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Steady Mhd Mixed Convective Flow in Presence of Inclined Magnetic Field and Thermal Radiation With Effects of Chemical Reaction and Soret Embedded in A Porous Medium

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ABSTRACT

An analysis is made to study the effects of Thermal Radiation and Inclined Magnetic field on a steady MHD mixed convective flow for an incompressible viscous fluid filled with a porous materials between the plates with chemical reaction and soret is presented. An analytical solutions of momentum, energy and species are solved by using perturbation technique. Appropriate solutions for velocity, temperature and concentration fields are obtained. Expressions for Skin friction, Nusselt number and Sherwood number are also estimated. The effects of various non-dimensional parameters Magnetic field M, Inclined angle α, Thermal Radiation R, Thermal Grashof number Gr, Mass Grashof number Gm, Soret number So, Prandtl number Pr, Schmidt number Sc and Chemical reaction Kr on Velocity, Temperature and Concentration fields are discussed through graphs.

Keywords: Thermal Radiation, Inclined Magnetic Field, Soret, Chemical reaction and MHD

I. INTRODUCTION

Mixed convection (forced and natural convection) used in very high power output devices to dissipate all of the heat necessary. MHD is the study of the magnetic properties of electrically conducting fluids and also controls the rate of cooling. The importance of MHD is enhanced in Geophysics, Astrophysics, Engineering, Magnetic drug targeting, etc. Heat and Mass transfer has broad application to functioning of numerous devices and systems. Fluid flow through porous medium is a study of common behaviour of porous media involving deformation of the solid frame. The movement of fluid in porous media has significant interest to study the fluid flow and has very good applications in inkjet printing and nuclear waste disposal technologies. Combined heat and mass transfer by mixed convection in a porous medium has many important climate engineering, green house effect, laser cooling, radiative cooling, astrophysics, chemical engineering, etc.

K.A. Yih (1997) studied the effect of uniform transpiration rate on the heat and mass transfer characteristics in mixed convection flow over a vertical permeable plate embedded in porous medium and subjected to uniform wall temperature and species concentration. N. Ahmed and D. Sarma (1997) discussed the problem of three dimensional flow when the medium is porous. They have been observed that the permeability has significant effect on the fluid flow and the heat transfer.

R. Muthucumaraswamy (2002) deals with the combined effects of heat and mass transfer on continuously moving vertical surface with suction

effect in the presence of first order homogeneous chemical reaction. R. Kandasamy, K. Periasamy, K.K. Sivagnana Prabhu (2004) studied the effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration due to
to suction or injection. N. Ananda Reddy, S.V.K. Varma and M.C. Raju (2009) analyzed the combined effects of thermal and mass diffusion with thermo diffusion and chemical effects on heat and mass transfer of mixed convective MHD flow in the propagation of thermal energy through electrolytic solution and mercury due to magnetic field. O.D. Makinde (2011) has studied the thermophoresis and diffusion thermo on MHD mixed convection past a vertical plate embedded in a porous medium. The numerical studies are performed to examine the effects of Soret and Dufour by both natural and forced convection act together to transfer heat. V. Ravikumar, M.C. Raju and G.S.S. Raju (2012) observed that the effects of heat and mass transfer on MHD flow of a viscous fluid through non-homogeneous porous medium in presence of temperature. It also observed that the non-homogeneous porous medium is taken for oscillatory flow of an incompressible and electrically conducting viscous on fluid flow in presence of magnetic field. S. Mohammed Ibrahim and K. Suneetha (2015) have examined the effects of Soret and chemical reaction on unsteady MHD flow of a viscoelastic fluid past an impulsively started infinite vertical plate in presence of viscous dissipation and heat source/sink.

The present work is proposed to study the effects of thermal radiation and inclined magnetic field on MHD mixed convection flow embedded in a porous medium due to the steady two dimensional flow of an incompressible electrically conducting viscous fluid. The objective of this work is to analyze the chemical reaction, thermal radiation, inclined magnetic field, Soret, viscous and joules dissipation of the heat and mass transfer and also analyzed the characteristic of the flow.

II. MATHEMATICAL ANALYSIS

The two dimensional steady MHD mixed convective flow of a viscous incompressible electrically conducting fluid embedded in a porous medium is considered in the presence of thermal radiation and inclined magnetic field. The flow is assumed to be in the x^* - direction which is taken along the vertically upward plate and y^* is taken perpendicular to the plate. A uniform magnetic flux density B_0 which is inclined at an angle α is applied to the flow of the fluid. Due to the infinite vertical plate neglects x^* and since the flow is steady so all the physical quantities are depend on y^* only. From these assumptions, the governing equations are formed by the following equations.

$$\frac{\partial v^*}{\partial y^*} = 0, v^* = -v_0 \ (v_0 > 0), \tag{1}$$

$$v^* \frac{d u^*}{dy^*} = \nu \frac{d^2u^*}{dy^{*2}} + g\beta(T^* - T_\infty) + g\beta^*(C^* - C_\infty) - \frac{\sigma {B_0}^2}{\rho} \sin^2\alpha \, u^* - \frac{\nu}{k^*} u^* \tag{2}$$

$$v^* \frac{d T^*}{dy^*} = \frac{k}{\rho C_P} \frac{d^2T^*}{dy^{*2}} + \frac{\nu}{C_P}\left(\frac{d u^*}{dy^*}\right)^2 + \frac{\sigma {B_0}^2}{\rho C_P} u^{*2} + \frac{Q_0}{\rho C_P}(T^* - T_\infty) - \frac{1}{\rho C_P}\frac{d{q_r}^*}{dy^*} \tag{3}$$

$$v^* \frac{d C^*}{dy^*} = D \frac{d^2C^*}{dy^{*2}} + D_1 \frac{d^2T^*}{dy^{*2}} - k_1(C^* - C_\infty) \tag{4}$$

where u^* and v^* are velocity components in x^* and y^* directions respectively, g is the acceleration due to gravity, β is the thermal expansion coefficient, T^* is the temperature of the fluid, T_∞ is the temperature away from the plate, T_W is the temperature near the plate, β^* is the mass expansion coefficient, C^* is the concentration of the fluid, C_∞ is the concentration away from the plate, C_W is the concentration near the plate, σ is the magnetic permeability of the fluid, B_0 is the coefficient of magnetic field, ρ is the density of the fluid, α is the angle between v and B_0 which means that the two fields able to be assessed at any one angle for $0 \le \alpha \le \pi$, ν is the kinematic viscosity, k^* is the permeability of porous medium, k is the thermal conductivity, C_P is the specific heat at constant pressure, q_r is the radiative heat flux, D is the chemical molecular diffusivity, D_1 is the thermal diffusivity, k_1 is the chemical reaction rate constant.

By the use of Rosseland approximation, the radiative heat flux q_r is given by,

$$q_r = -\frac{4}{3}\frac{\sigma}{k^*}\frac{dT^4}{dy^*} \tag{5}$$

Where T^4 denote the temperature difference of the fluid and considered as small then T^4 solve by using Taylor Series and removing the higher order terms,

$$T^4 = 4T_\infty{}^3 T - 3T_\infty{}^4 \tag{6}$$

By using equations (5) and(6), equation (3) reduces to

$$v^*\frac{dT^*}{dy^*} = \frac{k}{\rho C_P}\frac{d^2T^*}{dy^{*2}} + \frac{\nu}{C_P}\left(\frac{du^*}{dy^*}\right)^2 + \frac{\sigma B_0{}^2}{\rho C_P}u^{*2} + \frac{Q_0}{\rho C_P}(T^* - T_\infty) + \frac{1}{\rho C_P}\frac{16\sigma T_\infty{}^3}{3k^*}\frac{d^2T}{dy^{*2}} \tag{7}$$

Velocity, temperature and concentration boundary conditions are as follows:

$$y^* = 0\ :\ u^* = 0\ ;\ T^* = T_w;\ C^* = C_w$$
$$y^* \to \infty :\ u^* \to 0\ ;\ T^* \to T_\infty;\ C^* \to C_\infty \tag{8}$$

On introducing the following non-dimensional quantities,

$$u = \frac{u^*}{v_0}, y = \frac{y^* v_0}{\nu}, \nu = \frac{\mu}{\rho}, k^* = \frac{\nu}{K_0 v_0{}^2}, Q = \frac{Q_0 \nu}{\rho C_P v_0{}^2},$$
$$M^* = \frac{\sigma B_0{}^2 \nu}{\rho v_0{}^2}, M = M^* * \sin^2\alpha, \theta = \frac{T^* - T_\infty}{T_w - T_\infty},$$
$$\phi = \frac{C^* - C_\infty}{C_w - C_\infty}, Gr = \frac{\nu g\beta(T_w - T_\infty)}{v_0{}^3}, \quad Gm = \frac{\nu g\beta^*(C_w - C_\infty)}{v_0{}^3},$$
$$Pr = \frac{\nu\rho C_P}{k}, So = \frac{D_1(T_w - T_\infty)}{\nu(C_w - C_\infty)}, Sc = \frac{\nu}{D}, R = \frac{16\sigma T_\infty{}^3}{3kk^*},$$
$$Kr = \frac{\nu k_1}{v_0{}^2} \tag{9}$$

Where M is the inclined magnetic parameter, Gr is the thermal Grashof number, Gm is the mass Grashof number, Pr is the Prandtl number, Ec is the Eckert number, R is the Thermal radiation, So is the Soret number, Sc is the Schmidt number, Kr is the chemical reaction parameter.

By using dimensionless quantities (9) in equations (2), (3) and (7) then the governing equations are reduced in the form as,

$$u'' + u' - (M + K_0)\,u = -Gr\theta - Gm\phi \tag{10}$$

$$(1 + R)\theta'' + Pr\,\theta' + Pr\,Q\theta = -Pr\,Ec(u')^2 - Pr\,Ec\,M\,u^2 \tag{11}$$

$$\phi'' + Sc\,\phi' - Sc\,Kr\,\phi = -So\,Sc\,\theta'' \tag{12}$$

The boundary conditions in non-dimensional form as,

$$y = 0\ :\ u = 0\ ;\ \theta = 1;\ \phi = 1$$
$$y \to \infty\ :\ u \to 0;\ \theta \to 0;\ \phi \to 0 \tag{13}$$

Analytical Solution:

A set of obtained ordinary differential equations (10) – (12) can be solved analytically by using the perturbation technique to representing velocity, temperature and concentration of the fluid. The appropriate solutions for the equations are as follows,

$$u(y) = u_0(y) + Ec\,u_1(y) + O(Ec^2) \tag{14}$$

$$\theta(y) = \theta_0(y) + Ec\,\theta_1(y) + O(Ec^2) \tag{15}$$

$$\phi(y) = \phi_0(y) + Ec\,\phi_1(y) + O(Ec^2) \tag{16}$$

Substitutes (14) – (16) in (10) – (12) then equating the zeroth and first order of Eckert number (Ec) and neglecting the higher order of Eckert number $O(Ec^2)$ and simplifying to get the set of following equations

Zeroth Order:

$$u_0'' + u_0' - (M + K_0)\,u_0 = -Gr\theta_0 - Gm\phi_0 \tag{17}$$

$$(1 + R)\theta_0'' + Pr\,\theta_0' + Pr\,Q\theta_0 = 0 \tag{18}$$

$$\phi_0'' + Sc\,\phi_0' - Sc\,Kr\,\phi_0 = -So\,Sc\,\theta_0'' \tag{19}$$

First Order:

$$u_1'' + u_1' - (M + K_0)\,u_1 = -Gr\theta_1 - Gm\phi_1 \tag{20}$$

$$(1 + R)\theta_1'' + Pr\,\theta_1' + Pr\,Q\theta_1 = -Pr\,Ec(u_0')^2 - Pr\,Ec\,M\,u_0{}^2 \tag{21}$$

$$\phi_1'' + Sc\,\phi_1' - Sc\,Kr\,\phi_1 = -So\,Sc\,\theta_1'' \tag{22}$$

Initial and Boundary conditions are as follows,

$$y = 0: u_0 = 0, u_1 = 0; \theta_0 = 1, \theta_1 = 0; \phi_0 = 1, \phi_1 = 0$$
$$y \to \infty: u_0 \to 0, u_1 \to 0; \theta_0 \to 0, \theta_1 \to 0; \phi_0 \to 0, \phi_1 \to 0 \tag{23}$$

Applying the above condition (23) to the equations (17) to (22) then the obtained solutions are,

$$u_0 = B_5 e^{-h_3 y} + B_4 e^{-h_2 y} + B_3 e^{-h_1 y} \tag{24}$$

$$\theta_0 = e^{-h_1 y} \tag{25}$$

$$\phi_0 = B_2 e^{-h_2 y} + B_1 e^{-h_1 y} \tag{26}$$

$$u_1 = \begin{pmatrix} B_{29}e^{-h_6 y} + B_{21}e^{-h_5 y} + B_{22}e^{-h_4 y} + B_{23}e^{-2h_3 y} + B_{24}e^{-2h_2 y} \\ +B_{25}e^{-2h_1 y} + B_{26}e^{-(h_2+h_3)y} + B_{27}e^{-(h_1+h_2)y} + B_{28}e^{-(h_1+h_3)y} \end{pmatrix} \tag{27}$$

$$\theta_1 = \begin{pmatrix} B_{12}e^{-h_4 y} + B_6 e^{-2h_3 y} + B_7 e^{-2h_2 y} + B_8 e^{-2h_1 y} \\ +B_9 e^{-(h_2+h_3)y} + B_{10}e^{-(h_1+h_2)y} + B_{11}e^{-(h_1+h_3)y} \end{pmatrix} \tag{28}$$

$$\phi_1 = \begin{pmatrix} B_{20}e^{-h_5 y} + B_{13}e^{-h_4 y} + B_{14}e^{-2h_3 y} + B_{15}e^{-2h_2 y} + B_{16}e^{-2h_1 y} \\ +B_{17}e^{-(h_2+h_3)y} + B_{18}e^{-(h_1+h_2)y} + B_{19}e^{-(h_1+h_3)y} \end{pmatrix} \tag{29}$$

Substituting equations (24) – (29) in equations (14) – (16) then the obtained mean velocity, mean temperature and mean concentrations in the boundary layer as follows:

$$U(y) = (B_5 e^{-h_3 y} + B_4 e^{-h_2 y} + B_3 e^{-h_1 y}) + Ec\begin{pmatrix} B_{29}e^{-h_6 y} + B_{21}e^{-h_5 y} + B_{22}e^{-h_4 y} + B_{23}e^{-2h_3 y} + B_{24}e^{-2h_2 y} \\ +B_{25}e^{-2h_1 y} + B_{26}e^{-(h_2+h_3)y} + B_{27}e^{-(h_1+h_2)y} + B_{28}e^{-(h_1+h_3)y} \end{pmatrix} \tag{30}$$

$$\theta(y) = (e^{-h_1 y}) + Ec\begin{pmatrix} B_{12}e^{-h_4 y} + B_6 e^{-2h_3 y} + B_7 e^{-2h_2 y} + B_8 e^{-2h_1 y} \\ +B_9 e^{-(h_2+h_3)y} + B_{10}e^{-(h_1+h_2)y} + B_{11}e^{-(h_1+h_3)y} \end{pmatrix} \tag{31}$$

$$\phi(y) = (B_2 e^{-h_2 y} + B_1 e^{-h_1 y}) + Ec\begin{pmatrix} B_{20}e^{-h_5 y} + B_{13}e^{-h_4 y} + B_{14}e^{-2h_3 y} + B_{15}e^{-2h_2 y} + B_{16}e^{-2h_1 y} \\ +B_{17}e^{-(h_2+h_3)y} + B_{18}e^{-(h_1+h_2)y} + B_{19}e^{-(h_1+h_3)y} \end{pmatrix} \tag{32}$$

Skin Friction:

The non-dimensional form of the coefficient of Skin friction at the plate is obtained by the mean velocity profile then its form is given by,

$$Cf = \left(\frac{du}{dy}\right)_{y=0}$$

$$Cf = -(h_3 B_5 + h_2 B_4 + h_1 B_3) - Ec\begin{pmatrix} h_6 B_{29} + h_5 B_{21} + h_4 B_{22} + 2h_3 B_{23} + 2h_2 B_{24} + 2h_1 B_{25} \\ +(h_2+h_3)B_{26} + (h_1+h_2)B_{27} + (h_1+h_3)B_{28} \end{pmatrix} \tag{33}$$

Nusselt Number:

The non-dimensional form of the coefficient of rate of heat transfer is obtained by the mean temperature then the Nusselt number form is given by,

$$Nu = \left(\frac{d\theta}{dy}\right)_{y=0}$$

$$Nu = -(h_1) - Ec\begin{pmatrix} h_4 B_{12} + 2h_3 B_6 + 2h_2 B_7 + 2h_1 B_8 \\ +(h_2+h_3)B_9 + (h_1+h_2)B_{10} + (h_1+h_3)B_{11} \end{pmatrix} \tag{34}$$

Sherwood Number:

The non-dimensional form of the coefficient of rate of mass transfer is obtained by the mean concentration then the Sherwood number form is given by,

$$Cf = \left(\frac{d\phi}{dy}\right)_{y=0}$$

$$Cf = -(h_1 B_2 + h_1 B_1) - Ec\begin{pmatrix} h_5 B_{20} + h_4 B_{13} + 2h_3 B_{14} + 2h_2 B_{15} + 2h_1 B_{16} \\ +(h_2+h_3)B_{17} + (h_1+h_2)B_{18} + (h_1+h_3)B_{19} \end{pmatrix} \tag{35}$$

III. RESULT AND DISUCUSSION

The system of Ordinary differential equations (17) – (22) with boundary conditions (23) are solved analytically using perturbation technique. The solutions are obtained for the steady velocity fields (24) and (27), temperature fields (25) and (28) and concentration fields (26) and (29). In order to investigate the flow quantities like velocity, temperature and concentration profiles, the effects of non-dimensional parameters such as inclined magnetic field (M), permeability of porous medium (K_0), thermal Grashof number (Gr), mass Grashof number (Gm), Prandtl number (Pr), Eckert number (Ec), heat generation parameter (Q), Schmidt number (Sc), chemical reaction (Kr), thermal radiation (R) and Soret number (So) are exhibited in figure (1 – 12) and studied by choosing arbitrary values as $Gm = 1$, $Gr = 3$, $K_0 = 1$, $Pr = 0.71$, $Ec = 0.001$, $Q = 0.1$, $M = 1$, $R = 0.2$, $Sc = 0.6$, $So = 0.5$ and $Kr = 0.1$ then analyzed results by obtained graphs are given below.

Figures 1 and 2 exhibit the behaviour of velocity field of the fluid flow. It is seen that the velocity of the fluid decreases with increases of Magnetic parameter (M) and inclined angle (α). The reason behind this is increase in aligned angle causes to strengthen the magnetic field. Due to enhancement of magnetic field, it generates the opposite force to the flow, is called Lorentz force.

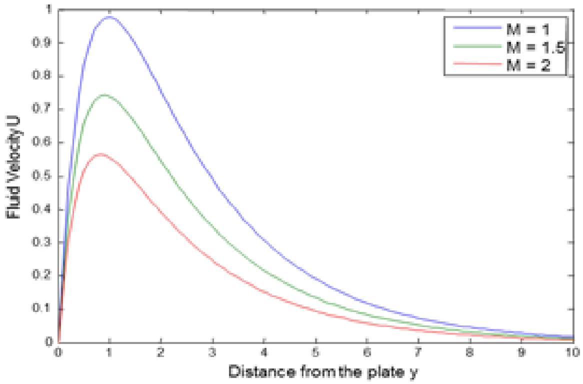

Figure 1. Velocity profile for different values of Magnetic field M

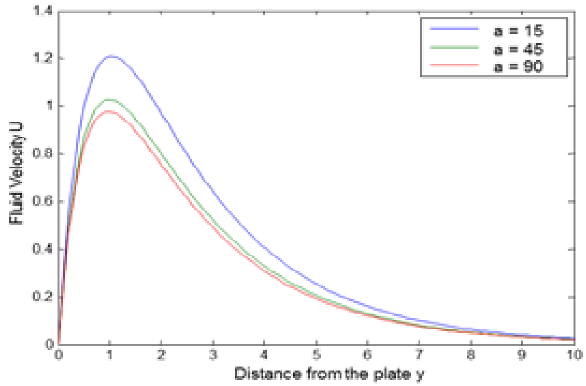

Figure 2. Velocity profile for different values of angle

Figure 3 illustrates the effect of thermal radiation (R) on velocity field. It is clear from figure that increase in thermal radiation parameter increase the velocity field of the fluid. The general fact that increase in R releases the heat energy to the flow and this helps to enhances the velocity field of the fluid.

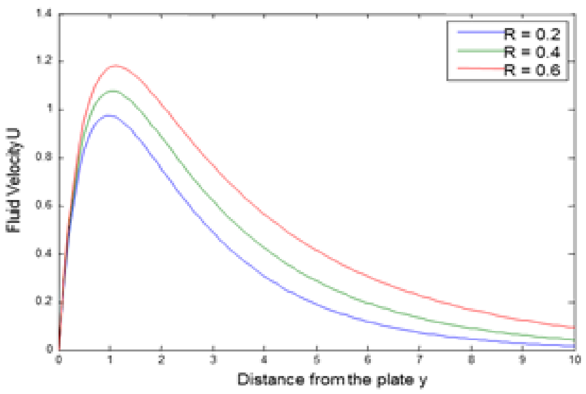

Figure 3. Velocity profile for different values of thermal radiation R

Figures 4 and 5 displays the effect thermal Grashof number Gr and mass Grashof number Gm on velocity field. It is observed that the velocity field of the fluid increases when Gr parameter and Gm parameter increases. Figure 6 investigates the effect of Soret number So on the velocity field. It is evident from figure that increase in Soret number causes the increase in velocity field of the fluid. Soret effect i.e., diffusion of thermal energy contributes to the growth of boundary layer.

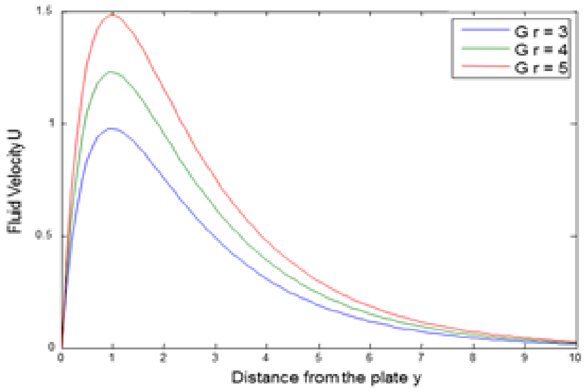

Figure 4. Velocity profile for different values of thermal Grashof number Gr

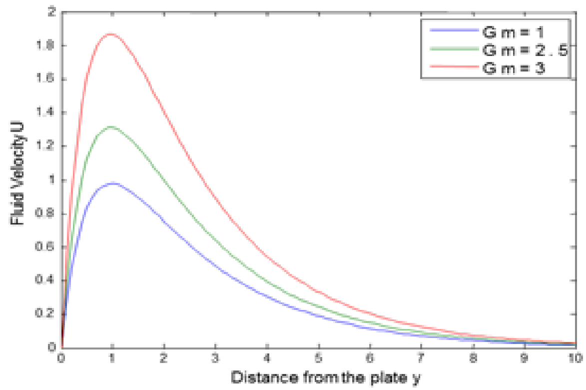

Figure 5. Velocity profile for different values of mass Grashof number Gm

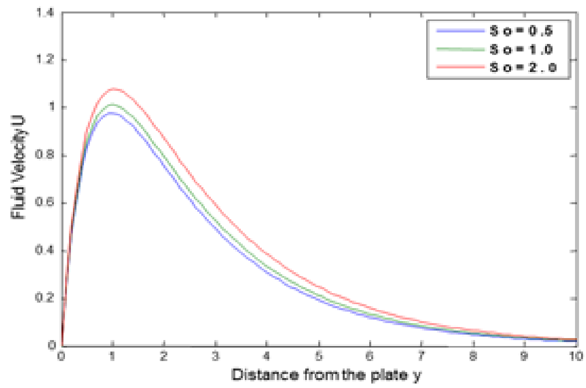

Figure 6. Velocity profile for different values of Soret number So

Figures 7 and 8 shows the variation of temperature field for the different values of thermal radiation R and Prandtl number Pr. From the figure 7, it can be seen that the temperature of the fluid increases when thermal radiation R parameter increases. It is due to the general fact that increase in R parameter releases the heat energy to the flow, it helps to enhances the temperature field. From the figure 8, it is observed that increases in Pr parameter decreases the temperature field. Because when Prandtl number increases, the rate of heat transfer decreases. Prandtl number can be used to increase the rate of cooling in conducting flow.

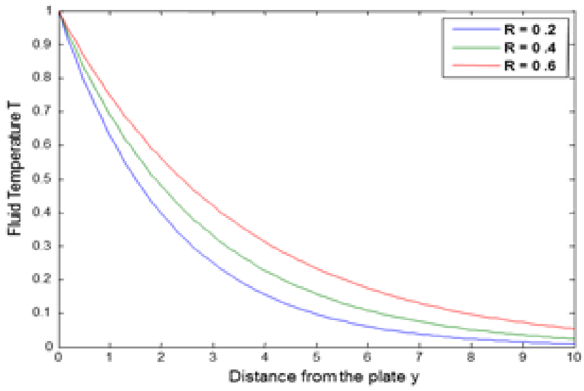

Figure 7. Temperature profile for different values of thermal radiation R

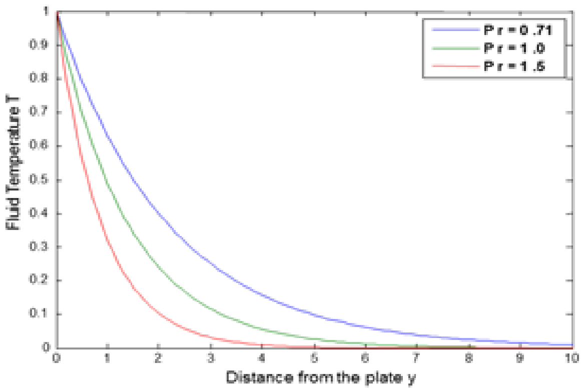

Figure 8. Temperature profile for different values Prandtl number Pr

Figure 9 displays the effect of the Soret number So on the concentration field.

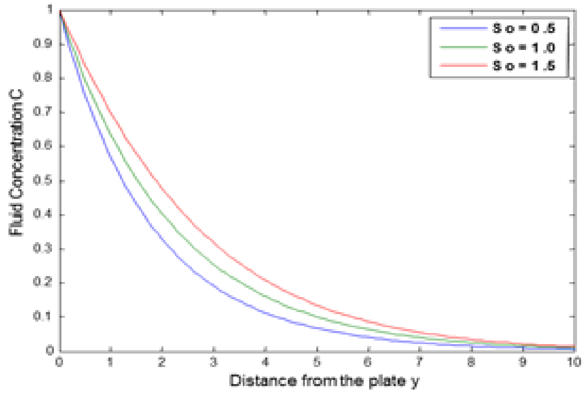

Figure 9. Concentration profile for different values of Soret number So

From the figure, it can be noticed that the fluid of the concentration field shows enhancement when increasing the value of Soret number.

Figure 10 represent the concentration field of the fluid for different values of chemical reaction Kr. It is evident from figure that the concentration field shows decrement with increasing Chemical reaction.

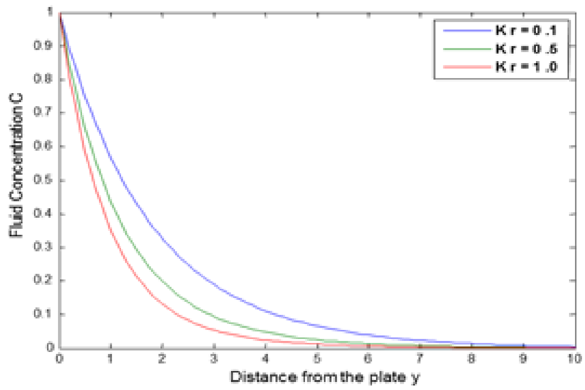

Figure 10. Concentration profile for different values of chemical reaction Kr

To analyze the effect of Schmidt parameter Sc on the Concentration profile in Figure 11. The result shows that the Concentration field decreases when Sc number increases. The boundary layer thickness suppressed by enlarging Sc number.

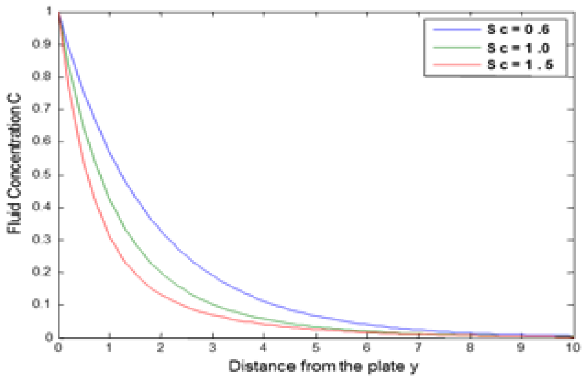

Figure 11. Concentration profile for different values of Schmidt number Sc

IV. CONCLUSION

A theoretical analysis is performed to study the effects of Soret, Chemical reaction and Heat source on Steady MHD mixed convective flow of an incompressible viscous fluid in presence of inclined magnetic field and thermal radiation with heat and mass transfer passing through a porous medium. A Perturbation technique is used to solve the equations governing the flow. Asymptotic solutions of velocity, temperature and concentration are obtained and also illustrate the results of flow characteristics for the fluid fields. The analysis is made and the results are summarized as follows:

- ✓ The effects of Radiation, thermal Grashof number, mass Grashof number and Soret are increased the velocity profile.
- ✓ As the magnetic field and inclined angle increases, the velocity profile decreases.
- ✓ The effect of thermal radiation increased the temperature profile while Prandtl number decreased the temperature profile.
- ✓ Soret effect increased the concentration of the fluid while Schmidt number and Chemical reaction decreased the concentration profile.

APPENDIX B

$$h_1 = \frac{Pr + \sqrt{Pr^2 - 4(1+R)QPr}}{2(1+R)}$$

$$h_2 = \frac{Sc + \sqrt{Sc^2 + 4\,Kr\,Sc}}{2}$$

$$h_3 = \frac{1 + \sqrt{1 + 4(M + K_0)}}{2}$$

$$h_4 = \frac{Pr + \sqrt{Pr^2 - 4(1+R)QPr}}{2(1+R)}$$

$$h_5 = \frac{Sc + \sqrt{Sc^2 + 4\,Sc\,Kr}}{2}$$

$$h_6 = \frac{1 + \sqrt{1 + 4(M + K_0)}}{2}$$

$$B_1 = \frac{-So\,Sc\,{h_1}^2}{{h_1}^2 - Sc\,h_1 - Kr\,Sc}$$

$$B_2 = 1 - B_1$$

$$B_3 = \frac{-(B_1\,Gm + Gr)}{{h_1}^2 - h_1 - (M + K_0)}$$

$$B_4 = \frac{-B_2\,Gm}{{h_2}^2 - h_2 - (M + K_0)}$$

$$B_5 = -B_3 - B_4$$

$$B_6 = \frac{-\Pr {B_5}^2 ({h_3}^2 + M)}{4(1+R)\,{h_3}^2 - 2\,Pr\,h_3 + \Pr Q}$$

$$B_7 = \frac{-\Pr {B_4}^2 ({h_2}^2 + M)}{4\,(1+R){h_2}^2 - 2\,Pr\,h_2 + \Pr Q}$$

$$B_8 = \frac{-\Pr {B_3}^2 ({h_1}^2 + M)}{4(1+R)\,{h_1}^2 - 2\,Pr\,h_1 + \Pr Q}$$

$$B_9 = \frac{-2\Pr B_4 B_5\,(h_2 h_3 + M)}{(1+R)(h_2+h_3)^2 - \;Pr\,(h_2+h_3) + \Pr Q}$$

$$B_{10} = \frac{-2\Pr B_3 B_4\,(h_1 h_2 + M)}{(1+R)(h_1+h_2)^2 - \;Pr\,(h_1+h_2) + \Pr Q}$$

$$B_{11} = \frac{-2\Pr B_3 B_5\,(h_1 h_3 + M)}{(1+R)(h_1+h_3)^2 - \;Pr\,(h_1+h_3) + \Pr Q}$$

$$B_{12} = -B_6 - B_7 - B_8 - B_9 - B_{10} - B_{11}$$

$$B_{13} = \frac{-So\,Sc\,{h_4}^2\,B_{12}}{{h_4}^2 - Sc\,h_4 - Kr\,Sc}$$

$$B_{14} = \frac{-4\,So\,Sc\,{h_3}^2\,B_6}{4\,{h_3}^2 - 2\,Sc\,h_3 - Kr\,Sc}$$

$$B_{15} = \frac{-4\,So\,Sc\,{h_2}^2\,B_7}{4\,{h_2}^2 - 2\,Sc\,h_2 - Kr\,Sc}$$

$$B_{16} = \frac{-4\,So\,Sc\,{h_1}^2\,B_8}{4\,{h_1}^2 - 2\,Sc\,h_1 - Kr\,Sc}$$

$$B_{17} = \frac{-So\,Sc\,(h_2 + h_3)^2\,B_9}{(h_2 + h_3)^2 - Sc\,(h_2 + h_3) - Kr\,Sc}$$

$$B_{18} = \frac{-So\,Sc\,(h_1 + h_2)^2\,B_{10}}{(h_1 + h_2)^2 - Sc\,(h_1 + h_2) - Kr\,Sc}$$

$$B_{19} = \frac{-So\,Sc\,(h_1 + h_3)^2\,B_{11}}{(h_1 + h_3)^2 - Sc\,(h_1 + h_3) - Kr\,Sc}$$

$$B_{20} = -B_{13} - B_{14} - B_{15} - B_{16} - B_{17} - B_{18} - B_{19}$$

$$B_{21} = \frac{-B_{20}\,Gm}{{h_5}^2 - h_5 - (M + K_0)}$$

$$B_{22} = \frac{(-B_{13}\,Gm - B_{12}\,Gr)}{{h_4}^2 - h_4 - (M + K_0)}$$

$$B_{23} = \frac{(-B_{14}\,Gm - B_6\,Gr)}{4\,{h_3}^2 - 2h_3 - (M + K_0)}$$

$$B_{24} = \frac{(-B_{15}\,Gm - B_7\,Gr)}{4\,{h_2}^2 - 2h_2 - (M + K_0)}$$

$$B_{25} = \frac{(-B_{16}\,Gm - B_8\,Gr)}{4\,{h_1}^2 - 2h_1 - (M + K_0)}$$

$$B_{26} = \frac{(-B_{17}\,Gm - B_9\,Gr)}{(h_2 + h_3)^2 - (h_2 + h_3) - (M + K_0)}$$

$$B_{27} = \frac{(-B_{18}\,Gm - B_{10}\,Gr)}{(h_1 + h_2)^2 - (h_1 + h_2) - (M + K_0)}$$

$$B_{28} = \frac{(-B_{19}\,Gm - B_{11}\,Gr)}{(h_1 + h_3)^2 - (h_1 + h_3) - (M + K_0)}$$

$$B_{29} = -B_{21} - B_{22} - B_{23} - B_{24} - B_{25} - B_{26} - B_{27} - B_{28}$$

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