UNSTEADY MHD FREE CONVECTION ALIGNED MAGNETIC EFFECT ON NON-NEWTONIAN FLUID FLOW PAST A VERTICAL POROUS PLATE WITH DUFOUR EFFECT AND CHEMICAL REACTION

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Abstract: The aim of the present study is to examine temperature gradient and chemical reaction effects on unsteady MHD flow past a vertical porous plate with variable temperature and mass diffusion in the presence of heat source or sink under the influence of applied transverse magnetic field. The governing equations are solved by analytical method. The velocity, the temperature and the concentration are studied through graphically with difference values and physical parameters.

***IndexTerms* -** MHD, non-Newtonian fluid, Dufour effect, Chemical reaction, Heat source/sink.

I. INTRODUCTION

This study of Magneto hydrodynamics (MHD) with heat and mass transfer in the incidence of thermal radiation, Dufour effects and chemical reaction has attention of many research scholars due to various applications. In astrophysics and geophysics, it is applied to study the stellar and solar structures, radio propagation through the ionosphere, etc. In engineering we discover its applications like in MHD pumps, MHD bearings, etc. Combined heat and mass transfer problem with chemical reaction are of importance in many processes. In processes such as drying, evaporation on the surface of a water, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas.

Abdul Hakeem et al. [1] observed Influence of inclined Lorentz forces on boundary layer flow of Casson fluid over an impermeable stretching sheet with heat transfer solved by numerical method. Abdul Hakeem et al. [2] have investigated Magnetic field effect on second order slip flow of nano fluid over a stretching/shrinking sheet with thermal radiation effect solved by numerical method. Bala Anki Reddy [3] studied Magnetohydrodynamic flow of a Casson fluid over an exponentially inclined permeable stretching surface with thermal radiation and chemical Reaction solved by numerical method. Dada et al. [4] to study Analysis of Heat and Mass Transfer of an Inclined Magnetic Field Pressure-driven Flow Past a Permeable Plate solved by numerical method. Dulal Pal et al. [5] have discussed Buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and Ohmic heating solved by analytical method. Ibrahim et al. [6] have reported Influence of chemical reaction and heat source on dissipative MHD mixed convection flow of a Casson nanofluid over a nonlinear permeable stretching sheet solved by numerical method. Kumaran et al. [7] have studied Computational analysis of magneto hydrodynamic Casson and Maxwell flows over a stretching sheet with cross diffusion solved by analytical method. Mabood et al. [8] obtained Non-uniform heat source/sink and Soret effects on MHD non-Darcian convective flow past a stretching sheet in a micropolar fluid with Radiation solved by numerical method. Makinde et al. [9] to study Bioconvection in MHD nanofluid flow with nonlinear thermal radiation and quartic autocatalysis chemical reaction past an upper surface of a paraboloid of revolution solved by numerical method. Mohamed Abd El-Aziz et al. 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The present study is to examine temperature gradient and chemical reaction effects on unsteady MHD flow past a vertical porous plate with variable temperature and mass diffusion in the presence of heat source or sink under the influence of applied transverse magnetic field. The governing equations are solved by analytical method. The velocity, the temperature and the concentration are studied through graphically with difference values and physical parameters.

II. FORMULATION OF THE PROBLEM

Let us consider the unsteady one dimensional flow of a viscous incompressible, electrically conducting, temperature gradient and chemical reaction effects on unsteady MHD flow past a vertical porous plate with variable temperature and mass diffusion in the presence of heat source or sink under the influence of applied transverse magnetic field. The plate is taken along x-axis in vertically upward direction and y-axis taken normal to the plate. Initially it is assumed that the plate and fluid are at the same temperature $\bar{T}_\infty$ and concentration level $\bar{C}_\infty$ in stationary condition for all the point. A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate. Then under by usual Boussinesq's approximation, the unsteady flow is governed by the following

$$\frac{\partial \bar{u}}{\partial \bar{t}} = \left(1+\frac{1}{\beta}\right)\nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + g\beta\left(\bar{T}-\bar{T}_\infty\right) + g\beta^*\left(\bar{C}-\bar{C}_\infty\right) + \frac{\sigma B_0^2}{\rho}\bar{u}\sin^2\psi - \frac{\nu}{\bar{K}}\bar{u} \quad (1)$$

$$\frac{\partial \bar{T}}{\partial \bar{t}} = \frac{1}{\rho C_p}\left[k\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \bar{Q}\left(\bar{T}-\bar{T}_\infty\right)\right] - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial \bar{y}} + \frac{D_m k_T}{C_s C_p}\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} \quad (2)$$

$$\frac{\partial \bar{C}}{\partial \bar{t}} = D\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} - \bar{K}r\left(\bar{C}-\bar{C}_\infty\right) \quad (3)$$

Where $\bar{x}$, $\bar{y}$ are the dimensional distance along and perpendicular to the plate respectively, $\bar{u}$ and $\bar{v}$ are the velocity components in the $\bar{x}$, $\bar{y}$ directions respectively. g is the gravitational acceleration, ρ is the fluid density, β and β^* are the thermal and concentration expansion coefficients respectively. $\bar{K}$ is the Darcy permeability, B_0 is the magnetic induction, $\bar{T}$ is the thermal temperature inside the thermal boundary layer and $\bar{C}$ is the corresponding concentration, σ is the electric conductivity, C_p is the specific constant pressure, D is the diffusion coefficient, q_r is the heat flux, Q_0 is the dimensional heat absorption coefficient, Du is the Dufour effect parameter and Kr is the chemical reaction parameter.

$$\left.\begin{array}{l} \bar{t} \le 0: \quad \bar{u}=0, \quad \bar{T}=\bar{T}_\infty, \qquad \bar{C}=\bar{C}_\infty \\ \bar{t}>0: \begin{cases} \bar{u}=u_0\bar{t}, \bar{T}=\bar{T}_\infty+\varepsilon\left(\bar{T}_w-\bar{T}_\infty\right)A\bar{t}, \bar{C}=\bar{C}_\infty+\varepsilon\left(C-\bar{C}_\infty\right)A\bar{t} & at \;\; \bar{y}=0 \\ \bar{u}=0, \quad \bar{T}\to\bar{T}_\infty, \qquad \bar{C}\to\bar{C}_\infty & as \;\; \bar{y}\to\infty \end{cases} \end{array}\right\} \tag{4}$$

Where $A=\frac{u_0^2}{v}$

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial \bar{y}}=-4a^*\sigma\bar{T}_\infty^3\left(\bar{T}_\infty^4-\bar{T}^4\right) \tag{5}$$

It is assumed that the temperature difference within the flow are sufficiently small and that $\bar{T}^4$ may be expressed as a linear function of the temperature. This is obtained by expanding $\bar{T}^4$ in the Taylor series about $\bar{T}_\infty$ and neglecting the higher order terms, thus we get

$$\bar{T}^4 \cong 4\bar{T}_\infty^3\bar{T}-3\bar{T}_\infty^4 \tag{6}$$

From equations (5) and (6), equation (2) reduces to

$$\rho C_p\frac{\partial \bar{T}}{\partial \bar{y}}=k\frac{\partial^2\bar{T}}{\partial \bar{y}^2}+16a^*\sigma\bar{T}_\infty^3\left(\bar{T}_\infty-\bar{T}\right) \tag{7}$$

On introducing the following non-dimensional quantities:

$$\left.\begin{array}{l} y=\frac{u_0\bar{y}}{v}, u=\frac{\bar{u}}{u_0}, t=\frac{\bar{t}u_0^2}{v}, \theta=\frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}, C=\frac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty}, K=\frac{\bar{K}u_0^2}{v^2}, \\ Gr=\frac{g\beta v\left(\bar{T}_w-\bar{T}_\infty\right)}{v_0^3}, \Pr=\frac{\mu\rho C_p}{k}, Gm=\frac{g\beta^* v\left(\bar{C}_w-\bar{C}_\infty\right)}{u_0^3}, Sc=\frac{v}{D}, \\ R=\frac{16a^*v^2\sigma\bar{T}_\infty^3}{ku_0^2}, M=\frac{\sigma B_0^2 v}{\rho u_0^2}, Du=\frac{D_m K_T\left(\bar{C}_w-\bar{C}_\infty\right)}{C_s C_p v\left(\bar{T}_w-\bar{T}_\infty\right)}, M=\frac{\sigma B_0^2 v}{\rho u_0^2}, \\ H=\frac{\bar{Q}v^2}{ku_0^2}, Kr=\frac{\bar{K}rv}{u_0^2}, \end{array}\right\} \tag{8}$$

The governing equations for momentum, the energy and the concentration in a dimensionless form are

$$\frac{\partial u}{\partial t}=\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+Gr\theta+GmC+\left(M\sin^2\psi-\frac{1}{K}\right)u \tag{9}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-\frac{(R+H)}{\Pr}\theta+Du\frac{\partial^2 C}{\partial y^2} \tag{10}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-KrC \tag{11}$$

Where Gr, Gm, M, K, $\Pr$, R, H, Du, Sc, Kr are the Grashof number, modified Grashof number, magnetic parameter, permeability parameter, Prandtl number, radiation parameter, heat source parameter, Dufour parameter, Schmidt number and chemical reaction parameter respectively.

The relevant corresponding boundary conditions for $t>0$ are transformed to:

$$\left.\begin{aligned} &u=t, \quad \theta=t, \ C=t \quad at\ y=0 \\ &u\to 0, \theta\to 0, C\to 0 \quad as\ y\to\infty \end{aligned}\right\} \tag{12}$$

III. SOLUTION OF THE PROBLEM

In order to solve equations (9)-(11) with respect to the boundary conditions (12) for the flow, let us take

$$u(y,t)=u_0(y)e^{i\omega t} \tag{13}$$

$$\theta(y,t)=\theta_0(y)e^{i\omega t} \tag{14}$$

$$C(y,t)=C_0(y)e^{i\omega t} \tag{15}$$

Substituting the equations (13)-(15) in equations (9)-(11), we obtain

$$\left(1+\frac{1}{\beta}\right)u_0''-\left(M\sin^2\psi+\frac{1}{K}+i\omega\right)u_0=-\left[Gr\theta_0+GmC_0\right] \tag{16}$$

$$\theta_0''-\left[R+H+\Pr i\omega\right]\theta_0=-\Pr DuC_0'' \tag{17}$$

$$C_0''-\left(Kr+i\omega\right)ScC_0=0 \tag{18}$$

Where the prime denotes ordinary differentiation with respect to y.

The corresponding boundary conditions can be written as

$$\left.\begin{aligned} &u_0=te^{-i\omega t}, \theta_0=te^{-i\omega t}, C_0=te^{-i\omega t} \quad at\ y=0 \\ &u_0\to 0, \quad \theta_0\to 0, \quad C_0\to 0 \quad as\ y\to\infty \end{aligned}\right\} \tag{19}$$

Solving the equations (16)-(18) with the boundary conditions (19), we obtain the velocity, temperature and concentration distribution in the boundary layer as:

$$u(y,t)=A_{10}e^{-A_6 y}+A_9e^{-A_1 y}+A_8e^{-A_1 y}+A_7e^{-A_2 y} \tag{20}$$

$$\theta(y,t)=A_4e^{-A_2 y}+A_3e^{-A_1 y} \tag{21}$$

$$C(y,t)=te^{-A_1 y} \tag{22}$$

Here

$$B = 1 + \frac{1}{\beta}; \quad A_1 = \sqrt{(Kr + i\omega)Sc}; \quad A_2 = \sqrt{R + H + \Pr i\omega}; \quad A_3 = \frac{\Pr Du\, A_1^2\, t}{A_1^2 - A_2^2}; \quad A_4 = t - A_3;$$

$$A_5 = \sqrt{M \sin^2 \psi + \frac{1}{K} + i\omega}; \quad A_6 = \frac{A_5}{\sqrt{B}}; \quad A_7 = -\frac{Gr\, A_4}{BA_2^2 - A_3^2}; \quad A_8 = --\frac{Gr\, A_3}{BA_1^2 - A_3^2}; \quad A_9 = -\frac{Gmt}{BA_1^2 - A_3^2};$$

$$A_{10} = t - A_9 - A_8 - A_7$$

IV. RESULTS AND DISCUSSION

In this section, we have explanation with plotted velocity, temperature and concentration for the different values of the physical parameters like then $\Pr$ =6.8, K =0.5, M =0.5, β =0.5, Gr =30, Gm =50, Du =0.5, H =0.1, R =0.5, Kr =0.5, ω =1.0, Sc =0.60, t =1.0, $\psi = \frac{\pi}{6}$. Fig.1. Shows that the influence of Prandtl number ($\Pr$) on the velocity is increases with increasing of the Prandtl number. Form Fig.2.observed that the velocity is increases with increasing of the Modified Grashof number (Gm). Fig.3.illustrate that the velocity profile for the different values of Dufour parameter (Du). It is noticed that the values of Dufour parameter increasing the velocity profiles is also decreases. Fig.4. and Fig.5 are illustrated the velocity profiles for increases and another one is decreases with increasing the values of Heat source (H) and Grashof number (Gr).

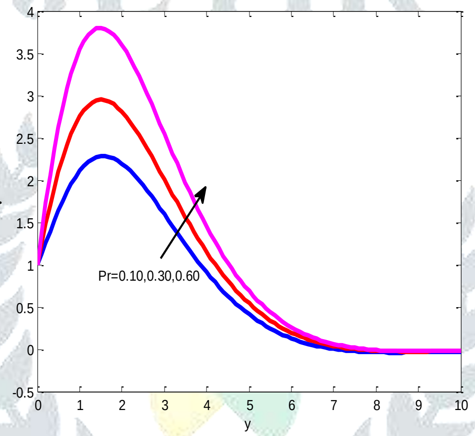

Fig.1. Velocity profile for different values of Prandtl number ($\Pr$)

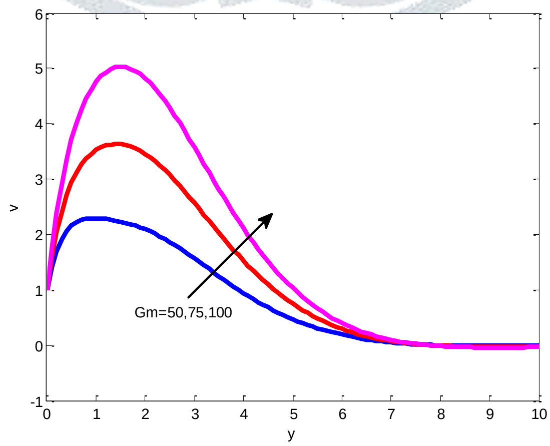

Fig.2. Velocity profile for different values of modified Grashof number (Gm)

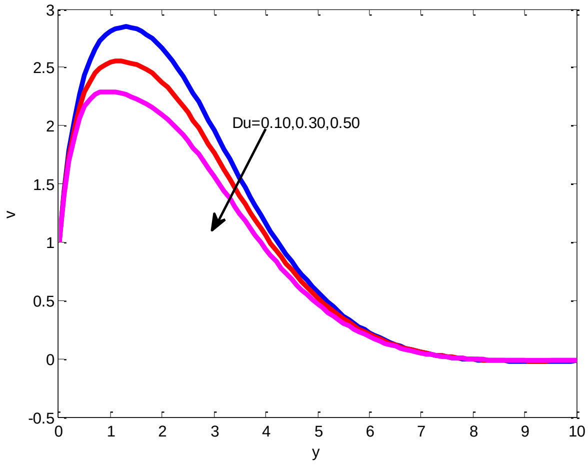

Fig.3. Velocity profile for different values of Dufour parameter (Du)

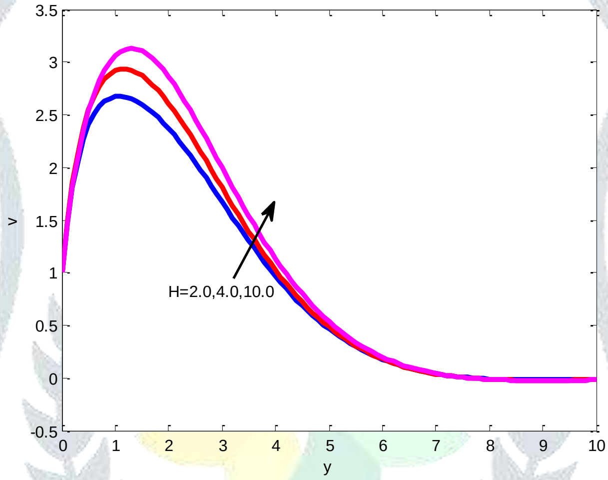

Fig.4. Velocity profile for different values of Heat Source parameter (H)

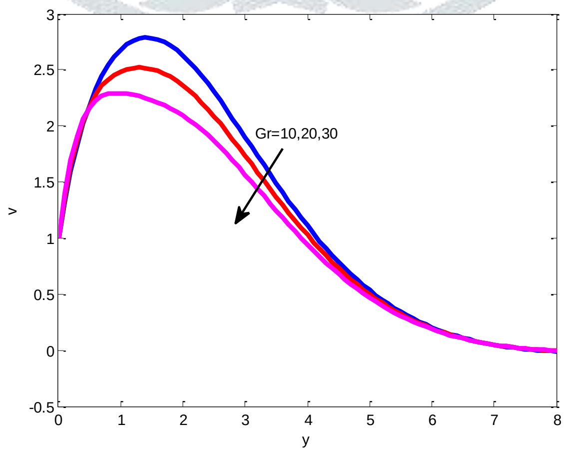

Fig.5. Velocity profile for different values of Grashof number (Gr)

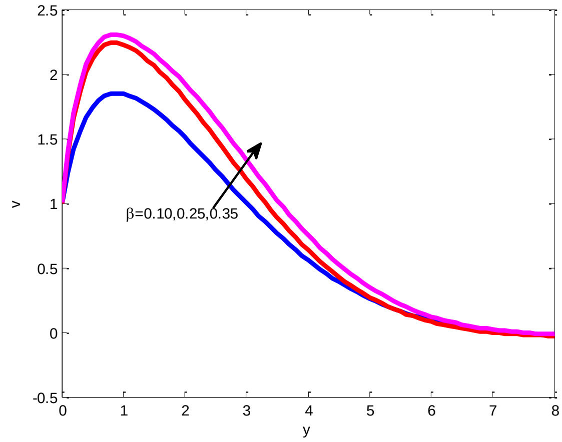

Fig.6. Velocity profile for different values of Casson parameter (β)

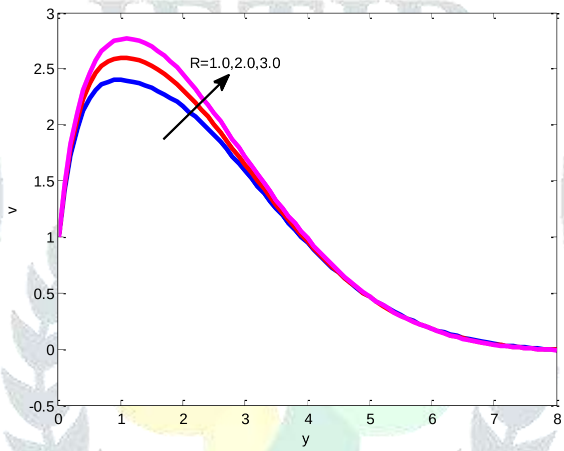

Fig.7. Velocity profile for different values of radiation parameter (R)

The influence of Casson parameter (β) and thermal radiation parameter (R) on the velocity profiles are illustrates graphically from Fig. 6. And Fig.7 respectively. It's explained that the velocity profiles are increases with increasing the values of Casson parameter and thermal radiation. Fig.8. observed that increasing the values of Schmidt number (Sc) is the velocity profile is decreases.

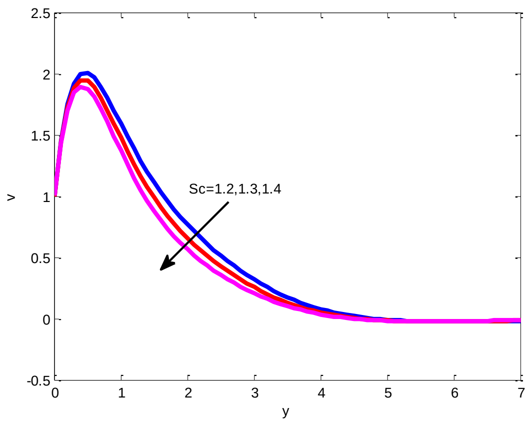

Fig.8. Velocity profile for different values of Schmidt number (Sc)

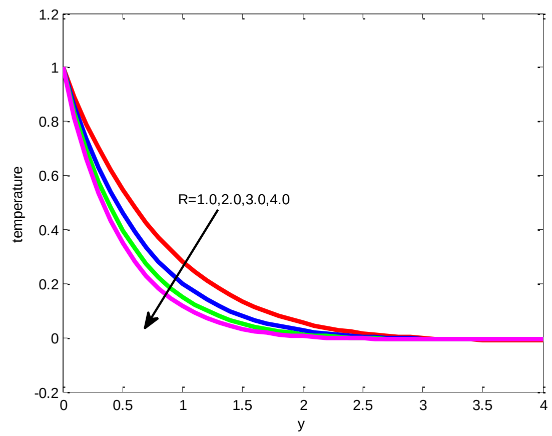

Fig.9. Temperature profile for different values of radiation parameter (R)

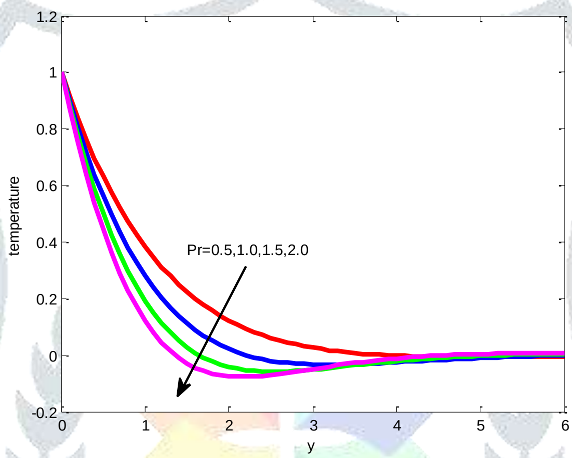

Fig.10. Temperature profile for different values of Prandtl number ($\Pr$)

From Figs. 9 and 10. Represent the effects of the thermal radiation (R) and Prandtl number ($\Pr$) values are increasing the velocity profiles are decreases.

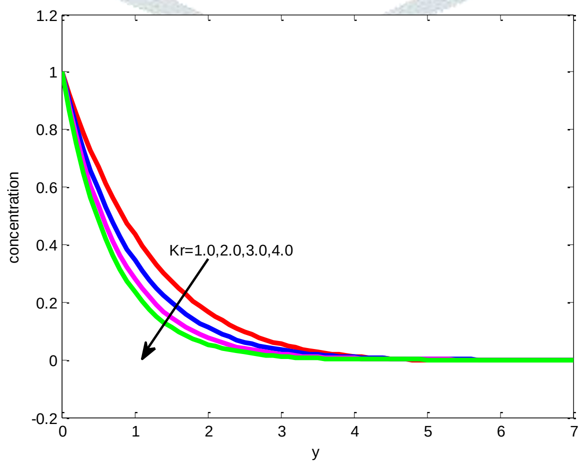

Fig.11. Concentration profile for different values of chemical reaction parameter (Kr)

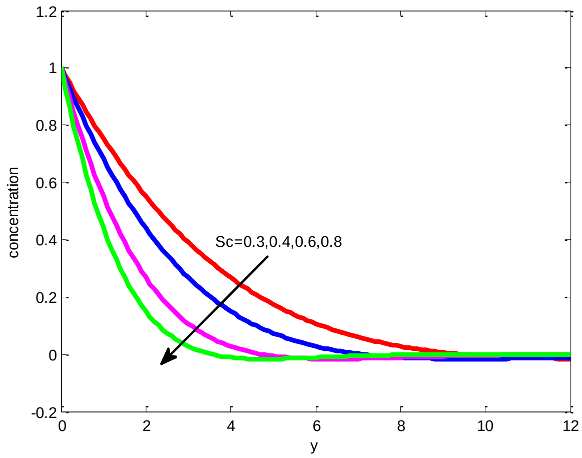

Fig.12. Concentration profile for different values of Schmidt number (Sc)

The contributions of the chemical reaction parameter (Kr) and Schmidt number (Sc) on the concentration profiles is noticed in Figs.11 and 12. It is noticed that the concentration profiles are decreases with an increasing the chemical reaction parameter and Schmidt number values.

V. CONCLUSION

In this mathematical problem has been developed for unsteady MHD flow past a vertical porous plate with variable temperature and mass diffusion in the presence of heat source or sink under the influence of applied transverse magnetic field. The mathematical equations are solved by perturbation technique. The present investigation some results given that follows

- Whenever the Prandtl number, Casson fluid parameter, Grashof number and Heat source values are increasing found that the velocity profiles are increased.
- The temperature profiles are decreased Prandtl number and thermal radiation parameter values increasing.
- Species concentration dereases with increasing the chemical reaction parameter and Schmidt number values.

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