RADIATION AND CHEMICAL REACTION EFFECTS WITH SIMULTANEOUS THERMAL DIFFUSION IN MHD MIXED CONVECTION HEAT AND MASS TRANSFER FLOW FROM A VERTICAL SURFACE WITH OHMIC HEATING

K.LAXMAIAH[1], Dr.M.CHENNA KRISHNA REDDY[2]
[1]Research Scholar of Rayalaseema University, Kurnool, A.P- 518007
[2] Department of Mathematics, Osmania University, Hyderabad, Telangana – 500 007

ABSTRACT

This Paper deals the effects of radiation and chemical reaction with viscous dissipation on steady MHD mixed convective heat and mass transfer flow past an infinite vertical plate embedded in a porous medium in the presence of Ohmic heating have been discussed. The governing equations are coupled and non - linear solved analytically by using multi parameter perturbation technique. Approximate solutions are obtained for velocity, temperature field, concentration profiles, skin - friction and rate heat transfer. The obtained results are discussed with the help of graphs to observe that the effect of various parameters in two cases viz. Case (I): when $Gr > 0$, (i.e. flow on cooled plate) and Case (II): $Gr < 0$ (i.e. flow on heated plate).

Keywords: *Magnetic field, Radiation, Ohmic heating, Chemical reaction*

INTRODUCTION

The effects of radiation on temperature have become more important industrially. Many processes in engineering areas occur at high temperature and acknowledge radiation heat transfer become very important for the design of pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for air craft, missiles, satellites and space vehicles are example of such engineering areas. Hossain and Takhar [15] Raptis and Massals [3] and Hossain et.al [16] studied the radiation effect on free and forced convection flows past a vertical plate, including various physical aspects. Aboeldhab Emad [17] studied the radiation effect in heat transfer in an electrically conducting fluid at stretching surface. At high operating temperature, radiation effect can be quite significant; radiation effect on MHD free convection flow of a gas at a stretching surface with uniform free stream Ghaly and Elabarbary [4]. Heat and mass transfer effects on moving plate in the presence of thermal radiation have been studied by Muthukumarswamy [21] using Laplace technique, Srinathuni Lavanya and Chenna Kesavaiah [23] has heat transfer to MHD free convection flow of viscoelastic dusty gas through a porous medium with chemical reaction, Basant Jha et.al [13] Effects of visocus dissipation on natural convection flow between vertical parallel plates with time – periodic bounday condition, Chaudhary et.al [20] Radiation effect with simultaneous thermal and mass diffusion in MHD mixed convection flow from a vertical surface with Ohmic heating, Mohammad Ibrahim and Suneetha [22] has heat source and chemical effects on MHD convection flow embedded in a porous medium with soret, viscous and joules dissipation. Cebeci and Bradshaw [24] has Physical and computational aspects of convective heat transfer.

The study of Magnotohydrodynamics (MHD) plays an important role in agriculture, engineering and petroleum industries and has its own practical applications. For instance, it may be used to deal with problems such as cooling of nuclear reactors by liquid sodium and induction flow meter, which depends on the potential difference in the fluid in the direction perpendicular to the motion and go the magnetic field. These flows have been studied by several authors – notable among them are Mahapatra et.al [25], Ibrahim Mohamad [11], and Chien – Hsin – Chen [5]. Elbashbeshy [8] studied the heat and mass transfer along a vertical plate under the combined buoyancy effects of thermal and species diffusion, in the presence of magnetic field. Gireesh Kumar and Satyanarayana [12] Mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink. Ch Kesavaiah et.al. [6] Analyzed effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, Makanda et.al [9] Effects of radiation on MHD free convection of a Casson fluid from a horizontal circular cylinder with partial slip in non - darcy proous medium with viscous dissipation, Sugunamma et. al. [26] studied inclined magnetic filed and chemiccal reaction effects on flow over a semi – infinite vertical porous plate through porous medium, Bhavana and Chenna Kesavaiah [27] Perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation.

Ohmic heating and viscous heating play significant roles in the thermal transport of a fluid past a heated surface, and it is also further realistic to incorporate the impact of both the effects on the thermal transport in the boundary layer. In the case of electrolytic refining of mixtures or electrolysis, Ohmic heating plays a vital role. Ohmic heating or Joule heating is the generation of excess heat in the fluid either due to direct current or applied magnetic fields. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer was examined by Pal and Talukdar [7] analyzed Buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and Ohmic heating. Bakr and Raizah [1] Unsteady MHD mixed convection flow of a viscous dissipating micropolar fluid in a boundary layer slip flow regime with Joule heating. Khaled et.al [14] investigated combined effects of Hall and ion-slip currents and Ohmic Heating on MHD of Non-Newtonian power-Law fluid with diffusion and chemical reaction over a moving cylinder. Ganesan et.al [19] considered viscous and Ohmic heating effects in doubly stratified free convective flow over vertical plate with radiation and chemical reaction. Hitesh Kumar studied [10] has been mixed convective–magnetohydrodynamic flow of a micropolar fluid with Ohmic heating, radiation and viscous dissipation over a chemically reacting porous plate subjected to a constant heat flux and concentration gradient. Ananda Reddy et.al [18] studied thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating.

The aim of the present paper is the propagation of thermal energy through air and water solution in the presence of magnetic field and radiation has wide range of applications. Hence, the object is to study the effect of the radiation and chemical reaction on MHD heat and mass transfer in air (Pr = 0.71) and water solution $(\Pr = 7.0)$ past an infinite porous hot vertical plate in the presence of Ohmic heating and transverse magnetic field.

FORMULATION OF THE PROBLEM

We consider the mixed convection flow of an incompressible, electrically conducting viscous fluid radiating and chemically reacting fluid, such that x^*-axis is taken along the plate in upwards direction and y^*-axis is normal to it. A transverse constant magnetic field is applied i.e. in the direction of y^*- axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x^*. Let u^* and v^* be the components of velocity in x^* and y^* directions, respectively, taken along and perpendicular to the plate.

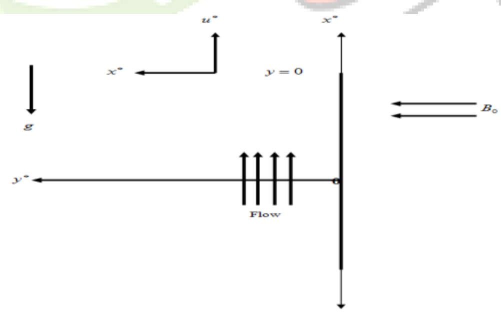

Figure (1): Physical model of the problem

The governing equations of continuity, momentum and energy for a flow of an electrically conducting fluid along a hot, non-conducting porous vertical plate in the presence of concentration and radiation is given by

$$\frac{dv^*}{dy^*} = 0 \tag{1}$$

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

$$\frac{dp^*}{dy^*} = 0 \Rightarrow p^* \text{ is independent of } y^* \tag{3}$$

$$\rho\left(v^* \frac{du^*}{dy^*}\right) = \mu \frac{d^2u^*}{dy^{*2}} + \rho g\,\beta(T^* - T_\infty) + \rho g\beta^*(C^* - C_\infty) - \sigma B_0^2 u^* - \frac{\nu}{K^*}u^* \tag{4}$$

$$\rho C_p\left(v^* \frac{dT^*}{dy^*}\right) = k\frac{d^2T^*}{dy^{*2}} + \mu\left(\frac{du^*}{dy^*}\right)^2 - \frac{\partial q_r^{\,*}}{\partial y^*} - Q_0\left(T^* - T_\infty\right) + \sigma B_0^{\,2} u^{*2} \tag{5}$$

$$v^* \frac{dC^*}{dy^*} = D\frac{d^2C^*}{dy^{*2}} - Kr^*\left(C^* - C_\infty\right) \tag{6}$$

Here, g is the acceleration due to gravity, T^* the temperature of the fluid near the plate, T_∞ the free stream temperature, C^* concentration, β the coefficient of thermal expansion, k the thermal conductivity, P^* the pressure, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ viscosity of the fluid, q^* the radiative heat flux, ρ the density, σ the magnetic permeability of fluid V_0 constant suction velocity, ν the kinematic viscosity and D molecular diffusivity.

The radiative heat flux $q_r^{\,*}$ is given by equation (5) in the sprit of Cogly et.al [2]

$$\frac{\partial q_r^{\,*}}{\partial y^*} = 4(T^* - T_\infty)I' \tag{7}$$

where $I' = \int_0^\infty K_{\lambda w} \frac{\partial e_{b\lambda}}{\partial T^*} d\lambda,$

$K_{\lambda w} -$ is the absorption coefficient at the wall and $e_{b\lambda} -$ is Planck's function, I is absorption coefficient

The boundary conditions are

$$\begin{aligned} &y^* = 0: \quad u^* = 0, \quad T^* = T_w, \; C^* = C_w \\ &y^* \to \infty : u^* \to 0, \; T^* \to T_\infty, \; C^* \to C_\infty \end{aligned} \tag{8}$$

Introducing the following non-dimensional quantities

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

SOLUTION OF THE PROBLEM

In the equations (4), (5), (6) and (8), we get

$$\frac{d^2u}{dy^2} + \frac{du}{dy} - \beta u = -Gr\theta - GmC \tag{10}$$

$$\frac{d^2\theta}{dy^2}+\Pr\frac{d\theta}{dy}+\Pr Ec\left(\frac{du}{dy}\right)^2-\left(R+Q\right)\Pr\theta+\Pr EcMu^2=0 \tag{11}$$

$$\frac{d^2C}{dy^2}+Sc\frac{dC}{dy}-ScKrC=0 \tag{12}$$

Where $\beta=\left(M+\frac{1}{K}\right)$, Gr is solutal Grashof number, Gm is thermal Grashof number, $\Pr$ is Prandtl number, M is Magnetic parameter, R is Radiation parameter, Sc is Schmidt number, Ec is Eckert number, Kr is Chemical reaction parameter, Q is Heat source parameter.

The corresponding boundary condition in dimensionless form are reduced to

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

The physical variables u,θ *and* C can be expanded in the power of Eckert number (Ec). This can be possible physically as Ec for the flow of an incompressible fluid is always less than unity. It can be interpreted physically as the flow due to the Joules dissipation is super imposed on the main flow. Hence we can assume that;

$$\begin{aligned} &u(y)=u_0(y)\ +Ec\,u_1(y)+0\left(E^2\right)\\ &\theta(y)=\theta_0(y)\ +Ec\,\theta_1(y)+0\left(E^2\right)\\ &C(y)=C_0(y)+E\,C_1(y)+0\left(E^2\right) \end{aligned} \tag{14}$$

Using equation (14) in equations (10) – (12) and equating the coefficient of like powers of E, we have

$$u_0''+u_0'-\beta u_0=-Gr\,\theta_0-Gm\,C_0 \tag{15}$$

$$\theta_0''+\Pr\ \theta_0'-\left(R+Q\right)\Pr\theta_0=0 \tag{16}$$

$$C_0''+Sc\,C_0'-KrC_0=0 \tag{17}$$

$$u_1''+u_1'-\beta u_1=-Gr\,\theta_1-Gm\,C_1 \tag{18}$$

$$\theta_1''+\Pr\theta_1'-\left(R+Q\right)\Pr\theta_1=-\Pr u_0'^2-\Pr Mu_0{}^2 \tag{19}$$

$$C_1''+Sc\,C_1'-KrC_1=0 \tag{20}$$

and the corresponding boundary conditions are

$$\begin{aligned} &u_0=0,\quad \theta_0=1, C_0=1 u_1=0,\quad \theta_1=0, C_1=0 \qquad y=0\\ &u_0\to 0, C_0\to 0,\ \theta_0\to 0 u_1\to 0,\ \theta_1\to 0, C_1\to 0 \quad y\to\infty \end{aligned} \tag{21}$$

Solving equations (15) to (20) with the help of (21), we get

$$\begin{aligned} u(y)={}&A_1e^{m_6y}+A_2e^{m_2y}+A_3e^{m_8y}\ +\ Ec\left\{A_{17}e^{m_{12}y}+A_4e^{m_6y}+\ A_5e^{2m_8y}+\ A_6e^{2m_6y}+A_7e^{2m_2y}\right.\\ &+A_8e^{(m_2+m_8)y}+A_9e^{(m_2+m_6)y}+A_{10}e^{(m_2+m_8)y}+\ A_{11}e^{2m_8y}+A_{12}e^{2m_6y}+A_{13}e^{2m_2y}+A_{14}e^{(m_6+m_8)y}\\ &\left.+A_{15}e^{(m_2+m_6)y}+A_{16}e^{(m_2+m_8)y}\right\} \end{aligned}$$

$$\theta(y) = e^{m_6 y} + Ec\left\{B_{13}e^{m_6 y} + B_1 e^{2m_8 y} + B_2 e^{2m_6 y} + B_3 e^{2m_2 y} + B_4 e^{(m_6+m_8)y} + B_5 e^{(m_2+m_6)y} + B_6 e^{(m_2+m_8)y} + B_7 e^{2m_8 y} + B_8 e^{2m_6 y} + B_9 e^{2m_2 y} + B_{10} e^{(m_6+m_8)y} + B_{11} e^{(m_2+m_6)y} + B_{12} e^{(m_2+m_8)y}\right\}$$

$$C(y) = e^{m_2 y}$$

Skin – friction:

The skin-friction coefficient at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_6 A_1 + m_2 A_2 + m_8 A_3 + Ec\{m_{12} A_{17} + m_{10} A_4 + 2m_8 A_5 + 2m_6 A_6 + 2m_2 A_7 + (m_2+m_4)A_8 + (m_2+m_6)A_9 + (m_2+m_8)A_{10} + 2m_8 A_{11} + 2m_6 A_{12} + 2m_2 A_{13} + (m_6+m_8)A_{14} + (m_2+m_6)A_{15} + (m_2+m_8)A_{16}\}$$

Heat Transfer:

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_6 + Ec\{m_{10} B_{13} + 2m_8 B_1 + 2m_6 B_2 + 2m_2 B_3 + (m_6+m_8)B_4 + (m_2+m_6)B_5 + (m_2+m_8)B_6 + 2m_8 B_7 + 2m_6 B_8 + 2m_2 B_9 + (m_6+m_8)B_{10} + (m_2+m_6)B_{11} + (m_2+m_8)B_{12}\}$$

Mass Transfer:

The rate of mass transfer in terms of Sherwood number at the plate is given by

$$Sh = \left(\frac{\partial \psi}{\partial y}\right)_{y=0} = m_2$$

RESULTS AND DISCUSSION

This study brings out of the MHD mixed convection flow of a viscous incompressible electrically conducting fluid over an infinite vertical porous plate in the presence of magnetic field with Ohmic heat has been carried out in the preceding sections, taking radiation effect and chemical reaction into account. To know the physics of the problem the graphical illustration of the velocity, temperature concentration, skin friction, heat and mass transfer for two cases viz. (i) for cooling of the plate $(Gr > 0)$ and (ii) for heating of the plate $(Gr < 0)$. The values of Prandtl number (Pr) are taken 0.71 which represent air respectively. The obtained results are illustrated in figures from (2) to (14).

Velocity profiles:

Figure (2) is plotted for velocity profiles for different values of permeability parameter (K). It is seen here that increasing permeability parameter the velocity increases. An increase in the porosity parameter physically means reduce the drag force and hence causes the flow velocity to increases. Figure (3) presents typical velocity profiles in the boundary layer for various values of the solutal Grashof number (Gm), 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 Gm. This is evident in the increase in the value of u as Gm increases in figure (3). Figure (4) shows the variation of u (the component of velocity in the direction of motion of the plate) with y for different values of the chemical reaction parameter (Kr). It can be seen that the axial velocity at any given instant and at a given height from the plate decreases with an increase in chemical reaction parameter. Figure (5) depict the velocity profiles for different values of magnetic parameter (M). It is found that the velocity profiles are decreased by increasing magnetic parameter. Lorentz force increases for larger magnetic parameter. Such force acts as a resistive agent to fluid motion. Consequently velocity and corresponding boundary layer are decreased. Figure (6) depicts velocity profiles (u) versus y for the various values of Prandtl number $(\Pr)$, it is observed that an increasing Prandtl number the velocity decreases. Physically this is true because the increase in the Prandtl number is due to increase in the viscosity of the fluid which makes the fluid thick and hence a decrease in the velocity of the fluid. The effect of increasing the value of the heat source parameter (Q) is to decrease the boundary layer as shown in figure (7), which is as expected due to the fact that when heat is absorbed the buoyancy force decreases which retards the flow rate and thereby giving rise to decrease in the velocity profiles. Effect of radiation parameter (R) on velocity profiles presented in figure (8) from which it is clear that increases radiation parameter lead to the decrease the boundary layer thickness and to enhance the heat transfer rate in the presence of thermal and solutal buoyancy force. To illustrate the effects of Schmidt number (Sc) on velocity distribution near the plate is presented in figure (9). The velocity gradient for air Pr (0.71) is always greater than the water Pr (7.0). Physically, this is true because the increase in the Schmidt number is due to increase in the viscosity of the fluid which makes the fluid thick and hence causes a decrease in the velocity of the fluid. An increase in Schmidt number leads to a fall in the velocity.

Temperature profiles:

The effects of the viscous dissipation parameter i.e., the Eckert number on the temperature are shown in figure (10), greater viscous dissipative heat causes a rise in the temperature. The temperature profiles for different values of solutal Grashof number and modified Grashof number are shown in figures (11) and (12). From these figures we observed that an increasing modified Grashof number the temperature profiles decrease, while the reverse effect observed in solutal Grashof number. Figure (13) shows the velocity and temperature profiles for different values of the permeability parameter (K). Clearly, as K increases the peak values of the velocity tends to decreases in the temperature. The effects of the chemical reaction parameter (Kr) on the temperature profiles are shown in figure (14). It is noticed that an increase in the chemical reaction parameter results a decrease in the temperature within the boundary layer. This emphasizes the influence of the injected flow in the cooling process. Figure (15) shows the effect of magnetic field parameter on temperature distribution. Temperature increases as magnetic field parameter increases. Figure (16) temperature decreases with the increasing value of the Prandtl number $(\Pr)$. Prandtl number is very important for temperature profiles. It is clear that increasing Prandtl number increases temperature profiles and the thickness of the thermal boundary layer. An increase Prandtl number leads to a fall in the temperature. Figure (17) has been plotted to depict the variation of temperature profiles against y for different values of heat source parameter (Q) by fixing other parameter. It is observed from this graph that temperature decrease with increasing heat source parameter. It is observed in figure (18) that the temperature (θ) decreases as the radiation parameter (R) increases. Figure (19) display the effects of Schmidt number on the temperature respectively. As the Schmidt number increases, temperature decreases.

Spices Concentration profiles:

Concentration profiles for different values of chemical reaction parameter (Kr) shown in figure (20). The species concentration decreases as chemical reaction parameter increases. In turn, this causes the concentration buoyancy effects to decrease as Kr increases. Consequently, less flow is induced along the cylinder resulting in decreases in the fluid velocity in the boundary layer. Schmidt number very important in concentration. From figure (21), we conclude that the concentration decreases as Schmidt number increases. As expected concentration is lower for system with larger values of Schmidt number. These behaviours are clearly depicted in figures (20) – (21). Figure (22) shows that the effect for different values of magnetic field parameter on the skin-friction. As the magnetic field parameter increases ski-friction versus Grashof number. Nusselt number observed for various values of radiation parameter in figure (23), it shows that the Nusselt number decreases with increases in radiation parameter.

Conclusion

In the present investigation an analysis in order to study radiation effect with simultaneous thermal diffusion in MHD mixed convection heat and mass transfer flow from a vertical surface with Ohmic heating and chemical reaction were carried out. The equations governing such flow are transformed to dimensionless form; the ultimate resulting equations obtained are solved use perturbation method. The results are shown graphically for different values of the parameters considered in the analysis. The present investigation can be concluded as follows:

- The velocity of the fluid decreases with $Kr, M, \Pr, Q, R, Sc$ on cooled plate but increases on heated plate
- Velocity field is considerably affected even for small values of K
- Magnetic field retards the motion of the fluid
- Chemical effects lowered the temperature of the fluid
- Velocity and temperature profiles are higher for mercury than electrolytic solution
- Chemical effect decreased the concentration of the fluid

Application

The results of this study can be applied in many chemical engineering processes such as drying, evaporation, condensation, sublimation and crystal growth as well as deposition of thin films. These processes take place in numerous industrial applications, e.g., polymer production, manufacturing of ceramics or glassware and food processing. In nature, the presence of pure air or water is rather impossible. It is always possible that some other foreign mass is either present naturally in air, water or foreign masses are mixed with air or water. Simple example is the naturally available water - vapour in nature which causes the flow of air. The flow is also caused by the differences in concentration or material constitution. The presence of foreign mass in air or water causes, many times, some kind of Soret and chemical effects combined, For e.g., ammonia, benzene, ethyl alcohol etc., react with air when they come in contact under certain conditions.

APPENDIX

$$m_2 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}\right) \quad m_6 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\beta_1}}{2}\right) \quad m_8 = -\left(\frac{1 + \sqrt{1 + 4\beta}}{2}\right)$$

$$A_1 = -\frac{Gr}{m_6^{\ 2} + m_6 - \beta} \quad A_2 = -\frac{Gr}{m_2^{\ 2} + m_2 - \beta}, \ A_3 = -\left(A_1 + A_2\right) \ \beta_1 = \left(F + Q\right)\Pr \ \beta = \left(M + \frac{1}{K}\right)$$

$$A_4 = -\frac{GrB_{13}}{m_{10}^{\ 2} + m_{10} - \beta} \ A_5 = -\frac{GrB_1}{4m_8^{\ 2} + 2m_8 - \beta} \ A_6 = -\frac{GrB_2}{4m_6^{\ 2} + 2m_6 - \beta} \ A_7 = -\frac{GrB_3}{4m_2^{\ 2} + 2m_2 - \beta}$$

$$A_8 = -\frac{GrB_4}{(m_6+m_8)^2+(m_6+m_8)-\beta} \quad A_9 = -\frac{GrB_5}{(m_2+m_6)^2+(m_2+m_6)-\beta} \quad A_{10} = -\frac{GrB_6}{(m_2+m_8)^2+(m_2+m_8)-\beta}$$

$$A_{11} = -\frac{GrB_7}{4m_8^{\ 2}+2m_8-\beta} \quad A_{12} = -\frac{GrB_8}{4m_6^{\ 2}+2m_6-\beta} \quad A_{13} = -\frac{GrB_9}{4m_2^{\ 2}+2m_2-\beta} \quad A_{14} = -\frac{GrB_{10}}{(m_6+m_8)^2+(m_6+m_8)-\beta}$$

$$A_{15} = -\frac{GrB_{11}}{(m_2+m_6)^2+(m_2+m_6)-\beta} \quad A_{16} = -\frac{GrB_{12}}{(m_2+m_8)^2+(m_2+m_8)-\beta}$$

$$A_{17} = -\left(A_4+A_5+A_6+A_7+A_8+A_9+A_{10}+A_{11}+A_{12}+A_{13}+A_{14}+A_{15}+A_{16}\right)$$

$$B_1 = -\frac{\Pr A_3^2 m_8^2}{4m_8^{\ 2}+2\Pr m_8-\beta_1} \quad B_2 = -\frac{\Pr A_1^2 m_6^2}{4m_6^{\ 2}+2\Pr m_6-\beta_1} \quad B_3 = -\frac{\Pr A_2^2 m_2^2}{4m_2^{\ 2}+2\Pr m_2-\beta_1}$$

$$B_4 = -\frac{2\Pr A_1 A_3 m_6 m_8}{(m_6+m_8)^2+(m_6+m_8)-\beta_1} \quad B_5 = -\frac{2\Pr A_1 A_2 m_2 m_6}{(m_2+m_6)^2+(m_2+m_6)-\beta_1} \quad B_6 = -\frac{2\Pr A_2 A_3 m_2 m_8}{(m_2+m_8)^2+(m_2+m_8)-\beta_1}$$

$$B_7 = -\frac{\Pr MA_3^2}{4m_8^{\ 2}+2\Pr m_8-\beta} \quad B_8 = -\frac{\Pr MA_1^2}{4m_6^{\ 2}+2\Pr m_6-\beta} \quad B_9 = -\frac{\Pr MA_2^2}{4m_2^{\ 2}+2\Pr m_2-\beta}$$

$$B_{10} = -\frac{2\Pr MA_1 A_3}{(m_6+m_8)^2+\Pr(m_6+m_8)-\beta_1} \quad B_{11} = -\frac{2\Pr MA_1 A_2}{(m_2+m_6)^2+\Pr(m_2+m_6)-\beta_1}$$

$$B_{12} = -\frac{2\Pr MA_2 A_3}{(m_2+m_8)^2+\Pr(m_2+m_8)-\beta_1}$$

$$B_{13} = -\left(B_1+B_2+B_3+B_4+B_5+B_6+B_7+B_8+B_9+B_{10}+B_{11}+B_{12}\right)$$

REFERENCES

1. A A Bakr and Z A S Raizah (2012): Unsteady MHD mixed convection flow of a viscous dissipating micropolar fluids in a boundary layer slip flow regime with Joule heating, *International Journal of Scientific & Engineering Research, Vol. 3, (8)*
2. A C Cogly, W C Vincentry and S E Gilles (1968): A Differential approximation for radiative transfer in a non-gray gas near equilibrium, *AIAA Journal*, *Vol. 6: pp. 551-555*
3. A Raptis C V Massals (1998): Flow pas a plateby the presence of radiation, *Heat and Mass Transfer, Vol. 34, p. 107*
4. A Y Ghaly and E M E Elbarbary (2002): Radiation effect on MHD free convection flow of a gas at a stretching surface with unifrom free stream, *J. Appl. Math, Vol. 2, p. 93*
5. Chien-Hsin-Chen (2004): Combined heat and mass transfer in MHD free convection from a vertical surface with ohimic heating and viscous dissipation, *Int. J. Eng Sci, 42 (7), 699-713*
6. D Ch Kesavaiah, P V Satyanarayana and S Venkataramana (2011): Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, *Int. J. of Appl. Math and Mech. Vol. 7 (1),* pp. 52-69

7. D Pal and B Talukdar (2010): Buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and Ohmic heating, *Commun Nonlinear Sci Numer Simul, Vol. 15 (2), pp. 878 893*

8. E M A Eilbashbeshy (1997): Heat and mass transfer along a vertical plate surface tension and concentration in the presence of magnetic field, *Int. J. Eng. Sci., Vol. 34 (5), pp. 515-522*

9. G Makanda, Sachin Shaw and Precious Sibanda (2015): Effects of radiation on MHD free convection of a Casson fluid from a horizontal circular cylinder with partial slip in non_darcy proous medium with viscous dissipation, *Boundary Value Problems, Vol. 75, pp. 1-14*

10. Hitesh Kumar (2014): Mixed convective–magnetohydrodynamic flow of a micropolar fluid with Ohmic heating, radiation and viscous dissipation over a chemically reacting porous plate subjected to a constant heat flux and concentration gradient, *J. Serb. Chem. Soc. Vol. 79 (4), pp. 469–480*

11. Ibrahim Mohamad (2013): Effects of mass trasnfer, radiation, Joule heating and viscous disssipation on steady MHD marangoni convection flow over a flat surface with suction and injection. *Int J Eng Math, 9, 903818*

12. J Gireesh Kumar and P V Satyanarayana (2011): Mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink, *Int. J. of Appl. Math and Mech., Vol. 7(19), pp. 97 – 109*

13. K Basant Jha, O Abiodun amd Ajibade (2012): Effects of visocus dissipation on natural convection flow between vertical parallel plates with time – periodic bounday condition, *Commun Nonlinear Sci Numer Simulat, Vol. 17, pp. 1576-1587*

14. K Khaled Jaber and Faris M. Al-Athari (2013): Combined Effects of Hall And Ion-Slip Currents and Ohmic Heating on MHD of Non-Newtonian Power-Law Fluid With Diffusion and Chemical Reaction Over a Moving Cylinder, *Journal of Purity, Utility Reaction and Environment., Vol. 2 (1), pp. 525-537*

15. M A Hossain, H S Takhar (1996): Radiation effect on mixed convection along a vertical plate with uniform surface temperature, *Heat and Mass Trasnfer, Vol. 31, p. 243*

16. M A Hossain, M A Alim and D A Ress (1999): The effect of radiation in free convection from a porous vertical plate, *Int. J. Heat and Mass Transfer, Vol. 42, p. 131*

17. M Aboeldahab Emad (2000): Radiation effect on heat transfe in an electrically conducting fluid at a stretching surface with uniform free stream, *J. Phys. D., Appl. Phys, Vol. 33, p. 3180*

18. N Ananda Reddy, S V K Varma and M C Raju (2009): Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating, *Journal of Naval Architecture and Marine Engineering, Vol, 6, pp. 84-93*

19. P Ganesan, R K Suganthi and P Loganathan (2013): Viscous and Ohmic heating effects in doubly stratified free convective flow over vertical plate with radiation and chemical reaction, *Appl. Math. Mech. -Engl. Ed.,* Vol. *34 (2), pp. 139–152*

20. R C Chaudhary, Bhupendra Kumar Sharma and Abhay Kumar Jha (2006): Radiation effect with simultaneous thermal and mass diffusion in MHD mixed convection flow from a vertical surface with Ohmic heating, rom. *Journ. phys., Vol. 51, nos. 7–8, p. 715–727, Bucharest, 2006*

21. R Muthukumaraswamy and G Kumar Senthil (2004): Heat and mass transfer effect on moving vertical plate in the presence of thermal radiation, *Theoret. Appl. Mec, Vol. 31, p. 35*

22. S Mohammad Ibrahim and K Suneetha (2016): Heat source and chemical effects on MHD convection flow embedded in a porous medium with soret, viscous and joules dissipation, *Ain Shams Engineering Journal, 7, pp. 811-818*

23. Srinathuni Lavanya and D Chenna Kesavaiah (2017): Heat transfer to MHD free convection flow of viscoelastic dusty gas through a porous medium with chemical reaction, *International Journal of Pure and Appllied Researches, Vol. 3 (1), pp. 43-56*

24. T Cebeci and P Bradshaw (1988): Physical and computational aspects of convective heat transfer, *Springer – Verlag, New York, USA*

25. T R Mahapatra, S Dholey and A S Gupta (2007): Momentum and heat trasnfer in the MHD stagnation point flow of a visco – elastic fluid toward a streaching surface, *Mechanica, 42:263 -272*

26. V Sugunamma, N Sandeep, P M Krishna, R Bahunandam (2013): Inclined magnetic filed and chemiccal reaction effects on flow over a semi – infinite vertical porous plate through porous medium, *Commun. Appl. Sci, Vol. 1, pp. 1-24*

27. M Bhavana and D Chenna Kesavaiah (2018): Perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation, *International Journal of Future Revolution in Computer Science & Communication Engineering, Vol. 4 (1), pp. 215-220.*

FIGURES:

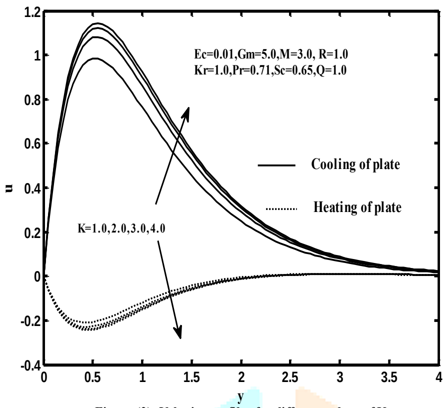

Figure (2): Velocity profiles for different values of K

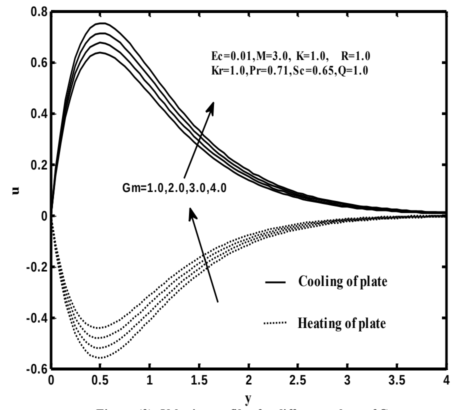

Figure (3): Velocity profiles for different values of Gm

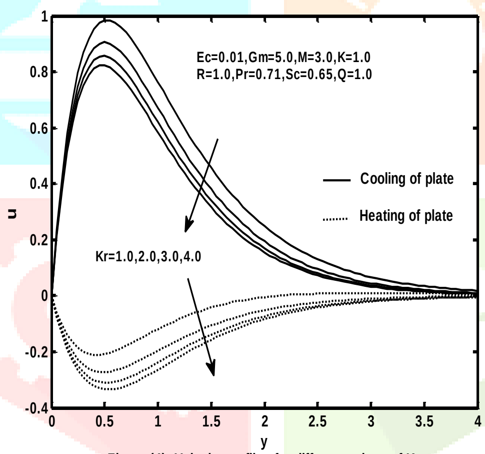

Figure (4): Velocity profiles for different values of Kr

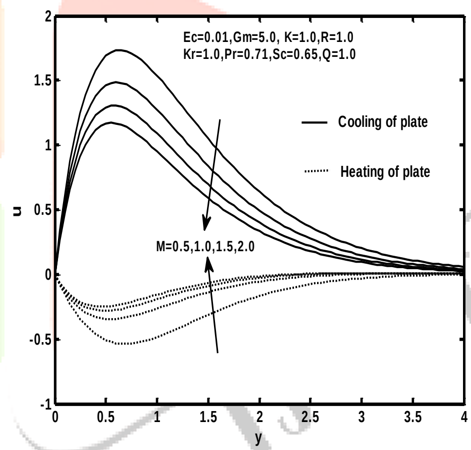

Figure (5): Velocity profiles different values of M

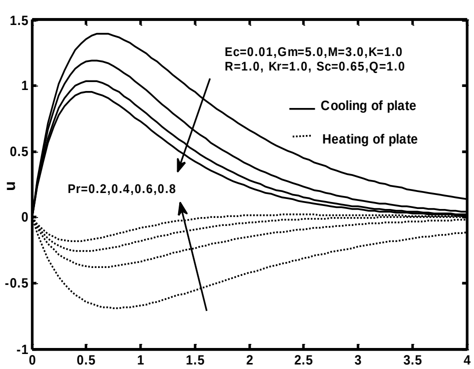

Figure (6): Velocity profiles for different values Pr

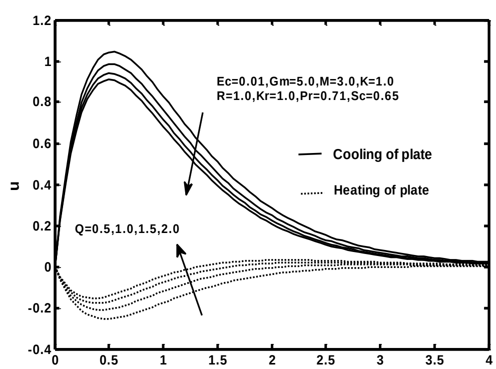

Figure (7): Velocity profiles for different values Q

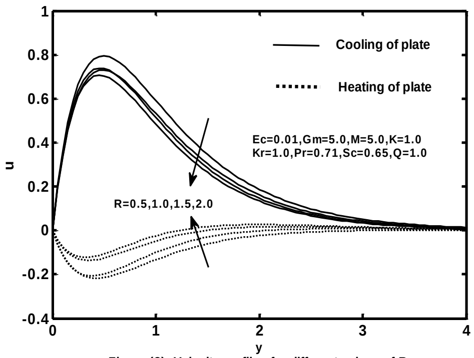

Figure (8): Velocity profiles for different values of R

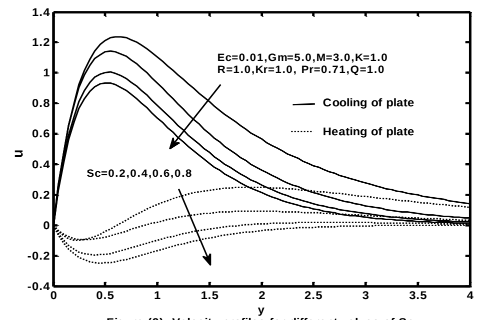

Figure (9): Velocity profiles for different values of Sc

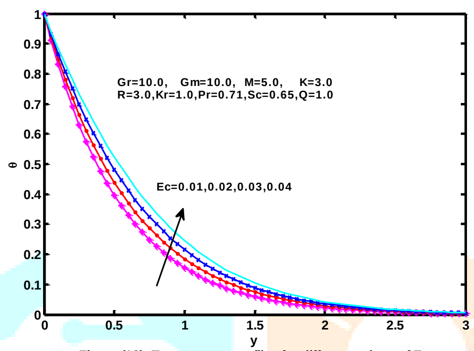

Figure (10): Temperature profiles for different values of Ec

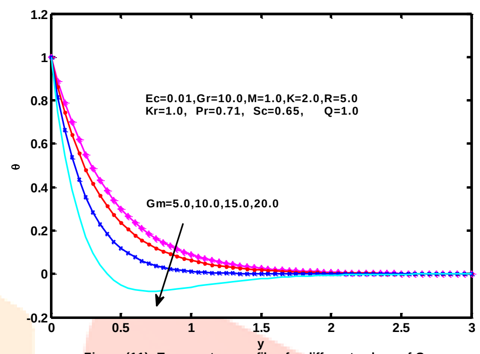

Figure (11): Temperature profiles for different values of Gm

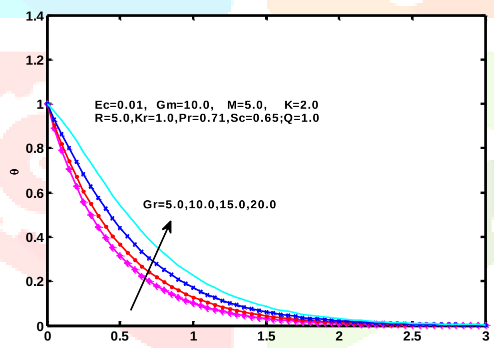

Figure (12): Temperature profiles for different values of Gr

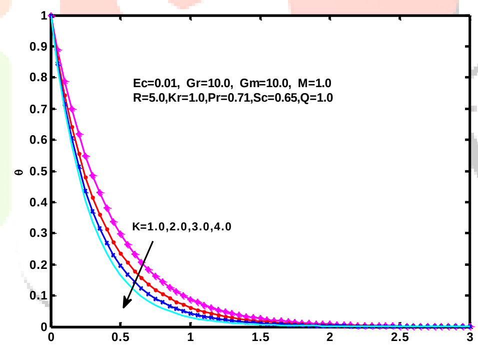

Figure (13): Temperature profiles for different values of K

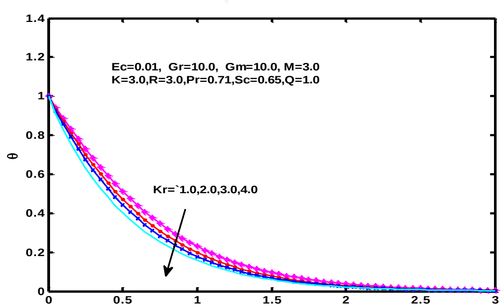

Figure (14): Temperature profiles for different values of Kr

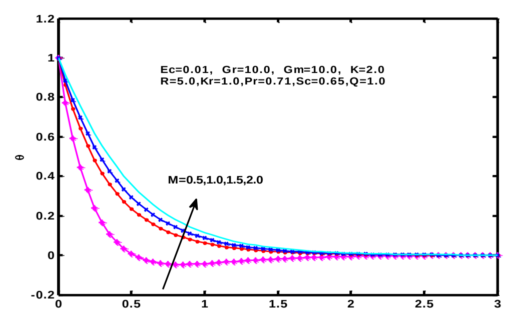

Figure (15): Temperature profiles for different values of Kr

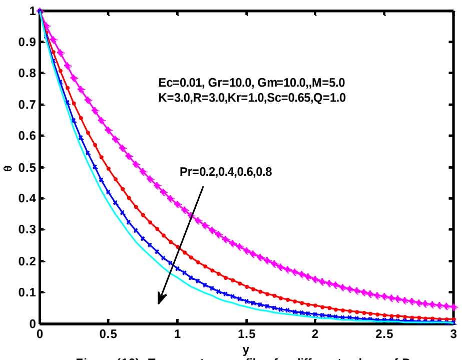

Figure (16): Temperature profiles for different values of Pr

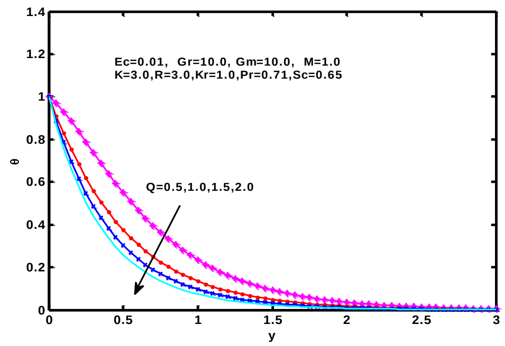

Figure (17): Temperature profiles for different values of Q

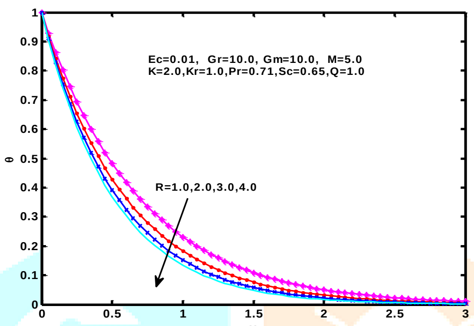

Figure (18): Temperature profiles for different values of R

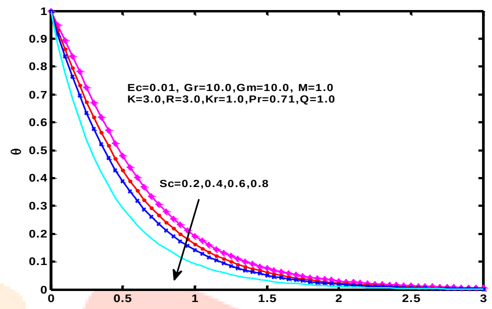

Figure (19): Temperature profiles for different values of Sc

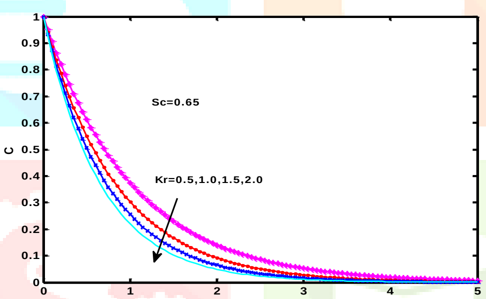

Figure (20): Concentration profiles for different values of Kr

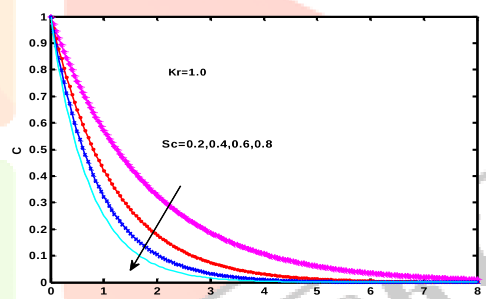

Figure (21): Concentration profiles for different values of Kr

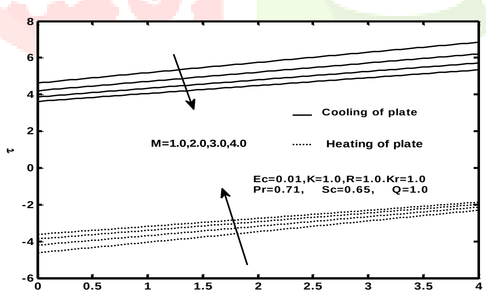

Figure (22): Skin friction for differnt values of M versus Gm

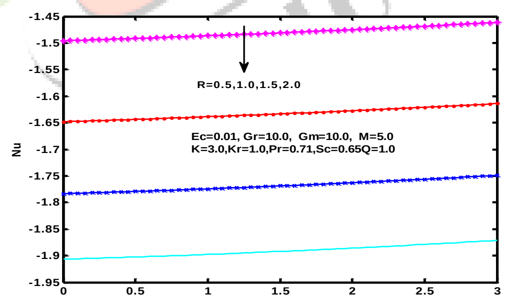

Figure (23): Nusselt number for differnt values of R versus Gr

Acknowledgment: I am very much Thankful to Rayalaseema University, Kurnool, A.P