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Effects of Soret and Radiation on Unsteady Heat and Mass Transfer of a Chemical Reactive Fluid Past a Semi-Infinite Vertical Plate with Viscous Dissipation

E Ranjit Kumar[1], J Anand Rao[2], MN Raja Shekar[3]

[1]Department of Mathematics, Rayalaseema University, Kurnool, Andhra Pradesh, India.

[2]Department of Mathematics, University College of Science, Osmania University, Hyderabad, Telangana State, India.

[3]Department of Mathematics, JNTUH College of Engineering Jagtial, Telangana State, India.

ABSTRACT

This paper probes the Soret and radiation effects on unsteady MHD free convection of a chemical reactive flow past a semi-infinite vertical plate with viscous dissipation. The resulting governing equations are transformed into dimensionless equations with the help of dimensionless quantities. These dimensionless equations are discretized by Galerkin finite element method and subsequently using the implicit finite difference scheme, we obtain the system of algebraic equations. This system is being solved by the Cranck-Nicolson method using C-programe. Numerical solutions were found on the varying governing parameters like the chemical reaction parameter (Kr), the Eckert number (Ec), the thermal Grashof number (Gr), the solutal Grashof number (Gc), heat absorption parameter (S),the Prandtl number(Pr), the radiation parameter(R), the Schmidt number(Sc), Soret number(S_0) the expressions for physical quantities namely concentration, temperature and velocity were obtained along with the respective numerical values. Velocity, Temperature and Concentration profiles graphs were drawn for different controlling parameters revealing the tendency of the solution.

INTRODUCTION

The area of simultaneous heat and mass transfer from different geometries considered in porous medium has applications in numerous areas like engineering and geophysics. These applications include geothermal reservoirs, thermal insulation, enhanced oil recovery, cooling of nuclear reactors and transportation of underground energy. Kinyanjui *et.al* [1] analyzed simultaneous heat and mass transfer in unsteady free convection flows with radiation absorption past an impulsively started infinite vertical porous plate subjected to a strong field. Seethemahalakshmi *et.al* [2] have studied effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi- infinite vertical moving in a porous medium with heat source and suction. Ogulu A [3] studied the influence of radiation absorption on unsteady free convection and mass transfer flow in the presence of a uniform magnetic field. Kishore PM *et.al* [4] analyzed the effect of chemical reaction on MHD Free convection flow of dissipative fluid past an exponentially accelerated vertical plate. Rajput US and Sahu PK [5] have examined effects of chemical reaction on free convection MHD flow past an exponentially accelerated infinite vertical plate through a porous medium temperature and mass diffusion. Chaudhary D *et.al* [6] discussed MHD unsteady mixed convective flow between two infinite vertical parallel plates through porous medium in slip flow regime with thermal diffusion. Raju RS *et.al* [7] have 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. Pandya N and Shukla AK [8] were discussed Soret- Dufour and radiation effect on unsteady MHD flow over an inclined porous plate embedded in porous medium with viscous dissipation. Anand Rao J *et.al* [9] discussed finite element analysis of unsteady MHD free convection flow past an infinite vertical plate with Soret, Dufour, thermal radiation and heat source.

MATHEMATICAL ANALYSIS

We consider the mixed convection flow of an incompressible an electrically conducting viscous fluid such that x^* -axis is taken along the vertical infinite plate in the upward direction and y^* - axis normal to the plate. All the fluid properties are put on to be constant except that the density variation with the temperature is conceived only in the body force term (Boussinesq's approximation [12]). It is also assumed that the plate temperature and concentration near the plate change exponentially. The level of concentration of mass is assumed to be low, so that the Dufour effect is negligible. Under the above assumptions, the governing equations of continuity, momentum, energy and mass for flow of an electrically conducting fluid are given as :

Continuity equation:

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

Momentum equation :

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

Energy equation:

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \alpha \frac{\partial T^{*2}}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} - \frac{Q_0}{\rho C_p}\left(T^* - T_\infty^*\right) + \frac{\mu}{\rho C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 \qquad \ldots 3$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial C^{*2}}{\partial y^{*2}} - K_r^*\left(C^* - C_\infty^*\right) + D_T \frac{\partial T^{*2}}{\partial y^{*2}} \qquad \ldots 4$$

where u^*, v^* are the velocity components in x^*, y^* directions respectively, t^* is the time, ρ - the fluid density, ν - the kinematic viscocity, C_p -the specific heat at constant pressure, g -the acceleration due to gravity, β, β^* are the volumetric coefficients of thermal and concentration expansions, α -the fluid thermal diffusivity, μ-the coefficient of viscosity, D -the mass diffisivity, Q_0 is the dimensional heat absorption coefficient, D_T - the molecular diffusivity, K_r^* -the chemical reaction parameter.

The boundary conditions are:

$$\left.\begin{array}{ll} u^* = U_0, T^* = T_w^* + \varepsilon\left(T_w^* - T_\infty^*\right)e^{n^*t^*}, C^* = C_w^* + \varepsilon\left(C_w^* - C_\infty^*\right)e^{n^*t^*} & at \quad y = 0 \\ u^* = 0, T^* \to T_\infty^*, C^* \to C_\infty^* & as \quad y \to \infty \end{array}\right\} \qquad \ldots 5$$

where U_0 is the scale of free stream velocity, n^* is constant. T_w^* and C_w^* are the wall dimensional temperature and concentrations respectively. T_∞^* and C_∞^* are the free stream dimensional temperature and concentrations.

From the equation (1), we consider the velocity as the exponential form

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

where A is the real positive constant, ε and εA are small less than unity and v_0 is a scale of suction velocity which has non zero positive constant.

By using the Rosseland approximation the radiative heat flux is given by

$$q_r = \frac{-4\sigma_s}{3k_s}\frac{\partial T^{*4}}{\partial y^*} \qquad \text{... 7}$$

where σ_s and k_s are the Stefan- Boltzmann constant and mean absorption coefficient. We assume that the temperature difference within the flow is sufficiently small such that T^{*4} may be expressed as linear function of temperature. Equation (6) can be linearized by expanding in Taylor series about T_∞^* and neglecting higher order terms, thus

$$T^{*4} \cong 4T_\infty^{*3}T^* - 3T_\infty^{*4} \qquad \text{... 8}$$

By using equations (7) and (8), the equation (3) is reduced to

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \alpha\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{16\sigma_s}{3\rho C_p k_s}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}\left(T^* - T_\infty^*\right) + \frac{\mu}{\rho C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 \qquad \text{... 9}$$

METHOD OF SOLUTION

To get the solution of the equations (1) to (4) with the boundary condition (5) we introduce the following non-dimensional quantities and parameters

$$\left.\begin{aligned} & u = \frac{u^*}{U_0}, y = \frac{v_0 y^*}{\nu}, t = \frac{v_0^2 t^*}{\nu}, \Pr = \frac{\rho C_p \nu}{k} = \frac{\nu}{\alpha}, Sc = \frac{\nu}{D}, \theta = \frac{T^* - T_w^*}{T_w^* - T_\infty^*}, \\ & C = \frac{C^* - C_w^*}{C_w^* - C_\infty^*}, n = \frac{n^*\nu}{v_0^2}, Kr = \frac{K_r^*\nu}{v_0^2}, R = \frac{16\sigma_s T_\infty^3}{3k_s k}, Gr = \frac{g\beta(T_w^* - T_\infty^*)}{U_0 v_0^2}, \\ & Gc = \frac{g\beta^*(C_w^* - C_\infty^*)}{U_0 v_0^2}, S = \frac{\nu Q}{\rho C_p v_0^2}, S_0 = \frac{D_T(T_w^* - T_\infty^*)}{(C_w^* - C_\infty^*)\nu}, Ec = \frac{v_0^2}{C_p(T_w^* - T_\infty^*)} \end{aligned}\right\} \qquad \text{… 10}$$

where $Gr, Gc, \Pr, Sc, Kr, R, Ec, S_0$ and S are the thermal Grashof number, Solutal Grashof number, Prandtl number, Schmidt number, chemical reaction parameter, radiation parameter, Eckert number, Soret number and heat absorption parameter respectively.

Therefore, the governing equations in the dimensionless form becomes (1) to (4) with the boundary conditions (5) as

$$\frac{\partial v}{\partial y} = 0 \qquad \text{... 11}$$

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

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

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A\, e^{nt}\right)\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC + S_0\frac{\partial^2 \theta}{\partial y^2} \qquad \ldots 14$$

The corresponding initial and boundary conditions are:

$$\left.\begin{array}{lll} u = 1, \theta = 1 + \varepsilon e^{nt}, C = 1 + \varepsilon e^{nt} & at & y = 0 \\ u \to 0, \theta \to 0, C \to 0 & as & y \to \infty \end{array}\right\} \qquad \ldots 15$$

By applying Galerkin finite element method for equations (12) to (14) over the element (e), $\left(y_j \le y \le y_k\right)$ is:

$$\int_{y_j}^{y_k} \left\{ N^{(e)T}\left[\frac{\partial^2 u^{(e)^T}}{\partial y^2} + B\frac{\partial u^{(e)T}}{\partial y} - \frac{\partial u^{(e)^T}}{\partial t} + P\right]\right\} dy = 0 \qquad \ldots 16$$

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

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

$$N^{(e)T}\left\{\frac{\partial u^{(e)^T}}{\partial y}\right\}_{y_j}^{y_k} - \int_{y_j}^{y_k}\left\{\frac{\partial N^{(e)T}}{\partial y}\frac{\partial u^{(e)^T}}{\partial y} + N^{(e)T}\left(\frac{\partial u^{(e)^T}}{\partial t} - B\frac{\partial u^{(e)^T}}{\partial y} - P\right)\right\} dy = 0 \qquad \ldots 17$$

Neglecting the first term in equation (17), we 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 $N^{(e)} = \begin{bmatrix} N_j & N_k \end{bmatrix}$, $\varphi^{(e)} = \begin{bmatrix} u_j & u_k \end{bmatrix}^T$ 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 obtain

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

On 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:

$$\frac{1}{l^{(e)^2}}\begin{bmatrix}1 & -1 & 0\\ -1 & 2 & -1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix}-\frac{B}{2l^{(e)}}\begin{bmatrix}-1 & 1 & 0\\ -1 & 0 & 1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix}+\frac{1}{6}\begin{bmatrix}2 & 1 & 0\\ 1 & 4 & 1\\ 0 & 1 & 2\end{bmatrix}\begin{bmatrix}\dot{u}_{i-1}\\ \dot{u}_i\\ \dot{u}_{i+1}\end{bmatrix}=\frac{P}{2}\begin{bmatrix}1\\ 2\\ 1\end{bmatrix} \quad \ldots 18$$

Now put row corresponding to the node i to zero, from equation (18) 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 Crank – Nicholson method to the above equation, we get

$$A_1u_{i-1}^{j+1}+A_2u_i^{j+1}+A_3u_{i+1}^{j+1}=A_4u_{i-1}^{j}+A_5u_i^{j}+A_6u_{i+1}^{j}+P^* \quad \ldots 19$$

where

$A_1 = 2-6r+3Brh$ $\quad$ $A_4 = 2+6r-3Brh$

$A_2 = 8+12r$ $\quad$ $A_5 = 8-12r$

$A_3 = 2-6r-3Brh$ $\quad$ $A_6 = 2+6r+3Brh$

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

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

$$B_1\theta_{i-1}^{j+1}+B_2\theta_i^{j+1}+B_3\theta_{i+1}^{j+1}=B_4\theta_{i-1}^{j}+B_5\theta_i^{j}+B_6\theta_{i+1}^{j}+P^{**} \quad \ldots 20$$

$$C_1C_{i-1}^{j+1}+C_2C_i^{j+1}+C_3C_{i+1}^{j+1}=C_4C_{i-1}^{j}+C_5C_i^{j}+C_6C_{i+1}^{j}+P^{***} \quad \ldots 21$$

where

$B_1 = 2L-6r+3LBrh-SLk$ $\quad$ $B_4 = 2L+6r-3LBrh+SLk$

$B_2 = 8L+12r-4LSk$ $\quad$ $B_5 = 8L-12r+4LSk$

$B_3 = 2L-6r-3LBrh-SLk$ $\quad$ $B_6 = 2L+6r+3LBrh+SLk$

$C_1 = 2Sc-6r+3rBh.Sc+kScKr$ $\quad$ $C_4 = 2Sc+6r-3rBh.Sc-kScKr$

$C_2 = 8Sc+12r+4kScKr$ $\quad$ $C_5 = 8Sc-12r-4kScKr$

$C_3 = 2Sc-6r-3rBh.Sc+kScKr$ $\quad$ $C_6 = 2Sc+6r+3rBh.Sc-kScKr$

$P^{**} = 12P_1kL = 12kLEc\left(\frac{\partial u_i}{\partial y_i}\right)^2$ $\quad$ $P^{***} = 12ScS_0\frac{\partial^2\theta_i}{\partial y_i^2}$

Here $r = \frac{k}{h^2}$ and h, k are mesh sizes along y - direction and t -direction respectively. i -refers to space and j refers to the time. In the equations (19), (20) and (21) taking $i = 1(1)$ and boundary conditions (3.15), then the following system of equations are obtained.

$$A_i X_i = B_i, \quad i = 1(1)3 \qquad \dots 22$$

where A_i 's are matrices of order n and X_i, B_i 's column matrices having n components. The above solutions of above system of equations are obtained by using Thomas algorithm for velocity, temperature and concentration. Also numerical solutions for these equations are obtained by C-Program. In order to prove the convergence and stability of Galerkian finite element method, the same C- program was run with the smaller values of h, k and no significant change was observed in the values of u, q and C. Hence, the Galerkian finite element method is stable and convergent.

RESULTS AND DISCUSSIONS

With varying governing parameters like the chemical reaction parameter (Kr),the Eckert number (Ec), the thermal Grashof number (Gr), the solutal Grashof number (Gc), heat absorption parameter (S),the Prandtl number(Pr), the radiation parameter(R), the Schmidt number(Sc), Soret number(S_0) the expressions for physical quantities namely concentration, temperature and velocity were obtained along with the respective numerical values.

Figure 1 illustrates the velocity profiles for varying governing parameter the thermal Grashof number Gr. We can analyze that increasing values of Gr leads to an increase in velocity profile and positive values of Gr causes cooling of the plate. Also, as value of Gr increases, the velocity increases rapidly near the wall and decays to the free stream velocity. Figure 2 shows that the velocity profiles in the boundary layer for varying solutal Grashof number. An observation can be drawn that increased velocity is due to an increased Gc value.

Figures 3 and 4 illustrate the velocity and temperature profiles for varying thermal radiation parameter R. It can be noted from the figure that an increase in the value of R leads to increase in both the temperature and velocity within the boundary layer.

Figures 5 and 6 focus on the effect of Eckert number (viscous dissipation parameter) on the velocity and temperature profiles. Greater the dissipation heat higher is the temperature and the velocity.

Figures 7 and 8 illustrate the behavior of the velocity and temperatures for different values of the Prandtl number Pr. The numerical results show that the effect of increasing values of Prandtl number results in decreasing the velocity. From figure 8 it is observed that an increase in the Prandtl number results a decrease in the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr 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 Pr. Hence in the case of smaller Prandtl numbers as the thermal boundary layer is thicker and therefore the rate of heat transfer is reduced.

Figures 9 and 10 focus on the effects of Schmidt number on the velocity and concentration profiles. Concentration decreases as Schmidt number increases leading to a decrease in concentration buoyancy effects and reduced fluid velocity. Also reduction in fluid velocity and concentration distributions and are followed by simultaneous reduction in concentration and velocity boundary layers.

Behaviors of velocity and concentration for varying chemical reaction parameter Kr are described in Figures 11 and 12. It is clear from the figures that there is a decrease in the velocity profile whereas concentration profile increases with an increase in the chemical reaction parameter.

Figures 13 and 14 displays the effect of Soret number S_0 on the velocity and concentration field it is found that the velocity and concentration increases with an increase in S_0.

CONCLUSIONS

In this paper we have studied effect of Soret and radiation on unsteady heat and mass transfer of a chemical reactive fluid past a semi – infinite vertical plate with viscous dissipation. The most important concluding remarks can be summarized as follows

- Both velocity and temperature increase with an increase in the radiation parameter.
- Greater the dissipation heat higher is the temperature and velocity.
- Velocity and temperature decreases as Prandtl number increases.
- Velocity and concentration decreases with an increase in the chemical reaction parameter, whereas they increase as thermal diffusion increases.
- An increase in the Schmidt number, both velocity and concentration decreases.

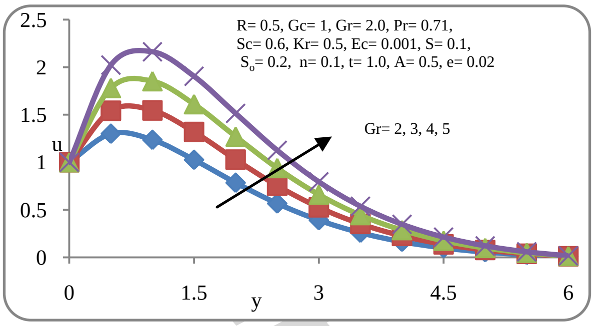

Figure1: Effect of Gr on velocity profile

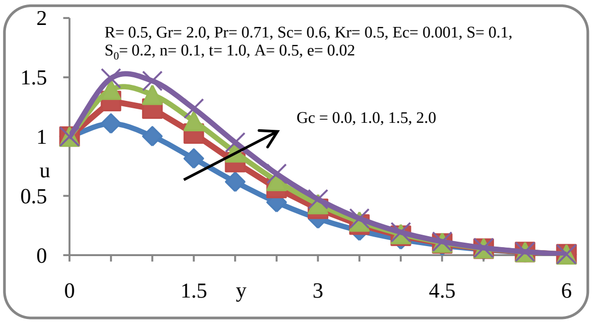

Figure 2: Effect of Gc on velocity profile

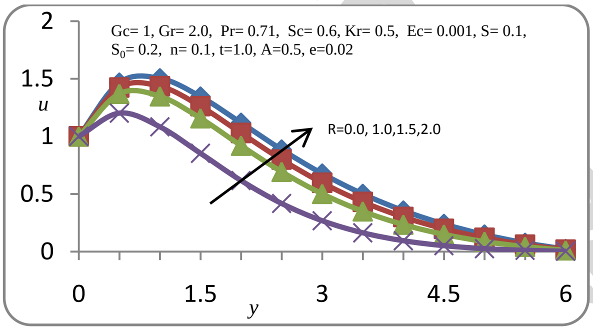

Figure 3: Effect of R on velocity profile

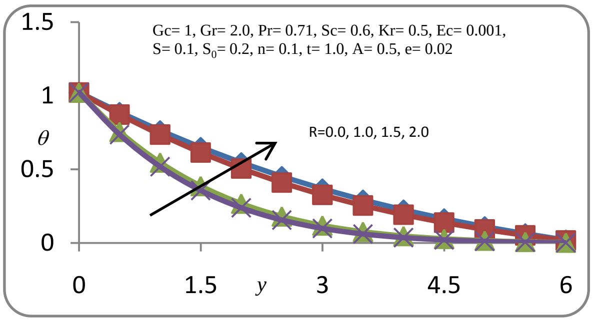

Figure 4: Effect of R on temperature profile

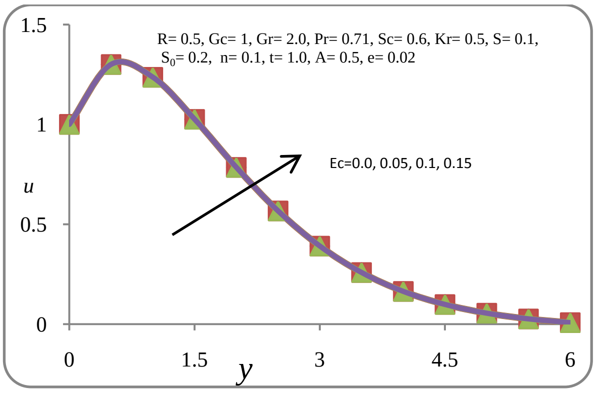

Figure 5: Effect of Ec on velocity profile

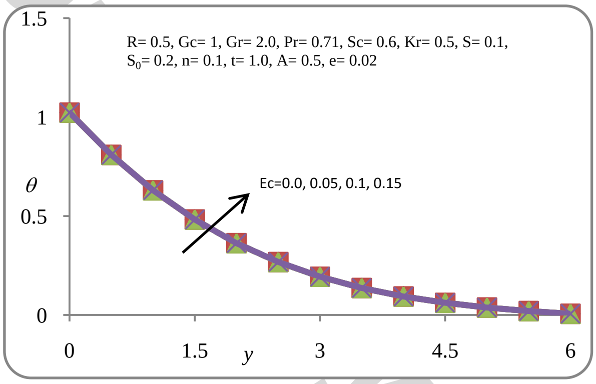

Figure 6: Effect of Ec on temperature profile

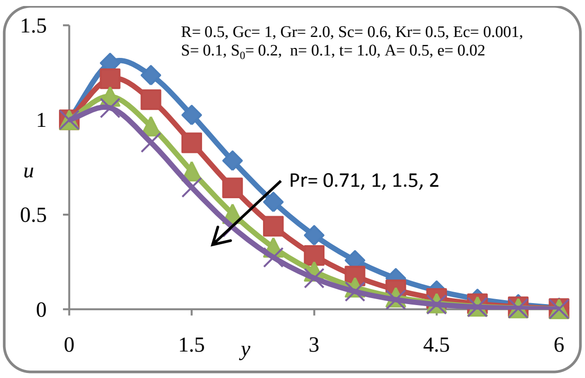

Figure 7: Effect of Pr on velocity profile

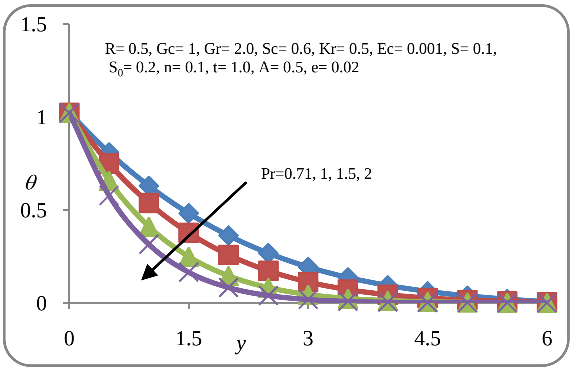

Figure 8: Effect of Pr on temperature profile

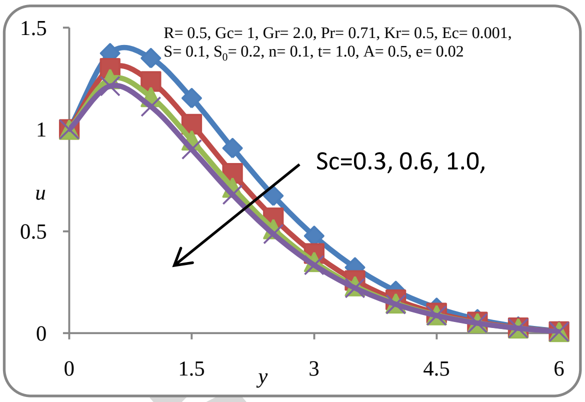

Figure 9: Effect of Sc on velocity profile

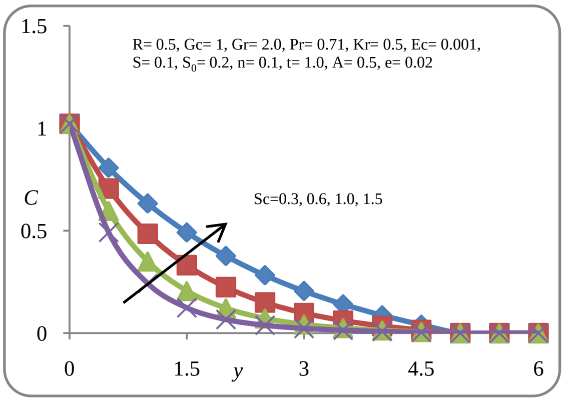

Figure 10: Effect of Sc on concentration profile

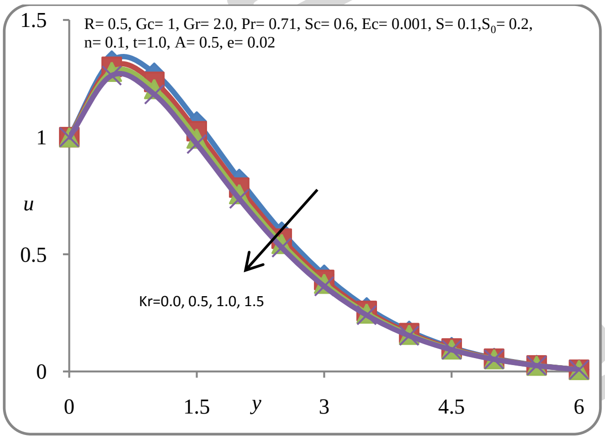

Figure 11: Effect of Kr on velocity profile

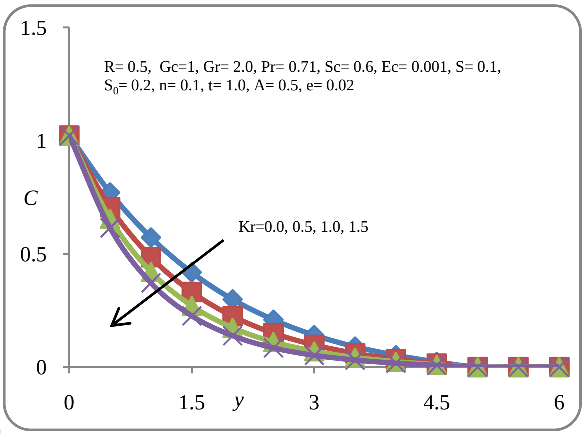

Figure 12: Effect of Kr on concentration profile

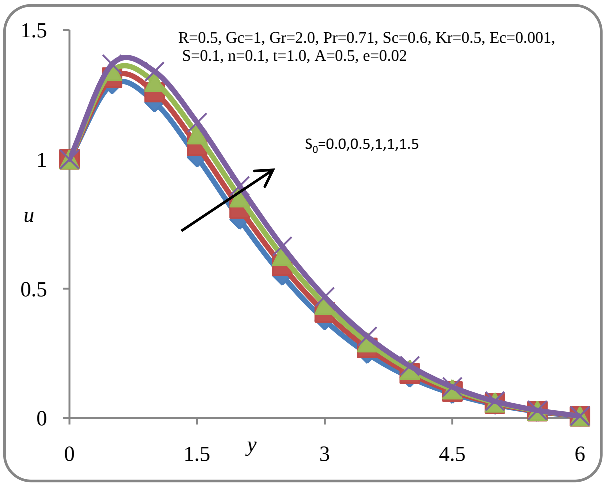

Figure 13: Effect of S_0 on velocity profile

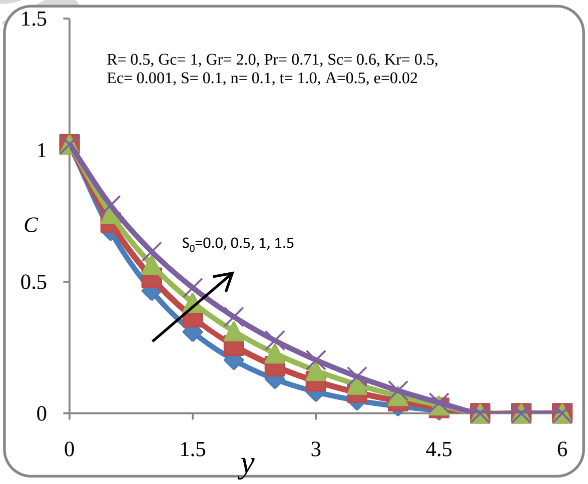

Figure14: Effect of S_0 on concentration profile

REFERENCES

1. Kinyanjui *et.al* (2001): Magneto-hydrodynamic free convection hea and mass transfer of a heat generating fluid past an impulsively started infinite vertical porous plate with hall current and radiation absorption, *Energy Conservation and Management*, **42(8)**, pp.917–931.
2. Seethamahalakshmi.,G.V. Ramana Reddy and D.C.N Prasad (2003): Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi- infinite vertical moving in a porous medium with heat source and suction" *International organization of Scientific Research (IOSR),* **1(1)**, pp.028-036.
3. Ogulu A (2005): The influence of radiation absorption on unsteady free convection and mass transfer flow in the presence of a uniform magnetic field, *International Journal of heat and mass transfer,* **48(23)**, pp.5078–5080.
4. Kishore PM *et.al* (2014): The effect of chemical reaction on MHD Free convection flow of dissipative fluid past an exponentially accelerated vertical plate, *Int. J. of computing engineering research*, **4(1)**, pp.11-26.
5. Rajput US and Sahu PK (2012):Effects of chemical reaction on free convection MHD flow past an exponentially accelerated infinite vertical plate through a porous medium temperature and mass diffusion, *Elixir Appl.Math*., **43**, pp.6520-6527.
6. Chaudhary D. *et.al*(2013): MHD unsteady mixed convective flow between two infinite vertical parallel plates through porous medium in slip flow regime with thermal diffusion, *American Journal of Engineering Research*, **02(7)**, pp.141-158.
7. Raju RS (2013): 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, *J. Inst. Eng. India Ser. C*., **94(2)**, pp.175-186.
8. Pandya N,Shukla AK (2014): Soret- Dufour and radiation effect on unsteady MHD flow over an inclined porous plate embedded in porous medium with viscous dissipation, *Int. J. Adv. Appl. Math. And Mech.,* **2(1)**, pp.107-119.
9. Anand Rao *et.al* (2015): Finite element analysis of unsteady MHD free convection flow past an infinite vertical plate with Soret, Dufour, thermal radiation and heat source, *ARPN Journal of Engineering and Applied Sciences*, **10(12)**, pp.5338-5351.