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Radiation absorption effects on MHD micro polar fluid past a vertical plate with chemical reaction and heat source

S . Samantha Kumari[1*] and G.Sankara Sekhar Raju[2]

[1] Dept. of Mathematics, JNTUA, Anantapuramu, A.P, India

[2]Dept. of Mathematics, JNTUA College of Eng., Pulivendula, Y.S.R. District-516390

*The corresponding Author mail ID: hkesavulu6@gmail.com

Abstract. This paper considers the effect of radiation absorption and chemical reaction on MHD free convection heat and mass transfer flow of a micropolar fluid**.** A uniform magnetic field acts perpendicular to the porous surface in which absorbs micropolar fluid with a constant suction velocity. The governing dimensionless equations for this investigation are solved computationally by using shooting method. The effects of the various flow parameters and physical properties on the velocity, microrotation, temperature and concentration profiles across the boundary layer are investigated through graphs. Also the numerical results of velocity profiles of micropolar fluids are compared with the corresponding flow problems for a Newtonian fluid.

Keywords: Chemical reaction, Micropolar fluid, MHD, Radiation absorption.

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1 Introduction

The micro polar fluids are those which contain micro constituents that can undergo rotation have developed by Eringen [1]. The presence of which can effect the hydro-dynamics of the flow so that it can be distinctly non-Newtonian, which can be used to analyzed the behavior of exotic lubricants, liquid crystals, animal blood, fluid flowing in brain, the flow of colloidal suspensions, paints, turbulent shear flows and body fluids both mathematically and industrially. Eringen [2] extended the theory of thermomicro polar fluids and derived the constitutive laws for fluids with micro-structure. An excellent review of micro polar fluids and their applications was given by Ariman et al.[3].Radhakrishnamacharya [4] analyzed the flow of micro polar fluid through a constricted channel. Rees and Pop [5] discussed the free convection boundary-layer flow of a micropolar fluid from a vertical flat plate, Sharma and Gupta [6] studied the effects of medium permeability on thermal convection in micropolar fluids. Vajraveluet al. [7] have studied the problem of peristaltic transport of a Williamson fluid in asymmetric channels with permeable walls. Muthu et al. [8] studied peristaltic motion of micropolarfluid in circular cylindrical tubes. Srinivasacharya et al. [9] analyzed the unsteady stokes flow ofmicropolar fluid between two parallel porous plates. Muthuraj and Srinivas [10] investigated, fully developed MHD flow of a micro polar and viscous fluids in a vertical porous space using HAM.The influence of magnetic field on heat and mass transfer of an electrically conducting micropolar fluid has attracted the interest of many investigators [11-13] in view of its applications in various fields of science and technology.

Chakraborti et al. [14] analyzed the flow of an electrically conducting incompressible viscous fluid past a porous plate which rotates with a uniform angular velocity and the fluid extending to infinity in a uniform transverse magnetic field. They observed that, in the presence of uniform magnetic field parallel to the axis of rotation the boundary layer thickness decreases with an increase in either suction at the plate or the magnetic parameter. Guria et al. [15] extended the above work for finite medium, including heat transfer characteristics.

From the scientific point of study, flow arising from temperature and material difference is applied in chemical engineering, geothermal reservoirs, aeronautics and astrophysics. In some

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

applications magnetic forces are present and at other times the flow is further complicated by the presence of radiation absorption, an excellent example of this is in the planetary atmosphere where there is radiation absorption from nearby stars. The influence of a magnetic field on the flow of an electrically conducting viscous fluid with mass transfer and radiation absorption is also useful in planetary atmosphere research [16]. Malashetty et.al [17] has studied the problem of double diffusive convection in a darcy porous medium saturated with a couple stress fluid. The effect of 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 were studied by [18-19].

In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications viz., polymer production, manufacturing of ceramics or glass ware and food processing. Dulal Pal and BabulalTalukdar [20] presented heat and mass transfer effects past a vertical surface with chemical reaction and thermal diffusion. Effects of the chemical reaction and radiation absorption on free convection flow past a semi-infinite vertical/inclined plate in the presence of uniform magnetic field were studied by [21-22]. Very recently Sivaraj et al. [23] studied the chemically reacting dusty viscoelastic fluid flow in an irregular channel. Damseh et al. [24] have studied the combined effect of heat generation or absorption and first order chemical reaction on micropolar fluid flows over a uniform stretched surface. Rahman et al. [25] analyzed the effect of higher order chemical reaction on micropolar fluid flow on a power law permeable stretched sheet with variable concentration in a porous medium. 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. Later the same work was extended by Das [27] with thermal radiation effects.

To the best of our knowledge, the problem of magnetohydrodynamics unsteady free convection flow of a micropolar fluid in a rotating frame of reference with radiation absorption has remained unexplored. So the main objective of this paper is to extend the work of reference [27] in two directions: (i) to consider MHD micropolar fluid in a rotating frame of reference (ii) to include the radiation absorption. The governing equations of the flow are solved analytically and the effects of various flow parameters on the flow field have been discussed. A comparison is made with the available results in the literature, and salient features of the new results are analyzed and discussed.

2 Mathematical analysis

Consider the unsteady three dimensional free convection flow of a micropolar fluid past a vertical permeable semi-infinite plate in the presence of an applied magnetic field with radiation absorption and chemical reaction. We consider a Cartesian coordinate system (x, y, z) as is shown in Fig.(i). The flow is assumed to be in the x-direction, which is taken along the plate, and z-axis is normal to the plate. We assume that the plate has an oscillatory movement on time t and frequency n.We consider that initially (t<0) the fluid as well as the plate are at rest but for t ≥0.A uniform external magnetic field $B_0$is taken to be acting along the z-axis. We consider the case of a short circuit problem in which the applied electric field $E = 0$, and also assume that the induced magnetic field is small compared to the external magnetic field B_0. This implies a small magnetic Reynolds number for the oscillating plate. Since the plate is electrically non-conducting, this constant is zero. It is assumed that the plate is infinite in extent and hence all physical quantities do not depend on x and y but depend only on z and t.

The governing equations of the problem are:

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = (\nu + \nu_r)\frac{\partial^2 u}{\partial z^2} + g\beta_T(T - T_\infty) + g\beta_C(C - C_\infty) - \frac{\sigma B_0^2 u}{\rho} - \nu_r \frac{\partial \bar{\omega}_2}{\partial z} \tag{2}$$

$$\frac{\partial v}{\partial t} + w\frac{\partial v}{\partial z} = (\nu + \nu_r)\frac{\partial^2 v}{\partial z^2} - \frac{\sigma B_0^2 v}{\rho} + \nu_r \frac{\partial \bar{\omega}_1}{\partial z} \tag{3}$$

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

$$\frac{\partial \bar{\omega}_1}{\partial t} + w\frac{\partial \bar{\omega}_1}{\partial z} = \frac{\Lambda}{\rho j}\frac{\partial^2 \bar{\omega}_1}{\partial z^2} \quad (4)$$

$$\frac{\partial \bar{\omega}_2}{\partial t} + w\frac{\partial \bar{\omega}_2}{\partial z} = \frac{\Lambda}{\rho j}\frac{\partial^2 \bar{\omega}_2}{\partial z^2} \quad (5)$$

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = \frac{k}{\rho C_P}\frac{\partial^2 T}{\partial z^2} - \frac{Q}{\rho C_P}(T - T_\infty) + \frac{Q_l'}{\rho C_P}(C - C_\infty) \quad (6)$$

$$\frac{\partial C}{\partial t} + w\frac{\partial C}{\partial z} = D_m\frac{\partial^2 C}{\partial z^2} - R_r(C - C_\infty) \quad (7)$$

The initial and boundary conditions for the model are:

$$u = v = 0,\ \bar{\omega}_1 = \bar{\omega}_2 = 0,\ T = T_\infty,\ C = C_\infty \text{ for } t \le 0 \quad (8)$$

$$u = U_r\{1 + \frac{\in}{2}(e^{\text{int}} + e^{-\text{int}})\},\ v = 0,\ \bar{\omega}_1 = -\frac{1}{2}\frac{\partial v}{\partial z},\ \bar{\omega}_2 = \frac{1}{2}\frac{\partial u}{\partial z}$$

$$T = T_\infty,\ C = C_\infty \quad at\ z = 0\ and$$

$$u = v = 0,\ \bar{\omega}_1 = \bar{\omega}_2 = 0, T = T_\infty,\ C = C_\infty \quad as\ z \to \infty \text{ for } t > 0 \quad (9)$$

The oscillatory plate velocity assumed in the equation (8) is based on the suggestion proposed by Ganapathety [28]. We now consider a convenient solution of the continuity equation (1) gives $w = -w_0$ (10), Where the w_0 represents the normal velocity at the plate which is positive for suction and negative for blowing.

Let us introduce the following dimensionless variables:

$$u' = \frac{u}{U},\quad v' = \frac{v}{U_r},\quad z' = \frac{zU_r}{\nu},\quad t' = \frac{tU_r^2 u}{\nu},\quad n' = \frac{n\nu}{U_r^2},\quad \bar{\omega}_1' = \frac{\bar{\omega}_1\nu}{U_r^2},\quad \bar{\omega}_2' = \frac{\bar{\omega}_2\nu}{U_r^2}$$

$$\lambda = \frac{\Lambda}{\mu j},\quad \Delta = \frac{v_r}{\nu},\quad Q' = \frac{Q\nu^2}{U_r^2 k},\quad \alpha = \frac{R_r\nu}{U_r^2},\quad S = \frac{w_0}{U_r},$$

$$M = \frac{B_0}{U}\sqrt{\frac{\sigma\nu}{\rho}},\quad Sc = \frac{\nu}{D_m},\quad Pr = \frac{\mu C_p}{k},\quad Q_l = \frac{Q_l'(C_w - C_\infty)}{(T_w - T_\infty)U_r^2} \quad (11)$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty},\quad \phi = \frac{C - C_\infty}{C_w - C_\infty},\quad Gr = \frac{\nu g\beta_T(T_w - T_\infty)}{U_r^3},\quad Gm = \frac{\nu g\beta_c(C_w - C_\infty)}{U_r^3}$$

Then substituting equation (11) into equations (1)-(7) yields the following dimensionless equations and dropping primes:

$$\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial z} = (1 + \Delta)\frac{\partial^2 u}{\partial z^2} + Gr\theta + Gm\phi - M^2 u - \Delta\frac{\partial \bar{\omega}_2}{\partial z} \quad (12)$$

$$\frac{\partial v}{\partial t} - S\frac{\partial v}{\partial z} = (1 + \Delta)\frac{\partial^2 v}{\partial z^2} - M^2 v + \Delta\frac{\partial \bar{\omega}_1}{\partial z} \quad (13)$$

$$\frac{\partial \bar{\omega}_1}{\partial t} - S\frac{\partial \bar{\omega}_1}{\partial z} = \lambda\frac{\partial^2 \bar{\omega}_1}{\partial z^2} \quad (14)$$

$$\frac{\partial \bar{\omega}_2}{\partial t} - S\frac{\partial \bar{\omega}_2}{\partial z} = \lambda\frac{\partial^2 \bar{\omega}_2}{\partial z^2} \quad (15)$$

$$\frac{\partial \theta}{\partial t} - S\frac{\partial \theta}{\partial z} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial z^2} - \frac{Q}{Pr}\theta + Q_l\phi \quad (16)$$

$$\frac{\partial \phi}{\partial t} - S\frac{\partial \phi}{\partial z} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial z^2} - \alpha\phi \quad (17)$$

The boundary conditions (8) and (9) are becomes

$$u = v = 0,\ \bar{\omega}_1 = \bar{\omega}_2 = 0,\ T = T_\infty,\ C = C_\infty \text{ for } t \le 0 \quad (18)$$

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

$$u = 1 + \frac{\in}{2}(e^{\text{int}} + e^{-\text{int}}),\ v = 0,\ \bar{\omega}_1 = -\frac{1}{2}\frac{\partial v}{\partial z},\ \bar{\omega}_2 = \frac{1}{2}\frac{\partial u}{\partial z}$$

$$\theta = 1,\ \phi = 1 \qquad at\ z = 0\ \ and \qquad \text{for}\, t > 0 \quad (19)$$

$$u = v = 0,\ \bar{\omega}_1 = \bar{\omega}_2 = 0,\ \theta = 0,\ \phi = 0 \qquad as\ z \to \infty$$

To obtain desired solutions, we now simplify Equations (11)-(17) by putting the fluid velocity and angular velocity in the complex form as

$V = u + iv, \quad \omega = \bar{\omega}_1 + i\bar{\omega}_2$ and we get

$$\frac{\partial V}{\partial t} - S\frac{\partial V}{\partial z} = (1+\Delta)\frac{\partial^2 V}{\partial z^2} + Gr\theta + Gm\phi - (M^2)V + i\Delta\frac{\partial \omega}{\partial z} \quad (20)$$

$$\frac{\partial \omega}{\partial t} - S\frac{\partial \omega}{\partial z} = \lambda\frac{\partial^2 \omega}{\partial z^2} \quad (21)$$

$$\frac{\partial \theta}{\partial t} - S\frac{\partial \theta}{\partial z} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial z^2} - \frac{Q}{Pr}\theta + Q_l\phi \quad (22)$$

$$\frac{\partial \phi}{\partial t} - S\frac{\partial \phi}{\partial z} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial z^2} - \alpha\phi \quad (23)$$

The associated boundary conditions (18) and (19) becomes

$$V = 0,\ \omega = 0,\ \theta = 0,\ \phi = 0 \ \text{for}\, t \le 0 \quad (24)$$

$$V = 1 + \frac{\in}{2}(e^{\text{int}} + e^{-\text{int}}),\ v = 0,\ \omega = \frac{i}{2}\frac{\partial v}{\partial z},\ \theta = 1,\ \phi = 1 \quad at\ z = 0$$

$$and\ \ V = 0,\ \omega = 0,\ \theta = 0,\ \phi = 0 \qquad as\ z \to \infty \qquad \text{for}\, t > 0 \quad (25)$$

3 Results and Discussion

The objective of the present analysis is to study the effects of chemical reaction and thermal radiation on MHD micropolar fluid in a rotating frame of reference. The analytical results are reported in the previous section was performed and a representative set of results is reported graphically in figures 1-6. These results are obtained to illustrate the influence of various parameters on the velocity, micro rotation, temperature and concentration profiles. In these calculations we consider $\varepsilon = 0.02$, $\lambda = 0.3$, $n = 10$, and $t = 0.1$ while other parameters are varied over a range which are listed in figure captions.

In order to verify the validity and accuracy of the present analysis, our results have been compared for the local skin friction coefficient, the local Nusselt number and share hood number with those obtained by [27] for various values of Δ. The results of this comparison are given in table1. We notice that the comparison shown good agreement for each value of Δ. Therefore we are confident that the present results are very accurate. It can be seen from this table that excellent agreement argument between the results exists. This favorable comparison leads confidence in the next section.

Figures 2(a) to 2(d) correspondingly show the translation velocity, micro rotation, temperature and concentration profiles for different values of the chemical reaction parameter α. It is obvious from the figures that the translation velocity, temperature and concentration profiles decrease with the increase of the parameter α where as the repeal trend is observed in case of micro rotation profile. The effect of α on velocity and concentration is reverse in case of Ref.[26]. This is due to the lead role of the radiation absorption in the flow field. These results are clearly supported from the physical point of view.

For various values of Q_l, the profiles of translation velocity, the micro rotation and temperature profiles across the boundary layer are shows in figures 3(a)-3(c). It is clear from the graphs that all the translation velocity, micro rotation and temperature increases with an increase of Q_l which is due to the fact that when heat is absorbed the buoyancy force which accelerated the flow. This

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

is because the large radiation absorption parameter Q_l values corresponding to an increased dominance of conduction over absorption radiation there by increasing buoyancy force and thickness of the thermal and momentum boundary layers.

Figures 4(a)-4(d) displays the variation of the local Skin friction coefficient C_f, Couple stress C_w, Nusselt number Nu and Sharehood number Sh_x with magnetic field M for various values of Δ and S. It is observed from figures that the local Skin friction coefficient and Couple stress both are reduced due to increase in the magnetic field strength, as expected since the applied magnetic field tends to impede the flow motion and thus reduce the surface friction force. On the other hand as Δ increases skin friction decrease and couple stress increase. Figures 4(c) and 4(d) displays the heat transfer coefficient and Sharehood number in terms of magneticfield parameter M corresponding to different values of S. These figures clearly shows that, Nusselt number and Sharehood number increase with increase in the value of S where as M has no effect on Nu and Sh_x. Also from equations (6) and (7) it is clear that the equations are independent of M. So M has no effect on Nu and Sh_x.

Figures 5 present the effect of magnetic field parameter M on translational velocity profile for both Newtonian and polar fluid conditions respectively. Increasing the magnetic field parameter has the tendency to increase for the translational velocity profile. In addition, it is seen that the fluid velocity is lower for polar fluids than for Newtonian fluids.

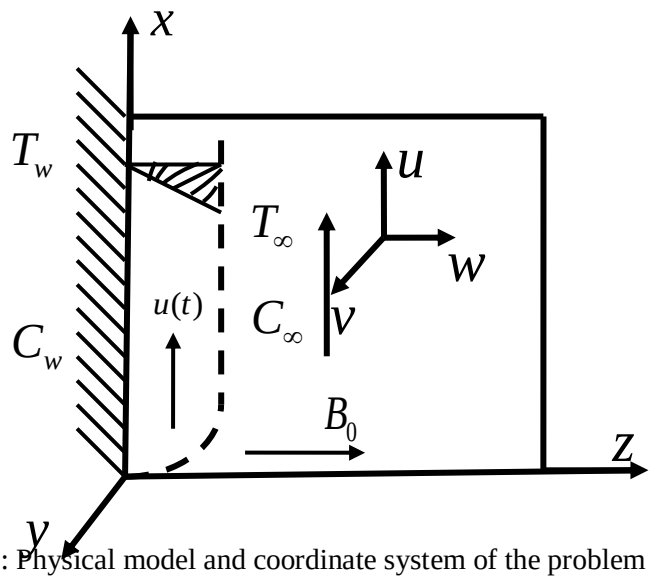

Fig 1: Physical model and coordinate system of the problem

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

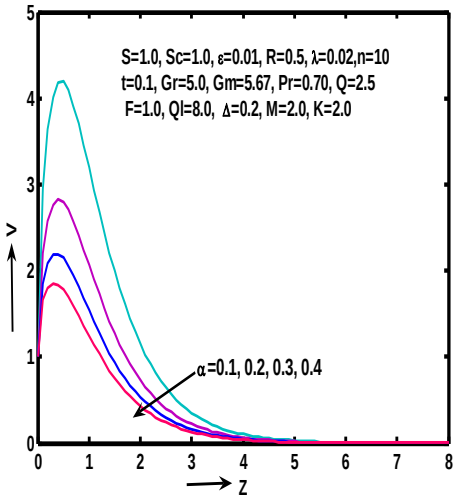

Fig 2(a). Velocity profiles for various values of α

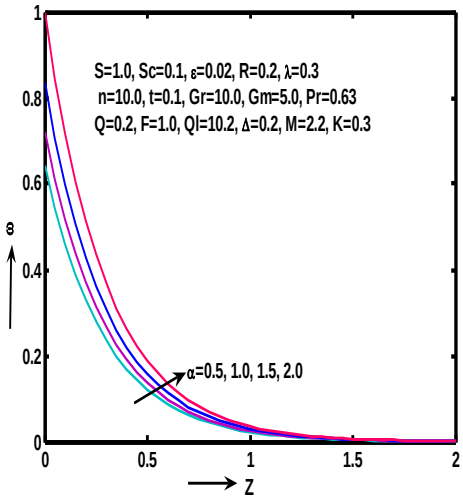

Fig 2(b). Microrotation profiles for various values of α

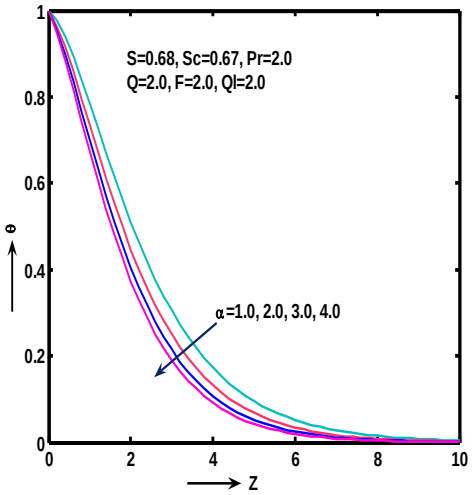

Fig 2(c).Temperature profiles for various values of α

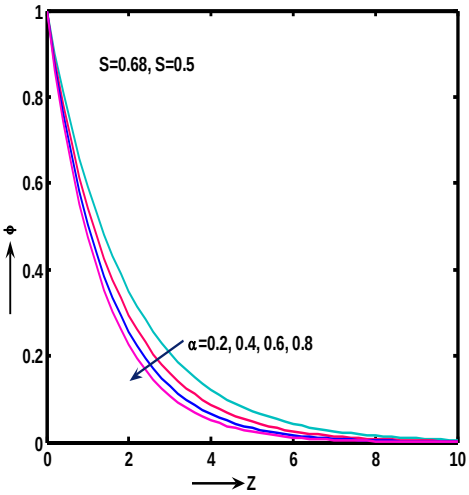

Fig 2(d).Concentration profiles for various valuesof α

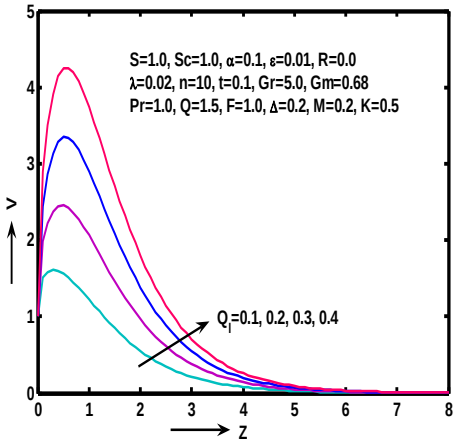

Fig 3(a). Velocity profiles for various values of Q_l

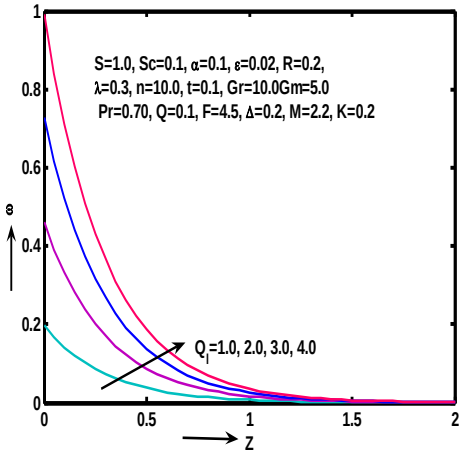

Fig 3(b). Microrotation profiles for various values of Q_l

ISSN- 2394-5125 VOL 7, ISSUE 05, 2020

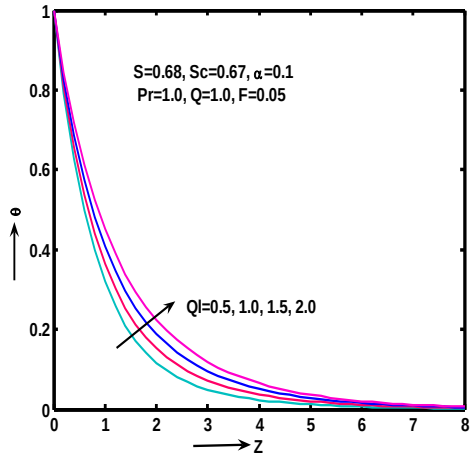

Fig 3(c). Temperature profiles for various values of Q_l

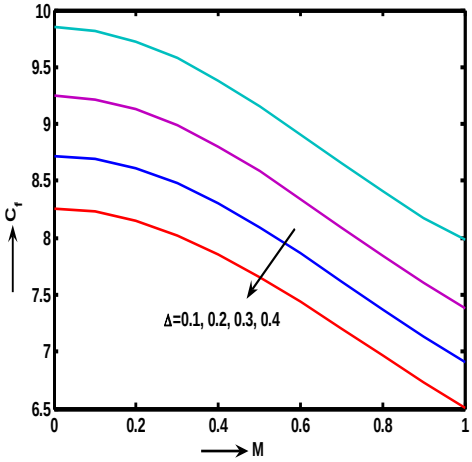

Fig 4(a) Skin friction for various values of Δ

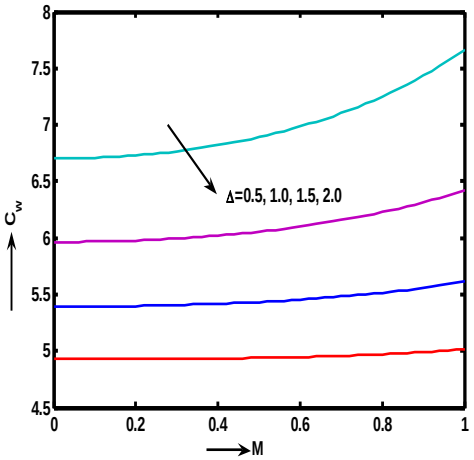

Fig 4(b) Couple Stress for various values of Δ

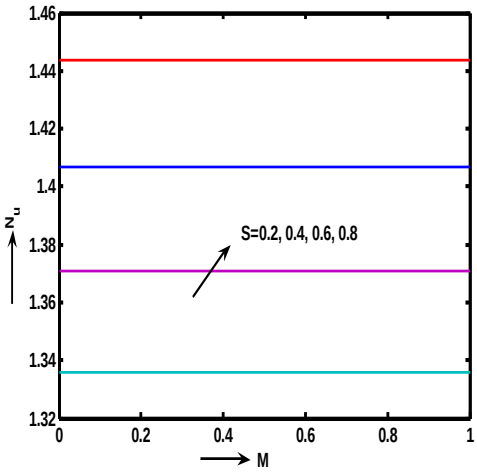

Fig 4(c) Nusselt number for various values of S

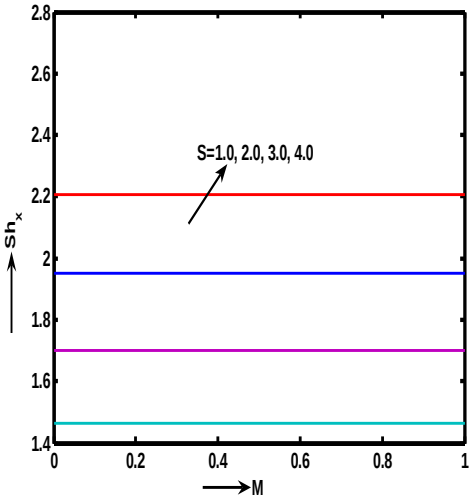

Fig 4(d) Share hood number for different S

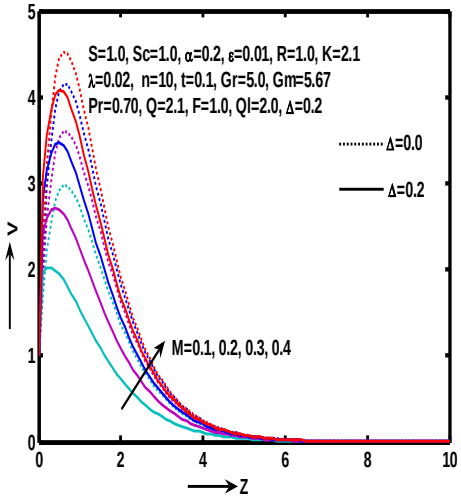

Fig 5 Velocity for various values of M

4 Conclusion

In this paper, we analyses the effect of rotation and radiation absorption and chemical reaction on MHD micropolar fluid past a vertical plate. The governing equations are solved computationally by using shooting technique. The effect of various parameter are evolutes on the velocity, micro rotation, temperature and concentration profiles as well as the local Skin-friction coefficient, the local Nusselt number and the local Sherwood number are presented. The present calculations we may conclude that the following conclusions.

1. The fluid velocity in the case of Newtonian fluids was predicated higher than that for the case of polar fluids and it decreased as the polarity.
2. The temperature increases with an increasing values of Q_l whereas opposite effect is seen by enhancing the value of α.
3. The result obtained in this work are more generalized form of Das [27] and can be taken as a limiting case by taking $Q_l \to 0$.

It is hoped that the findings of this investigation may be useful for applications in power engineering, geothermal energy extractions, generators and boundary layer control in the field of aero-dynamics, but also serve as a complement to the previous studies.

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