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Simultaneous effects of soret and ohmic heating on MHD free convective heat and mass transfer flow of micropolar fluid with porous medium

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ABSTRACT

We investigate the simultaneous effects of soret and ohmic heating on MHD free convective heat and mass transfer flow for a micro polar fluid bounded by a vertical infinite surface. Approximate solutions have been derived for the velocity, angular velocity, temperature field, concentration profiles, skin friction and rate of heat transfer using multi-parameter perturbation method. The effects of various pertinent parameters on flow, heat and mass transfer properties are discussed numerically and explained graphically. Also the velocity profiles of micropolar fluid is compared with the corresponding flow problem for a Newtonian fluid and found that the polar fluid velocity is decreasing

Introduction

The theory of micropolar fluids was developed by Eringen [1-3] describes some physical systems which do not satisfy the Navier-Stokes equations. This theory may be applied to the explanation for the phenomenon of the flow of colloidal fluids, liquid crystals, polymeric suspensions, animal blood, etc. Radhakrishnamacharya [4] analyzed the flow of micropolar 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. Prathap Kumar *et al.* [7] have investigated the problem of fully developed free convective flow of micropolar and viscous fluids in a vertical channel. Muthu et.al. [8] studied peristaltic motion of micropolar fluid in circular cylindrical tubes. Srinivasacharya et.al. [9] analyzed the unsteady stokes flow of micropolar fluid between two parallel porous plates. Recently Muthuraj and Srinivas [10] investigated, fully developed MHD flow of a micropolar and viscous fluids in a vertical porous space using HAM. Kim [11] investigated the effects of heat and mass transfer in the MHD micropolar fluid flow past a vertical moving plate. The simultaneous effects of heat and mass transfer with chemical reaction are of great importance to engineers and scientists because of its occurrence in many branches of science and engineering. The effects of the chemical reaction and mass transfer on MHD unsteady free convection flow past an infinite/semi infinite vertical was analyzed by [12-17].

The study of fluid flows and heat transfer through porous medium has attracted much attention recently. This is primarily because of numerous applications of flow through porous medium, such as separation processes in chemical industries, filtration, transpiration cooling, ground water pollution etc. Effect of heat generation or absorption on free convective flow with heat and mass transfer in geometries with and without porous media has been studied by many scientists and technologists [18-24].The free convection effects on the oscillatory flow of couple stress fluids through a porous medium have been investigated by Hiremath and Patil [25]. Sharma and Sharma [26] have discussed effects of the thermo solutal convection of micropolar fluids with MHD through a porous medium. Ibrahim et al.[27] have examined the effects of unsteady MHD micropolar fluids over a vertical porous plate through a porous medium in the presence of thermal and mass diffusion with a constant heat source. Kim [28] has studied the effects of heat and mass transfer on MHD micropolar flow over a vertical moving porous plate in a porous medium. Recently Rajagopal et.al. [29] investigated the linear stability of Hagen-Poiseuille flow in a chemically reacting fluid. Ogulu [30] has studied the effects of oscillating temperature flow of a polar fluid past a vertical porous plate in the presence of couple stresses and radiation. Rehman and sattar [31] have analyzed the effect of magnetohydrodynamic convective flow of a micropolar fluid past a continuously moving porous plate in the presence of heat generation/ absorption.

The role of thermal radiation on the flow and heat transfer process is major importance in the design of many advanced energy conversion systems operating at higher temperatures. Thermal radiation with in the system is the result of emission by hot walls and the working fluid. Sunil et al. [32] have analyzed the effects of radiation on a layer of micropolar ferromagnetic fluids heated from below saturating a porous medium are investigated. Effects of chemical reaction and thermal radiation on heat and mass transfer flow of MHD micropolar fluid in rotation frame of reference is investigated by Das [33]. A

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complete analytic solution to heat transfer of a micropolar fluid through a porous medium was analyzed by Rashidi et al. [34].MHD flow of a micropolar fluid towards a vertical permeable plate with prescribed surface heat flux is investigated by Nor Azizah et al. [35]. Ezzat et al. [36] steadied the combined heat and mass transfer for unsteady MHD flow of perfect conducting micropolar fluid with thermal relaxation. Peristaltic motion of a magnetohydrodynamic micropolar fluid in tube is analyzed by Yongqi Wang et al. [37]. When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driven potential are important. It has been found that the energy flux can be generated not only by temperatures gradients but by composition gradient as well. The energy caused by a composition gradient is called the Dufor or the diffusion-thermo effect, the Dufor effect is neglected in this study because it is of a smaller order of magnitude than the volumetric heat generation effect which exerts a stronger effect on the energy flux generation. Also the mass fluxes can be created by the temperature gradients and this is called the Soret or thermal diffusion effect.

In all the above investigations, the effects of Soret and Ohmic heating are not considered in the problem of coupled heat mass transfer in the presence of magnetic field. However, it is more realistic to include Soret and Ohmic effect in order to explore the impact of the magnetic field on the thermal transport in the boundary layer. Therefore, the main goal here is to study the Soret and Ohmic heating effects on the steady two dimensional laminar, polar fluid flows through porous medium in the presence of magnetic field and chemical reaction. The flow configuration is modeled as hot vertical plate bounding the porous region filled with water containing soluble and insoluble chemical materials. The flow is due to buoyancy forces generated by the temperature gradient. From the results obtained, it is clear that the flow field is influenced by the presence of soret effect, chemical reaction, thermal radiation, magnetic fields.

Formulation

A steady, laminar, two-dimensional free convective flow of a viscous incompressible polar fluid with heat and mass transfer through a porous medium occupying a semi-infinite region of the space bounded by an infinite vertical porous plate is considered. The X^*-axis measured along the porous plate, in the upward direction and a magnetic field of uniform strength is applied in the Y^* direction which is normal to the flow direction. The surface temperature is T'_∞ and the porous medium temperature is T'_ω sufficiently away from the surface and allows a constant suction. To allow possible heat generation effects, a heat source is placed within the flow. The concentration of the porous medium is C'_ω concentration of species far from the surface C'_∞. The effects of the viscous dissipation and Darcy dissipation are accounted in the energy balance equation. The chemical reactions are taking place in the flow and all thermo physical properties are assumed to be constant. The flow is due to buoyancy effects arising from density variations caused by differences in the temperature as well as species concentration. Taking into consideration these assumptions, the equations that describe the physical situation can be written in Cartesian frame of references, as follows:

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

$$v'\frac{\partial u'}{\partial y'} = g\beta_t(T'-T'_\infty) + g\beta_c(C'-C'_\infty) + (v+v_r)\frac{\partial^2 u'}{\partial y'^2} + 2v_r\frac{\partial \omega'}{\partial y'} - \frac{v+v_r}{K'}u' - \frac{\sigma B_0^2 u'}{\rho} \tag{2}$$

$$v'\frac{\partial \omega'}{\partial y'} = \frac{\gamma}{I}\frac{\partial^2 \omega'}{\partial y'^2} \tag{3}$$

$$v'\frac{\partial T'}{\partial y'} = \frac{\lambda}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{v}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 + \frac{v}{K'C_p}u'^2 - \frac{Q_0}{\rho C_p}(T'-T'_\infty) - \frac{1}{\rho C_p}\frac{\partial q'_r}{\partial y'} \tag{4}$$

$$v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - k_1 C' + D_1\frac{\partial^2 T'}{\partial y'^2} \tag{5}$$

The appropriate boundary conditions are

$$\begin{aligned} &y' = 0 : u' = 0, \frac{\partial \omega'}{\partial y'} = -\frac{\partial^2 u'}{\partial y'^2}, T' = T'_\omega, C' = C'_\omega \\ &y' \to \infty : u' \to 0, \omega' \to 0, T' \to C'_\omega, C' \to C'_\infty \end{aligned} \tag{6}$$

The boundary conditions (6) are derived from the assumption that the couple stresses are dominant during the rotation of the particles.

The integration of the continuity equation (1) yields

$$v' = -v_0 \tag{7}$$

Where v_0 the constant suction velocity at the wall and the negative sign is indicates that the suction velocity is directed towards the plate.

The radiative heat flux is given by

$$\frac{\partial q'_r}{\partial y'} = 4(T'-T'_\infty)I' \tag{8}$$

Where $I' = \int_0^\infty K_{\lambda\omega}\frac{\partial e_{b\lambda}}{\partial T'}d\lambda, K_{\lambda\omega}$ the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function.

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

$$\begin{aligned} &y = \frac{y'v_0}{v}, u = \frac{u'}{v_0}, \theta = \frac{(T'-T'_\infty)}{(T'_\omega - T'_\infty)}, \phi = \frac{(C'-C'_\infty)}{(C'_\omega - C'_\infty)}, \omega = \frac{\omega' v}{v_0}, \alpha = \frac{v_r}{v}, \beta = \frac{Iv}{\gamma}, \Pr = \frac{\rho v C_p}{\lambda} \\ &E = \frac{v_0^2}{C_p(T'_\omega - T'_\infty)}, Gr = \frac{vg\beta_t(T'_\omega - -T'_\infty)}{v_0^3}, Gm = \frac{vg\beta_c(C'_\omega - C'_\infty)}{v_0^3}, K = \frac{K'v_0^2}{v^2}, \\ &Q = \frac{Q_0 v}{\rho C_p v_0^2}, Sc = \frac{v}{D}, \Delta = \frac{k_1 v}{v_0^2}, M = \frac{\sigma B_0^2 v}{\rho v_0^2}, S_o = \frac{D_1(T'_\omega - T'_\infty)}{v(C'_\omega - C'_\infty)}, F = \frac{4vI'}{\rho C_p v_0^2} \end{aligned} \tag{9}$$

In the view of the above non-dimensional variables, the basic equations (2)-(5) can be expressed in non dimensional form as

$$(1+\alpha)u'' + u' - \left(\frac{1+\alpha}{K} + M\right)u = -\left\{\theta Gr + \phi Gm + 2\alpha\omega'\right\} \tag{10}$$

$$\omega'' + \beta\omega' = 0 \tag{11}$$

$$\theta'' + \Pr\theta' - \Pr(Q+F)\theta = -\Pr E\left\{u'^2 + \frac{u^2}{K}\right\} \tag{12}$$

$$\phi'' + Sc\phi' - Sc\Delta\phi = -ScS_o\theta'' \tag{13}$$

Where *Gr* is the Grashof number, *Gm* is the solutal Grashof number, *Pr* is the Prandtl number, *M* is the magnetic field parameter, F is the radiation parameter, Sc is the Schimidt number, ϕ is the heat source parameter, and Δ is the chemical reaction parameter , Q is heat generation parameter , α, β are the polar (material) parameters, K is the permeability of the porous medium, E is the viscous and Darcy's dissipation parameter and S_o is the Soret number.

The corresponding boundary conditions in dimensionless form are

$$\begin{aligned} &y=0: \; u=0, \omega' = -u'', \theta = 1, \phi = 1 \\ &y \to \infty: \; u \to 0, \omega \to 0, \theta \to 0, \phi \to 0 \end{aligned} \tag{14}$$

Where the prime denote the differentiation with respect to y. the mathematical statement of the problem is now complete and now move on to obtain the solution of Eqns. (10) - (13) subject to boundary conditions (14).

Solution of the problem:

A set of partial differential Eqns. (10) – (13) cannot be solved in closed – form. However, it can be solved analytically after these equations are reduced to a set of ordinary differential equations in dimensionless form which can be done by representing the velocity, angular velocity, temperature and concentration as follows:

$$\begin{aligned} u(y) &= u_0(y) + Eu_1(y) + o(E^2) \\ \omega(y) &= \omega_0(y) + E\omega_1(y) + o(E^2) \\ \theta(y) &= \theta_0(y) + E\theta_1(y) + o(E^2) \\ \phi(y) &= \phi_0(y) + E\phi_1(y) + o(E^2) \end{aligned} \tag{15}$$

Where the zeroth order term correspond to the case in which the viscous and Darcy's dissipation is neglected (E=0).the substitution of Eqn. (15) into Eqns. (10) - (13) and the conditions (14), we get the following system of equations.

Zeroth- order:

$$(1+\alpha)u_0'' + u_0' - \left(\frac{1+\alpha}{K} + M\right)u_0 = -\{\theta_0 Gr + \phi_0 Gm + 2\alpha\omega_0'\} \tag{16}$$

$$\omega_0'' + \beta\omega_0' = 0 \tag{17}$$

$$\theta_0'' + \Pr\theta_0' - \Pr(Q+F)\theta_0 = 0 \tag{18}$$

$$\phi_0'' + Sc\phi_0' - Sc\Delta\phi_0 = -ScS_0\theta_0'' \tag{19}$$

Subjected to the reduced boundary conditions

$$\begin{aligned} &y=0: \; u_0 = 0, \omega_0' = -u_0'', \theta_0 = 1, \phi_0 = 1 \\ &y \to \infty: \; u_0 \to 0, \omega_0 \to 0, \theta_0 \to 0, \phi_0 \to 0 \end{aligned} \tag{20}$$

First-order:

$$(1+\alpha)u_1'' + u_1' - \left(\frac{1+\alpha}{K} + M\right)u_1 = -\{\theta_1 Gr + \phi_1 Gm + 2\alpha\omega_1'\} \tag{21}$$

$$\omega_1'' + \beta\omega_1' = 0 \tag{22}$$

$$\theta_1'' + \Pr\theta_1' - \Pr(Q+F)\theta_1 = -\Pr\left\{u_0'^2 + \frac{u_0^2}{K}\right\} \tag{23}$$

$$\phi_1'' + Sc\phi_1' - Sc\Delta\phi_1 = -ScS_0\theta_1'' \tag{24}$$

Subjected to the reduced boundary conditions

$$\begin{aligned} &y=0: \; u_1 = 0, \omega_1' = -u_1'', \theta_1 = 0, \phi_1 = 1 \\ &y \to \infty: \; u_1 \to 0, \omega_1 \to 0, \theta_1 \to 0, \phi_1 \to 0 \end{aligned} \tag{25}$$

By solving Eqns. (16) - (19) under the conditions (20) and Eqns. (21)- (24) under the conditions (25) and the substituting the obtained solutions in Equation (15), we obtain

$$\begin{aligned} u(y) = {} & c_1 e^{R_5 y} + A_4 e^{R_3 y} + A_5 e^{R_1 y} + A_3 c_2 e^{-\beta y} + E\{c_4 e^{R_5 y} + A_{27} e^{R_1 y} + A_{28} e^{R_3 y} + A_{29} e^{2R_1 y} + \\ & A_{30} e^{2R_3 y} + A_{31} e^{2R_5 y} + A_{32} e^{-2\beta y} + A_{33} e^{(R_3+R_5)y} + A_{34} e^{(R_1-\beta)y} + A_{35} e^{(R_1+R_5)y} + A_{36} e^{(R_5-\beta)y} \\ & + A_{37} e^{(R_3+R_1)y} + A_{38} e^{(R_3-\beta)y} + A_3 c_3 e^{-\beta y}\} + O(E^2) \end{aligned} \tag{26}$$

$$\omega(y) = c_2 e^{-\beta y} + E\left\{c_3 e^{-\beta y}\right\} + O(E^2) \tag{27}$$

$$\begin{aligned} \theta(y) = {} & e^{R_3 y} + E\{D_2 e^{R_3 y} + A_6 e^{2R_1 y} + A_7 e^{2R_3 y} + A_8 e^{2R_5 y} + A_9 e^{-2\beta y} + A_{10} e^{(R_3+R_5)y} \\ & + A_{11} e^{(R_1-\beta)y} + A_{12} e^{(R_1+R_5)y} + A_{13} e^{(R_5-\beta)y} + A_{14} e^{(R_3+R_1)y} + A_{15} e^{(R_3-\beta)y}\} + O(E^2) \end{aligned} \tag{28}$$

$$\begin{aligned} \phi(y) = {} & A_2 e^{R_1 y} + A_1 e^{R_3 y} + E\{D_3 e^{R_1 y} + A_{16} e^{R_3 y} + A_{17} e^{2R_1 y} + A_{18} e^{2R_3 y} \\ & + A_{19} e^{2R_5 y} + A_{20} e^{-2\beta y} + A_{21} e^{(R_3+R_5)y} + A_{22} e^{(R_1-\beta)y} + A_{23} e^{(R_1+R_5)y} + \\ & A_{24} e^{(R_5-\beta)y} + A_{25} e^{(R_3+R_1)y} + A_{26} e^{(R_3-\beta)y}\} + O(E^2) \end{aligned} \tag{29}$$

From the engineering point of view, the most important characteristics of the flow are the skin-friction co-efficient c_f, Nusselt number Nu and Sherwood number Sh are given below:

$$c_f = \left[\frac{du}{dy}\right]_{y=0} = \left[\frac{du_0}{dy} + E\frac{du_1}{dy}\right]_{y=0} \tag{30}$$

$$\begin{aligned} = {} & c_1 R_5 + A_4 R_3 + A_5 R_1 - A_3 c_2 \beta + E\{c_4 R_5 + A_{27} R_1 + A_{28} R_3 + 2A_{29} R_1 + 2A_{30} R_3 + \\ & 2A_{31} R_5 - 2A_{32}\beta + A_{33}(R_3+R_5) + A_{34}(R_1-\beta) + A_{35}(R_1+R_5) + A_{36}(R_5-\beta) + \\ & A_{37}(R_3+R_1) + A_{38}(R_3-\beta) - A_3 c_3 \beta\} \end{aligned} \tag{31}$$

$$Nu = -\left[\frac{d\theta}{dy}\right]_{y=0} = -\left[\frac{d\theta_0}{dy}\right]_{y=0} - E\left[\frac{d\theta_1}{dy}\right]_{y=o} \tag{32}$$

$$\begin{aligned} = {} & -R_3 - E\{D_2 R_3 + 2A_6 R_1 2A_7 R_3 + 2R_5 A_8 - 2\beta A_9 + A_{10}(R_3+R_5) + A_{11}(R_1-\beta) \\ & + A_{12}(R_1+R_5) + A_{13}(R_5-\beta) + A_{14}(R_3+R_1) + A_{15}(R_3-\beta)\} \end{aligned} \tag{33}$$

$$Sh = -\left[\frac{d\phi}{dy}\right]_{y=0} = -\left[\frac{d\phi_0}{dy}\right]_{y=0} - E\left[\frac{d\phi_1}{dy}\right]_{y=0} \tag{34}$$

$$\begin{aligned} = {} & -A_2 R_1 - A_1 R_3 - E\{D_3 R_1 + A_{16} R_3 + 2A_{17} R_1 + 2R_3 A_{18} + 2R_5 A_{19} - 2\beta A_{20} + A_{21}(R_3+R_5) \\ & + A_{22}(R_1-\beta) + A_{23}(R_1+R_5) + A_{24}(R_5-\beta) + A_{25}(R_3+R_1) + A_{26}(R_3-\beta)\} \end{aligned} \tag{35}$$

Where the expressions for the constants are given in the Appendix.

Results and Discussions

Numerical evaluation of analytical results reported in the previous section was performed and a representative set of results is reported graphically in figures 1-15. These results are obtained to illustrate the influence of various parameters on the velocity u, angular velocity ω, temperature θ and concentration ϕ profiles etc. In these calculations, the values of chemical reaction parameter Δ, Soret number S_o, the polar parameters α and β are 0.5,1.0,0.1 and 2.0 respectively. The values of the remaining parameters are mentioned in the corresponding graphs itself.

Figure (1) presents typical profiles of the velocity and angular velocity for various values of Schmidt number Sc. It is noted from figure that an increase in the value of Sc, leads to a decrease in the velocity of fluid. Further it is observed that the velocity of the polar fluid is found to decrease in comparison with Newtonian fluid (α=0 and β=0). This is due to the fact that as the Schmidt number increases the concentration decreases which leads to decrease in concentration buoyancy effect, hence a decrease in fluid velocity. The opposite behavior is found in the case of angular velocity. The negative values of the angular velocity indicate that the micro rotation of sub structures in the polar fluid is clock-wise. We can observe the same behavior from fig. (2) when *Sc* is replaced by the chemical reaction parameter Δ.

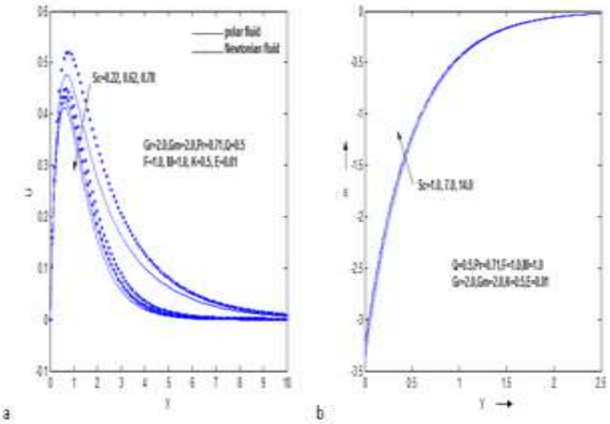

Figure 1. Effects of Schimidt number Sc on velocity profiles

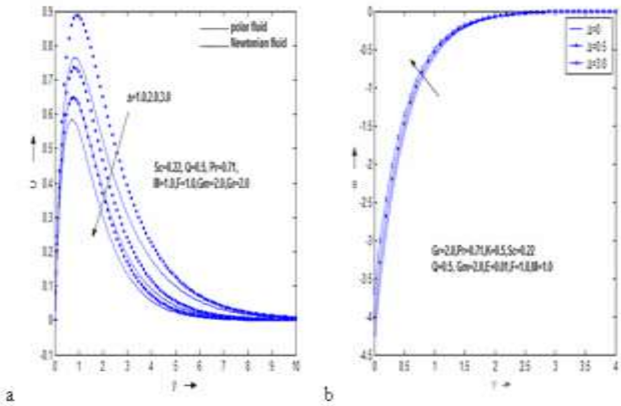

Figure 2. Effects of chemical reaction parameter Δ on velocity profiles

The effects of internal heat generation parameter *Q* on the velocity and angular velocity is displayed in the fig. (3). It is clear from the figure that as the parameter *Q* increases there is a fall in the velocity in both polar and Newtonian cases. This is due to homogeneous chemical reaction and constant suction. Further, the velocity in the case of Newtonian fluid decreased more remarkably as compared to polar fluids. Hence, it is noticed that the influence of internal heat generation is more on the Newtonian fluid when compared to the polar fluid. The opposite behavior we can see in the case of angular velocity also.

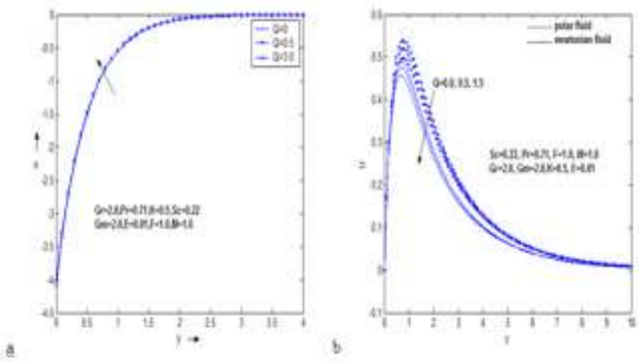

Figure 3. Effects of heat generation parameter Q on velocity profiles

The effect of the material parameters α and β, Grashof number *Gr*, solutal Grashof number Gm, permeability of the porous medium *K* and Prandtl number *Pr* on velocity and angular velocity are observed from fig. (4). The velocity and angular velocity fields are influenced by the combined effect of chemical reaction, internal heat generation, constant suction and viscous and Darcy's dissipation. We observe that velocity increases as *Gr*, *Gm*, *K* and *Pr* increase while it decreases as α and β increase. The opposite behavior is found in the case of angular velocity.

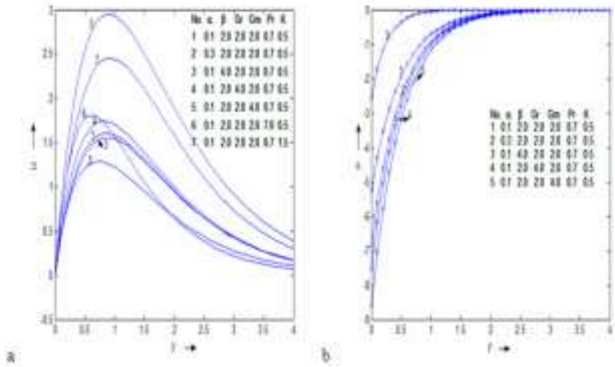

Figure 4.Velocity profiles for various parameters

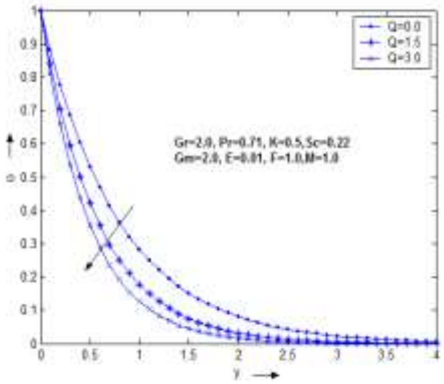

Fig. 5: Effects of heat source parameter Q on temperature profiles

Figure (5) illustrate the influence of heat generation on the temperatureθ. From the graph it is clear that there is a decrease in temperature with the increase of heat generation parameter *Q*, this is due to the fact that when heat is generated the buoyancy force decreases which retards the flow rate there by decrease in temperature.

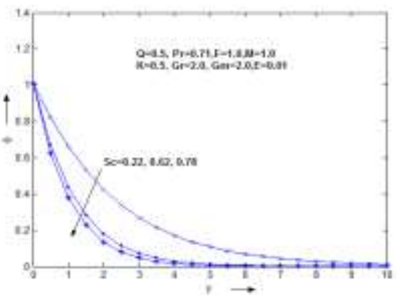

Fig. 6: Effects of Schimidt number Sc on Concentration profile

Figures (6) and (7) show typical concentration profile for various values of Schmidt number *Sc* and the chemical reaction parameter Δ, respectively. As the destructive chemical reduces the solutal boundary layer thickness and increases the mass transfer there is a decrease in the concentration of species in the boundary layer. Also, the concentration of the species is higher for small values of *Sc*, as the increase of *Sc* means decrease of molecular diffusion. Hence there is a decrease in concentration with the increase of Sc.

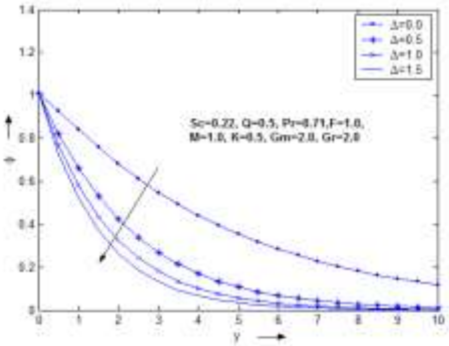

Fig. 7 : Effects of chemical reaction parameter Δ on concentration profile

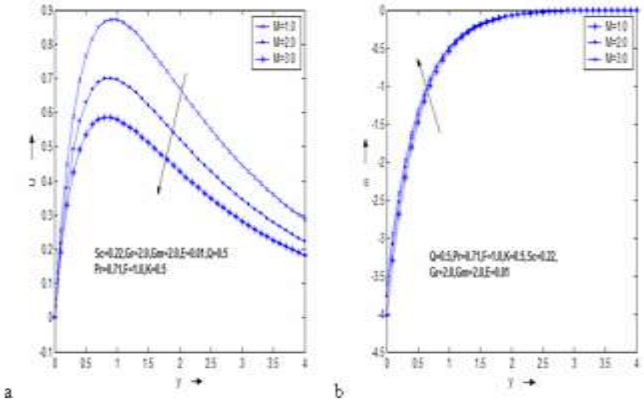

Figure 8. Effects of Magnetic field parameter M on velocity and angular velocity profiles

The effects of magnetic field parameter *M* on the velocity and angular velocity is displayed in Fig. (8). It is obvious that as the parameter *M* increases velocity decreases, this is due to the fact that the presence of magnetic field in an electrically conducting fluid introduces a force called Lorentz force, which resist the flow if the applied magnetic field is in normal direction. The opposite behavior is found in angular velocity.

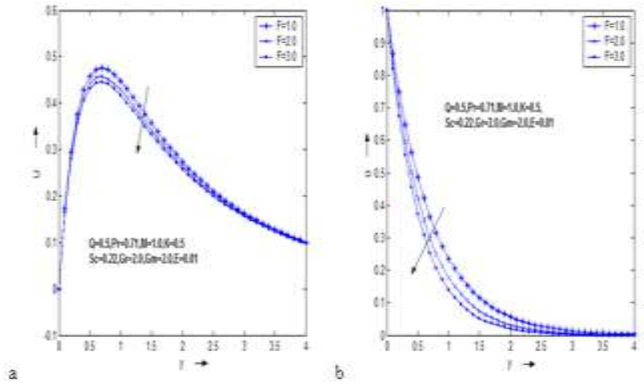

Figure 9. Effects of radiation parameter F on velocity and temperature profiles

The effects of Radiation parameter *F* on velocity and temperature profiles is shown in the Fig. (9). It can be seen that both velocity and temperature leads to fall as the Radiation parameter increases. It is due to the fact that increase in radiation parameter *F* results in a increase in the velocity and temperature within the boundary layer, as well as decreased thickness of the velocity and temperature boundary layers.

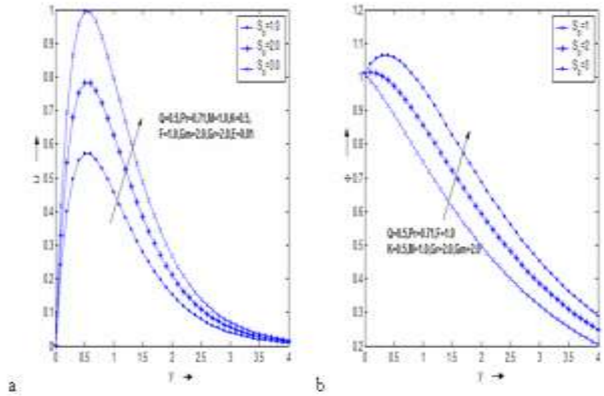

Figure 10. Effects of Soret number So on velocity and concentration profiles

Figure (10) shows the effects of Soret number $S_o$on the velocity and concentration profiles. It is clear that as the parameter increases both velocity and concentration increases.

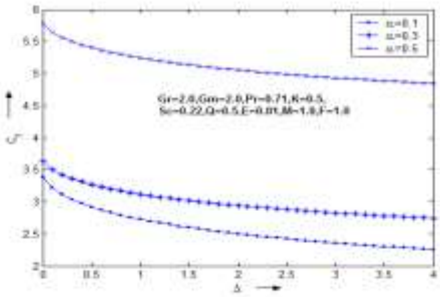

Fig. 11 (a): Effects of polar parameter α on skin friction against chemical reaction parameter Δ

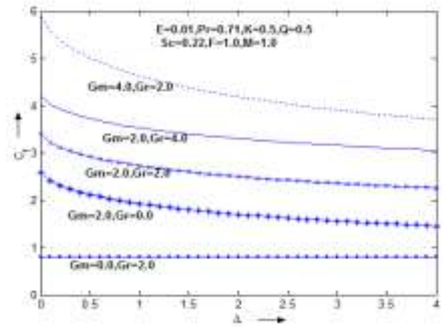

Fig. 11 (b): Effects of Gr and Gm on skin friction against chemical reaction parameter Δ

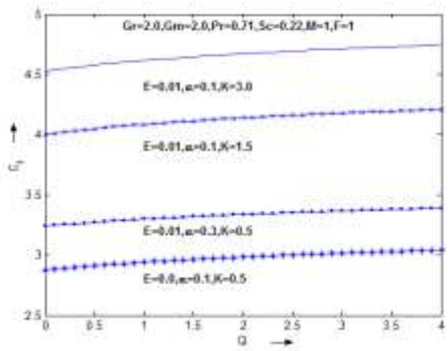

Fig.11(c) Effects of polar parameter α and permeability K on skin friction against heat generation parameter Q

In Fig. (11), skin friction coefficient is plotted against chemical reaction parameter Δ and heat generation parameter *Q*. It is observed that the (wall slope of the velocity) skin friction increases against the chemical reaction parameter Δ, as the polar parameter α, Grashof number *Gr* and solutal Grashof number *Gm* increase (Fig. 11(a), (b)) while it decrease with *K* and increase with α as the heat generation parameter Q increases (Fig. 11(c)).

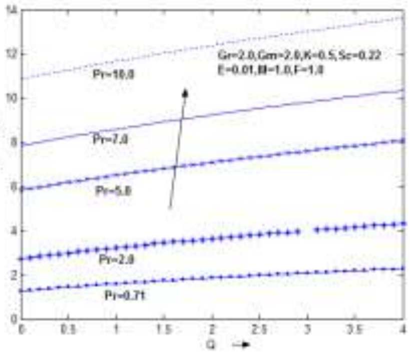

Fig. (12): Effects of Prandtl number Pr on wall Heat transfer Nu against heat generation Parameter Q.

Figure (12) shows that the Nussult number *Nu* (wall slope of the temperature profile) increases as *Pr* increases. Finally, Fig. (13) displays the influence of chemical reaction on the Sherwood number (wall mass transfer) *Sh* in the absence of viscous and Darcy's dissipations. It is observed that wall mass transfer increases as chemical reaction parameter Δ is increased.

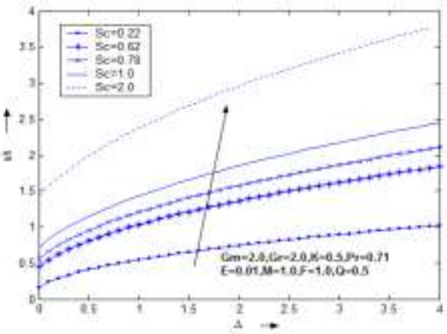

Fig. (13): Effects of Schmidt number Sc on wall mass transfer Sh against chemical reaction parameter Δ.

Tables (1) and (2) represents a comparison of the numerical values of skin-friction C_f, Nusselt number *Nu* and Sherwood number *Sh* obtained in the present case with those of Dulal pal et al. [38] and Chaudhary[39], for different values of Schmidt number *Sc* and prandtl number Pr and fixed values of the remaining parameters. It is clearly seen that there is an agreement between the respective results of our study and those of Dulal pal et al. [38] and Chaudhary [39].

Conclusions:

In this study, a numerical analysis is presented to investigate the influence of soret and thermal radiation on steady, laminar, viscous incompressible free convective flow of a polar fluid through a porous medium occupied by a semi infinite region of the space over a porous flat surface. A set of non-linear coupled governing differential equations are solved by two-term perturbation method. The parameters that arise in the perturbation analysis are Eckert number E (viscous dissipation), prandtl number *Pr* (thermal diffusivity), Schmidt number *Sc* (mass diffusivity), Grashof number *Gm*, chemical reaction parameter Δ (rate constant), internal heat generation parameter *Q*, material parameters α and β (characterizes the polarity of the fluid), magnetic field parameter *M*, radiation parameter *F*, Sorret number S_o, C_f skin friction coefficient, nusselt number *Nu* (wall heat transfer coefficient) and Sherwood number *Sh* (wall mass transfer coefficient). A set of graphical results for the velocity, angular velocity, temperature and concentration is presented and discussed. It can be easily observed that skin friction, nussult number and Sherwood number are effected by the presence of radiation, magnetic field and sorret effect. It is also investigated that the velocity of the polar fluid is considerably reduced as compared to the Newtonian fluid in the presence of combined effects of chemical reaction, soret and ohmic heating, internal heat generation and viscous and Darcy's dissipation. The analytical results obtained in this work are more generalized form of Dulal pal [38] , Chaudhary[39] and can be taken as a limiting case by taking α=0, β=0, S_o =0 and Δ=0, α=0 β=0, S_o =0 respectively.

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Table (1): Comparison of Skin friction C_f, Nussult number Nu and Sherwood number Sh of present case with those of Dulal pal et al. [38] and Chaudhary [39]. for different values of Sc

Sc	Chaudhary[39] (Δ=0, S_o=0.0,α=0.0,β=0.0)			Dulal Pal et al. [38] (S_o=0.0, α=0.0, β=0.0)			Present (F=0.1,M=0.1,S_o=0.1,α=0.1,β=2.0)		
	C_f	NuR_x^{-1}	ShR_x^{-1}	C_f	NuR_x^{-1}	ShR_x^{-1}	C_f	NuR_x^{-1}	ShR_x^{-1}
0.22	2.4202	1.0296	0.4640	2.3662	1.0275	0.4640	2.4196	1.0301	0.4638
0.62	2.1274	1.0376	0.9567	2.0160	1.0381	0.9567	2.1270	1.0381	0.9562
0.78	2.0518	1.0389	1.1375	1.9282	1.0397	1.1375	2.0516	1.0395	1.1369

Table (2): Comparison of Skin friction C_f, Nussult number Nu and Sherwood number Sh of present case with those of Dulal pal et al. [38] and Chaudhary [39]. for different values of Pr.

Pr	Chaudhary[39] (Δ=0,S_o=0.0,α=0.0,β=0.0)			Dulal Pal et al. [38] (S_o=0.0,α=0.0,β=0.0)			Present (F=0.1,M=0.1,S_o=0.1,α=0.1,β=2.0)		
	C_f	NuR_x^{-1}	ShR_x^{-1}	C_f	NuR_x^{-1}	ShR_x^{-1}	C_f	NuR_x^{-1}	ShR_x^{-1}
0.71	2.4202	1.0296	0.4640	2.4196	1.0301	0.4638	2.4162	1.0275	0.4640
1.00	2.3064	1.3435	0.4640	2.3059	1.3441	0.4638	2.3052	1.3416	0.4640
1.25	2.2309	1.6074	0.4640	2.2305	1.6081	0.4638	2.2396	1.6056	0.4640