CHAPTER IV

****

RADIATION AND CHEMICAL REACTION EFFECTS ON MHD FREE CONVECTION FLOW OF A MICROPOLAR FLUID BOUNDED BY A VERTICAL INFINITE SURFACE WITH VISCOUS DISSIPATION AND CONSTANT SUCTION

****

1. INTRODUCTION

The dynamics of micropolar fluids has attracted considerable attention during the last few decades because traditional Newtonian fluids cannot precisely describe the characteristics of fluid flow with suspended particles. Eringen [1] developed the theory that the local effects arising from the microstructure and the intrinsic motion of the fluid elements should be taken into account. The theory is expected to provide a mathematical model for the Non-Newtonian fluid behaviour observed in certain man-made liquids such as polymers, lubricants, fluids with additives, paints, animal blood and colloidal and suspension solutions, etc. The presence of dust or smoke, particularly in a gas, may also be modeled using micropolar fluid dynamics. Later, Eringen [2] extended the theory of thermo-micropolar fluids and derived the constitutive laws for fluids with microstructures.

Also, the study of micropolar fluids is very significant due to their potential application in many industrial processes; for example, in continuous casting glass-fiber production, paper production, metal extrusion, hot rolling, wire drawing, drawing of plastic films, metal and polymer extrusion and metal spinning. Balaram and Sastry [3] solved the problem of a fully developed free convection flow in a micropolar flow. Agarwal and Dhanapal [4] obtained a numerical solution to study the fully developed free convection micropolar fluid flow between two parallel with constant suction (or injection). Srinivasacharya et al. [5] studied the effects of microrotation and frequency parameters on an unsteady flow of micropolar fluid between two parallel porous plates with a periodic suction. El-Hakiem [6] obtained a similarity solution for the flow of a micropolar fluid along an isothermal vertical plate with an exponentially decaying heat generation term and thermal dispersion.

The interaction of magnetic field and microrotation plays a vital role in several engineering applications such as in MHD electrical power generation, designing cooling system for nuclear reactors, etc., where microrotation provides an important parameter for deciding the rate of heat flow. Gorla et al. [7] developed a numerical scheme to solve the steady free convection from a vertical isothermal plate in a strong cross magnetic field immersed in a micropolar fluid. El-Hakiem et al. [8] analyzed the effect of viscous and Joule heating on the flow of an electrically conducting and micropolar fluid past a plate whose temperature varies linearly with the distance from the leading edge in the presence of a uniform transverse magnetic field. Helmy et al. [9] studied the unsteady flow MHD of a conducting micropolar fluid, through a porous medium, over an infinite plate that is set in motion in its own plane by an impulse. Bhargava et al. [10] obtained a numerical solution of a free convection MHD micropolar fluid flow between two parallel porous vertical plates by means of the quasi-linearization method.

The effect of radiation on MHD flow and heat transfer problem has become more important industrially. At high operating temperatures, radiation effect can be quite significant. Many processes in engineering areas occur at high temperatures and knowledge of radiation heat transfer becomes very important for design of reliable equipment, nuclear plants, gas turbines and various propulsion devices or aircraft, missiles, satellites and space vehicles. Based on these applications, Cogley et al. [11] showed that in the optically thin limit, the fluid does not absorb its own emitted radiation but the fluid does absorb radiation emitted by the boundaries. Sattar and Hamid [12] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Hossain and Takhar [13] considered the radiation effect on mixed convection boundary layer flow of an optically dense viscous incompressible fluid along a vertical plate with uniform surface temperature. Raptis [14] investigated the steady flow of a viscous fluid through a porous medium bounded by a porous plate subjected to a constant suction velocity by the presence of thermal radiation. Ibrahim et al. [15] discussed the case of mixed convection flow of a micropolar fluid past a semi infinite steady moving porous plate with varying suction velocity normal to the plate in the presence of thermal radiation and viscous dissipation. Rahman and Sattar [16] studied transient convective flow of micropolar fluid past a continuous moving porous plate in the presence of radiation. Rahman and Sultana [17] examined radiative heat flux with variable heat flux in a porous medium.

In certain applications such as those involving heat removal from nuclear fuel debris, underground disposal of radioactive waste material, storage of food stuffs, and exothermic chemical reactions and dissociating fluids in packed-bed reactors, the working fluid heat generation or absorption effects are important. In addition, in many chemical engineering processes, chemical reactions take place between a foreign mass and the working fluid which moves due to the stretching of a surface. The order of the chemical reaction depends on several factors. One of the simplest chemical reactions is the first-order reaction in which the rate of reaction is directly proportional to the species concentration. Das et al. [18] have studied the effects of mass transfer on the flow past impulsively started infinite vertical plate with constant heat flux and chemical reaction. Diffusion of a chemically reactive species from a stretching sheet is studied by Andersson et al. [19]. Muthucumaraswamy and Ganesan [20-21] studied the impulsive motion of a vertical plate with heat flux/mass flux/suction and diffusion of chemically reactive species. Ghaly and Seddeek [22] discussed the effects of chemical reaction, heat and mass transfer on laminar flow along a semi infinite horizontal plate with temperature dependent viscosity, using Chebyshev finite difference method. Seddeek [23] studied the effects of chemical reaction, variable viscosity, thermophoresis and heat generation/absorption on a boundary layer hydromagnetic flow with heat and mass transfer over a heat surface, using the finite element method. Raptis and Perdikis [24] discussed the viscous flow over a non-linearly stretching sheet in the presence of chemical reaction and magnetic field. The effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction has been studied by Ibrahim et al. [25]. Recently, Bakr [26] presented an analysis on MHD free convection and mass transfer adjacent to moving vertical plate for micropolar fluid in a rotating frame of reference in presence of heat generation/absorption and a chemical reaction.

In all these investigations, the viscous dissipation is neglected. The viscous dissipation heat in the natural convective flow is important, when the flow field is of extreme size or at low temperature or in high gravitational field. Such effects are also important in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number. When the viscosity of the fluid is high, the dissipation term becomes important. For many cases, such as polymer processing which is operated at a very high temperature, viscous dissipation cannot be neglected. A number of authors have considered viscous dissipation effects on micropolar fluid flows [27-28].

The object of the present chapter is to study the combined effect of thermal radiation and a first-order chemical reaction on a steady free convection mass transfer flow of a viscous electrically conducting, micropolar fluid, occupying a semi-infinite region of the space bounded by an infinite vertical porous limiting surface with constant suction velocity in the presence of a uniform transverse magnetic field and viscous dissipation. The dimensionless governing equations of the flow, heat and mass transfer are solved analytically using Runge-Kutta fourth order technique along with shooting method. Numerical results are reported in figures for various values of the physical parameters of interest.

2. MATHEMATICAL ANALYSIS

A steady two-dimensional MHD free convection with mass transfer flow of an electrically conducting incompressible, chemically reacting, radiative and dissipative micropolar fluid, occupying a semi-infinite region of the space bounded by an infinite vertical porous limiting surface in the presence of thermal and concentration buoyancy forces, is considered. The x' - axis is taken along in the upward direction and y' - axis is taken normal to it. The applied magnetic field is considered in the direction perpendicular to the plate. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field is negligible. It is also assumed that there is no applied voltage which implies the absence of an electrical field. The fluid is assumed to have constant properties except that the influence of the density variation with temperature is considered only in the body force term (Boussinesq's approximation). Since the plate is of infinite length, the physical variables are functions of y' only. Under the above assumptions, the governing equations of mass, linear momentum, angular momentum, energy and concentration can be written as:

Continuity

$$\frac{\partial v}{\partial y}=0 \tag{2.1}$$

Linear Momentum

$$v'\frac{\partial u'}{\partial y'}=\left(v+\frac{\chi}{\rho}\right)\frac{\partial^2 u'}{\partial y'^2}+g\beta_f\left(T-T_\infty\right)+g\beta_f\left(C-C_\infty\right)-\frac{\sigma B_0^2}{\rho}u'+\frac{\chi}{\rho}\frac{\partial \omega'}{\partial y'} \tag{2.2}$$

Angular Momentum

$$v'\frac{\partial \omega'}{\partial y'}=\gamma\frac{\partial^2\omega'}{\partial y'^2}-\frac{\chi}{\rho j}\left(\frac{\partial u'}{\partial y'}+2\omega'\right) \tag{2.3}$$

Energy (Heat transfer)

$$v'\frac{\partial T}{\partial y'}=\alpha\left(\frac{\partial^2 T}{\partial y'^2}-\frac{1}{k}\frac{\partial q'}{\partial y'}\right)+\frac{(\mu+\chi)}{\rho c_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{2.4}$$

Concentration (Mass transfer)

$$v'\frac{\partial C}{\partial y'}=D'\frac{\partial^2 C}{\partial y'^2}-K_r\left(C-C_\infty\right) \tag{2.5}$$

where u', v' are the velocity components in the x', y' directions, respectively, g is the acceleration due to gravity, ρ is the fluid density, $\nu=\mu/\rho$ is the kinematic viscosity, χ is vortex velocity, β_f and β_c are the thermal and concentration expansion coefficients, respectively, ω^* is the component of the microrotation (angular velocity) vector normal to the $x'y'$-plane, γ is the spin gradient viscosity, j is the micro inertia density, T is the temperature of the fluid in the thermal boundary layer , α is the fluid thermal diffusivity, C is the concentration of fluid in the thermal boundary layer, D' is the chemical molecular diffusivity. The second and third terms on the right hand side of the momentum equation (2.2) denotes thermal and concentration buoyancy effects, respectively. The second and third terms on the right-hand side of the equation (2.4) represents the thermal radiation and viscous dissipation effects, respectively. Also, the last term in the equation (2.5) represents a first-order chemical reaction.

The corresponding boundary conditions are

$$\begin{gathered} u'=0, \omega'=-n\frac{\partial u'}{\partial y'}, T=T_w, C=C_w \ at\ y'=0 \\ u'\to 0,\ \omega\to 0,\ T=T_\infty,\ C=C_\infty, as\ y'\to\infty \end{gathered} \tag{2.6}$$

where C_w, T_w are the concentration and temperature on the limiting surface, respectively and T_∞, C_∞ are the temperature and concentration of fluid in the free steam, respectively.

In equation (2.6), the boundary condition for the micro-rotation variable ω at the wall is proportional to the surface shear stress, the proportional parameter n ranges between 0 and 1. The value for $n=0$ corresponds to the case where the particle density is sufficiently large so that microelements close to the wall are unable to rotate. The value of $n = 0.5$ represents a weak representation of the microelements and the value of $n = 1.0$ corresponds to the turbulent flow inside boundary layers of micro-rotation (Rees and Bassom [29]).

By using the Rosseland approximation (Brewster [30]), the radiative heat flux in the y' direction is given by

$$q_r = \frac{-4\sigma_s \partial T'^4}{3K_e \partial y'} \tag{2.7}$$

where σ_s is the Stefan - Boltzmann constant and K_e - the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If temperature differences with in the flow are sufficiently small, then equation (2.7) can be linearised by expanding T'^4 into the Taylor series about T'_∞, which after neglecting higher order terms takes the form.

$$T'^4 \cong 4T_\infty'^3 T' - 3T_\infty'^4 \tag{2.8}$$

From the continuity equation (2.1), it is clear that the suction velocity normal to the plate is either a constant or a function of time. Here, it is assumed to be

$$v' = -V_0 \tag{2.9}$$

where V_0 is the scale of suction velocity which is a non-zero positive constant. The negative sign indicates that the suction is towards the plate.

In order to write the governing equations and the boundary conditions dimensionless form, the following non-dimensional quantities are introduced.

$$u = \frac{u'}{v_0}, v = \frac{v'}{V_0}, y = \frac{V_0 y'}{\nu}, \omega = \frac{\nu}{V_0^2}\omega', M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, B = \frac{\nu^2}{j v_0^2}$$

$$\beta = \frac{\chi}{\rho\nu} = \frac{\chi}{\mu}, \lambda = \frac{\gamma}{\mu j}, G_r = \frac{\nu\beta_f g(T_w - T_\infty)}{V_0^3}, Gc = \frac{\nu\beta_c g(C_w - C_\infty)}{V_0^3} \tag{2.10}$$

$$B = \frac{\nu^2}{\upsilon_0^2 j} \Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k}, Ec = \frac{V_0^2}{c_p(T_w - T_\infty)}, Sc = \frac{\nu}{D'}, K_r = \frac{K_r' \nu}{V_0^2}$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \quad C = \frac{C - C_\infty}{C_w - C_\infty}, R = \frac{kk_e}{4\sigma_s T_\infty^3}$$

By substituting equations (2.8) and (2.10) into equations (2.2)-(2.5), we obtain

$$(1+\beta)u'' + u' - Mu = -Gr\theta - GcC - \beta\omega', \tag{2.11}$$

$$\lambda\omega'' + \omega' - \beta B(u' + 2\omega) = 0, \tag{2.12}$$

$$(3R+4)\theta'' + 3RPr\theta' + 3RPrEc(1+\beta)u'^2 = 0, \tag{2.13}$$

$$C'' + ScC' - KrScC = 0, \tag{2.14}$$

where the primes denote differentiation with respect to y and Gr, Gm, M, Pr, R, Ec, Sc, Kr, is the Grashof number, is the modified Grashof number, is the magnetic parameter, is the Prandtl number, is the radiation parameter, is the Eckert number, is the Schmidt number and is the chemical reaction parameter, respectively.

The corresponding dimensionless boundary conditions are

$$u = 0,\ \omega = -n\frac{\partial u}{\partial y},\ \theta = 1,\ C = 1,\ at\ y = 0$$
$$u \to 0, \omega \to 0, \theta \to 0, C \to 0\ as\ y \to \infty \tag{2.15}$$

From the engineering point of view, the most important characteristics of the flow are the skin friction coefficient C_f, couple stress coefficient C_w, Nusselt number Nu and Sherwood number Sh for this type of boundary layer, which are discussed below

Knowing the velocity field, the skin-friction at the plate can be obtained, which in non-dimensional form is given by

$$C_f = \frac{2\tau_w}{\rho V_0^2} = 2[1+(1-n)\beta]u'(0)$$

$$\tau_w = [\mu + \chi]\frac{\partial u'}{\partial y'}\bigg|_{y'=0} + \chi\omega'\big|_{y'=0} \tag{2.16}$$

Knowing the microrotation field in the boundary layer, we can now calculate the couple stress coefficient at the plate, which in the non-dimensional form is given by

$$M_w = \frac{\nu}{\mu l^2}\frac{\partial \omega'}{\partial y'}\bigg|_{y'=0} = \frac{V_0^2}{\mu \nu_r^2 l^2}\omega'(0) \tag{2.17}$$

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non-dimensional form, in terms of the Nusselt number, is given by

$$Nu_x = \frac{q_w}{T_w - T_\infty}\frac{x'}{K} = -\mathrm{Re}_x\,\theta'(0); q_w = -K\frac{\partial T}{\partial y'}\bigg|_{y'=0} \tag{2.18}$$

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non-dimensional form, in terms of the Sherwood number, is given by

$$Sh_x = \frac{x' j_w}{D(C_w - C_\infty)} = -\mathrm{Re}_x\, C'(0);\; j_w = -D\left.\frac{\partial C}{\partial y'}\right|_{y'=0} \tag{2.19}$$

where $\mathrm{Re}_x = {V_0 x}/{\nu}$ is the Reynolds number

3. NUMERICAL TECHNEQUE

The resulting ordinary differential equations (9)-(12) with the corresponding boundary conditions (13) have been solved numerically by means of the fourth-order Runge–Kutta method with systematic estimates of $u'(0)$, $\omega'(0)$, $\theta'(0)$ and $C'(0)$ by a shooting technique. The step size $\Delta\eta = 0.01$ is used while obtaining the numerical solution with η=4.0 and five-decimal accuracy as the criterion for convergence. Numerical computations are carried out for various values of the parameters λ, β, M, Gr, Gc, Pr, R, Ec, Sc and Kr.

4. RESULTS AND DISCUSSION

In this chapter, the combined effect of first-order chemical reaction and thermal radiation on MHD free convection heat and mass transfer flow of an incompressible micropolar fluid along a vertical infinite surface in the presence of viscous dissipation with constant suction has been investigated using Runge-Kutta fourth order technique along with shooting method. In order to get a physical insight of the problem, a parametric study is carried out to illustrate the effect of various thermophysical parameters β, Gr, Gm, M, Pr, R, Ec, Kr and Sc on the velocity, microrotation, temperature, concentration, local skin friction, couples stress, local Nusselt number and Sherwood number and are presented in figures and tables. In the present study, we have chosen β=0.1, B=0.1, G= 0.5, Gr = 2.0, Gm = 2.0, λ = 0.01, Pr=0.71, R = 1.0, Ec=0.01, Sc = 0.22 and Kr=0.1.

The effect of viscosity ratio β on the translational velocity and microrotation across the boundary layer are presented in Fig. 1. It is seen that as β increases, the velocity decreases. Also, the velocity distribution across the boundary layer is higher for a Newtonian fluid (β =0) for the same flow conditions and fluid properties, as compared with that of a micropolar fluid. Further, the magnitude of microrotation decreases, as β increases.

Fig. 2 shows the pattern of the translational velocity and microrotation for different values of magnetic field parameter M, respectively. It is seen that as M increases, the translational velocity decreases, whereas the microrotation increases.

The translational velocity and microrotation profiles against spanwise coordinate y for different values of Grashof number Gr and modified Grashof number Gc are described in Fig. 3. It is observed that an increase in Gr or Gc leads to a rise in the velocity and a fall in the microrotation. Here the positive values of Gr corresponds to a cooling of the surface by natural convection.

For different values of the Schmidt number Sc, the translational velocity and the microrotation and concentration profiles are plotted in Figs. 4(a)-4(c), respectively. It is observed that as Sc increases, the velocity as well as the concentration decreases, whereas the microrotation increases.

Figs. 5(a)-(c) illustrate the variation of the translational velocity, microrotation and concentration distribution across the boundary layer for various values of the chemical reaction parameter Kr. It is seen that as the chemical reaction parameter Kr increases, the translational velocity as well as the concentration decreases, whereas the microrotation increases.

Figs. 6(a)-(c) show the translational velocity, microrotation and temperature profiles across the boundary layer for different values of Prandtl number Pr. It is noticed that as Pr increases, the translational velocity as well as the temperature decreases whereas the microrotation increases.

Figs. 7(a)-(c) display the translational velocity, microrotation and temperature profiles across the boundary layer for different values of the thermal radiation parameter R. It is noticed that as R increases, there a fall in the translational velocity and temperature and there is a rise in the microrotation.

The effect of the viscous dissipation parameter i.e., the Eckert number Ec on the translational velocity, microrotation and temperature distributions are shown in Figs.

8(a)- (c). It is observed that, as Ec increases there is a rise in the translational velocity, microrotation and temperature.

Table 1 illustrates the effects of the parameters β, M, Gr, Gc, Sc and Kr on the skin-friction coefficient ($u'(0)$), the wall couple stress coefficient ($\omega'(0)$), the Nusselt number ($-\theta'(0)$) and Sherwood number ($-C'(0)$). It is observed as β or M or Sc or Kr increases, .the skin friction and couple stress coefficients decrease while the Nusselt number increases. As Gr or Gc increases, there is a decrease in the skin-friction and there is a rise in the wall couple stress and rate of heat transfer. It interesting to note that the Sherwood number increases as Sc increases and remains unchanged for all other variations. From Table 2, it is seen that as Pr or R increases, the local skin friction coefficient and couple stress coefficient decrease, while the Nusselt number increases. The opposite trend is observed as Ec increases. It is also observed that the Sherwood number remains unchanged, as Pr or R or Ec increases.

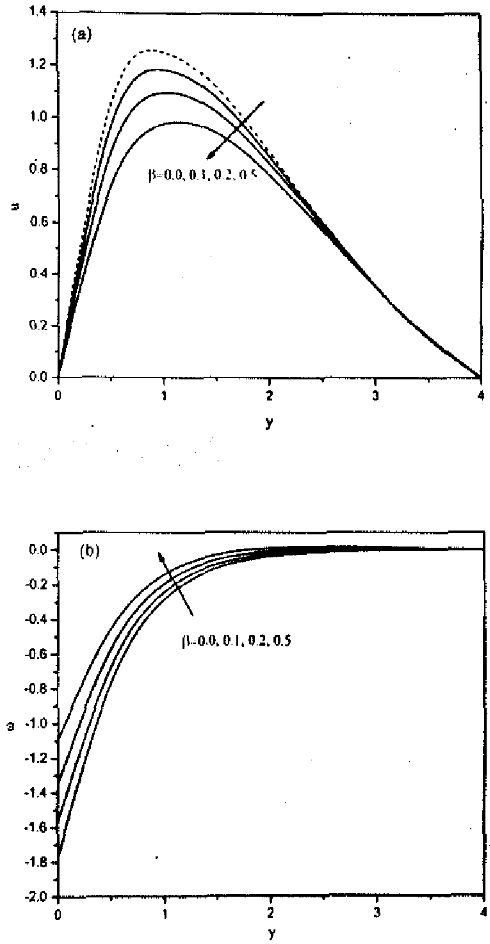

Fig. 1 Velocity and microrotation profiles for different values of β

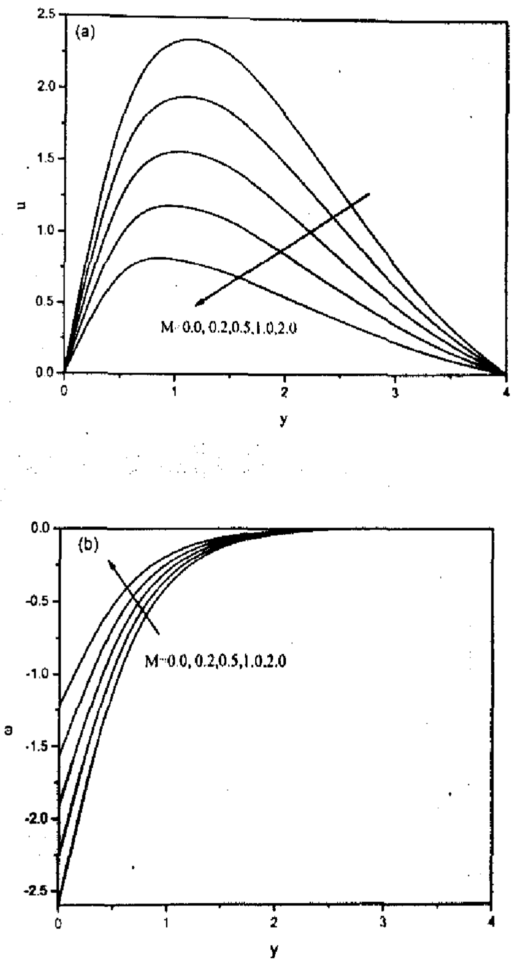

Fig. 2 Velocity and microrotation profiles for different values of M

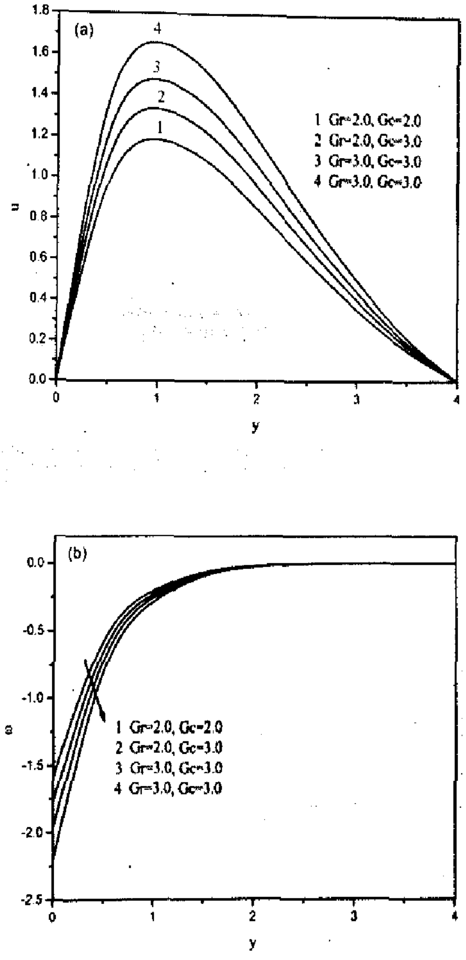

Fig. 3 Velocity and microrotation profiles for different values of *Gr* & *Gc*

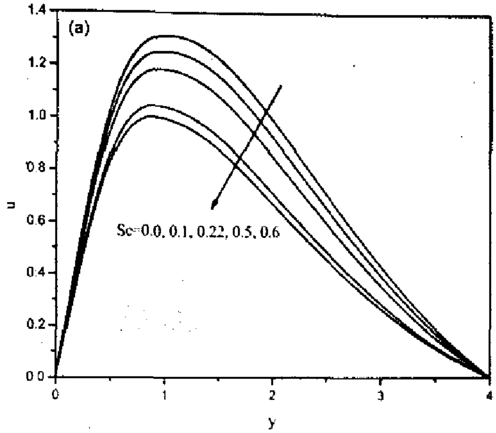

Fig. 4(a) Velocity profiles for different values of *Sc*

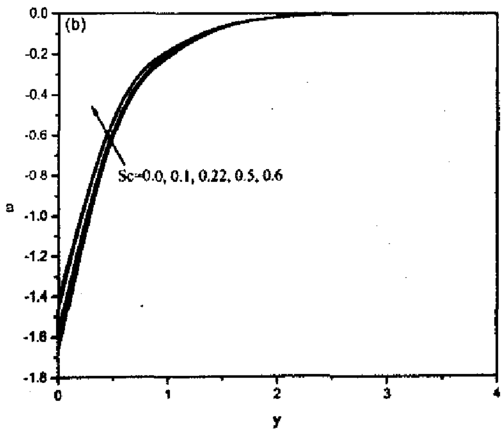

Fig. 4(b) Microrotation profiles for different values of Sc

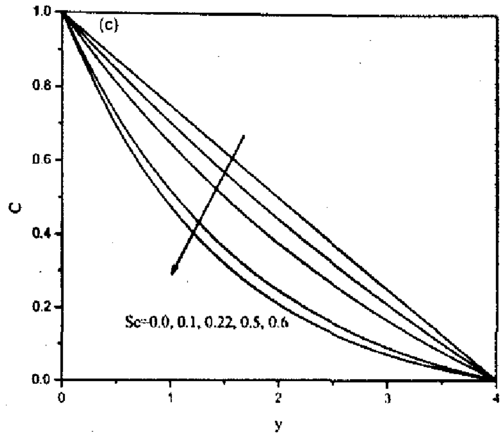

Fig. 4(c) Concentration profiles for different values of *Sc*

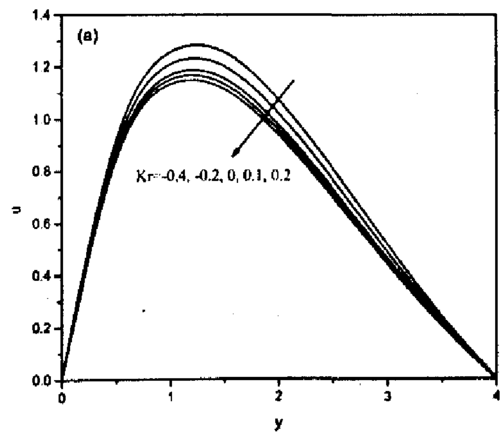

Fig. 5(a) Velocity profiles for different values of *Kr*

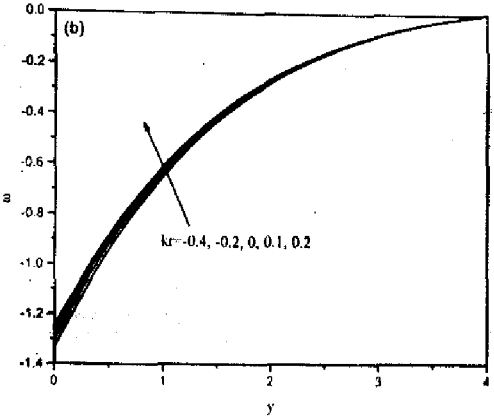

Fig. 5(b) Microrotation profiles for different values of *Kr*

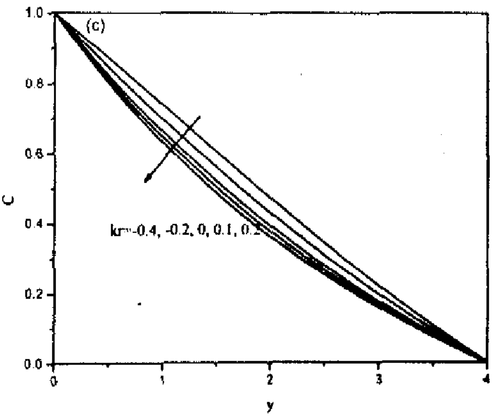

Fig. 5(c) Concentration profiles for different values of *Kr*

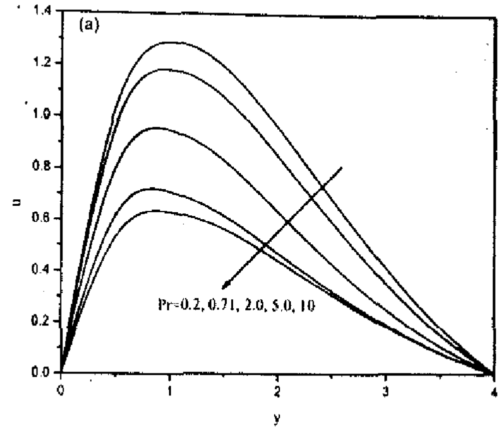

Fig. 6(a) Velocity profiles for different values of *Pr*

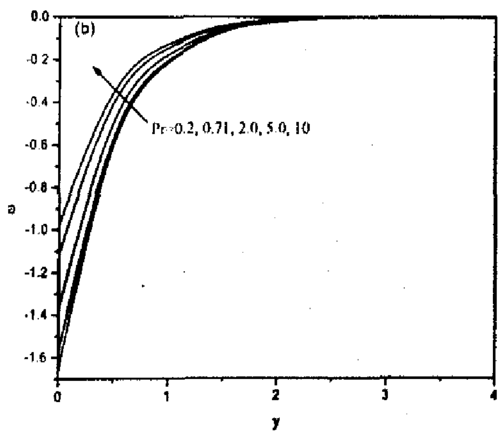

Fig. 6(b) Microrotation profiles for different values of *Pr*

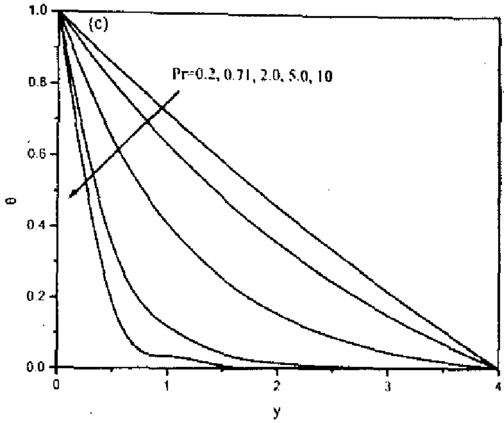

Fig. 6(c) Temperature profiles for different values of Pr

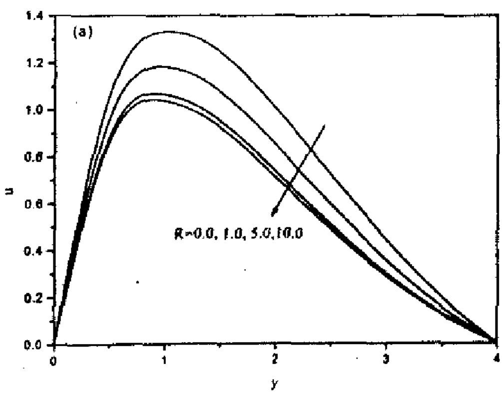

Fig. 7(a) Velocity profiles for different values of R

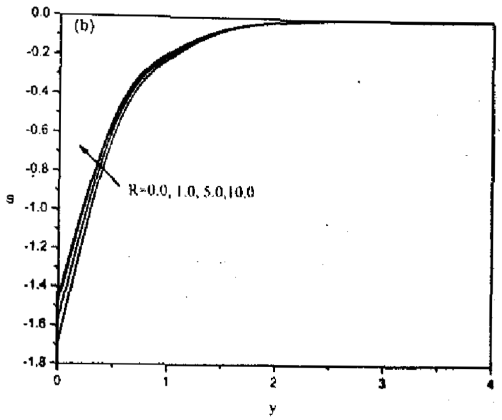

Fig. 7(b) Microrotation profiles for different values of R

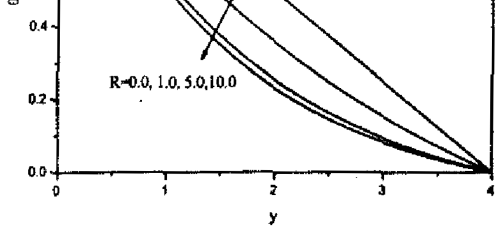

Fig. 7(c) Temperature profiles for different values of R

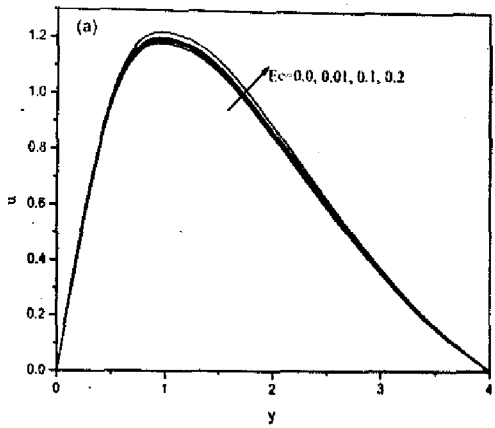

Fig. 8(a) Velocity profiles for different values of *Ec*

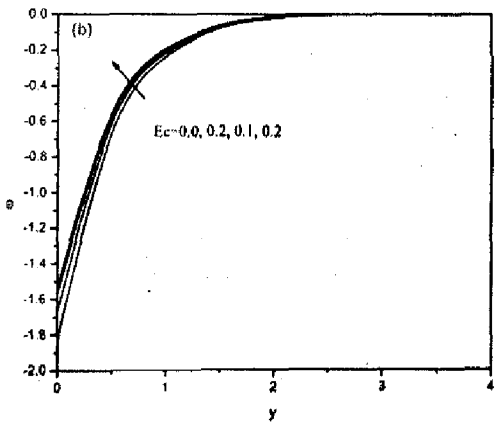

Fig. 8(b) Microrotation profiles for different values of *Ec*

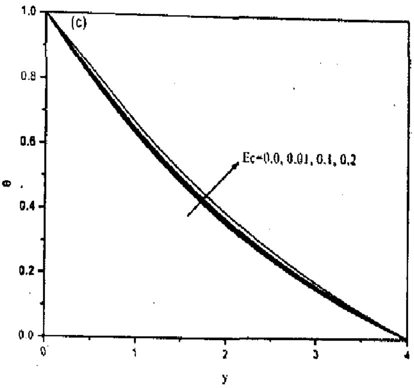

Fig. 8(c) Temperature profiles for different values of Ec

Table 1: Values of $-u'(0)$, $\omega'(0)$, $-\theta'(0)$ and $-C'(0)$ for various values of M, Gr, Gc, Sc and Kr with G=0.5, Pr = 0:71, B = 0.1, R =1.0 and Ec=0.01.

β	Mn	Gr	Gc	Sc	Kr	$u'(0)$	$\omega'(0)$	$-\theta'(0)$	$-C'(0)$
0.0	1.0	2.0	2.0	0.22	0.1	3.14849	3.14955	0.424304	0.403894
0.1	1.0	2.0	2.0	0.22	0.1	3.14787	3.17582	0.424306	0.403894
0.2	1.0	2.0	2.0	0.22	0.1	3.14728	3.20019	0.424307	0.403894
0.1	0.0	2.0	2.0	0.22	0.1	5.19650	5.24061	0.405093	0.403894
0.1	0.2	2.0	2.0	0.22	0.1	4.51083	4.54954	0.412903	0.403894
0.1	0.5	2.0	2.0	0.22	0.1	3.83201	3.86544	0.419261	0.403894
0.1	1.0	2.0	2.0	0.22	0.1	3.14787	3.17582	0.424306	0.403894
0.0	1.0	2.0	2.0	0.22	0.1	3.14787	3.17582	0.424306	0.403894
0.0	1.0	2.0	3.0	0.22	0.1	3.94554	3.98055	0.419737	0.403894
0.0	1.0	3.0	2.0	0.22	0.1	3.92906	3.96397	0.419875	0.403894
0.0	1.0	3.0	3.0	0.22	0.1	4.72841	4.77040	0. 414288	0.403894
0.0	1.0	2.0	2.0	0.0	0.1	3.35620	3.38549	0.422848	0.250000
0.0	1.0	2.0	2.0	0.1	0.1	3.26043	3.28918	0.423537	0.316449
0.0	1.0	2.0	2.0	0.22	0.1	3.14787	3.17512	0.424306	0.403894
0.0	1.0	2.0	2.0	0.22	-0.1	3.21055	3.23896	0.423885	0.346658
0.0	1.0	2.0	2.0	0.22	0.0	3.17821	3.20638	0.424204	0.375929
0.0	1.0	2.0	2.0	0.22	0.1	3.14787	3.17512	0.424306	0.403894

Table 2: Values of $u'(0)$, $\omega'(0)$, $-\theta'(0)$ and $-C'(0)$ for various Pr, R and Ec with G=0.5, Mn=1.0, B=0.1, Gr=2.0, Gc=2.0, Sc=0.22 and Kr=0.1.

Pr	R	Ec	$u'(0)$	$\omega'(0)$	$-\theta'(0)$	$-C'(0)$
0.2	1.0	0.01	3.32309	3.35219	0.29283	0.403894
0.71	1.0	0.01	3.14787	3.17582	0.424306	0.403894
2.0	1.0	0.01	2.74479	2.76975	0.869351	0.403894
5.0	0.0	0.01	2.23545	2.25594	2.11795	0.403894
0.71	0.0	0.01	3.39019	3.41970	0.25000	0.403894
0.71	1.0	0.01	3.14787	3.17582	0.424306	0.403894
0.71	5.0	0.01	3.0514	3.07868	0.510314	0.403894
0.71	10.0	0.01	2.94866	2.97519	0.614412	0.403894
0.71	1.0	0.0	3.14437	3.17229	0.432270	0.403894
0.71	1.0	0.01	3.14787	3.17582	0.424306	0.403894
0.71	1.0	0.1	3.18040	3.20859	0.350589	0.403894
0.71	1.0	0.2	3.21884	3.24732	0.264022	0.403894

REFERENCES

1. Eringen A.C. (1966), Theory of micropolar fluids, J. Math. Mech., Vol. 16, pp. 1-18.
2. Eringen A.C. (1972), Theory of thermomicrofluids, J. Math. Anal. Appl., Vol. 38, pp. 480–496.
3. Balaram M and Sastry V.U.K. (1973), Micropolar free convection flow, Int. J. Heat Mass Transf., Vol.16, pp.437–440.
4. Agarwal R.S. Dhanapal C (1988),, Numerical solution of free convectionmicropolarfluid flow between two parallel porous vertical plates, Int. J. Eng. Sci., Vol. 26, pp.1247–1255.
5. Srinivasacharya D., Ramana Murthy J.V.and Venugopalam D (2001), Unsteady stokes flow of micropolarfluidbetweentwoparallel porous plates, Int. J. Eng. Sci., Vol. 39, pp. 1557–1563.
6. El-Hakiem M.A. (2004), Natural convection in a micropolar fluid with thermal dispersion and internal heat generation, Int. Commun. Heat Mass Transf., Vol. 31, pp. 1177–1186.
7. Gorla R.S.R., Takhar H.S., and Slaout A. (1998), Magnetohydrodynamic free convection boundary layer flow of a thermomicropolar fluid over a vertical plate, Int. J. Eng. Sci., Vol. 36, pp. 315–327.
8. El-Hakiem M.A., Mohammadein A.A., El-Kabeir S.M.M. and Gorla R.S.R (1999), Joule heating effects on magnetohydrodynamic free convection flow of a micropolar fluid, Int. Commun. Heat Mass Transf. Vol. 26, pp. 219–227.
9. Helmy K.A., Idriss H.F. and Kassem S.E. (2002), MHD free convection flow of a micropolar fluid past a vertical porous plate, Can. J. Phys./Rev. Can. Phys. Vol.80, pp. 1661–1673.
10. Bhargara R., Kumar L. and Takhar H.S. (2003), Numerical solution of free convection MHD micropolar fluid flow between two parallel porous vertical plates, Int. J. Eng. Sci., Vol.41, pp.123–136.
11. Cogley A.C., Vincenty W.E. and Gilles S.E. (1968), Differential approximation for radiation in a non-gray gas near equilibrium, AIAA J., Vol. 6, pp.551–553.

12. Abdus Sattar M.D. and Hamid K.M.D.(1996), Unsteady free-convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate, J. Math. Phys. Sci., Vol. 30, pp.25–37.

13. Hossain M.A. and Takhar H.S. (1996), Radiation effect on mixed convection along a vertical plate with uniform surface temperature, Heat Mass Transfer, Vol. 31, pp.243–248.

14. Raptis A (1998), Radiation and free convection flow through a porous medium, Int. Commun. Heat Mass Transfer, Vol.25, pp.289–295.

15. Ibrahim F.S, Elaiw A.M. and Bakr A.A. (2008), Influence of viscous dissipation and radiation on unsteady MHD mixed convection flow of micropolar fluids, Appl. Math. Inf. Sci., Vol. 2, pp.143–162.

16. Rahman .M.M and Sattar M.A. (2007), Transient convective flow of micropolar fluid past a continuously moving vertical porous plate in the presence of radiation, Int. J. Appl. Mech. Eng., Vol.12, pp. 497–513.

17. Rahman M.M. and Sultana (2009), Convective flows of micropolar fluids from radiate isothermal porous surfaces with viscous dissipation and Joule heating, Commun. Nonlinear Sci. Numer. Simul., Vol.14, pp. 3018–3030.

18. Das U.N, Deka R.K and Soundalgekar V.M. (1984), Effects of mass transfer on the flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction, Forsch. Ingenieurwes., Vol. 37, pp.284-287.

19. Andersson H.I, Hansen O.R and Holmedal B (1994), Diffusion of a chemically reactive species from a stretching sheet, Int. J. Heat Mass Transfer, Vol. 37, p.465.

20. Muthucumarswamy R and Ganesan P (2001), First order chemical reaction on flow past an impulsively started vertical plate with uniform heat and mass flux, Acta Mechanica, Vol. 147, p.45.

21. Muthucumarswamy R and Ganesan P (2002), Effects of suction on heat and mass transfer along a moving vertical surface in the presence of chemical reaction, Forsch. Ingenieurwes, Vol.67, p.129.

22. Ghaly A.Y. and Seddeek M.A. (2004), Chebyshev finite difference method for the effects of chemical reaction, heat and mass transfer on laminar flow along a semi

infinite horizontal plate with temperature dependent viscosity, Chaos Solitons Fractals, Vol. 19, p.61.

23. Seddeek M.A. (2005), Finite element method for the effects of chemical reaction, variable viscosity, thermophoresis and heat generation/absorption on a boundary layer hydromagnetic flow with heat and mass transfer over a heat source, Acta Mechanica, Vol. 177, P.1.
24. Raptis A and Perdikis C (2006), Viscous flow over a non-linearly stretching sheet in the presence of a chemical reaction and magnetic field, Int. J. Nonlinear Mech., Vol.41, p.527.
25. Ibrahim F.S., Elaiw A.M. and Bakr A.A. (2008), Effect of the chemical reaction and radiation absorption on unsteady MHD mixed convection flow past a semi-infinite vertical permeable moving plate with heat source and suction, Commun. Nonlinear Sci. Numer. Simul., Vol.13, pp.1056–1066.
26. Bakr A.A. (2011), Effects of chemical reaction on MHD free convection and mass transfer flow of a micropolar fluid with oscillatory plate velocity and constant heat source in a rotating frame of reference, Commun. Nonlinear Sci. Numer. Simul. Vol.16, pp.698–710.
27. Ibrahim F.S, Elaiw A.M and Bakr A.A (2008), Influence of viscous dissipation and radiation on unsteady MHD mixed convection flow of micropolar fluids, App. Math. & Inf. Sciences., Vol2(2), pp.143-162.
28. Khedr M.E.M, Chamkha A.G, and Bayomi M (2009), MHD flow of a micropolar fluid past a stretched permeable surface with heat generation or absorption, Nonlinear analysis Modeling and Control, V0l.14(1), pp.27-40
29. Rees D.A. S. and Bassom A. P (1996), The Blasius boundary-layer flow of a micropolar fluid, Int. J. Eng.Sci., Vol.34, pp. 113–124.
30. Brewster M.Q. (1992), Thermal radiative Transfer and properties, John Wiley and Sons, New York.