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EFFECT OF THERMAL RADIATION AND RADIATION ABSORPTION ON MHD HEAT AND MASS TRANSFER FLOW OF A VISCOUS INCOMPRESSIBLE CHEMICALLY REACTIVE FLUID IN PRESENCE OF HEAT SOURCE

BIKASH CHANDRA PARIDA*[1], BHARAT KESHARI SWAIN[2] AND NITYANANDA SENAPATI[3]

[1]Department of Mathematics, Utkal University, BBSR, Odisha, India.

[2]Department of Mathematics, IGIT, Sarang, Dhenkanal, Odisha, India.

[3]Department of Mathematics, Ravenshaw University, Cuttack, Odisha, India.

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ABSTRACT

The objective of this paper is to study the effects of thermal radiation, radiation absorption and chemical reaction on MHD free convective and chemically reactive boundary layer flow of a viscous incompressible rotating fluid through a porous medium past an infinite vertical porous plate in the presence of heat source. The Governing equations are solved by perturbation technique. The effects of different governing parameters on the flow field and mass transfer are shown in graphs and tables. The governing physical parameters significantly influence the flow field and mass transfer. Also, existing results in the literature are compared with the present study. Here it is found that the temperature profiles θ, being a decreasing function of F, decelerate the flow and reduce the fluid velocity. The primary velocity and temperature increase with increase of Q_c which is due to the fact that when heat is absorbed the buoyancy force which accelerates the flow. But Secondary velocity decreases with increase in Q_c. Applications of the present study arise in material processing systems and different industries.

Keywords: *MHD, Chemical reaction, Thermal Radiation, Radiation absorption, Nusselt number, Sherwood number, Skin friction.*

Nomenclature:
C' Species concentration (kgm^{-3}),
C_p Specific heat at constant pressure (Jkg−1K)
C'_∞ Species concentration in the free stream (kgm^{-3}),
C'_w Species concentration at the surface (kgm^{-3}), D Chemical molecular diffusivity (m^2s^{-1}) g Acceleration due to gravity (ms^{-2}), G_r Thermal Grashof number, G_m Mass Grashof number, K Permeability parameter, M Hartmann number, N_u Nusselt number, P_r Prandtl number, q_r Radiative heat flux, S_h Sherwood number, S_c Schmidt number, T' Temperature (K), Q Heat source parameter, Qc Radiation absorption parameter, E Rotation parameter, F Thermal radiation parameter, T'_w Fluid temperature at the surface (K) , T'_∞ Fluid temperature in the free stream (K), u, w- Dimensionless velocity component (ms^{-1}), R Chemical reaction parameter.

Greek symbols:
β Coefficient of volume expansion for heat transfer (K^{-1}), β_cCoefficient of volume expansion for mass transfer(K^{-1}), θ Dimensionless fluid temperature (K), k Thermal conductivity (${W_m}^{-1}K^{-1}$), ν Kinematic viscosity (m^2s^{-1}), ρ Density (kgm^{-3}),), τ Shearing stress (Nm^{-2}), φ Dimensionless species concentration (kgm^{-3}),

Subscripts:
w Conditions on the wall, ∞ Free stream condition.

Corresponding Author: Bikash Chandra Parida*[1],
[1]Department of Mathematics, Utkal University, BBSR, Odisha, India.

1. INTRODUCTION

Many natural phenomena and technological problems are susceptible to MHD analysis. Geophysics encounters MHD characteristics in the interactions of conducting fluids and magnetic fields. Engineers employ MHD principle, in the design of heat exchangers pumps and flow meters, in space vehicle propulsion, thermal protection, braking, control and re-entry, in creating novel power generating systems etc. From technological point of view, MHD convection flow problems are also very significant in the fields of stellar and planetary magnetospheres, aeronautics, chemical engineering and electronics. Model studies of the above phenomena of MHD convection have been made by many. Some of them are Sanyal and Bhattacharya (1992), Ferraro and Plumpt on (1966) and Cramer and Pai (1973). When technological processes take place at higher temperatures thermal radiation heat transfer has become very important and its effects cannot be neglected (Siegel and Howel, 2001). The effect of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur at high temperature and a knowledge of radiation heat transfer becomes a very important for the design of the pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors, and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. Different researches have been forwarded to analyze the effects of thermal radiation on different flows (Cortell, 2008; Bataller, 2008; Ibrahim et al. 2008; Shateyi, 2008; Shateyi and Motsa, 2009; Aliakba et al., 2009; Shateyi *et al.*, 2010, Hayat, 2010; Cortell, 2010; among other researchers). Heat flow and mass transfer over a vertical porous plate with variable suction and heat absorption/ generation have been studied by many workers. Raji Reddy and Srihari (2009) studied numerical solution of unsteady flow of a radiating and chemically reacting fluid with time-dependent suction. Chen (2006) studied heat and mass transfer in MHD flow by natural convection from a permeable, inclined surface with variable wall temperature and concentration. Perdikis and Rapti (2006) studied the unsteady MHD flow in the presence of radiation. Rahman and Sattar (2006) analyzed the MHD convective flow of a micro polar fluid past a continuously moving vertical porous plate in the presence of heat generation/ absorption. Kim (2000) investigated unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction by assuming that the free stream velocity follows the exponentially increasing small perturb action law. Chamkha (2004) extended the problem of Kim (2000) to heat absorption and mass transfer effects. Elbashbeshy (1997) studied heat and mass transfer along a vertical plate under the combined buoyancy effects of thermal and species diffusion, in the presence of magnetic field. Here it is proposed to study the effects of heat radiation and radiation absorption and chemical reaction parameters on the free convective fluid flow considered in the previous study by Ravi Kumar *et al.* [14].

2. FORMULATION OF PROBLEM

An unsteady free convection, incompressible and electrically conducting viscous rotating fluid through porous medium past an infinite isothermal, vertical porous plate with constant heat source, chemical reaction and variable suction is considered. Let (X' ,Y' ,Z') be the Cartesian coordinate system, and let us assume that X' -axis & Z' -axis in the plane of the plate and Y' -axis is normal to the plate with velocity components (u', v', w') in X', Y', Z' directions respectively. A uniform magnetic field B_0 is applied perpendicular to the plate. Both the liquid and the plate are considered in a state of rigid body rotation about Y'-axis with uniform angular velocity Ω. Initially surrounding fluid is at rest and the temperature is T'_∞ and mass concentration C'_∞ is at all points. As the plate temperature and mass concentration are considered infinite along X' direction; all physical quantities will be independent of x'. In this analysis of the flow, it is assumed that the magnetic Reynolds number is very small and hence the induced magnetic field is negligible in comparison to the applied magnetic field. It is also assumed that there is no applied voltage which implies the absence of an electric field. Viscous dissipation and joule heating terms are neglected as small velocity usually encountered in free convection flows and constant heat source Q is assumed at $y' = 0$.

By usual Boussinesq approximation the unsteady flow is governed by the following equations.

Equation of continuity: $\frac{\partial v'}{\partial y'} = 0$ (2.1)

which is satisfied with $v' = -v_0(1 + \varepsilon A e^{i\omega' t'})$ variable suction/injection.

Momentum equations:

X-component:

$$\frac{\partial u'}{\partial t'} - v_0\left(1 + \varepsilon A e^{i\omega' t'}\right)\frac{\partial u'}{\partial y'} - 2\Omega w' = \nu \frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta_c(C' - C'_\infty) - \frac{\nu u'}{K_0\left(1+\varepsilon A e^{i\omega' t'}\right)} - \frac{\sigma B_0^2 u'}{\rho} \quad (2.2)$$

Z-component:

$$\frac{\partial w'}{\partial t'} - v_0\left(1 + \varepsilon A e^{i\omega' t'}\right)\frac{\partial w'}{\partial y'} + 2\Omega u' = \nu \frac{\partial^2 w'}{\partial y'^2} - \frac{\nu w'}{K_0\left(1+\varepsilon A e^{i\omega' t'}\right)} - \frac{\sigma B_0^2 u'}{\rho} \quad (2.3)$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} - v_0\left(1 + \varepsilon A e^{i\omega' t'}\right)\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{q}{\rho C_p}(T' - T'_\infty) + \frac{1}{\rho C_p}\frac{\partial q_r'}{\partial y'} + Q_c'(C' - C'_\infty) \tag{2.4}$$

Mass concentration equation:

$$\frac{\partial C'}{\partial t'} - v_0\left(1 + \varepsilon A e^{i\omega' t'}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - R'(C' - C'_\infty) \tag{2.5}$$

The radiative heat flux is considered, which has been given by Cogley et al. [15] as well as Pal and Talukdar [16] as

$$\frac{\partial q_r'}{\partial y'} = 4(T' - T'_\infty)I' \tag{2.6}$$

where $I' = \int_0^\infty K_{\lambda w}\frac{\partial e_{b\lambda}}{\partial T^*}d\lambda$, $K_{\lambda w}$ is the coefficient of absorption near the wall and $e_{b\lambda}$ is Planck's function. Now introducing the following nondimensional quantities

$$\begin{aligned}
&y = \frac{y' v_0}{v}, t = \frac{t' v_0^2}{4v}, u = \frac{u'}{v_0}, w = \frac{w'}{v_0}, \theta = \frac{(T' - T'_\infty)}{(T'_w - T'_\infty)}\\
&\varphi = \frac{(C' - C'_\infty)}{(C'_w - C'_\infty)}, S_c = \frac{\vartheta}{D}, P_r = \frac{\mu C_p}{k}, R = \frac{R' v}{V_0^2}, K = \frac{K_0 v_0^2}{v^2}\\
&F = \frac{4vI'}{V_0^2 \rho C_p}, M = \frac{\sigma B_0^2 v}{\rho v_0^2}, E = \frac{\Omega v}{v_0^2}, Q = \frac{qv}{\rho C_p v_0^2}, \omega = \frac{4v\omega'}{v_0^2}\\
&G_r = \frac{vg\beta\,(T'_w - T'_\infty)}{v_0^2}, G_m = \frac{vg\beta_c(C'_w - C'_\infty)}{v_0^2}, Q_c = \frac{Q_c' v(C'_w - C'_\infty)}{v_0^2(T'_w - T'_\infty)}
\end{aligned} \tag{2.7}$$

The governing equations in nondimensional form are given by;

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial u}{\partial y} - 2Ew = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m\varphi - \frac{u}{K(1+\varepsilon A e^{i\omega t})} - Mu, \tag{2.8}$$

$$\frac{1}{4}\frac{\partial w}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial w}{\partial y} + 2Eu = \frac{\partial^2 w}{\partial y^2} - \frac{w}{K(1+\varepsilon A e^{i\omega t})} - Mw, \tag{2.9}$$

$$\frac{1}{4}\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - Q\theta - F\theta + Qc\varphi, \tag{2.10}$$

$$\frac{1}{4}\frac{\partial \varphi}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial \varphi}{\partial y} = \frac{1}{S_c}\frac{\partial^2 \varphi}{\partial y^2} - R\varphi, \tag{2.11}$$

Taking $p = u + iw$, equation (2.8) and equation (2.9) can be changed to

$$\frac{1}{4}\frac{\partial p}{\partial t} - (1 + \varepsilon A e^{i\omega t})\frac{\partial p}{\partial y} + 2E_i p = \frac{\partial^2 p}{\partial y^2} + G_r\theta + G_m\varphi - \frac{p}{K(1+\varepsilon A e^{i\omega t})} - Mp, \tag{2.12}$$

The boundary conditions to the problem in the dimensionless form are

$$\begin{aligned}
&p = 0, \theta = 1 + \varepsilon e^{i\omega t}, \varphi = 1 + \varepsilon e^{i\omega t} \; at\; y = 0\\
&p \to 0, \theta \to 0, \varphi \to 0 \; as\; y \to \infty
\end{aligned} \tag{2.13}$$

3. SOLUTION OF THE PROBLEM

In order to solve the equations, we assume the velocity $p(y,t)$ temperature $\theta(y,t)$ and concentration $\varphi(y,t)$ as:

$$\begin{aligned}
p(y,t) &= p_0(y) + \varepsilon p_1(y)e^{i\omega t}\\
\theta(y,t) &= \theta_0(y) + \varepsilon\theta_1(y)e^{i\omega t}\\
\varphi(y,t) &= \varphi_0(y) + \varepsilon\varphi_1(y)e^{i\omega t}
\end{aligned} \tag{3.1}$$

Using equation (3.1) into equations (2.10) to (2.13), we get the following set of equations

$$\frac{\partial^2 p_0}{\partial y^2} + \frac{\partial p_0}{\partial y} - \left(2iE + \frac{1}{K} + M\right)p_0 = -G_r\theta_0 - G_m\varphi_0 \tag{3.2}$$

$$\frac{\partial^2 p_1}{\partial y^2} + \frac{\partial p_1}{\partial y} - \left(2iE + \frac{1}{K} + M + \frac{1}{4}i\omega\right)p_1 = -\frac{Ap_0}{K} - \frac{A\partial p_0}{\partial y} - G_r\theta_1 - G_m\varphi_1 \tag{3.3}$$

$$\frac{\partial^2 \theta_0}{\partial y^2} + P_r\frac{\partial \theta_0}{\partial y} - (QP_r + FP_r)\theta_0 = -Q_c P_r\varphi_0 \tag{3.4}$$

$$\frac{\partial^2 \theta_1}{\partial y^2} + P_r\frac{\partial \theta_1}{\partial y} - P_r\left(\frac{1}{4}i\omega P_r + Q + F\right)\theta_1 = -\frac{AP_r\partial\theta_0}{\partial y} - Q_c P_r\varphi_1 \tag{3.5}$$

$$\frac{\partial^2 \varphi_0}{\partial y^2} + S_c\frac{\partial \varphi_0}{\partial y} - RS_c\varphi_0 = 0 \tag{3.6}$$

$$\frac{\partial^2 \varphi_1}{\partial y^2} + S_c\frac{\partial \varphi_1}{\partial y} - S_c\left(\frac{1}{4}i\omega + R\right)\varphi_1 = -\frac{AS_c\partial\varphi_0}{\partial y} \tag{3.7}$$

And the boundary conditions are

$$\begin{aligned}
&p_0 = p_1 = 0, \theta_0 = \theta_1 = 1, \varphi_0 = \varphi_1 = 1 \; at\; y = 0,\\
&p_0 = p_1 = 0, \theta_0 = \theta_1 = 0, \varphi_0 = \varphi_1 = 0 \; as\; y \to \infty
\end{aligned} \tag{3.8}$$

Solving the equations (3.2) to (3.7), we get

$$\varphi = e^{\lambda_2 y} + \varepsilon\left((1+k_1)e^{\lambda_4 y} - k_1 e^{\lambda_2 y}\right)e^{i\omega t}, \tag{3.9}$$

$$\theta = (1+k_2)e^{\lambda_6 y} - k_2 e^{\lambda_2 y} + \varepsilon((1+k_3+k_4+k_5+k_6)e^{\lambda_8 y} - k_3 e^{\lambda_6 y} - k_4 e^{\lambda_2 y} - k_5 e^{\lambda_4 y} - k_6 e^{\lambda_2 y})\, e^{i\omega t}, \tag{3.10}$$

$$p = (k_7 - k_8 + k_9)\, e^{\lambda_{10} y} - k_7 e^{\lambda_6 y} + k_8 e^{\lambda_2 y} - k_9 e^{\lambda_2 y} + \varepsilon e^{i\omega t}\left((k_{22} e^{\lambda_{12} y} - (k_{10}+k_{13})e^{\lambda_{10} y}\right) - k_{16} e^{\lambda_8 y} + (k_{11}+k_{14}+k_{17})e^{\lambda_6 y} + (k_{19}-k_{20})e^{\lambda_4 y} - (k_{12}+k_{15}+k_{18}- k_{21})e^{\lambda_2 y}) \tag{3.11}$$

Skin friction (τ) at the plate is given by

$$\left(\frac{\partial p}{\partial y}\right)_{y=0} = (k_7 - k_8 + k_9)\lambda_{10} - k_7\lambda_6 + k_8\lambda_2 - k_9\lambda_2 + \varepsilon e^{i\omega t}((k_{22}\lambda_{12} - (k_{10}+k_{13})\lambda_{10}) - k_{16}\lambda_8 + (k_{11}+k_{14}+ k17\lambda6+k19-k20\lambda4-(k12+k15+k18-k21)\lambda2) \tag{3.12}$$

Mean skin friction (τ_m) is given by

$$\tau_m = \frac{\int_0^{2\pi/\omega} \tau dt}{2\pi/\omega} = (k_7 - k_8 + k_9)\lambda_{10} - k_7\lambda_6 + k_8\lambda_2 - k_9\lambda_2 \tag{3.13}$$

Nusselt number is given by

$$N_u = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = (1+k_2)\lambda_6 - k_2\lambda_2 + \varepsilon((1+k_3+k_4+k_5+k_6)\lambda_8 - k_3\lambda_6 - k_4\lambda_2 - k_5\lambda_4 - k_6\lambda_2)e^{i\omega t} \tag{3.14}$$

Sherwood number is given by

$$S_h = \left(\frac{\partial \varphi}{\partial y}\right)_{y=0} = \lambda_2 + \varepsilon e^{i\omega t}((1+k_1)\lambda_4 - k_1\lambda_2) \tag{3.15}$$

where

$$\lambda_2 = \frac{-(Sc+\sqrt{Sc^2+4RSc})}{2},\ \lambda_4 = \frac{-(Sc+\sqrt{Sc^2+4Sc\left(\left(\frac{i\omega}{4}\right)+R\right)})}{2},$$

$$\lambda_6 = \frac{-(P_r+\sqrt{{P_r}^2+4P_r(Q+F)})}{2},\ \lambda_8 = \frac{-(P_r+\sqrt{{P_r}^2+4P_r\left(\left(\frac{i\omega}{4}\right)+Q+F\right)})}{2},$$

$$\lambda_{10} = \frac{-\left(1+\sqrt{1+4\left(2iE+M+\left(\frac{1}{k}\right)\right)}\right)}{2},\ \lambda_{12} = \frac{-\left(1+\sqrt{1+4\left(2iE+M+\left(\frac{1}{k}\right)+\left(\frac{i\omega}{4}\right)\right)}\right)}{2}$$

$$k_1 = \frac{AS_c\lambda_2}{{\lambda_2}^2+S_c\lambda_2-S_c\left(\frac{1}{4}i\omega+R\right)},\ k_2 = \frac{P_rQ_c}{{\lambda_2}^2+P_r\lambda_2-P_r(Q+F)},\ k_3 = \frac{AP_r(1+k_2)\lambda_6}{{\lambda_6}^2+P_r\lambda_6-P_r\left(\frac{1}{4}i\omega+Q+F\right)},$$

$$k_4 = \frac{k_2\lambda_2}{{\lambda_2}^2+P_r\lambda_2-P_r\left(\frac{1}{4}i\omega+Q+F\right)},\ k_5 = \frac{P_rQ_c(1+k_1)}{{\lambda_4}^2+P_r\lambda_4-P_r\left(\frac{1}{4}i\omega+Q+F\right)},\ k_6 = \frac{P_rQ_ck_1}{{\lambda_2}^2+P_r\lambda_2-P_r\left(\frac{1}{4}i\omega+Q+F\right)},$$

$$k_7 = \frac{G_r(1+k_2)}{{\lambda_6}^2+\lambda_6-\left(2iE+M+\left(\frac{1}{K}\right)\right)},\ k_8 = \frac{G_rk_2}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)\right)},\ k_9 = \frac{G_m}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)\right)},$$

$$k_{10} = \frac{(A/K)(k_7-k_8+k_9)}{{\lambda_{10}}^2+\lambda_{10}-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{11} = \frac{(A/K)k_7}{{\lambda_6}^2+\lambda_6-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},$$

$$k_{12} = \frac{\left(\frac{A}{K}\right)(k_8-k_9)}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{13} = \frac{A(k_7-k_8+k_9)\lambda_{10}}{{\lambda_{10}}^2+\lambda_{10}-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},$$

$$k_{14} = \frac{Ak_7\lambda_6}{{\lambda_6}^2+\lambda_6-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{15} = \frac{A(k_8-k_9)\lambda_2}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},$$

$$k_{16} = \frac{G_r(1+k_3+k_4+k_5+k_6)}{{\lambda_8}^2+\lambda_8-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{17} = \frac{G_rk_3}{{\lambda_6}^2+\lambda_6-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},$$

$$k_{19} = \frac{G_rk_5}{{\lambda_4}^2+\lambda_4-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{18} = \frac{G_r(k_4+k_6)}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},$$

$$k_{20} = \frac{G_m(1+k_1)}{{\lambda_4}^2+\lambda_4-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)},\ k_{21} = \frac{G_mk_1}{{\lambda_2}^2+\lambda_2-\left(2iE+M+\left(\frac{1}{K}\right)+(i\omega/4)\right)}.$$

4. RESULTS AND DISCUSSION

To discuss the physical significance of various parameters involved in the results (3.9) to (3.15), the numerical calculations have been carried out. The effects of the various parameters entering in the governing equations on the velocity, temperature, skin friction, Nusselt number and Sherwood number are shown through graphs.

The effects of some parameters are given below.

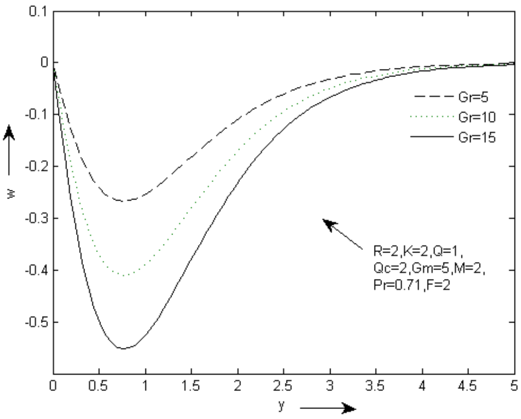

Figure-1: Primary velocity profiles for Gr

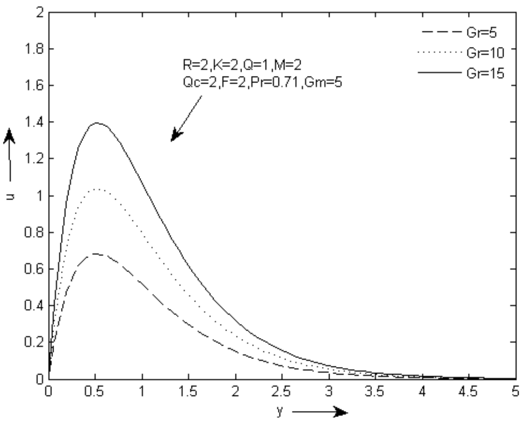

Figure-2: Secondary velocity profiles for Gr

Fig:1 & Fig.2 represent velocity profiles for various values of the thermal Grashof number (Gr). It is observed that an increase in Gr leads to a rise in the values of the primary velocity due to enhancement in buoyancy force. Here the positive values of Gr correspond to cooling of the plate. In addition, it is observed that velocity increases sharply near the wall of the porous plate as Gr increases and then decays to the free stream value. On the other hand, the secondary velocity is totally opposite in nature.

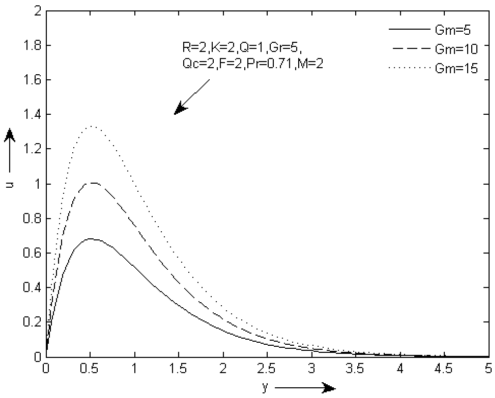

Figure-3: Primary velocity profiles for Gm

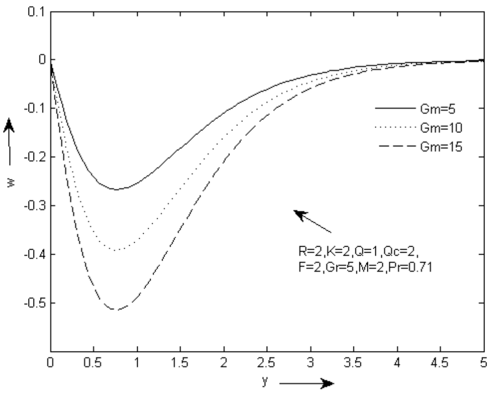

Figure-4: Secondary velocity profiles for Gm

Fig:3 & Fig.4: Here it is noticed that the fluid velocity distribution attains a distinctive maximum value in the vicinity of the plate and then decreases properly to approach a free stream value. As expected, the fluid velocity increases and the peak value becomes more distinctive due to increase in the buoyancy force represented by Gm. But it is opposite in case of Ravi kumar *et.al* [14]. Again, secondary velocity decreases due to increase in Gm.

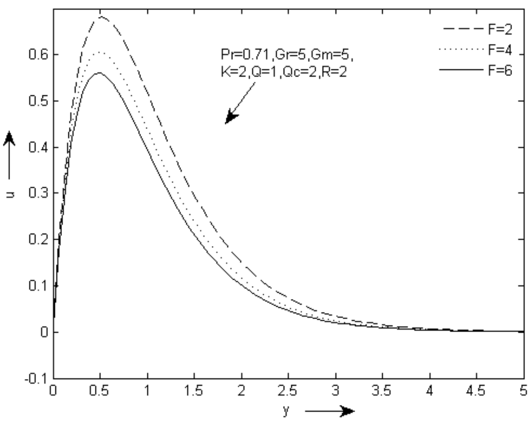

Figure-5: Primary velocity profiles for F

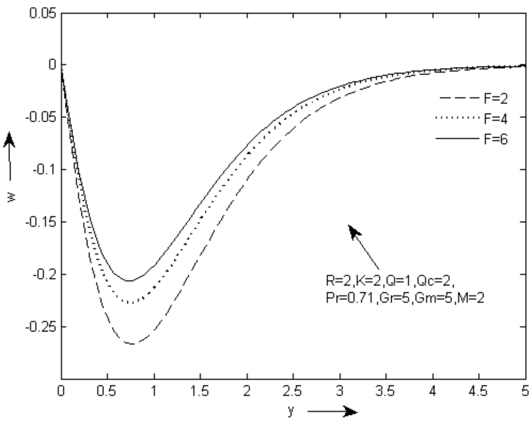

Figure-6: Secondary velocity profiles for F

In Fig:5, Fig.6 & Fig.7, for different values of thermal radiation parameter, profiles of velocity and temperature profiles are shown. It is found that the temperature profiles θ, being a decreasing function of F, decelerate the flow and reduce the fluid velocity. Physically speaking, the thermal boundary layer thickness decreases with an increase in the thermal radiation. Thus, it is pointed out that the radiation should be maximized to have the cooling process at a faster rate.

Again, there is a decrease in the velocity with the increase in F. Increase of F leads to decrease boundary layer thickness and to enhance the heat transfer rate in the presence of thermal buoyancy force. Here also secondary velocity is reversely affected. First it decreases to some extent then increases to a free stream value.

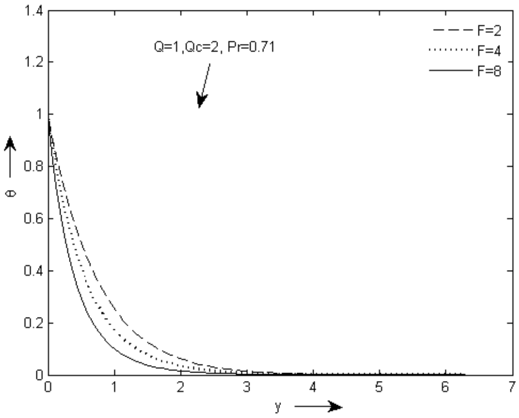

Figure-7: Temperature profiles for F

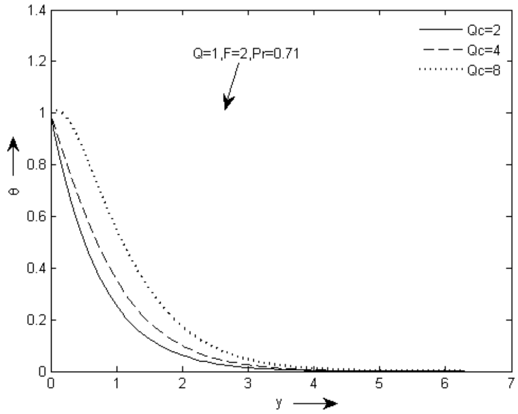

Figure-8: Temperature profiles for Qc

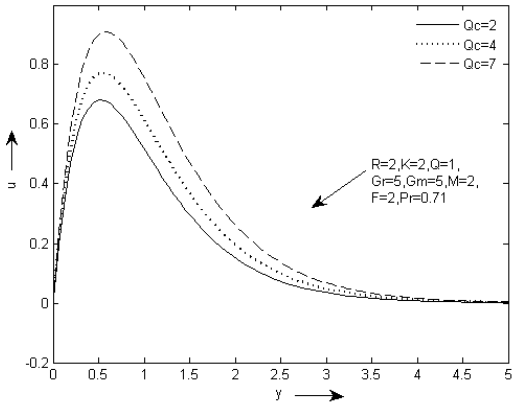

Figure-9: Primary velocity profiles for Qc

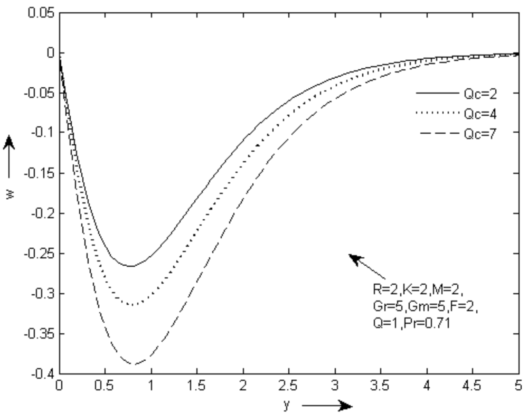

Figure-10: Secondary velocity profiles for Qc

For various values of Qc, the profiles of temperature and velocity profiles are shown in Fig.8, Fig.9 & Fig.10. It is clear from the graphs that all the primary velocity and temperature increase with increase of Qc which is due to the fact that when heat is absorbed the buoyancy force which accelerates the flow. But Secondary velocity decreases with increase in Qc.

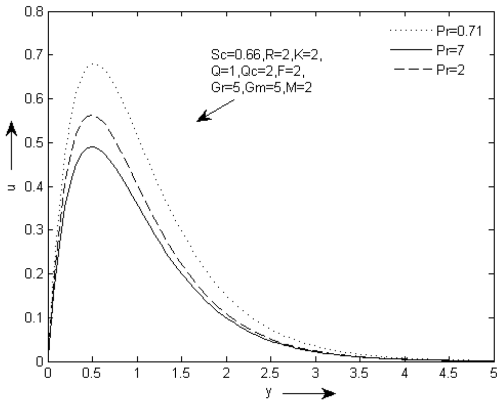

Figure-11: Primary velocity profiles for Pr

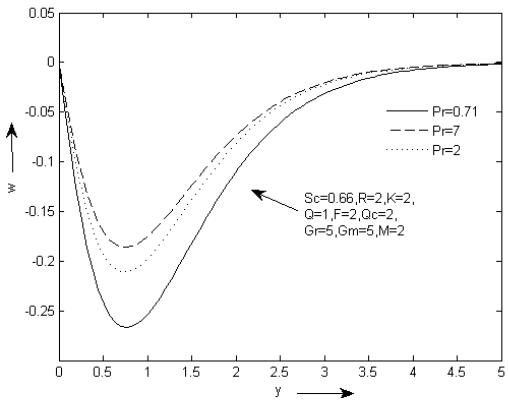

Figure-12: Secondary velocity profiles for Pr

In Fig.11 & Fig.12, It is observed that the velocity increases rapidly near to the wall of the porous plate, reaches a maximum and then decays to the free stream value of y. Again it is noticed that when the primary fluid velocity decreases with increasing Prandtl number Pr. Same result is shown in the previous study by Ravi Kumar *et.al* [14].This is because Pr is the ratio of viscous diffusion rate to thermal diffusion rate and higher Pr possess higher viscosities implying that such fluids will flow slower than lower Pr fluids. As a result, velocity will decrease substantially with increase in Pr.

Fig.13: It shows the behavior of temperature for different values of Prandtl number. It is observed that an increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to di ffuse away from the heated surface more rapidly for higher values of Pr. Hence in the case of smaller Prandtl number as the thermal boundary layer is thicker, the rate of heat transfer is reduced. Same result is shown in the previous study [14].

Fig: 14, Fig.15 & Fig.16 show the Velocity profiles and temperature profiles for various values of Q. Primary Velocity and temperature distributions decreases with increase of Q. On the other hand secondary velocity increases with increase in Q.

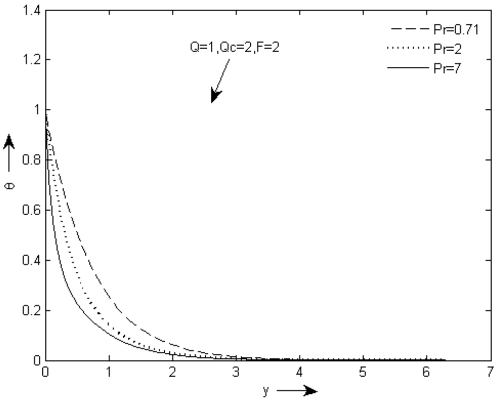

Figure-13: Temperature profiles for Pr

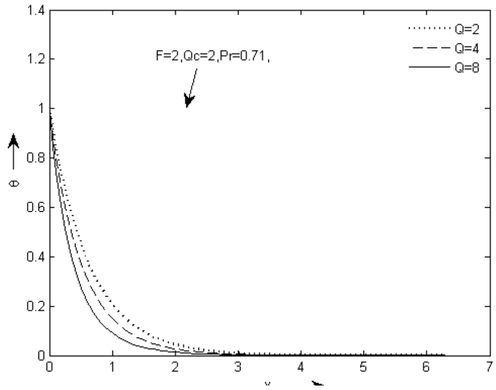

Figure-14: Temperature profiles for Q

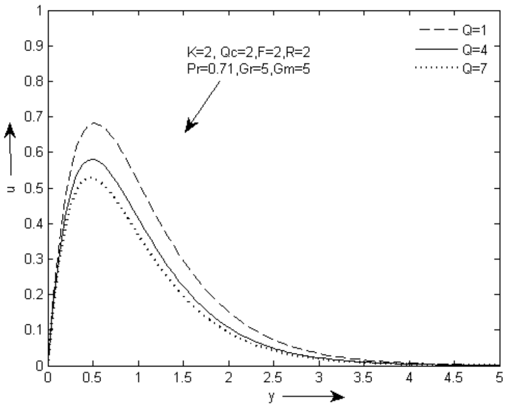

Figure-15: Primary velocity profiles for Q

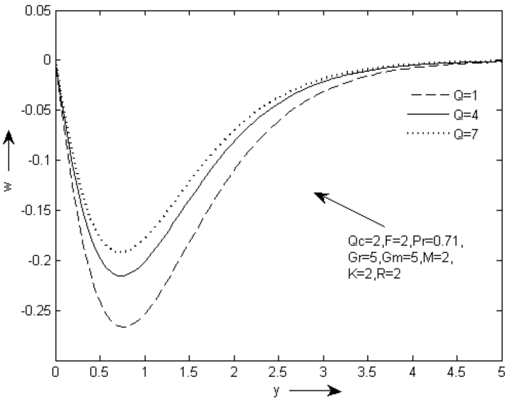

Figure-16: Secondary velocity profiles for Q

Fig: 17 depicts the velocity profiles for di fferent values of M. It shows that velocity decreases with increase in a magnetic parameter M along the surface. These effects are much stronger near the surface of the plate. This indicates that the fluid velocity is reduced by increasing the magnetic field and confines the fact that the application of a magnetic field to an electrically conducting fluid produces a dragline force which causes reduction in the fluid velocity. Here, M shows the same result as reported by Ravi Kumar et al [14].

In Fig.18 & Fig.19, it is noticed that chemical reaction parameter has a reducing effect on both velocity and concentration distribution.

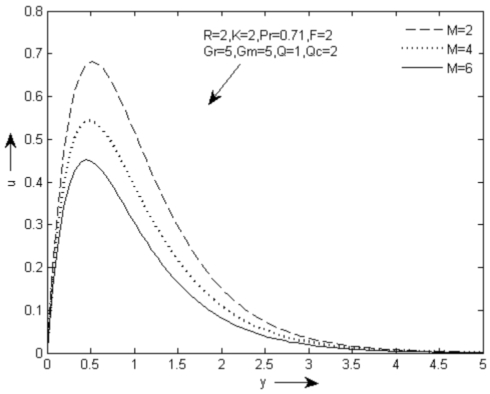

Figure-17: Primary velocity profiles for M

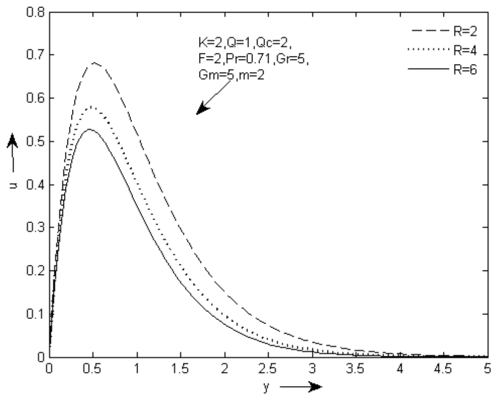

Figure-18: Primary velocity profiles for R

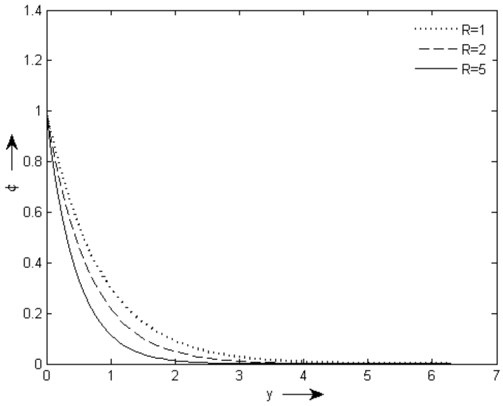

Figure-19: Concentration profiles for R

Q	Q_C	P_r	F	N_u
1	2	0.71	2	1.3258
4	2	0.71	2	2.0152
7	2	0.71	2	2.5275
1	4	0.71	2	0.7936
1	7	0.71	2	0.0053
1	2	2	2	2.3854
1	2	7	2	5.5765
1	2	0.71	4	1.8132
1	2	0.71	6	2.1992

Table-1

R	S_c	S_h
2	0.66	1.5261
4	0.66	1.9890
6	0.66	2.3484
2	2	3.2377
2	4	5.4669

Table-2

Table-1 gives the idea about Nusselt number N_u . The parameters Q, F and P_r are directly proportional to the rate of heat transfer. But radiation absorption parameter Q_c adversely a affect the heat transfer.

From Table-2, it is noted that both chemical reaction parameter R and Schimdt number enhances the mass transfer

G_r	G_m	P_r	F	Q_c	Q	R	M	τ_m
5	5	0.71	2	2	1	2	2	3.6345
10	5	0.71	2	2	1	2	2	5.5066
15	5	0.71	2	2	1	2	2	7.3787
5	10	0.71	2	2	1	2	2	5.3970
5	15	0.71	2	2	1	2	2	7.1595
5	5	2	2	2	1	2	2	3.2203
5	5	7	2	2	1	2	2	2.8489
5	5	0.71	4	2	1	2	2	3.3852
5	5	0.71	6	2	1	2	2	3.2251
5	5	0.71	2	4	1	2	2	3.9264
5	5	0.71	2	7	1	2	2	4.3654
5	5	0.71	2	2	4	2	2	3.2978

5	5	0.71	2	2	7	2	2	3.1094
5	5	0.71	2	2	1	4	2	3.3145
5	5	0.71	2	2	1	6	2	3.1262
5	5	0.71	2	2	1	2	4	3.1310
5	5	0.71	2	2	1	2	6	2.7917

Table-3

In Table-3, Some numerical values of mean skin friction are obtained for different values of parameters G_r, G_m, P_r, F, Q_c, Q, R, M. It is noted that skin friction increases due to increase in F, G_r and G_m and increasing values of other parameters result a decrease in skin friction.

5. CONCLUSION

In this paper, the influences of thermal radiation parameter and radiation absorption parameter on MHD free convective and chemically reactiveflow of a viscous i ncompressible rotatingfluid through a porous medium past an infinite vertical porous plate in the presence of heat source were studied. The governing system of equations was solved by Perturbation technique. The effects of di fferent parameters on velocity, temperature, skin friction were studied. Some important conclusions are given below.

- For most of the parameters, the primary velocity increases to a peak value near to the wall and then decreases to the free stream value of y. But in case of secondary velocity, it decreases to some extent then gradually increases with increasing values of y.
- All the parameters show opposite effects on secondary velocity. For example, when Pr increases primary velocity decreases but secondary velocity increases.
- The effects of Pr, Gr, M on velocity are same as the previous study [14].
- The effect of Gm on velocity is opposite to the result of the previous study [14].
- Primary velocity decreases with increasing values of the radiation parameter F.
- Increasing values of the radiation absorption parameter Qc enhances the primary velocity.
- Temperature rises with increasing values of Qc but falls with increasing values of Q, Pr and F.

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23. Prakash J, (2016), Diffusion-thermo effects on MHD free convective radiative and chemically reactive boundary layer flow through a porous medium, Journal of Computational and Applied Research, 5(2), 111-126. over a vertical plate.

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