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ANALYTICAL STUDY ON INDUCED MAGNETIC FIELD WITH RADIATING FLUID OVER A POROUS VERTICAL PLATE WITH HEAT GENERATION

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Abstract. The objective of this investigation is analytical study on the influence of thermal radiation and magnetic field of steady MHD heat and mass transfer by mixed convection flow of a viscous, incompressible, electrically-conducting, Newtonian fluid which is an optically thin gray gas over a vertical porous plate taking into account the induced magnetic field. The transformed dimensionless governing equations are obtained by using by perturbation technique.

KEYWORDS: *Thermal Radiation, Mixed Convection, MHD, Boundary layers, Heat source*

1. INTRODUCTION

Magnetohydrodynamics (MHD) is the branch of continuum mechanics which deals with the flow of electrically conducting fluids in electric and magnetic fields. Many natural phenomena and engineering problems are worth being subjected to an MHD analysis. Magneto-hydrodynamic equations are ordinary electromagnetic and hydrodynamic equations modified to take into account the interaction between the motion of the fluid and the electromagnetic field. The formulation of the electromagnetic theory in a mathematical form is known as Maxwell's equation. The effect of the gravity field is always present in forced flow heat transfer as a result of the buoyancy forces connected with the temperature differences. Usually they are of a small order of magnitude so that the external forces may be neglected. There has recently been a considerable interest in the effect of body forces on forced convection phenomena. Rajaiah et. al. [1] communicated through their research work on chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium, Ch Kesavaiah et. al. [2] revealed that the radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, Yeddala et. al. [3] expressed their view on finite difference solution for an MHD free convective rotating flow past an accelerated vertical plate, Rajaiah et. al. [4] has been studied unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating in the Presence of suction or injection, Chenna Kesavaiah and Satyanarayana [5] carried out MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, Haranth and Sudhakaraiah [6] explained on viscosity and Soret effects on Unsteady Hydromagnetic gas flow along an inclined plane, Chenna Kesavaiah et. al. [7] explained on radiation and thermo - diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, Rajaiah and Sudhakaraiah [8] shows that the radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, The radiation effects have important applications in physics and engineering, particularly in space technology and high temperature processes. But very little is known about the effects of radiation on the boundary layer. Thermal radiation effects on the boundary layer may play important role in controlling heat transfer in polymer processing industry where the quality of the final product depends on the heat controlling factors to some extent. High temperature plasmas, cooling of nuclear reactors, liquid metal fluids and power generation systems are some important applications of radiative heat transfer. Natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate has been communicated by Chenna Kesavaiah et. al. [9], Srinathuni Lavanya and Chenna Kesavaiah [10] has been studied on radiation and Soret effects to MHD flow in vertical surface with chemical reaction and heat generation through a porous medium, Rajaiah and Sudhakaraiah [11] expressed on unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, Bhavana et. al. [12] shows that the Soret effect on free convective unsteady MHD flow over a vertical plate with heat source, Satyanarayana et. al. [13] has been considered the viscous dissipation and thermal radiation effects on an unsteady MHD convection flow past a semi-infinite vertical permeable moving porous plate, Ch Kesavaiah et. al. [14] explained on radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, Srinathuni Lavanya et. al. [15] carried out their research work on radiation, heat and mass transfer effects on magnetohydrodynamic unsteady free convective Walter's memory flow past a vertical plate with chemical reaction through a porous medium, Chenna Kesavaiah et. al. [16] indicated the radiation effect on unsteady flow past an accelerated isothermal infinite vertical plate with chemical reaction and heat source, Ch Kesavaiah et. al. [17] depicted the radiation and mass transfer effects on MHD mixed convection flow from a vertical surface with Ohmic heating in the presence of chemical reaction.

In the present report, the specific problem selected for study is mixed convection flow involving coupled heat and mass transfer in an electrically conducting fluid adjacent to an isothermal porous plate, with radiation heat transfer effects accounted for. There is an interesting aspect involving MHD effects in forced convection boundary layers; induced magnetic forces modify the free stream flow and this, in turn, affects the external pressure gradient or the free stream velocity that is imposed in the boundary layer. Thus, a complete boundary layer solution would involve a MHD solution for the inviscid free stream.

2. MATHEMATICAL FORMULATION

The two-dimensional steady magnetohydrodynamic mixed convective heat and mass transfer flow of a Newtonian, electrically-conducting and viscous incompressible fluid over a porous vertical infinite plate with induced magnetic field and conduction-radiation with heat generation has been considered in figure (1). Exact solutions of equations are obtained by perturbation technique. The following assumptions are implicit in our analysis:

- All the fluid properties except the density in the buoyancy force term are constant.
- The Eckert number Ec is small, as appropriate for viscous incompressible regimes.
- The plate is subjected to a constant suction velocity.

- The plate is non-conducting and the applied magnetic field is of uniform strength (H_0) and applied transversely to the direction of the main stream taking into account the induced magnetic field.
- The magnetic Reynolds number of the flow is not taken to be small enough so that the induced magnetic field is not negligible.
- The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species, which are present, and hence the Soret and Dufour effects are negligible;
- The equation of conservation of electric charge is $\nabla . j = 0$ where $j = \left(j_x, j_y, j_z \right)$
- The direction of propagation is considered only along the y-axis and does not have any variation along the y-axis and so $\frac{\partial j}{\partial y} = 0$ which gives $j_y =$ constant Since the plate is electrically non-conducting, this constant is zero and hence $j_y = 0$ everywhere in the flow, following Sutton and Sherman [1].
- The wall is maintained at constant temperature $\overline{T_w}$ and concentration $\overline{C_w}$ higher than the ambient temperature $\overline{T_\infty}$ and concentration $\overline{C_\infty}$ respectively.
- The fluid is non-magnetic, neglecting the thermoelectric effect as well as viscous and electrical dissipation together with the short circuit condition.

Let $\vec{q} = \left(\overline{u}(y), \overline{v}, 0 \right)$ be the fluid velocity and $\vec{H} = \left(\overline{H_x}(y), \overline{H}_y, 0 \right)$ be the magnetic induction vector at a $\left(\overline{x}, \overline{y}, \overline{z} \right)$ point in the fluid. The $\overline{x}$-axis is taken along the plate in the upward direction, $\overline{y}$-axis is normal to the plate into the fluid region. Since the plate is infinite in length in $\overline{x}$-direction, therefore all the physical quantities except possibly the pressure are assumed to be independent of $\overline{x}$.

For a steady-state incompressible magnetohydrodynamic mixed convection flow and mass transfer with radiation, given by Sherman and Sutton [1], and Maxwell's equations, the fundamental equations are:

$div\,\vec{q} = 0$ Conservation of mass (2.1)

$div\,\vec{q} = 0$ Gauss's law's of magnetism (2.2)

Conservation of momentum

$$\rho\left(\vec{q}.\nabla\right)\vec{q} = -\nabla p + \mu^2\vec{q} + \mu_e\left(\vec{J} \times \vec{H}\right) + \rho\vec{g} \tag{2.3}$$

Conservation of energy

$$\rho\left(\vec{q}.\nabla\right)\vec{T} = \frac{1}{\rho C_p}\left(\kappa\nabla^2\vec{T} - \frac{\partial q_r}{\partial y}\right) - \frac{Q_0}{\rho C_p}\left(\overline{T} - \overline{T}_\infty\right) \tag{2.4}$$

$\nabla \times \left(\vec{q} \times \overrightarrow{H} \right) + \kappa \nabla^2 \overrightarrow{H} = 0$ Conservation of magnetic induction (2.5)

$\left(\vec{q}.\nabla \right) \overline{C} = D \nabla^2 \overline{C} - K_r' \left(\overline{C} - \overline{C}_\infty \right)$ Conservation of species (2.6)

$\nabla \times \overrightarrow{H} = \vec{J}$ (2.7)

With the foregoing assumptions and under the usual boundary layer and Boussinesq's approximations, Equations
(2.1) to (2.6) reduces to:

$\frac{\partial \overline{v}}{\partial \overline{y}} = 0$ which is satisfied with $\overline{v} = -v_0 =$ a constant. (2.8)

$$\frac{\partial \overline{H_y}}{\partial \overline{y}} = 0 \tag{2.9}$$

which holds for $\overline{H_y} = H_0$ a constant = strength from applied magnetic field

$$\rho \overline{v} \frac{\partial \overline{u}}{\partial \overline{y}} = \frac{\partial p}{\partial \overline{x}} - \rho g + \mu \frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \mu_e H_0 \frac{\partial \overline{H_x}}{\partial \overline{y}} \tag{2.10}$$

$$\overline{v} \frac{\partial \overline{T}}{\partial y} = \frac{\kappa}{\rho C_p} \frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial \overline{y}} - \frac{Q_0}{\rho C_p} \left(\overline{T} - \overline{T}_\infty \right) \tag{2.11}$$

$$\overline{v} \frac{\partial \overline{H}_x}{\partial \overline{y}} = \frac{1}{\sigma \mu_e} \frac{\partial^2 \overline{H_x}}{\partial \overline{y}^2} + H_0 \frac{\partial \overline{u}}{\partial \overline{y}} \tag{2.12}$$

$$\overline{v} \frac{\partial \overline{C}}{\partial \overline{y}} = D \frac{\partial^2 \overline{C}}{\partial \overline{y}^2} - K_r' \left(\overline{C} - \overline{C}_\infty \right) \tag{2.13}$$

Since there is no large velocity gradient here, the viscous term in equation (2.10) vanishes for small μ and hence for the outer flow, beside there is no induced magnetic field along x-direction gradient, so we have

$$0 = -\frac{\partial p}{\partial \overline{x}} - \rho_\infty g \tag{2.14}$$

By eliminating the pressure term from Equations (2.10) and (2.14), we obtain

$$\rho \overline{v} \frac{\partial \overline{u}}{\partial \overline{y}} = \left(\rho_\infty - \rho \right) + \mu \frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \mu_e H_0 \frac{\partial \overline{H_x}}{\partial \overline{y}} \tag{2.15}$$

The Boussinesq's approximation gives

$$\rho_\infty - \rho = \rho_\infty \beta \left(\overline{T} - \overline{T}_\infty \right) + \rho_\infty \overline{\beta} \left(\overline{C} - \overline{C}_\infty \right) \tag{2.16}$$

On using (2.16) in the equation (2.15) and noting that ρ_∞ is approximately equal to 1, the momentum equation reduces to

$$-v_0 \frac{\partial \overline{u}}{\partial \overline{y}} = \rho_\infty \beta \left(\overline{T} - \overline{T}_\infty \right) + \rho_\infty \overline{\beta} \left(\overline{C} - \overline{C}_\infty \right) + \nu \frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \frac{\mu_e H_0}{\rho} \frac{d \overline{b_x}}{d \overline{y}} \tag{2.17}$$

The boundary conditions are:

$$\begin{aligned}&\bar{y}=0:\bar{u}=0,\bar{v}=v_0,\bar{T}-\bar{T}_w,\overline{H_x}=0,\bar{C}-\bar{C}_w\\&\bar{y}\to\infty:\bar{u}=U_0,\bar{T}-\bar{T}_\infty,\overline{H_x}\to 0,\bar{C}\to\bar{C}_\infty\end{aligned}\qquad(2.18)$$

The non-dimensional quantities are:

$$y=\frac{v_0\bar{y}}{\nu},\ u=\frac{\bar{u}}{U_0},\ \theta=\frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty},\ \phi=\frac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty},\ Sc=\frac{\nu}{D},\ Q=\frac{\nu Q_0}{\rho C_p {v_0}^2}$$

$$Gr=\frac{\nu g\beta\left(\bar{T}_w-\bar{T}_\infty\right)}{U_0{v_0}^2},\qquad Gm=\frac{\nu g\beta\left(\bar{C}_w-\bar{C}_\infty\right)}{U_0{v_0}^2},\qquad \Pr_m=\rho\nu\mu_e$$

$$M=\sqrt{\frac{\mu_e H_0}{\rho v_0}},\ B=\sqrt{\frac{\mu_e\bar{H}_x}{\rho U_0}},\ \Pr=\frac{\rho\nu C_p}{\kappa},R=\frac{64a\nu\bar{\sigma}\bar{T}^3_\infty}{\rho C_p {v_0}^2},Kr=\frac{Kr'\nu}{{v_0}^2}\qquad(2.19)$$

For the case of an optically thin gray gas, the local radiant absorption is expressed as

$$\frac{\partial q_r}{\partial\bar{y}}=-4a\bar{\sigma}\left(\bar{T}^4_\infty-\bar{T}^4\right)\qquad(2.20)$$

where $'a'$ the mean absorption coefficient and $\bar{\sigma}$ is the Stefan-Boltzmann constant. It is assumed that the temperature differences within the flow are sufficiently small such that $\bar{T}^4$ may be expressed as linear function of the temperature $\bar{T}$. This is accomplished by expanding $\bar{T}^4$ in Taylor series about $\bar{T}_\infty$ and neglecting higher order terms, thus

$$\bar{T}^4\cong 4\bar{T}^4_\infty\bar{T}-3\bar{T}^4_\infty\qquad(2.21)$$

Using the transformations (2.19) and with help of (2.20) and (2.21), the non-dimensional forms of (2.11), (2.12), (2.13) and (2.17) are

$$\frac{d^2u}{dy^2}+\frac{du}{dy}+M\frac{dB}{dy}+Gr\theta+Gm\phi=0\qquad(2.22)$$

$$\frac{d^2\theta}{dy^2}+\Pr\frac{d\theta}{dy}+\frac{1}{4}\Pr R\theta-\Pr Q\theta=0\qquad(2.23)$$

$$\frac{d^2B}{dy^2}+M\Pr_m\frac{du}{dy}+\Pr_m\frac{dB}{dy}=0\qquad(2.24)$$

$$\frac{d^2\phi}{dy^2}+Sc\frac{d\phi}{dy}-KrSc\phi=0\qquad(2.25)$$

The corresponding boundary conditions are:

$$\begin{aligned}&y=0:u=0,\theta=1,\ B=0,\ \phi=1\\&y=\infty:u\to 1,\theta\to 0,B\to 0,\phi\to 0\end{aligned}\qquad(2.26)$$

3. METHOD OF SOLUTION

Perturbation theory leads to an expression for the desired solution in terms of a power series in some "small" parameter that quantifies the deviation from the exactly solvable problem. The leading term in this power series is the solution of the exactly solvable problem, while further terms describe the deviation in the solution, due to the deviation from the initial problem. Perturbation theory is applicable if the problem at hand can be formulated by adding a "small" term (Eckert number in this work) to the mathematical description of the exactly solvable problem.

Now, in order to solve the equations (2.22) and (2.25) under the boundary condition (2.26), we note that $Ec << 1$ (Eckert number) for all the incompressible fluids and it is assumed the solutions of the equations to be of the form

The solutions of the equations (2.23) and (2.25) subject to the boundary condition (2.26) are

$$\theta(y) = e^{m_2 y}, \; \phi(y) = e^{m_1 y} \tag{3.1}$$

Now, in order to solve the equations (2.22) and (2.24) under the boundary condition (2.26), we note that $Ec << 1$ (Eckert number) for all the incompressible fluids and it is assumed the solutions of the equations to be of the form

$$\Re(y) = \Re_0(y) + Ec\,\Re_1(y) + 0\left(Ec^2\right) \tag{3.2}$$

In which $\Re$ stands for u or B, and $\Re_0$ is the mean part and $\Re_1$ is the perturbed part. Substituting (3.2) into the equations (2.22) and (2.24) and equating the coefficients of the same degree terms and neglecting terms of $0\left(Ec^2\right)$, the following ordinary differential equations are obtained, in which O designates $\frac{d}{dy}$:

$$u_0'' + u_0' = -Gr\theta_0 - Gm\phi_0 - MB_0' \tag{3.3}$$

$$u_1'' + u_1' = -Gr\theta_1 - Gm\phi_1 - MB_1' \tag{3.4}$$

$$B_0'' + \Pr_m B_0' = -M \Pr_m u_0' \tag{3.5}$$

$$B_1'' + \Pr_m B_1' = -M \Pr_m u_1' \tag{3.6}$$

The corresponding boundary conditions (2.26) reduce to:

$$\begin{aligned} &y = 0 : u_0 = 0, u_1 = 0,\; B_0 = 0,\; B_1 = 0, \phi_0 = 1, \phi_1 = 0 \\ &y = \infty : u_0 \to 1, u_1 \to, B_0 \to 0, B_1 \to 0, \phi_0 \to 0, \phi_1 \to 0 \end{aligned} \tag{3.7}$$

The solutions of the velocity and induced magnetic field subject to the boundary conditions are:

$$u(y) = 1 + A_1 e^{m_2 y} + A_2 e^{m_1 y} + A_3 e^{m_3 y}$$

$$B(y) = B_1 e^{m_2 y} + B_2 e^{m_1 y} + B_3 e^{m_3 y} + B_4 e^{-\Pr_m y}$$

Skin-Friction

The boundary layer produces a drag on the plate due to the viscous stresses which are developed at the wall. The viscous stress at the surface of the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_2 A_1 + m_1 A_2 + m_3 A_3$$

4. RESULTS AND DISCUSSION

To assess the effects of the dimensionless thermo physical parameters on the regime, we have carried out the calculations for the velocity field, induced magnetic field and electric current density at the plate. The results are presented graphically in figures 3 to 10. All data is provided in each figure.

Figure 3 illustrate the velocity response for magnetic field (M) and Prandtl number $(\Pr)$ due to cooling of the plate $(Gr > 0)$ i.e. free convection currents convey heat away from the plate in to the boundary layer. With an increase in M from the non-conducting i.e. purely hydrodynamic case $(M = 0)$ through 0.50 to 0.75, there is a strong deceleration in the flow is achieved. The presence of a magnetic field in an electrically-conducting fluid introduces a force called Lorentz force which acts against the flow if the magnetic field is applied in the normal direction as considered in the present problem. This type of resistive force tends to slow down the flow field. Since the magnetic field has a stabilizing effect, the maximum velocity overshoot is observed for the conducting air, while minimum overshoot takes place for the water. Moreover, there is clear decrease in velocity values at the wall accompanying a rise in $(\Pr)$ from 0.71 (conducting air) to 7.0 (water) i.e. the flow is decelerated. Higher *Pr* fluids will therefore posses higher viscosities (and lower thermal conductivities) implying that such fluids will flow slower than lower *Pr* fluids. As a result the velocity will be decreased substantially with increasing Prandtl number.

Fig. 4 shows the influence of the radiation parameter (R) and magnetic Prandtl number $(\Pr_m)$ on the velocity field (u) in presence of conducting air $(\Pr = 0.71)$ and weak magnetohydrodynamic flow $(M = 0.25)$. The velocity remains positive for all values of *R* and $(\Pr_m)$ i.e. there is no flow reversal within the boundary layer. With an increase in R from 0.0 (non-radiating) through 0.3 to 0.7 (thermal conduction is dominant over radiation), there is a clear decrease in velocity i.e. the flow is decelerated. This may be attributed to the fact that the increase in R implies less interaction of radiation with the momentum boundary layer. Moreover, a rise in $\Pr_m$ value from 0.1 through 0.5 to 0.6 (in all these cases magnetic diffusion rate exceeds the viscous diffusion rate) causes a noticeable decreasing in the flow velocity, in particular at short distance from the wall.

The effects of Hartmann number M and Prandtl number $\Pr$ on the induced magnetic field, M has been presented in Figure 5 in presence of weak magnetohydrodynamic flow (M = 0.25) and Oxygen $(Sc = 0.60)$, diffusing in air, $(\Pr = 0.71)$. For all combinations of M and $\Pr$, values of H are remains negative i.e. induced magnetic flux reversal arises for all distances into the boundary layer, transverse to the plate. In all the cases, H values peak a short distance from the plate; profiles thereafter decay to the zero value in the free stream. For $(\Pr = 0.71)$, the *H* values become increasingly negative i.e. greater flux reversal arises in the boundary layer when $M = 0.75$; but for $\Pr = 7.0$, the induced magnetic is found to less negative when $M = 0.25$. Therefore, when $\Pr$ increases from 0.71 to 7.0, the induced magnetic field is found to decrease absolutely. Moreover, a rise in *M* from 0.25 through 0.50 to 0.75 serves to elevated the induced magnetic field magnitudes throughout the regime for both cases of $(\Pr = 0.71)$ and $(\Pr = 7.0)$. Figure 6 depicts the same results mentioned as above for various values of radiation parameter R. But the quite opposite results showed in figure 7 for different values of magnetic Prandtl number $(\Pr_m)$. It is observed that increasing in magnetic Prandtl number $(\Pr_m)$ the induced magnetic field is also increasing Figure (8) - (10) shows that concentration profiles for different values of $Kr, Sc \text{ and } R$. In all parameter increases the concentration profiles decreases.

5. CONCLUSION:

This study presents a theoretical treatment of steady magnetohydrodynamic boundary layer flow and combined heat and mass transfer of an incompressible, electrically-conducting and radiating fluid over an infinite vertical permeable plate, taking into account the magnetic Prandtl number. The observations are:

- An increase in radiation parameter/Hartmann number leads to decelerate the flow velocity, while increasing Hartmann number elevated the Induced magnetic field.
- Increasing conduction-radiation acts to depress flow velocity and induced magnetic field.
- It was also observed that increasing magnetic Prandtl number effects elevated the induced magnetic field near the plate, while this trend is reversed away from the plate.
- Velocity is reduced considerably with a rise in Schmidt number or Prandtl number.
- Temperature is reduced by the increase of radiation.
- Skin friction is strongly elevated by the increase of Hartmann number or magnetic Prandtl number.
- Using magnetic field we can control the flow characteristics and heat transfer.
- Radiation has significant effects on the velocity as well as temperature distributions.

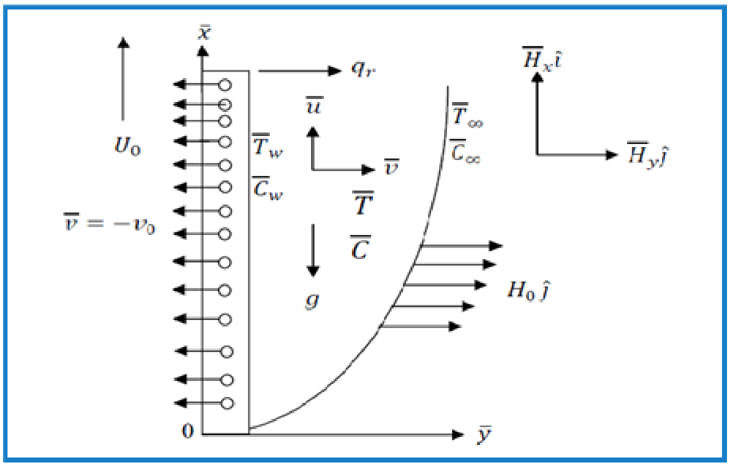

Figure 1: Physical configuration and coordinate system

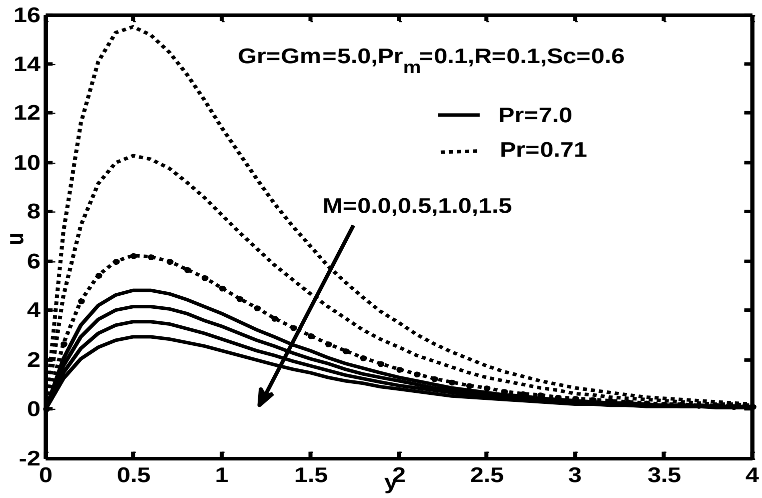

Figure 2. Velocity distribution for M and Pr

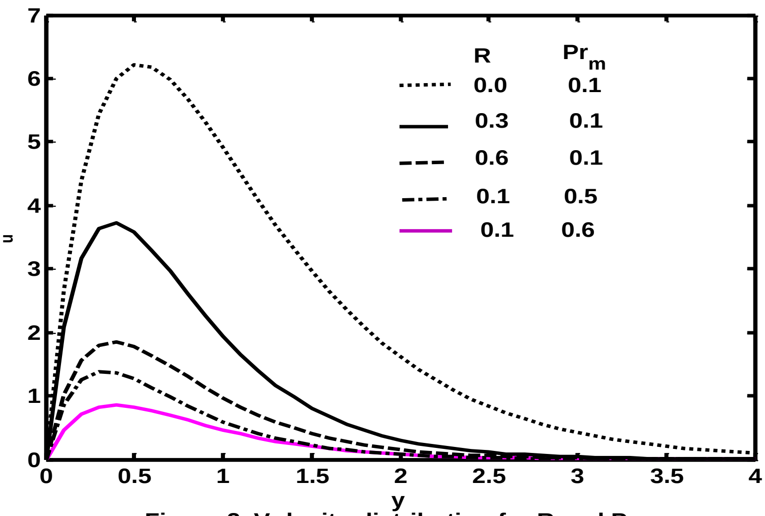

Figure 2. Velocity distribution for R and Pr$_m$

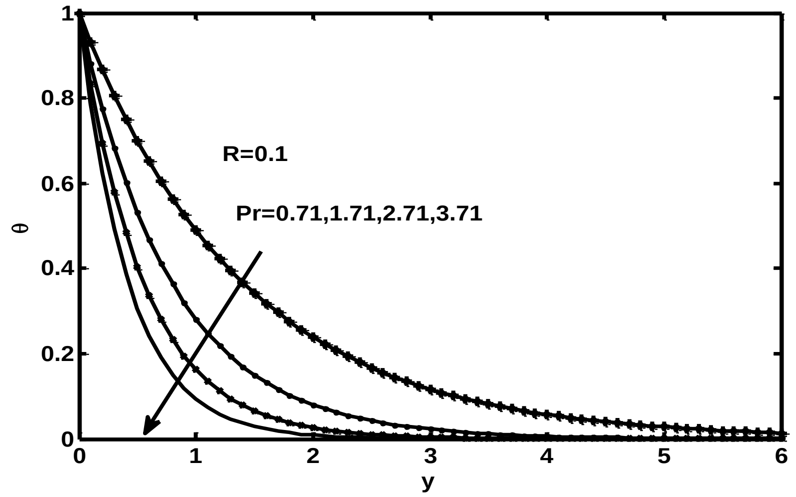

Figure 4. Temperature field for Pr

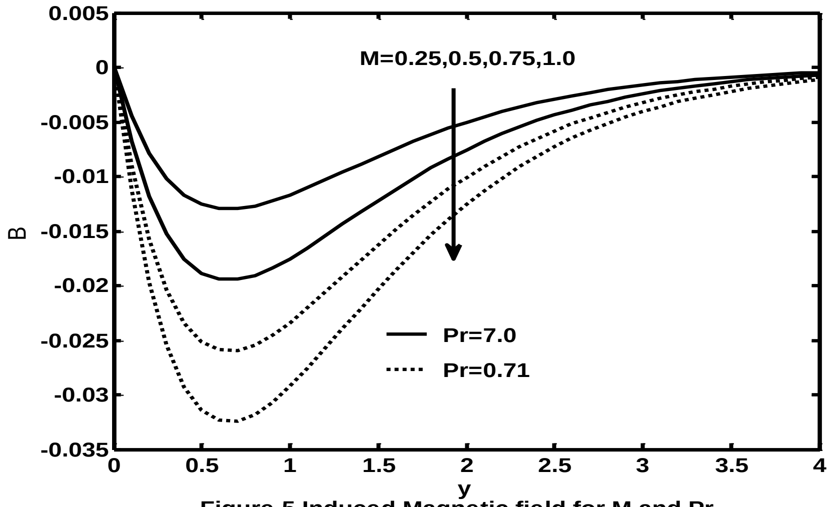

Figure 5 Induced Magnetic field for M and Pr_m

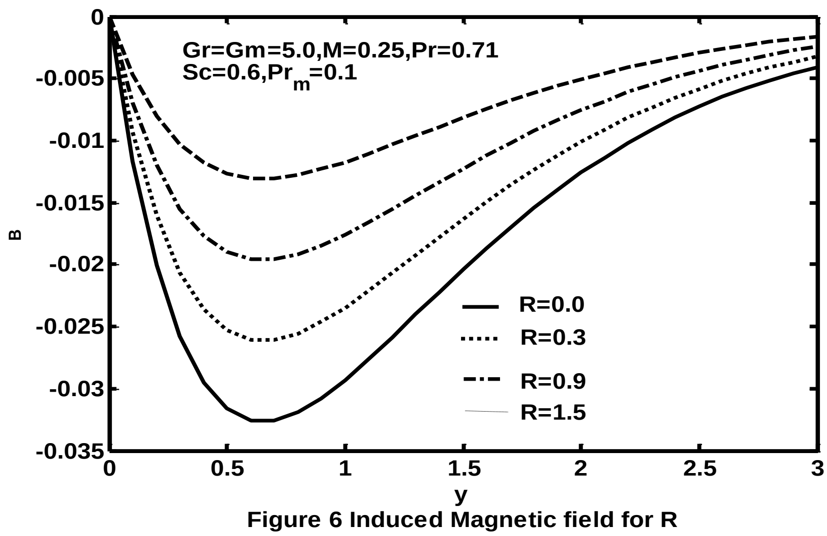

Figure 6 Induced Magnetic field for R

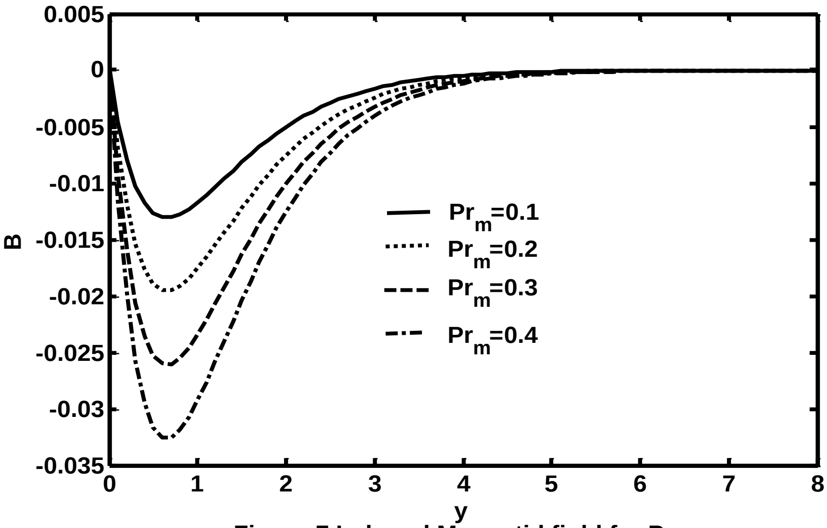

Figure 7 Induced Magnetid field for Pr_m

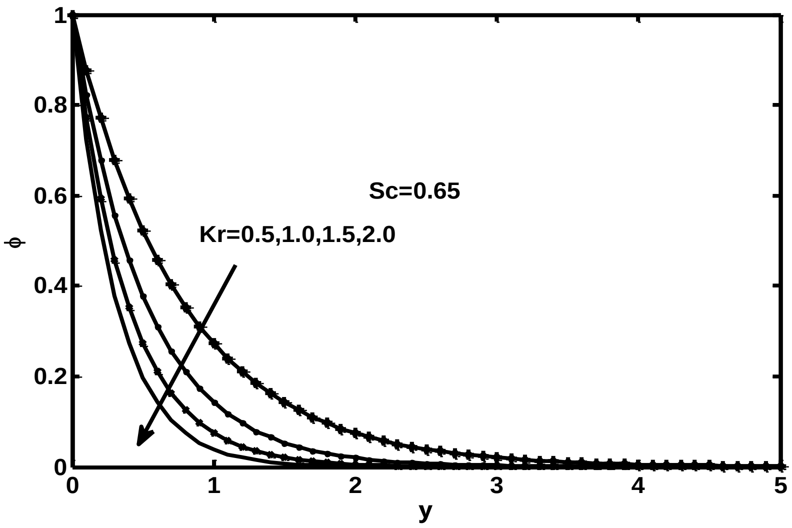

Figure 8. Concentration field for Kr

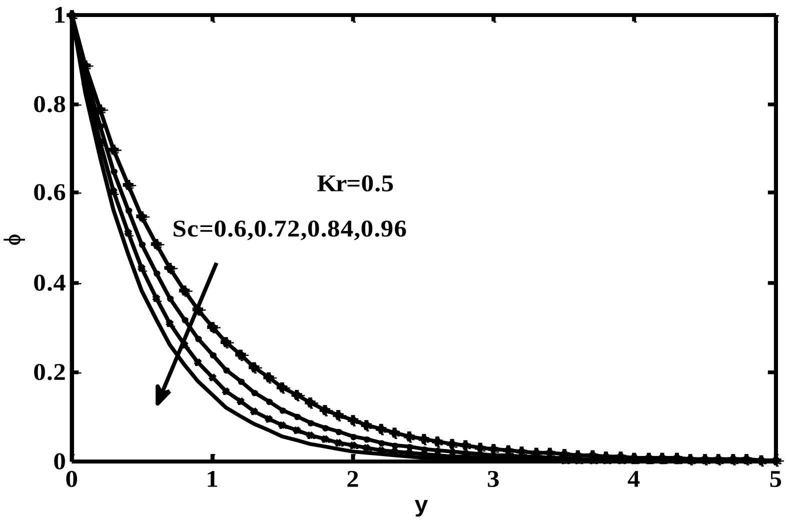

Figure 9. Concentration field for Sc

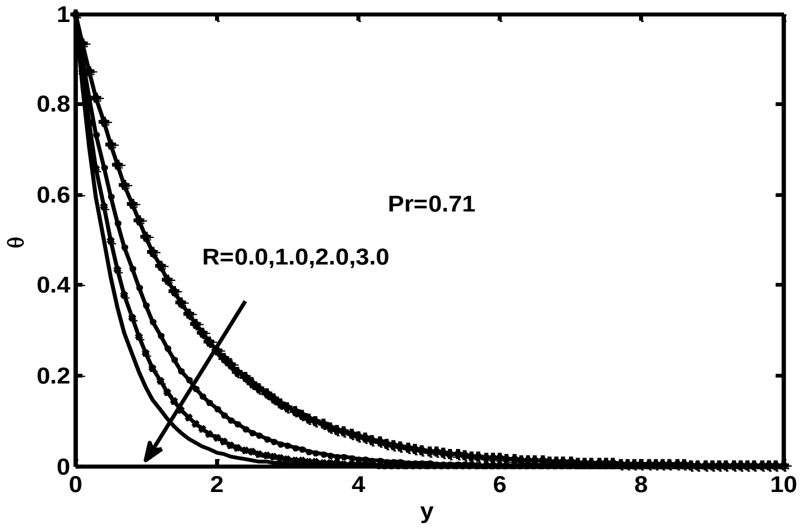

Figure 10. Temperature field for R

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APPENDIX

$$m_1 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}\right),$$

$$m_2 = -\left(\frac{\Pr + \sqrt{\Pr^2 + (\Pr R - 4\Pr Q)}}{2}\right)$$

$$m_3 = -\left(\frac{1 + \Pr_m + \sqrt{(1 - \Pr_m)^2 + 4M^2 \Pr_m}}{2}\right),$$

$$A_1 = \frac{Gr(m_2 - \Pr_m)}{m_2^3 + (1 + \Pr_m)m_2^2 + m_2(M^2 - 1)\Pr_m}$$

$$A_2 = \frac{Gm(\eta - \Pr_m)}{m_1^3 + (1 + \Pr_m)m_1^2 + m_1(M^2 - 1)\Pr_m}, A_3 = -(1 + A_1 + A_2)$$

$$B_1 = \frac{MA_1 \Pr_m}{m_2 - \Pr_m}, B_2 = \frac{MA_2 \Pr_m}{m_1 - \Pr_m}, B_3 = \frac{MA_3 \Pr_m}{m_3 - \Pr_m}, B_4 = -(B_1 + B_2 + B_3)$$

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ANALYTICAL STUDY ON INDUCED MAGNETIC FIELD WITH RADIATING FLUID OVER A POROUS VERTICAL PLATE WITH HEAT GENERATION

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