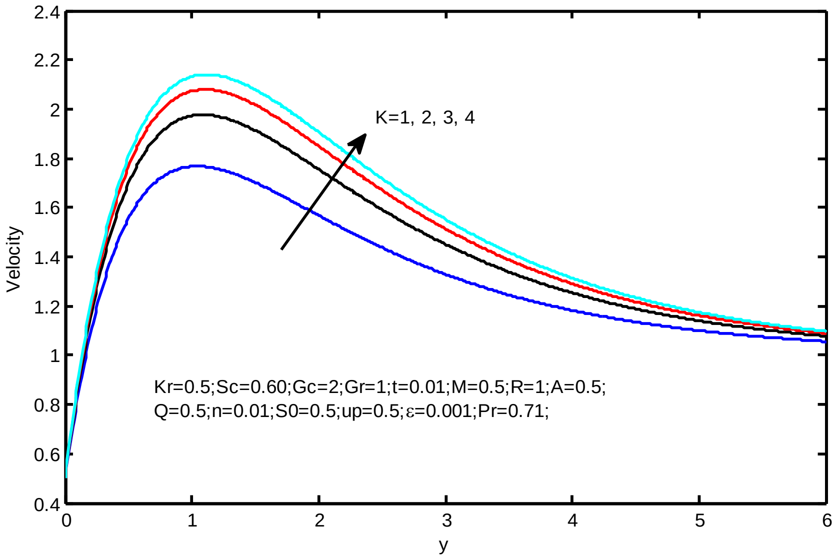

Fig.3. Velocity profiles for different values of permeability parameter (K).

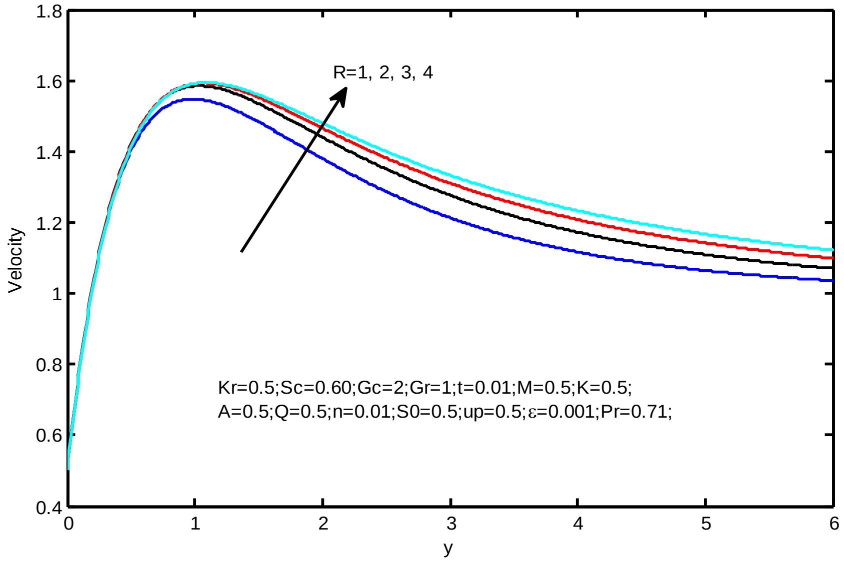

Fig.4. Velocity profiles for different values of radiation parameter (R).

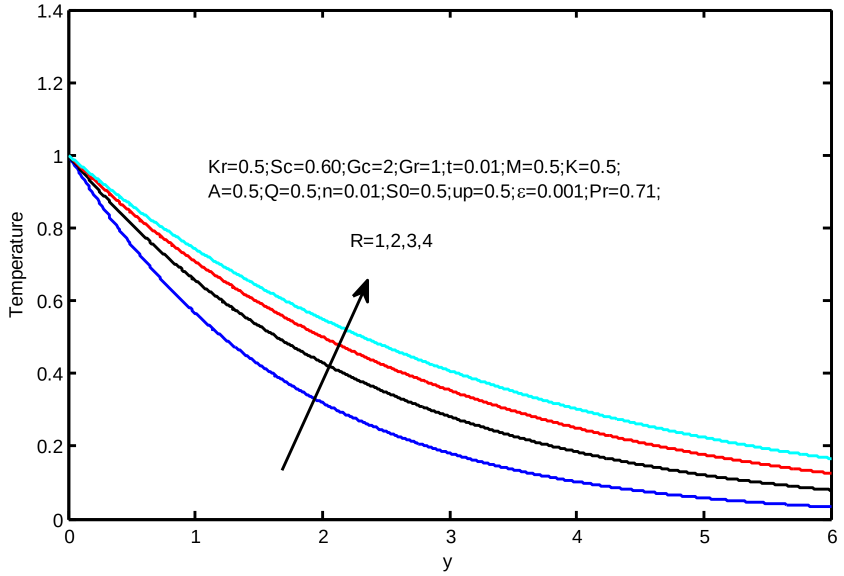

Fig.5. Temperature profiles for different values of radiation parameter (R).

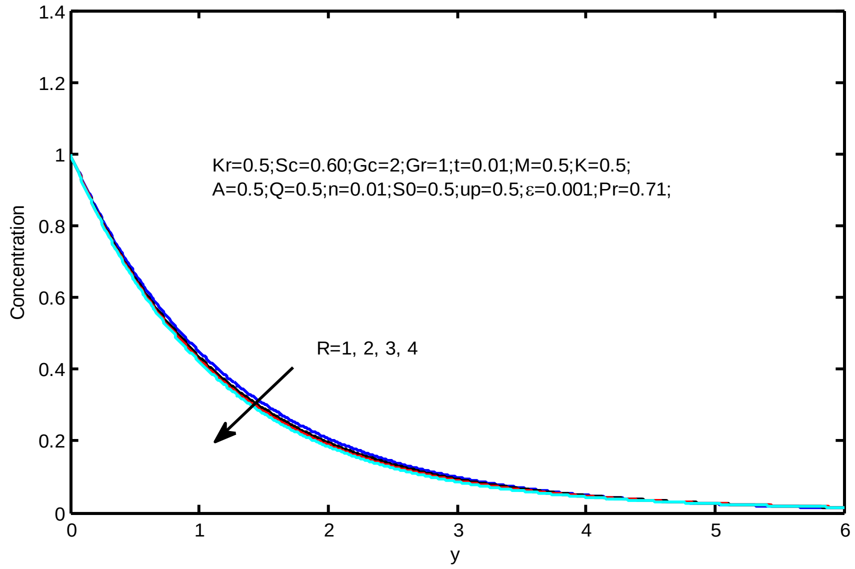

Fig.6. Concentration profiles for different values of radiation parameter (R).

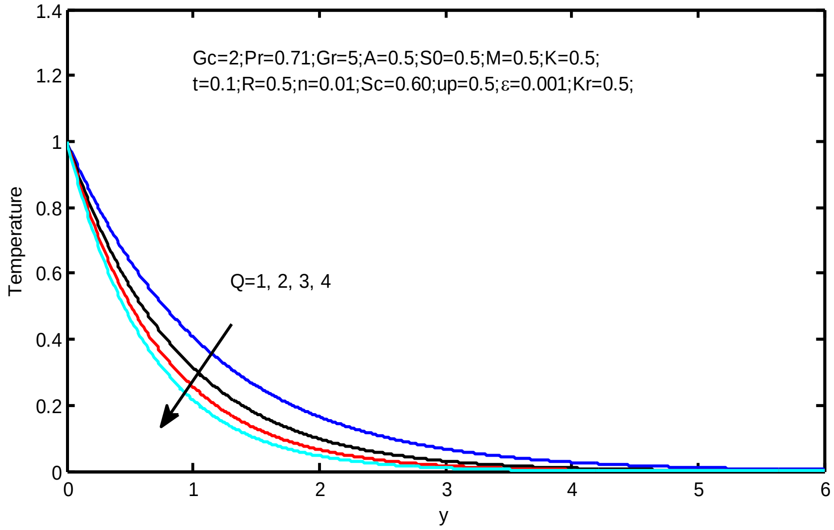

Fig.7. Temperature profiles for different values of heat source parameter (Q).

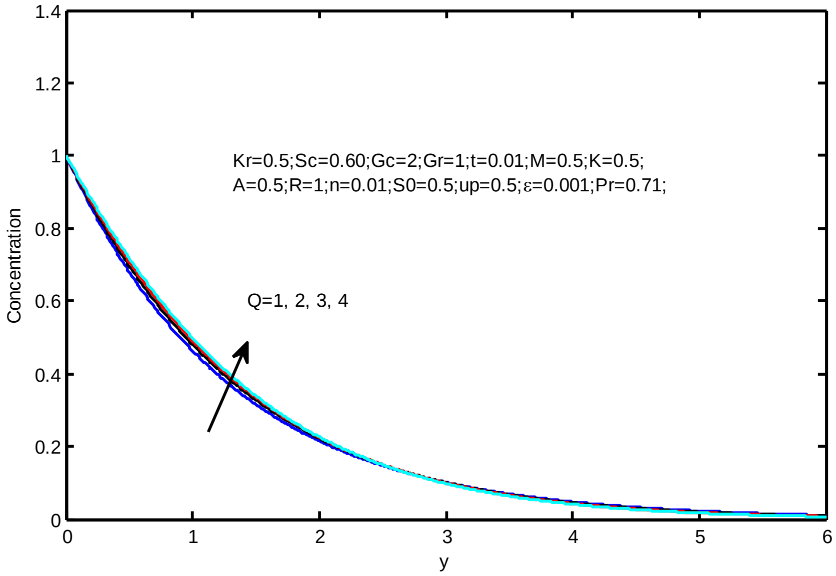

Fig.8. Concentration profiles for different values of heat source parameter (Q).

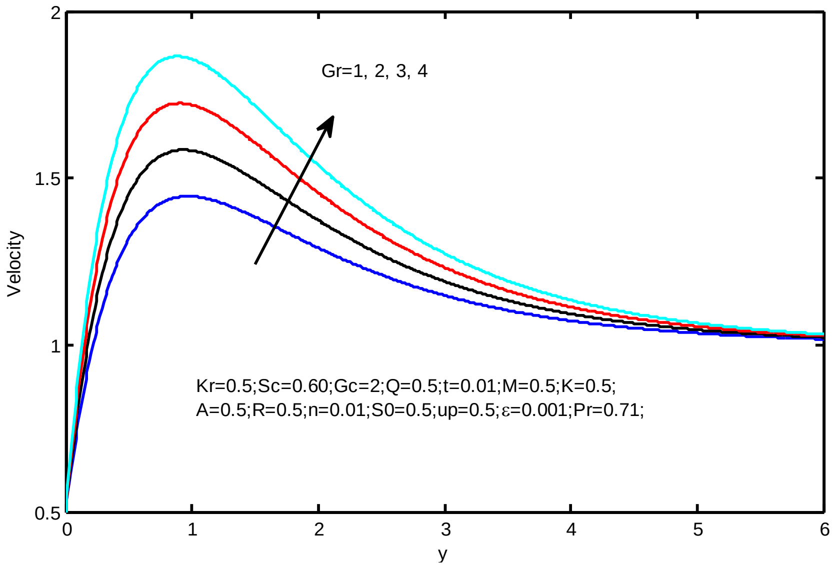

Fig.9. Velocity profiles for different values of Grashof number (Gr).

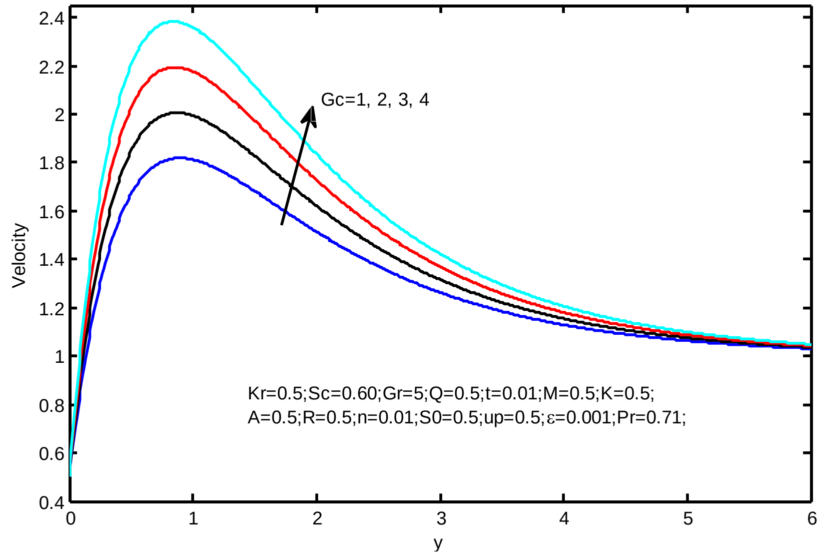

Fig.10. Velocity profiles for different values of modified Grashof number (Gc).

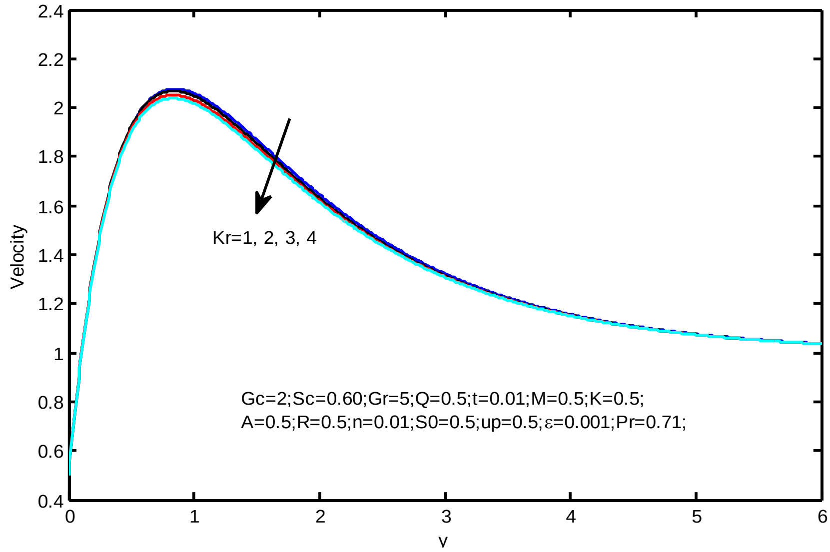

Fig.11. Velocity profiles for different values of chemical reaction parameter (Kr).

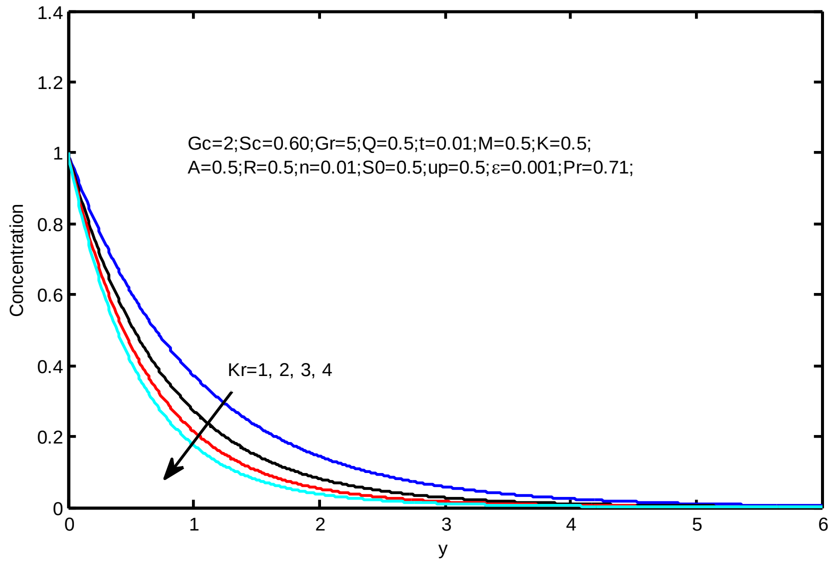

Fig.12. Concentration profiles for different values of chemical reaction parameter (Kr).

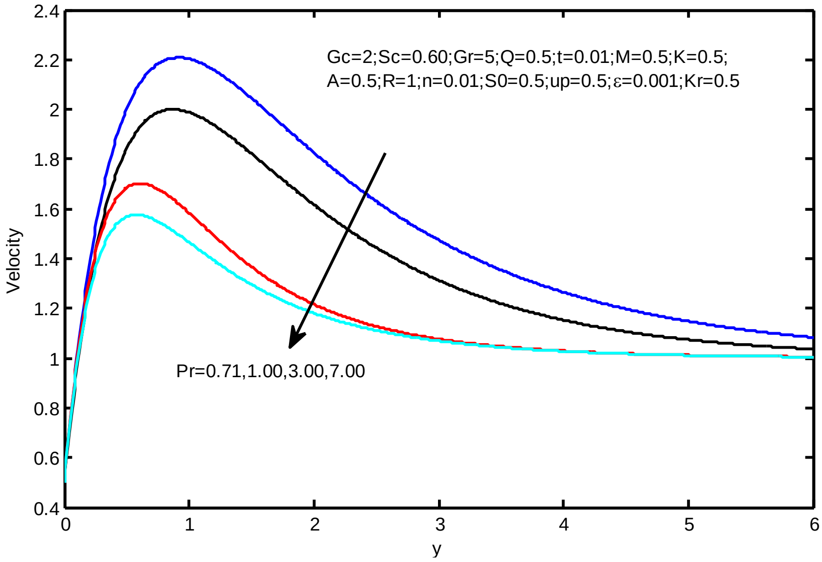

Fig.13. Velocity profiles for different values of Prandtl number (Pr).

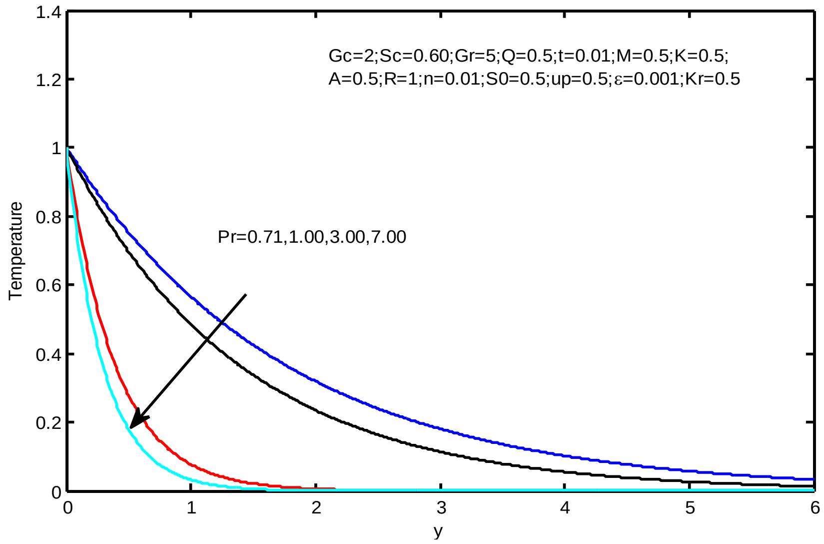

Fig.14. Temperature profiles for different values of Prandtl number (Pr).

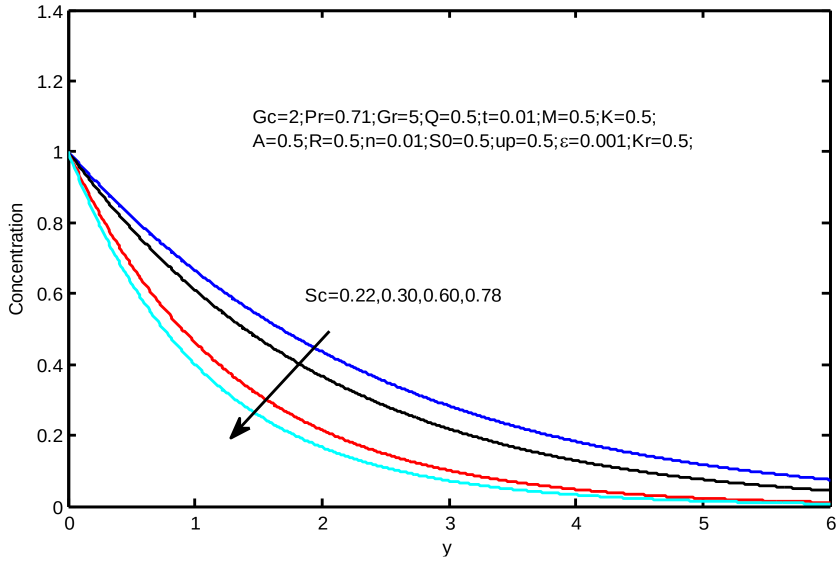

Fig.15. Concentration profiles for different values of Schmidt number (Sc).

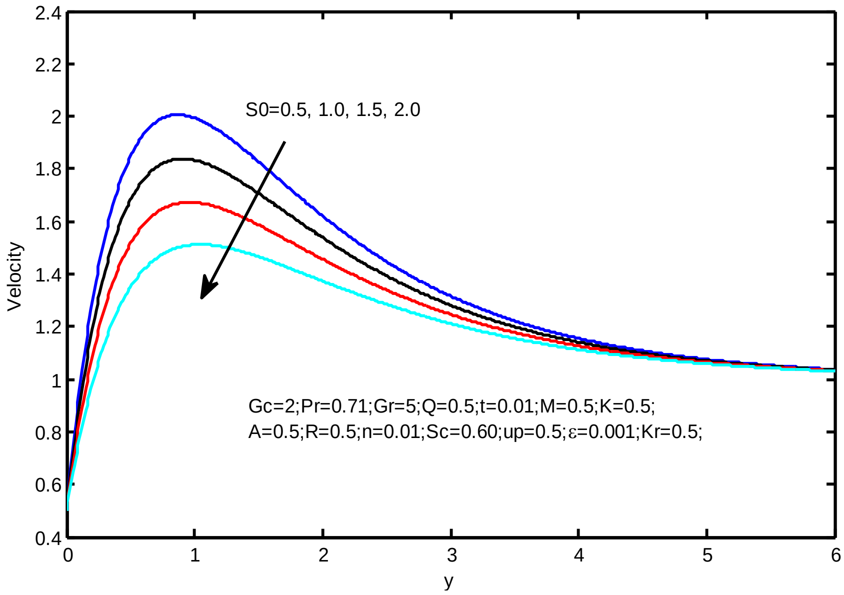

Fig.16. Velocity profiles for different values of Soret number (S0).

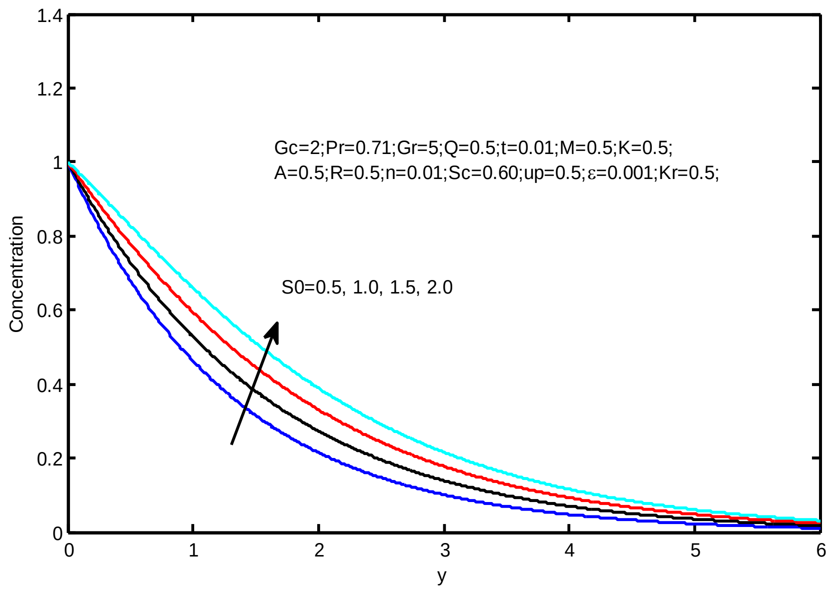

Fig.17. Concentration profiles for different values of Soret number (S0).

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