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Chemical Reaction and Radiation Effects on Unsteady MHD Mixed Convective Oscillatory Flow of Micro Polar Fluid Embedded In A Porous Medium With Heat Absorption

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ABSTRACT

Magneto hydrodynamic mixed convective, radiative heat and mass transfer of an electrically conducting, viscous incompressible, chemically reacting oscillatory flow of micro polar fluid past a moving infinite vertical permeable plate embedded in a porous medium taking into the account of viscous dissipation under the influence of heat absorption is studied. The governing equations of momentum, energy and concentration are solved analytically by using perturbation technique. The velocity, temperature and concentration profiles are reported graphically for different parameters with various values.

Key words: Chemical reaction, Heat absorption, Heat and mass transfer, Micro polar fluid, Mixed convection, Magneto-hydrodynamics, Porous medium, Thermal radiation, Viscous dissipation.

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I. INTRODUCTION

Eringen (1965) proposed a theory of molecular fluids. Micro polar fluids contain micro-constituents that can undergo rotation, and this can affect the hydrodynamics of the flow so that it distinctly as non-Newtonian fluid. This flow has many practical applications, such as analysing the behaviour of exotic lubricants, the flow of colloidal suspensions, polymeric fluids, liquid crystals, additive suspensions, human and animal blood, turbulent shear flow and so forth. Kiran Kumar et al. [1] have given perturbation analysis on the influence of diffusion thermo and chemical reaction effects on MHD oscillatory flow of micropolar fluid over an infinite moving permeable plate in a saturated porous medium. Sreelatha et al. [2] made an attempt to study the two-dimensional MHD free convective electrically conducting incompressible viscous fluid oscillatory flow past an infinite vertical porous plate in the presence of porous medium, through which suction occurs with constant velocity and chemical reaction in the presence of a heat source. Helmy et al. [3] analysed the MHD free convection micro polar fluid flow past a vertical porous plate by using Laplace transform technique. Kima and Lee [4] investigated about the oscillatory two-dimensional laminar, viscous incompressible electrically conducting micro polar fluid flow over a semi-infinite vertical moving porous plate in the presence of a transverse magnetic field. Mohammed and Dahab [5] discussed the effects of chemical reaction and thermal radiation on hydro magnetic free convection heat and mass transfer for a micro polar fluid via a porous medium bounded by a semi-infinite vertical porous plate in the presence of heat generation. Modather et.al.[6] gave an analytical solution is presented for the problem of heat and mass transfer of an oscillatory two-dimensional viscous, electrically conducting micro polar fluid over an infinite moving permeable plate in a saturated porous medium in the presence of a transverse magnetic field. Darbhashayanam and Upendar [7] analysed the flow and the flow and heat and mass transfer characteristics of the free convection on a vertical plate with uniform wall temperature and concentration in a micropolar fluid in the presence of a first-order chemical reaction and radiation. Dulal Pal and Biswas [8] analysed the MHD oscillatory flow on convective-radiative heat and mass transfer of micropolar fluid in a porous medium with chemical reaction using perturbation technique.

The objective of this work is to study the combined effects of magnetic field and chemical reaction of first order in two-dimensional unsteady MHD oscillatory flow, heat and mass transfer of a viscous incompressible fluid past a permeable vertical plate embedded in a porous medium in the presence of viscous dissipation and thermal radiation with heat absorption using perturbation technique. The effects of various physical parameters on the velocity, temperature and concentration profiles are analysed through the graphs.

II. FORMULATION OF THE PROBLEM

Let us consider two dimensional unsteady mixed convection, viscous incompressible electrically conducting micro polar fluid with heat and mass transfer over an infinite vertical porous moving permeable plate embedded in a porous medium in the presence of viscous dissipation, thermal radiation, heat absorption and chemical reaction. The flow is assumed to be in the *x*-direction, which is taken along the plate and *y* is taken normal to the plate. A constant magnetic field of strength B_0 is applied in *y*-direction. It is assumed that the induced magnetic field is negligible in comparison to the applied magnetic field. Also assuming the Joule heating is negligible. The fluid is considered to be emitting, grey absorbing or radiating but not scatting medium. The plate moves with uniform velocity u_p^* continuously in its own plane. It is assumed that the temperature of the surface is held uniform at T_w and the ambient temperature are taken as T_∞ so that $T_w > T_\infty$. The species concentration at the surface is maintained uniformly at C_w and that of the ambient fluid is taken as C_∞. Since the rate of reaction is directly proportional to the concentration difference which is associated with the concentration of the species *C* in the solutal boundary layer and the ambient fluid concentration C_∞, so first-order chemical reaction is considered .The chemical reaction is assumed to be irreversible. Under these assumptions, the governing equations are as follows:

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = (\nu + \nu_r)\frac{\partial^2 u^*}{\partial y^{*2}} + 2\nu_r \frac{\partial \omega^*}{\partial y^*} + g\beta_T (T - T_\infty) + g\beta_C (C - C_\infty) - \frac{\sigma B_0^2}{\rho} u^* - \frac{(\nu + \nu_r)}{K} \tag{2}$$

$$\rho j^* \left(\frac{\partial \omega^*}{\partial t^*} + v^* \frac{\partial \omega^*}{\partial y^*} \right) = \gamma \frac{\partial^2 \omega^*}{\partial y^{*2}} \tag{3}$$

$$\frac{\partial T}{\partial T^*} + v^* \frac{\partial T}{\partial y^*} = \alpha \frac{\partial^2 T}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q^*}{\partial y^*} + \frac{\mu}{\rho C_p}\left(\frac{\partial u^{*2}}{\partial y^{*2}}\right) - \frac{Q^*}{\rho C_p}(T - T_\infty) \tag{4}$$

$$\frac{\partial C}{\partial t^*} + v^* \frac{\partial C}{\partial y^*} = D\frac{\partial^2 C}{\partial y^{*2}} + \gamma_1^* (C - C_\infty) \tag{5}$$

where (u^*, v^*) are the velocity components at any point (x^*, y^*); ω^* is the angular velocity components normal to the x^*y^* plane; T is the temperature of the fluid; and C is the mass concentration of the species in the flow ρ, ν, ν_r, g, β_T, β_C, σ , K, j^*, γ ,α, D, Q^* and γ_1^* are the density, kinematic viscosity, kinematic rotational viscosity, acceleration due to gravity, coefficient of volumetric thermal expansion of the fluid, coefficient of volumetric mass expansion of the fluid, electrical conductivity of the fluid, permeability of the medium, micro inertia per unit mass, spin gradient viscosity, thermal diffusivity, molecular diffusivity, the dimensional heat absorption parameter and the dimensional chemical reaction parameter respectively. As we know that the change in the concentration of species gives rise to the solutal buoyancy Eq. (2) and Eq. (5) are coupled. The appropriate boundary conditions for the problem are as follows

$$\left.\begin{array}{l} u^* = U_P^*, \omega^* = -n_1 \dfrac{\partial u^*}{\partial y^*}, T = T_\infty + \varepsilon (T_w - T_\infty) e^{n^*t^*}, C = C_\infty + \varepsilon (C_w - C_\infty) e^{n^*t^*} \quad at\ y = 0 \\ u^* \to 0, \quad \omega^* \to 0, \quad T \to T_\infty, \quad C \to C_\infty \quad as \quad y^* \to \infty \end{array}\right\} \tag{6}$$

When $n_1 = 0$, we obtain from the boundary condition stated in Eq. (6), for the micro rotation, $\omega^* = 0$. This represents that the microelements in concentrated particle flows in which close to the wall are not able to rotate. However, when $n_1 = 0.5$ or $n_1 = 1.0$, the micro- rotation term gets augmented and induces flow enhancement.

From the Eq. (1), it is clear that the suction velocity is considered to be in the form

$$v^* = -(1 + \varepsilon A e^{n^*t^*}) V_0 \tag{7}$$

where A is a real positive constant, εA small less than unity and V_0 is a scale of suction velocity which has a non-zero positive constant. The radiative heat flux term by using the Rosseland approximation is given by

$$q_r^* = -\frac{4\sigma^*}{3K_1^*}\frac{\partial T^{*^4}}{\partial y^*} \qquad (8)$$

We assume that the differences in temperature are sufficiently small within the flow such that T^{*^4} may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about T_∞^* and neglecting higher order terms (second order onwards) we get

$$T^{*^4} \cong 4T_\infty^{*^3}T^* - 3T_\infty^{*^4} \qquad (9)$$

It is convenient to employ the following dimensionless variables

$$\left.\begin{array}{l}
u^* = U_0 u,\ v^* = V_0 v,\ y^* = \dfrac{\upsilon}{V_0}y,\ U_p^* = U_0 U_p,\ \ \omega^* = \dfrac{U_0 V_0}{\upsilon}\omega,\ \ t^* = \dfrac{\upsilon}{V_0^2},\\
(T - T_\infty) = (T_w - T_\infty)\theta,\quad (C - C_\infty) = (C_w - C_\infty)\varphi,\ \ n^* = \dfrac{V_0^2}{\upsilon}n,\ \ j^* = \dfrac{\upsilon^2}{V_0^2}j\\
\Pr = \dfrac{\upsilon}{\alpha},\quad Sc = \dfrac{\upsilon}{D},\ M = \dfrac{\sigma B_0^2\upsilon}{\rho V_0^2},\ Gr = \dfrac{\upsilon g\beta_T(T_w - T_\infty)}{U_0 V_0^2},\ Gc = \dfrac{\upsilon g\beta_C(C_w - C_\infty)}{U_0 V_0^2}\\
\gamma = \left(\mu + \dfrac{\Lambda}{2}\right)j^* = \mu j^*\left(1 + \dfrac{\beta}{2}\right),\ \beta = \dfrac{\Lambda}{\mu} = \dfrac{v_r}{\upsilon},\ \ K_2 = \dfrac{KU_0V_0^2}{\upsilon^2},\ \eta = \dfrac{\mu j^*}{\gamma} = \dfrac{2}{2+\beta}\\
Kr = \dfrac{\upsilon\gamma_1^*}{V_0^2},\ Ec = \dfrac{U_0^2}{c_p(T_w - T_\infty)},\ \Pr = \dfrac{\mu\rho c_p}{K} =,\ \upsilon = \dfrac{\mu}{\rho},\ \ R = \dfrac{4\sigma^* T_\infty^{*^3}}{KK_1^*}, Q = \dfrac{Q^*\upsilon}{\rho c_p V_0^2}
\end{array}\right\} \qquad (10)$$

With the help of Eqns. (7), (8), (9) and (10) Eqns. (1)–(6) reduced to the following:

$$\frac{\partial v}{\partial y} = 0 \qquad (11)$$

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon Ae^{nt}\right)\frac{\partial u}{\partial y} = (1+\beta)\frac{\partial^2 u}{\partial y^2} + 2\beta\frac{\partial \omega}{\partial y} + Gr\theta + Gc\ \varphi - Mu - \frac{(1+\beta)}{K_2}u \qquad (12)$$

$$\frac{\partial \omega}{\partial t} - \left(1 + \varepsilon Ae^{nt}\right)\frac{\partial \omega}{\partial y} = \frac{1}{\eta}\frac{\partial^2 \omega}{\partial y^2} \qquad (13)$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon Ae^{nt}\right)\frac{\partial \theta}{\partial y} = \frac{1}{\Pr}\left(1 + \frac{4}{3}R\right)\frac{\partial^2 \theta}{\partial y^2} + Ec\left(\frac{\partial u}{\partial y}\right)^2 - Q\theta \qquad (14)$$

$$\frac{\partial \phi}{\partial t} - \left(1 + \varepsilon Ae^{nt}\right)\frac{\partial \phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} + Kr\ \phi \qquad (15)$$

with dimensionless Boundary conditions

$$\left.\begin{array}{l}
u = U_p,\ \omega = -n_1\dfrac{\partial u}{\partial y},\ \ \theta = 1 + \varepsilon e^{nt},\ \ \varphi = 1 + \varepsilon e^{nt}\quad at\ \ y = 0\\
u \to 0,\ \ \omega \to 0,\qquad \theta \to 0,\qquad \varphi \to 0\qquad as\ \ y \to \infty
\end{array}\right\} \qquad (16)$$

To solve Eqs. (11) – (15) subject to the boundary conditions Eq. (16) we may use the following linear transformations for low value of ε

$$\begin{array}{ll}
u(y,t) = u_0(y) + \varepsilon e^{nt}u_1(y) + O(\varepsilon^2) & \omega(y,t) = \omega_0(y) + \varepsilon e^{nt}\omega_1(y) + O(\varepsilon^2)\\
\theta(y,t) = \theta_0(y) + \varepsilon e^{nt}\theta_1(y) + O(\varepsilon^2) & \varphi(y,t) = \varphi_0(y) + \varepsilon e^{nt}\varphi_1(y) + O(\varepsilon^2)
\end{array} \qquad (17)$$

After substituting Eq. (17) into Eqs. (11) to (13), we have

$$(1+\beta)u_0'' + u_0' - \left(M + \frac{1+\beta}{K_2}\right)u_0 = -Gr\theta_0 - Gc\varphi_0 - 2\beta\omega_0' \qquad (18)$$

$$\left(1+\beta\right)u_1''+u_1'-\left(M+\frac{1+\beta}{K_2}+n\right)u_1=-Au_0'-Gr\theta_1-Gc\varphi_1-2\beta\omega_1' \quad (19)$$

$$\omega_0''+\eta\omega_0'=0 \quad (20)$$

$$\omega_1''+\eta\omega_1'-n\eta\omega_1=-A\eta\omega_0' \quad (21)$$

$$\left(3+4R\right)\theta_0''+3\Pr\theta_0'-3\Pr Q\theta_0=-3\Pr Ecu_0' \quad (22)$$

$$\left(3+4R\right)\theta_1''+3\Pr\theta_1'-3\Pr\left(n+Q\right)\theta_1=-3\Pr A\theta_0''-6\Pr Ecu_0'u_1' \quad (23)$$

$$\varphi_0''+Sc\varphi_0'+KrSc\varphi_0=0 \quad (24)$$

$$\varphi_1''+Sc\varphi_1'+\left(Kr-n\right)Sc\varphi_1=-ASc\varphi_0' \quad (25)$$

With the following boundary conditions

$$u_0=U_p,\ u_1=0,\ \omega_0=-n_1u_0',\ \omega_1=-n_1u_1',\ \theta_0=1,\ \theta_1=1,\varphi_0=1,\varphi_1=1\ \ at\ \ y=0$$

$$u_0=u_1=\omega_0=\omega_1=\theta_0=\theta_1=\varphi_0=\varphi_1=0 \quad as\ \ y\to\infty \quad (26)$$

To solve the nonlinear coupled Eqs. (18) – (26), we assume that the viscous dissipation parameter (Eckert number Ec) is small, so we can write the asymptotic expansion as follows

$$u_0(y)=u_{01}(y)+Ec\,u_{02}(y)+O(\mathrm{Ec}^2) \qquad u_1(y)=u_{11}(y)+Ec\,u_{12}(y)+O(\mathrm{Ec}^2)$$

$$\omega_0(y)=\omega_{01}(y)+Ec\,\omega_{02}(y)+O(\mathrm{Ec}^2) \qquad \omega_1(y)=\omega_{11}(y)+Ec\,\omega_{12}(y)+O(\mathrm{Ec}^2)$$

$$\theta_0(y)=\theta_{01}(y)+Ec\,\theta_{02}(y)+O(\mathrm{Ec}^2) \qquad \theta_1(y)=\theta_{11}(y)+Ec\,\theta_{12}(y)+O(\mathrm{Ec}^2)$$

$$\varphi_0(y)=\varphi_{01}(y)+Ec\,\varphi_{02}(y)+O(\mathrm{Ec}^2) \qquad \varphi_1(y)=\varphi_{11}(y)+Ec\,\varphi_{12}(y)+O(\mathrm{Ec}^2) \quad (27)$$

Substituting Eq. (27) into Eqns. (18)–(26), we obtain the following sequence of approximations for O(0) of Ec:

$$\left(1+\beta\right)u_{01}''+u_{01}'-\left(M+\frac{1+\beta}{K_2}\right)u_{01}=-Gr\theta_{01}-Gc\varphi_{01}-2\beta\omega_{01}' \quad (28)$$

$$\left(1+\beta\right)u_{02}''+u_{02}'-\left(M+\frac{1+\beta}{K_2}\right)u_{02}=-Gr\theta_{02}-Gc\varphi_{02}-2\beta\omega_{02}' \quad (29)$$

$$\omega_{01}''+\eta\omega_{01}'=0 \quad (30)$$

$$\omega_{02}''+\eta\omega_{02}'=0 \quad (31)$$

$$\left(3+4R\right)\theta_{01}''+3\Pr\theta_{01}'-3\Pr Q\theta_{01}=0 \quad (32)$$

$$\left(3+4R\right)\theta_{02}''+3\Pr\theta_{02}'-3\Pr Q\theta_{02}=-3\Pr u_{01}'^2 \quad (33)$$

$$\varphi_{01}''+Sc\varphi_{01}'+KrSc\varphi_{01}=0 \quad (34)$$

$$\varphi_{02}''+Sc\varphi_{02}'+KrSc\varphi_{02}=0 \quad (35)$$

Subjected to the boundary conditions

$$u_{01}=U_p,\ u_{02}=0,\ \omega_{01}=-n_1u_{01}',\ \omega_{02}=-n_1u_{02}',\ \theta_{01}=1,\ \theta_{02}=0,\varphi_{01}=1,\varphi_{02}=0\ \ at\ \ y=0$$

$$u_{01}=u_{02}=\omega_{01}=\omega_{02}=\theta_{01}=\theta_{02}=\varphi_{01}=\varphi_{02}=0 \quad as\ \ y\to\infty \quad (36)$$

Also we get the following equations for O(1) of Ec

$$\left(1+\beta\right)u_{11}''+u_{11}'-\left(M+\frac{1+\beta}{K_2}+n\right)u_{11}=-Au_{01}'-Gr\theta_{11}-Gc\varphi_{11}-2\beta\omega_{11}' \quad (37)$$

$$\left(1+\beta\right)u_{12}''+u_{12}'-\left(M+\frac{1+\beta}{K_2}+n\right)u_{12}=-Au_{02}'-Gr\theta_{12}-Gc\varphi_{12}-2\beta\omega_{12}' \quad (38)$$

$$\omega_{11}''+\eta\omega_{11}'-n\eta\omega_{11}=-A\eta\omega_{01}' \quad (39)$$

$$\omega_{12}''+\eta\omega_{12}'-n\eta\omega_{12}=-A\eta\omega_{02}' \quad (40)$$

$$\left(3+4R\right)\theta_{11}''+3\Pr\theta_{11}'-3\Pr\left(n+Q\right)\theta_{11}=-3\Pr A\theta_{01}' \tag{41}$$

$$\left(3+4R\right)\theta_{12}''+3\Pr\theta_{12}'-3\Pr\left(n+Q\right)\theta_{12}=-3\Pr A\theta_{02}''-6\Pr Ecu_{01}'u_{11}' \tag{42}$$

$$\varphi_{11}''+Sc\varphi_{11}'+\left(Kr-n\right)Sc\varphi_{11}=-ASc\varphi_{01}' \tag{43}$$

$$\varphi_{12}''+Sc\varphi_{12}'+\left(Kr-n\right)Sc\varphi_{12}=-ASc\varphi_{02}' \tag{44}$$

Subject to the boundary conditions

$$u_{11}=0\ ,\ u_{12}=0,\ \omega_{11}=-n_1u_{11}',\ \omega_{12}=-n_1u_{12}',\ \theta_{11}=1,\ \theta_{12}=0,\varphi_{11}=1,\varphi_{12}=0\quad at\ \ y=0$$

$$u_{11}=u_{12}=\omega_{11}=\omega_{12}=\theta_{11}=\theta_{12}=\varphi_{11}=\varphi_{12}=0\qquad as\ \ y\to\infty \tag{45}$$

Solving equations (25) – (32) under the boundary conditions Eq. (33) and equations (34) – (41) under the boundary conditions Eq. (42) and substituting into equations (24) and (14), we obtain the concentration, temperature, angular velocity and velocity profiles of all the flow respectively as follows:

$$u_{01}=c_{15}e^{-h_6y}+a_1e^{-h_4y}+a_2e^{-h_1y}+c_{14}a_3e^{-\eta y}$$

$$u_{02}=c_{21}e^{-h_8y}+a_9e^{-h_7y}+a_{10}e^{-d_{13}y}+a_{11}e^{-d_{14}y}+a_{12}e^{-d_{15}y}+a_{13}e^{-d_{16}y}+a_{14}e^{-d_{17}y}+a_{15}e^{-d_{18}y}$$
$$+a_{16}e^{-d_{19}y}+a_{17}e^{-d_{20}y}+a_{18}e^{-d_{21}y}+a_{19}e^{-d_{22}y}+a_{20}c_{18}e^{-\eta y}$$

$$u_{11}=c_{25}e^{-h_{10}y}+a_{29}e^{-h_6y}+a_{30}e^{-h_4y}+a_{31}e^{-h_1y}+a_{32}e^{-\eta y}+a_{33}e^{-h_5y}+a_{34}e^{-h_2y}+a_{35}c_{23}e^{-h_9y}$$

$$u_{12}=c_{31}e^{-h_{12}y}+a_{91}e^{-h_6y}+a_{92}e^{-h_7y}+a_{93}e^{-d_{13}y}+a_{94}e^{-d_{14}y}+a_{95}e^{-d_{15}y}+a_{96}e^{-d_{16}y}+a_{97}e^{-d_{17}y}+$$
$$a_{98}e^{-d_{18}y}+a_{99}e^{-d_{19}y}+a_{100}e^{-d_{20}y}+a_{101}e^{-d_{21}y}+a_{102}e^{-d_{22}y}+a_{103}e^{-\eta y}+a_{104}e^{-h_{11}y}+a_{105}e^{-h_7y}+$$
$$a_{106}e^{-d_{13}y}+a_{107}e^{-d_{14}y}+a_{108}e^{-d_{15}y}+a_{109}e^{-d_{16}y}+a_{110}e^{-d_{17}y}+a_{111}e^{-d_{18}y}+a_{112}e^{-d_{19}y}+$$
$$a_{113}e^{-d_{20}y}+a_{114}e^{-d_{21}y}+a_{115}e^{-d_{22}y}+a_{116}e^{-d_{35}y}+a_{117}e^{-2h_6y}+a_{118}e^{-d_{38}y}+a_{119}e^{-d_{40}y}+$$
$$a_{120}e^{-d_{42}y}+a_{121}e^{-d_{44}y}+a_{122}e^{-d_{46}y}+a_{123}e^{-d_{48}y}+a_{124}e^{-d_{50}y}+a_{125}e^{-d_{52}y}+a_{126}e^{-2h_4y}+$$
$$a_{127}e^{-d_{55}y}+a_{128}e^{-d_{57}y}+a_{129}e^{-d_{59}y}+a_{130}e^{-d_{61}y}+a_{131}e^{-d_{63}y}+a_{132}e^{-d_{65}y}+a_{133}e^{-d_{67}y}+$$
$$a_{134}e^{-d_{69}y}+a_{135}e^{-2h_1y}+a_{136}e^{-d_{72}y}+a_{137}e^{-d_{74}y}+a_{138}e^{-d_{76}y}+a_{139}e^{-d_{78}y}+a_{140}e^{-d_{80}y}+$$
$$a_{141}e^{-d_{82}y}+a_{143}e^{-d_{86}y}+a_{144}c_{29}e^{-h_8y}+a_{145}e^{-\eta y}$$

$$\omega_{01}=c_{14}e^{-\eta y}\ ,\omega_{02}=c_{18}e^{-\eta y},\ \omega_{11}=c_{23}e^{-h_9y}+g_1e^{-\eta y},\ \omega_{12}=c_{19}e^{-h_{13}y}-\frac{A\eta c_{18}}{n}e^{-\eta y},\theta_{01}=e^{-h_4y}$$

$$\theta_{02}=c_{19}e^{-h_7y}+d_2e^{-d_{13}y}+d_3e^{-d_{14}y}+d_4e^{-d_{15}y}+d_5e^{-d_{16}y}+d_6e^{-d_{17}y}+d_7e^{-d_{18}y}+d_8e^{-d_{19}y}+$$
$$d_9e^{-d_{20}y}+d_{10}e^{-d_{21}y}+d_{11}e^{-d_{22}y}$$

$$\theta_{11}=\left(1-d_1\right)e^{-h_5y}+d_1e^{-h_4y}$$

$$\theta_{12}=c_{27}e^{-h_{11}y}+d_{97}e^{-h_7y}+d_{98}e^{-d_{13}y}+d_{99}e^{-d_{14}y}+d_{100}e^{-d_{15}y}+d_{101}e^{-d_{16}y}+d_{102}e^{-d_{17}y}+$$
$$d_{103}e^{-d_{18}y}+d_{104}e^{-d_{18}y}+d_{105}e^{-d_{20}y}+d_{106}e^{-d_{21}y}+d_{107}e^{-d_{22}y}+d_{108}e^{-d_{35}y}+d_{109}e^{-2h_6y}+$$
$$d_{110}e^{-d_{38}y}+d_{111}e^{-d_{40}y}+d_{112}e^{-d_{42}y}+d_{113}e^{-d_{44}y}+d_{114}e^{-d_{46}y}+d_{115}e^{-d_{48}y}+d_{116}e^{-d_{50}y}+$$
$$d_{117}e^{-d_{52}y}+d_{118}e^{-2h_4y}+d_{119}e^{-d_{55}y}+d_{120}e^{-d_{57}y}+d_{121}e^{-d_{59}y}+d_{122}e^{-d_{61}y}+d_{123}e^{-d_{63}y}$$
$$+d_{124}e^{-d_{65}y}+d_{125}e^{-d_{67}y}+d_{126}e^{-d_{69}y}+d_{127}e^{-2h_1y}+d_{128}e^{-d_{72}y}+d_{129}e^{-d_{74}y}+d_{130}e^{-d_{76}y}+$$
$$d_{131}e^{-d_{78}y}+d_{132}e^{-d_{80}y}+d_{133}e^{-d_{82}y}+d_{134}e^{-d_{84}y}+d_{135}e^{-d_{86}y}+d_{136}e^{-2\eta y}+d_{137}e^{-d_{89}y}+$$
$$d_{138}e^{-d_{91}y}+d_{139}e^{-d_{93}y}$$

$$\varphi_{01}=e^{-h\ y},\quad \varphi_{02}=0,\ \varphi_{11}=\left(1-b_1\right)e^{-h_2y}+b_1e^{-h_1y},\ \varphi_{12}=0$$

Where $a_{i,}$'s,c_i's, d_i's and h_i's are constants obtained in terms of dimensionless parameters.

III. RESULTS AND DISCUSSIONS

In the entire discussion we considered the following

$A=1, Sc=2, Gr=1, Gc=1, \Pr=1, U_p=0.5, n_1=0.1, n=0.1, \beta=1, \varepsilon=0.0001, \mathrm{K}_2=5, t=1,$
$Ec=0.01$

Effect of chemical reaction parameter Kr:

From the figures 1, 2 and 3 we observe the velocity, micro-rotational velocity and concentration profiles respectively for different values of chemical reaction parameter (Kr) with M=2, R=0.1 & Q=1. It is observed from the figures that the effect of increasing values of chemical reaction parameter results decrease in velocity and increase in micro-rotation velocity and decrease in concentration.

Effect of Radiation parameter R:

For various values of the radiation parameter R figure.4 exhibits the velocity profile with Kr=0.1,M=1,Q=0.1 and figure.5 asserts that micro-rotation velocity profiles Kr=0.1,M=2,Q=0.1. It is noticed that velocity distribution along boundary layer increases and hence there would be increase of thermal boundary layer thickness. Also it is noticed that the micro-rotation velocity decreases with the increase in radiation parameter R.

Effect of heat absorption parameter Q:

The influence of heat absorption parameter Q on velocity profile with M=1, Kr=0.1&R=0.1 represented by Figure.6 which asserts that the velocity decreases as heat absorption parameter increases. Figure.7 depicts micro-rotational velocity distributions across the boundary layer for various values of heat absorption parameter with M=2, Kr=0.1&R=0.1 which shows the micro-rotation distribution increases as Q increases. Figure.8, indicates that the temperature profile decreases as Q increases for various values of hear absorption parameter Q with M=2, Kr=0.1&R=0.1 . This happens due to the thickness of thermal boundary layer is reduced.

Graphs

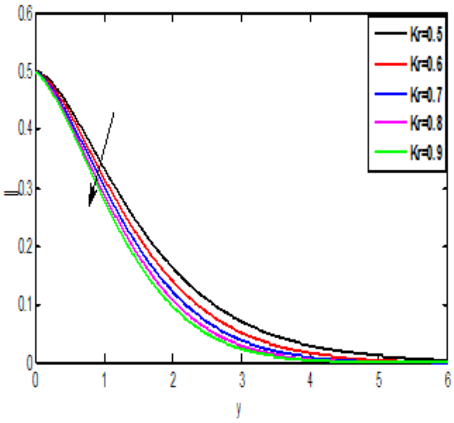

Figure 1.Velocity profile

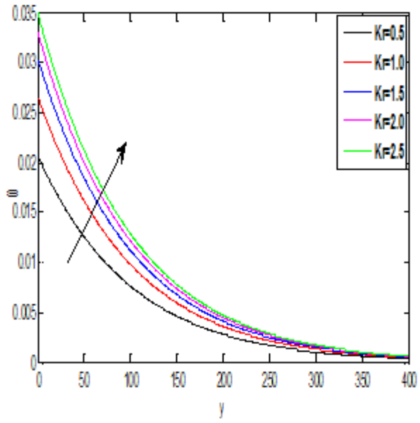

Figure 2.Micro-rotation velocity profile

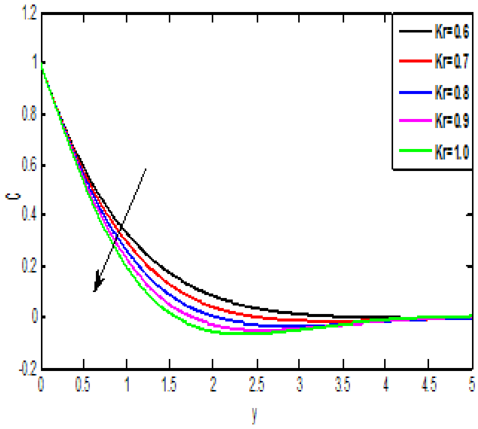

Figure 3.Concentration profile

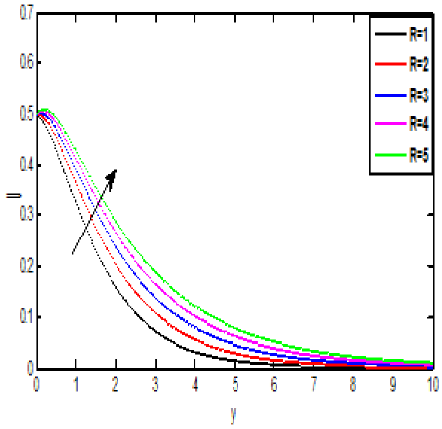

Figure 4.Velocity profile

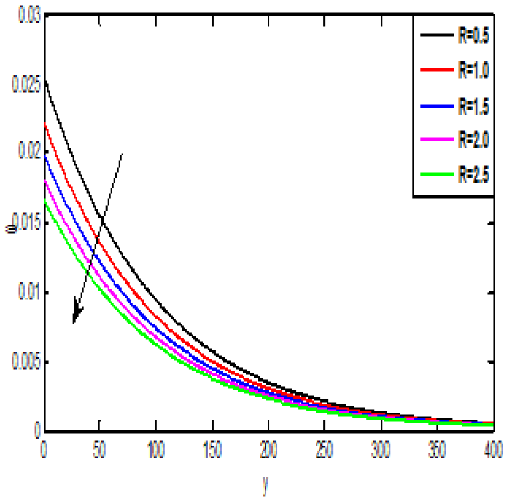

Figure 5.Micro-rotation velocity profile

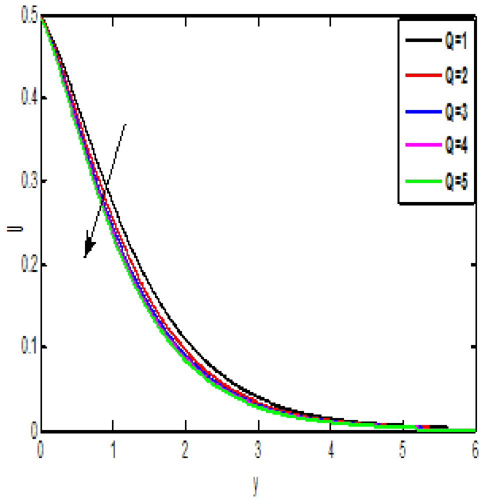

Figure 6.Velocity profile

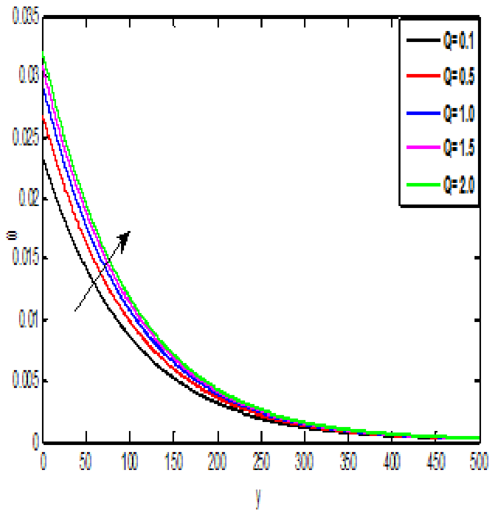

Figure 7.Micro-rotation velocity profile

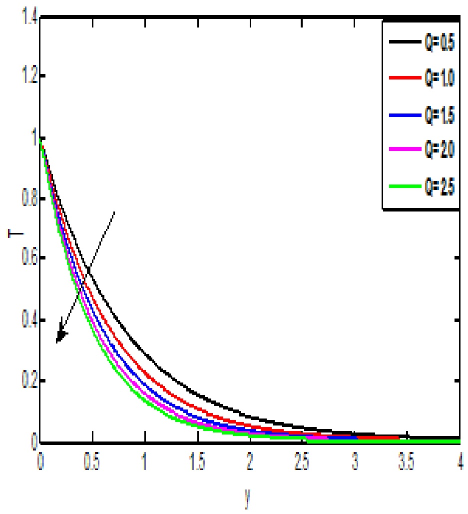

Figure 8. Temparature profile

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