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EFFECT OF RADIATIONS ON UNSTEADY HEAT AND MASS TRANSFER OF A CHEMICALLY REACTIVE FLUID PAST A SEMI-INFINITE VERTICAL PLATE WITH VISCOUS DISSIPATION- FINITE ELEMENT SOLUTION

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ABSTRACT

The effect of radiation on unsteady heat and mass transfer of a chemically reactive fluid past a semi-infinite vertical plate is investigated in the presence of the viscous dissipation. The governing equations for velocity, temperature, and concentrations fields are derived and solved by Galerkin finite element method. The effect of the governing parameters on the temperature, concentration and velocity fields are discussed numerically and shown in figures.

Keywords: Viscous dissipation, FEM, Radiation, MHD, Heat and Mass Transfer, vertical plate.

Introduction

The study of heat and mass transfer problems are impartment in many reactive chemicals and chemical formulations. The analysis of free convection flows is great concern due to its useful applications in many branches of engineering and sciences e.g geophysics agriculture and thermal insulation. A. Raptis [1] studied and presented the radiation and free convection flow through a porous medium. Khem chand *et.al* [2] analyzed Heat transfer in MHD oscillatory flow of dusty fluid in a rotating porous vertical channel was studied. Bikash shoo [3] studied effects of slip, viscous dissipation and joul heating on MHD flow and heat transfer of a second grade fluid past a radially stretching sheet. R.S Raju *et.al* [4] investigated the effects of thermal radiation and heat source on an unsteady MHD free convection flow past an infinite vertical plate with thermal diffusion and diffusion thermo. The governing equations are solved by the finite element method. Aarti Manglesh and M.G Gorla [5] investigated MHD free convective flow through porous medium in the presence of hall current, radiation and thermal diffusion. Ibrahim and Makinde [6] have investigated the effects of chemically reacting MHD boundary layer flow of heat and mass transfer over a moving vertical plate with suction. A.Ogulu [7] discussed the influence of radiation absorption on unsteady free convection and mass transfer flow in the presence of a uniform magnetic field. Hari R. Kataria and Harshad R Patel [8] investigated the radiation and chemical effects on MHD casson fluid flow past an oscillating vertical plate embedded in porous medium. Mohmed Abd Ei-Aziz [9] presented unsteady mixed convection heat transfer along a vertical stretching surface with variable viscosity and viscous dissipation. Jai singh[10] studied viscous dissipation and chemical reaction effects on flow past a stretching porous surface in a porous medium. J.Anand Rao and S.Shivaiah [11] analized chemical reaction effects on an unsteady MHD free convective flow past in infinite vertical plate with constant suction and heat source. M. Turkyilmazoglu and Pop [12] analyzed Soret and heat source effects on the unsteady radiative MHD free convection floe from an impulsively starter infinite vertical plate. Alam and Rahman [13] investigated the Dufour and Soret effects on the mixed convection flow past a vertical porous flat plate with variable suction. P.A Lakshmi Narayana and P.Sibanda [14] considered the influence of the Soret effect and double dispersion on MHD mixed convection along a vertical plate in Non – Darcy porous medium. G.Seth *et. al* [15] presented the effects of hall current, radiation and rotation on natural convection heat and mass transfer flow past a moving vertical plate. Ahmed M. Salem and Mohamed Abd El-Aziz [16] have studied the Effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption. U S Ralput and P K Sahu was found [17] effects of chemical reaction on free convection MHD flow past an exponentially accelerated infinite vertical plate through a porous medium temperature and mass diffusion. D.Chaudhary *et.al* [18] discussed MHD unsteady mixed convective flow between two infinite vertical parallel plates through porous medium in slip flow regime with thermal diffusion. N.Pandya and A.K.Shukla[19] was found Soret- Dufour and radiation effect on unsteady MHD flow over an inclined porous plate embedded in porous medium with viscous dissipation. J. Anand Rao et.al [20] discussed finite element analysis of unsteady MHD free convection flow past an infinite vertical plate with Soret, Dufour, thermal radiation and heat source.
The objective of the this paper is to study the effects radiation on an unsteady heat and mass transfer of a two dimensional laminar convective boundary layer flow of incompressible, viscous , chemically reacting and dissipative fluid along a semi infinite vertical plate with suction.

Formulation of the problem

An unsteady MHD flow of a viscous, incompressible, radiating fluid by a semi – infinite vertical plate with the presence of viscous dissipation taking into account. The $x^* -$ axis is taken along the vertical plate in the upward direction and the flow is assumed to be in $x^* -$ axis direction and y^* - axis normal to the plate. The level of foreign mass is assumed to be low and hence the Dufour and Soret effects are negligible, the governing equations of flow field under the Boussinesq's approximations are

Continuity equation

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad \text{--- (1)}$$

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta \left(T^* - T^*_\infty\right) + g\beta^* \left(C^* - C^*_\infty\right) \qquad \text{--- (2)}$$

Energy equation:

$$\frac{\partial T^*}{\partial t^*} + \nu^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p} \frac{\partial T^{*2}}{\partial y^{*2}} - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial y^*} + \frac{\mu}{\rho C_p} \left(\frac{\partial u^*}{\partial y^*}\right)^2 \qquad \text{--- (3)}$$

Mass diffusion equation:

$$\frac{\partial C^*}{\partial t^*} + \nu^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - K_r^* \left(C^* - C^*_\infty\right) \qquad \text{--- (4)}$$

Where $u^*, v^* -$ are the velocity components in $x^*, y^* -$ directions, g is the gravitational acceleration, β and β^* are the thermal and concentration expansion coefficients respectively, ρ is the fluid density, $\mu -$ is the coefficient of viscosity, T^* is the thermal temperature inside the thermal boundary layer and C^* is the corresponding concentration, C_p is the specific heat at constant pressure, D - is the molecular diffusivity, K_r^* is the chemical reaction parameter,
The boundary conditions are:

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

Where u_p^* is the velocity of the fluid, T_w^* and C_w^* are the temperature and concentration of the wall respectively, n^* are the constants. From equation (1), it is clear that the suction velocity at the plate is either a constant and or a function of time. Hence the suction velocity normal to the plate is assumed in the form:

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

Where A is a real constant, and ε and εA is small tand v_0 is a non-zero positive constant, the negative sign indicates that suction is towards the plate.
By using the Rosseland diffusion approximation the radioactive heat flux, q_r is given by

$$q_r = -\frac{4\sigma'}{3K_s}\frac{\partial T^{*4}}{\partial y^*} \quad \text{--- (7)}$$

Where σ' and K_s are the Stefan - Boltzmann constant and the Rosseland mean adsorption coefficient respectively. We assume the temperature difference within the flow is sufficiently small such that T^4 may be expressed as a linear function of temperature.

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \quad \text{--- (8)}$$

Using (8) and (9), in the last term of equation (3) we obtain

$$\frac{\partial T^*}{\partial t^*} + \nu^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial T^{*2}}{\partial y^{*2}} + \frac{16\sigma_S}{3\rho C_p K_e}\frac{\partial^2 T}{\partial y^{2*}} + \frac{\mu}{\rho C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 \quad \text{--- (10)}$$

Introducing the following non- dimensional quantities,

$$\left.\begin{array}{l} y = \dfrac{\nu_0 y^*}{\nu}, u = \dfrac{u^*}{U_0}, \nu = \dfrac{\nu^*}{\nu_0}, U_p = \dfrac{Up}{U_0}, \theta = \dfrac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, C = \dfrac{C^* - C_\infty^*}{C_w^* - C_\infty^*} \\ Gr = \dfrac{g\beta v\ T_w^* - T_\infty^*}{U_0 v_0^2}, Gc = \dfrac{g\beta^* v\ C_w^* - C_\infty^*}{U_0 v_0^2}, Sc = \dfrac{v}{D}, t = \dfrac{t' v_0^2}{v} \\ n = \dfrac{v n^*}{v_0^2}, Kr = \dfrac{K_r^* v}{v_0^2}, R = \dfrac{4\sigma' T_\infty^3}{K_s}, \Pr = \dfrac{v\rho C_p}{k}, Ec = \dfrac{U_0^2}{c_p (T_w^* - T_\infty^*)} \end{array}\right\} \quad \text{--- (11)}$$

Where $Gr, Gc, Sc, Ec\ Kr, R, \Pr$ ssand So are the thermal Grashof number, Solutal Grashof number, Schmidt number, Eckert number ,Chemical reaction number, and thermal radiation parameter, Prandtl number respectively.
With the help of non- dimensional quantities, equations (2), (3) and (4) becomes

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A\, e^{nt}\right)\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GcC \quad \text{--- (12)}$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A\, e^{nt}\right)\frac{\partial \theta}{\partial y} = \left(\frac{1+R}{\Pr}\right)\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 \quad \text{--- (13)}$$

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A\, e^{nt}\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC \quad \text{--- (14)}$$

the corresponding dimension less boundary conditions are

$$\left.\begin{array}{ll} u = 1, \theta = 1 + e^{nt}, C = 1 + e^{nt} & at\ y = 0 \\ u \to 0\ \ T \to 0,\ \ C \to 0, & as\ y^* \to \infty \end{array}\right\} \quad \text{--- (15)}$$

METHOD OF SOLUTION

By applying Galerkin finite element method for equation (12) over the element (e), $\left(y_j \le y \le y_k\right)$ is:

$$\int_{y_j}^{y_k}\left\{N^{(e)T}\left[\frac{\partial^2 u^{(e)^T}}{\partial y^2} + B\frac{\partial u^{(e)T}}{\partial y} - \frac{\partial u^{(e)^T}}{\partial t} + P\right]\right\}dy = 0$$

Where $P = (Gr)\theta + (Gc)C,\ B = 1 + \varepsilon A e^{nt}$

Integrating the first term in equation (15) by parts one obtains

$$N^{(e)T}\left\{\frac{\partial u^{(e)^T}}{\partial y}\right\}_{y_j}^{y_k}-\int_{y_j}^{y_k}\left\{\frac{\partial N^{(e)T}}{\partial y}\frac{\partial u^{(e)^T}}{\partial y}+N^{(e)T}\left(\frac{\partial u^{(e)^T}}{\partial t}-B\frac{\partial u^{(e)^T}}{\partial y}-P\right)\right\}dy=0 \qquad \text{--- (16)}$$

Neglecting the first term in equation (16), one gets:

$$\int_{y_j}^{y_k}\left\{\frac{\partial N^{(e)T}}{\partial y}\frac{\partial u^{(e)^T}}{\partial y}+N^{(e)T}\left(\frac{\partial u^{(e)^T}}{\partial t}-B\frac{\partial u^{(e)^T}}{\partial y}-P\right)\right\}dy=0$$

Let $u^{(e)}=N^{(e)}\phi^{(e)}$= be the linear piecewise approximation solution over the element (e), ($y_j \le y \le y_k$) where $N^{(e)}=\begin{bmatrix}N_j & N_k\end{bmatrix}$, $\phi^{(e)}=\begin{bmatrix}u_j & u_k\end{bmatrix}^T$ and $N_j=\dfrac{y_k-y}{y_k-y_j}, N_k=\dfrac{y-y_j}{y_k-y_j}$ are the basis functions. We get:

$$\int_{y_j}^{y_k}\left\{\begin{bmatrix}N_j^{'}N_j^{'} & N_j^{'}N_k^{'}\\ N_j^{'}N_k^{'} & N_k^{'}N_k^{'}\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix}\right\}dy+\int_{y_j}^{y_k}\left\{\begin{bmatrix}N_jN_j & N_jN_k\\ N_jN_k & N_kN_k\end{bmatrix}\begin{bmatrix}\dot{u}_j\\ \dot{u}_k\end{bmatrix}\right\}dy-B\int_{y_j}^{y_k}\left\{\begin{bmatrix}N_jN_j^{'} & N_jN_k^{'}\\ N_j^{'}N_k & N_k^{'}N_k\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix}\right\}dy=P\int_{y_j}^{y_k}\begin{bmatrix}N_j\\ N_k\end{bmatrix}dy$$

Simplifying we get

$$\frac{1}{l^{(e)}}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix}+\frac{l^{(e)}}{6}\begin{bmatrix}2 & 1\\ 1 & 2\end{bmatrix}\begin{bmatrix}\dot{u}_j\\ \dot{u}_k\end{bmatrix}-\frac{B}{2}\begin{bmatrix}-1 & 1\\ -1 & 1\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix}=\frac{Pl^{(e)}}{2}\begin{bmatrix}1\\ 1\end{bmatrix}$$

Where prime and dot are denotes differentiation with respect to y and time t respectively. Assembling the element equations for two consecutive elements $(y_{i-1}\le y\le y_i)$ and $(y_i \le y \le y_{i+1})$ following is obtained:

$$\frac{1}{l^{(e)^2}}\begin{bmatrix}1 & -1 & 0\\ -1 & 2 & -1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix}-\frac{B}{2l^{(e)}}\begin{bmatrix}-1 & 1 & 0\\ -1 & 0 & 1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix}+\frac{1}{6}\begin{bmatrix}2 & 1 & 0\\ 1 & 4 & 1\\ 0 & 1 & 2\end{bmatrix}\begin{bmatrix}\dot{u}_{i-1}\\ \dot{u}_i\\ \dot{u}_{i+1}\end{bmatrix}=\frac{P}{2}\begin{bmatrix}1\\ 2\\ 1\end{bmatrix} \qquad \text{--- (17)}$$

Now put row corresponding to the node i to zero, from equation (14) the difference schemes with $l^{(e)}=h$ is:

$$\frac{1}{6}\left[\dot{u}_{i-1}+4\dot{u}_i+\dot{u}_{i+1}\right]+\frac{1}{h^2}\left[-u_{i-1}+2u_i-u_{i+1}\right]-\frac{B}{2h}\left[-u_{i-1}+u_{i+1}\right]=P$$

Applying the trapezoidal rule, following system of equations in Crank – Nicholson method are obtained:

$$A_1u_{i-1}^{j+1}+A_2u_i^{j+1}+A_3u_{i+1}^{j+1}=A_4u_{i-1}^{j}+A_5u_i^{j}+A_6u_{i+1}^{j}+P^* \qquad \text{--- (18)}$$

Where

$$\begin{aligned}A_1&=2-6r+3Brh & A_4&=2+6r-3Brh\\ A_2&=8+12r & A_5&=8-12r\\ A_3&=2-6r-3Brh & A_6&=2+6r+3Brh\end{aligned}$$

$$P^*=12Pk=12k((Gr)\theta_i^j+(Gc)C_i^j)$$

Now from equation (13) and (14) following equations are obtained:

$$B_1\theta_{i-1}^{j+1}+B_2\theta_i^{j+1}+B_3\theta_{i+1}^{j+1}=B_4\theta_{i-1}^{j}+B_5\theta_i^{j}+B_6\theta_{i+1}^{j}+P^{**} \qquad \text{--- (19)}$$

$$C_1C_{i-1}^{j+1}+C_2C_i^{j+1}+C_3C_{i+1}^{j+1}=C_4C_{i-1}^{j}+C_5C_i^{j}+C_6C_{i+1}^{j} \qquad \text{--- (20)}$$

Where

$B_1 = 2L - 6r + 3LBrh,\ B_2 = 8L + 12r,\ B_3 = 2L - 6r - 3LBrh,\ B_4 = 2L + 6r - 3LBrh,$
$B_5 = 8L - 12r,\ B_6 = 2L + 6r + 3LBrh,\ C_1 = 2Sc - 6r + 3rBh.Sc + kScKr,\ C_2 = 8Sc + 12r + 4kScKr,$
$C_3 = 2Sc - 6r - 3rBh.Sc + kScKr,\ C_4 = 2Sc + 6r - 3rBh.Sc - kScKr\ C_5 = 8Sc - 12r - 4kScKr,$

$$C_6 = 2Sc + 6r + 3rBh.Sc - kScKr,\ P^{**} = 12P_1kL = 12kLEc\left(\frac{\partial u_i}{\partial y_i}\right)^2$$

Here, $r = k/h^2$ and h, k are mesh size along the y direction and the time direction respectively. Index i refers to the space, and j refers to the time. In the Equations (18) – (20), taking $i = 1,...,n$ and using boundary conditions (15), the following system of equations is obtained:

$$A_i X_i = B_i, \qquad i = 1,...n \qquad \text{--- (21)}$$

Where A_i's are matrix of order n and X_i, B_i's column matrices having n components. The solutions of above systems of equations are obtained by using the Thomas algorithm for velocity, temperature and concentration. Also the numerical solutions are obtained by executing the C-program with the smaller values of h and k. No significant change was observed in u, θ and C, then the Galerkin finite element method is stable and convergent.

Results and Discussion

The investigation of the The effect of radiation on unsteady heat and mass transfer of a chemically reactive fluid past a semi infinite vertical plate is investigated in the presence of the viscous dissipation has been carried out in the previous section. The numerical values were computed with respect to the physical parameter.

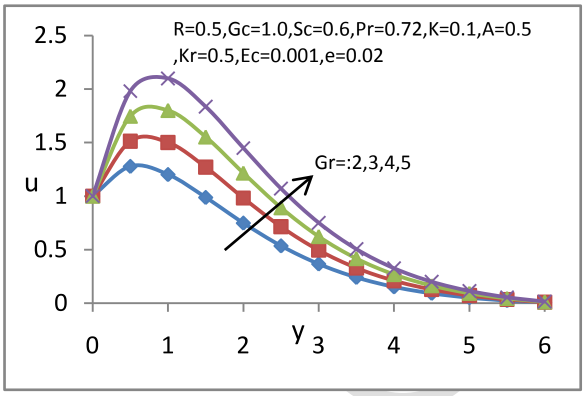


Fig 1.Effect of Gr on Velocity profiles

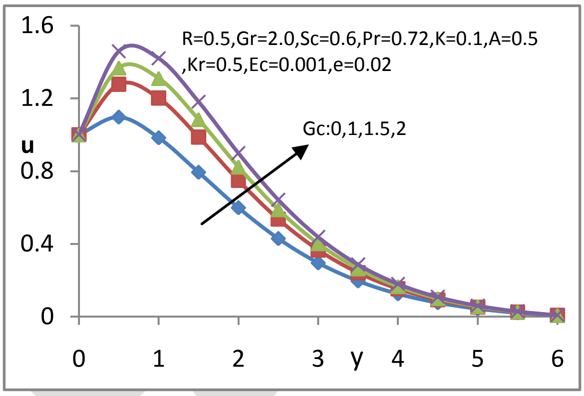


Fig 2.Effect of Gr on Velocity profiles

Figure 1. Represent the velocity profiles for different values of thermal Grashof number (Gr). It is observed that an increase in Gr leads to rise in the values of velocity. The velocity increases with the increase in the solutal Grashof number *Gc* are shown in figure 2.

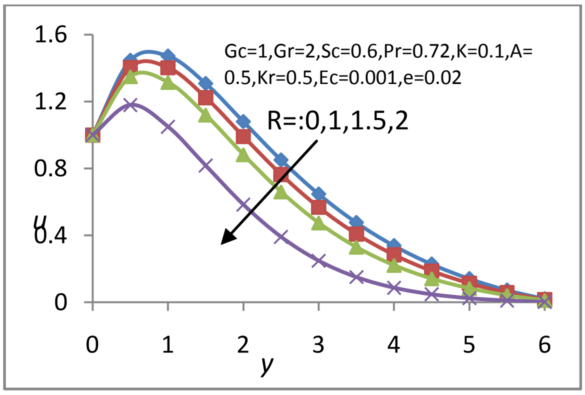


Fig.3 Effect of R on velocity profiles

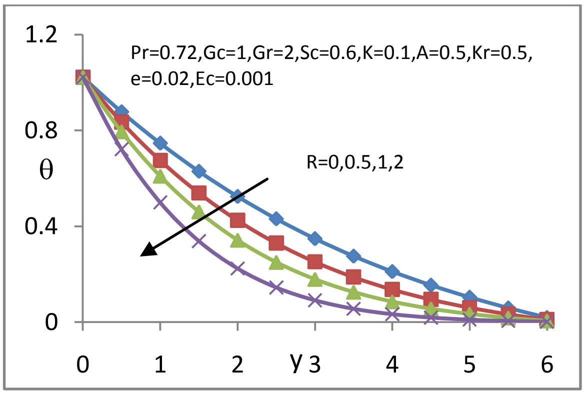
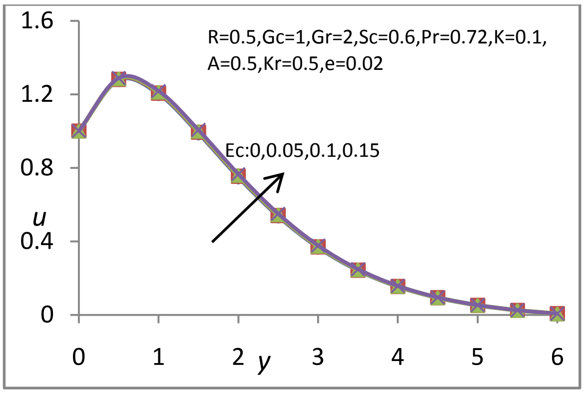


Fig.4 Effect of R on velocity profiles

Figure 3 and 4 illustrate the behavior of velocity and temperature profiles for different values of thermal radiation parameter R. The numerical results show that the effect of increasing the R values results in a decreasing the velocity and temperature. Figure 5 and 6 represent the velocity and temperature profiles for different values of Eckert numbers. It observed that velocity and temperature increases with increase in Ec values. The effect of the Prandtl number (Pr) on the velocity and temperature are shown in figure 7 and 8, the velocity and temperature decreases when increasing the $\Pr$ values. Figure 9 and 10 illustrate the behavior of the velocity and concentration profiles for different values of Schmidt numbers. As the Schmidt number increases, the velocity and concentration decreases. The effects of the chemical reaction parameters on the velocity and concentration profile are depicted on figure 11 and 12. It is observed that increase in chemical reaction pararmeter Kr leads to a decrease in both the results in velocity and concentration.



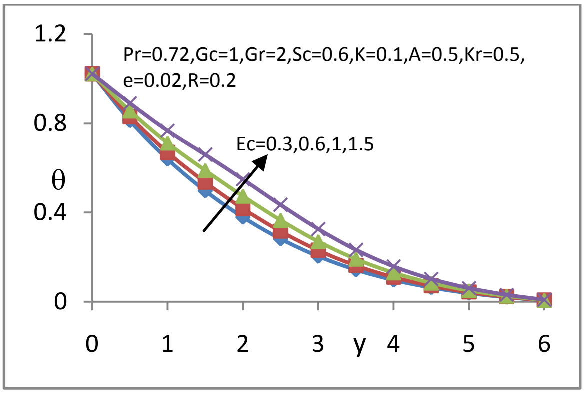
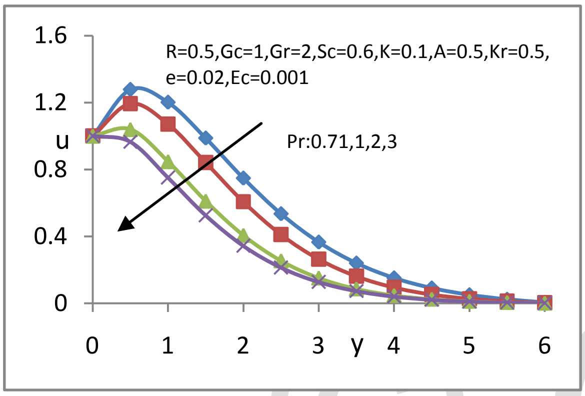


Fig 5. Effect of Ec on velocity profiles

Fig 6. Effect of Ec on temperature profiles



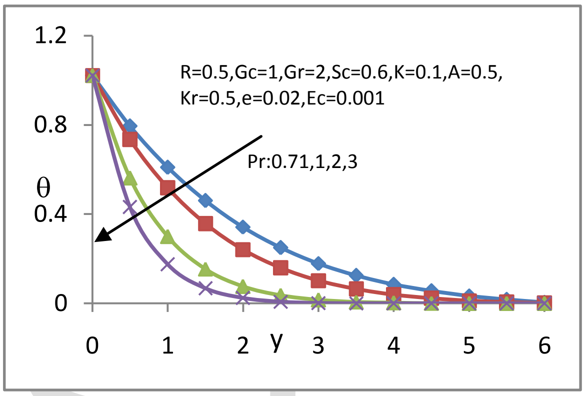
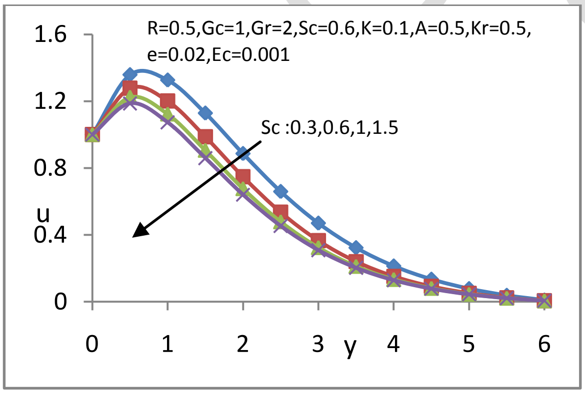


Fig 7. Effect of Pr on Velocity profiles

Fig8. Effect of Pr on Velocity profiles



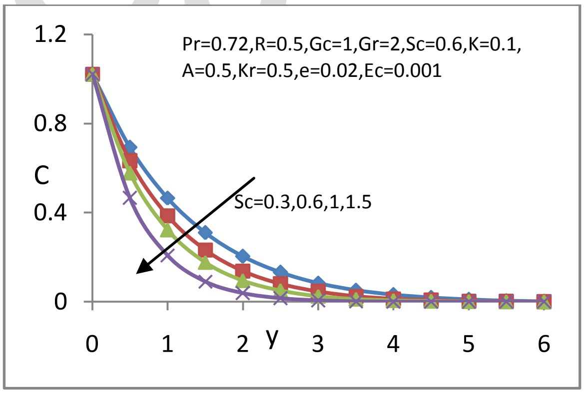
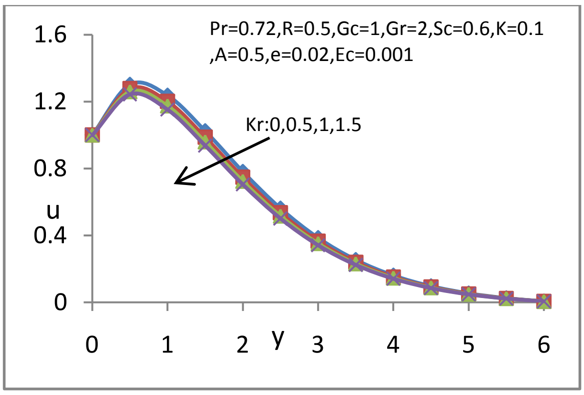


Fig 9. Effect of Sc on Velocity profiles

Fig10. Effect of Sc on concentration profiles



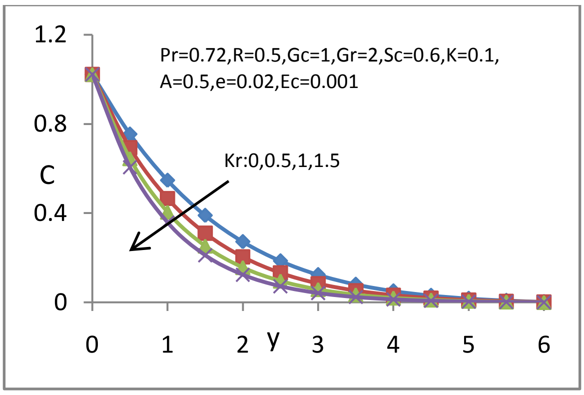


Fig 9. Effect of Sc on Velocity profiles

Fig10. Effect of Sc on concentration profiles

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