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SORET AND ELECTROMAGNETIC RADIATION EFFECT OF MHD MICRO POLAR FLUID PAST A POROUS MEDIUM IN THE PRESENCE OF CHEMICAL REACTION

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Abstract. In this study the magneto hydrodynamic (MHD) micro polar fluid flow of a viscous incompressible fluid past a porous medium in the presence of chemical reaction is considered. This work is devoted to investigate the Soret effect and Electromagnetic radiation effect and analyze analytically. In the energy equation the applied magnetic field strength and in the concentration equation the Soret effect are incorporated. The basic PDE (partial differential equations) are reduced to ODE (ordinary differential equations) using non dimensional variables. Then the analytical solution of the dimensionless equations are found using perturbation technique. The features of the fluid flow parameters are analyzed, discussed and explained graphically. The graphical solutions are found using MATLAB R2019b. Skin friction coefficient at the wall, Couple stress coefficient at the plate and the local surface heat flux are also thoroughly examined. Overall, this study sheds light on the complex interplay between physical parameters in the behavior of MHD micro-polar fluid past a porous medium in the presence of chemical reaction.

AMS Mathematics Subject Classification : 65D30, 65D32.
Key words : MHD flow, micro polar fluid, soret effect, electromagnetic radiation, chemical reaction.

1. Introduction

The theory of micro-polar fluid was first introduced by Eringen (1964). The micro-polar fluid through porous media has vast applications in different industrial and engineering fields. Many researchers have studied it theoretically because of its numerous applications in various fields of science and technology. For example, flow of blood in the arteries, the cochlea mechanism in the human ear uses in the metallurgical industry, petroleum industry, plastic film,

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glass-fiber, and paper making industry, stellar and solar structure learning in Astrophysics, learning heat transfer measures of a speed flight in Aerodynamics, device making industries of power transformers, MHD generators, MHD pumps, etc are some applications in various fields. Saeed Islam et.al [1] discussed that the influences of hall current and radiation on MHD micro polar non-Newtonian hybrid nano-fluid flow between two surfaces. Mohamed Abd El-Aziz[2] explained about the mixed convection flow of a micro polar fluid from an unsteady stretching surface with viscous dissipation. I.L.Animasaun [3] studied the effects of thermophoresis, variable viscosity and thermal conductivity on free convective heat and mass transfer of non-darcian MHD dissipative Casson fluid flow with suction and nth order of chemical reaction. T.Armaghani et.al [4] obtained the MHD mixed convection of localized heat source/sink in an Al2O3-Cu/water hybrid nanofluid in L-shaped cavity. Anuar Ishaka et.al [5] explained the magneto hydrodynamic (MHD) flow of a micro polar fluid towards a stagnation point on a vertical surface. J.V.Ramana Reddy et.al [6] researched about thermo phorosis and Brownian motion effects on unsteady MHD nano fluid flow over a slandering stretching surface with slip effects. M.Vidhya et.al [7] demonstrated the effect of radiation and heat source on unsteady MHD free convective flow past a vertical porous plate. M.Bilal [8] considered the micro polar flow of EMHD nanofluid with nonlinear thermal radiation and slip effects. Siddiqa et.al [9] analyzed the corrigendum to periodic magneto hydrodynamic natural convection flow of a micro polar fluid with radiation. Ramamohan Reddy et.al [10] demonstrated the chemical reaction and thermal radiation effects on MHD micro polar fluid past a stretching sheet embedded in a non-Darcian porous medium. Mishra et.al [11] described about the chemical reaction and Soret effects on hydromagnetic micropolar fluid along a stretching sheet. Krishnandan Verma et.al [12] defined the Soret and Dufour effects on MHD flow about a rotating vertical cone in presence of radiation. Bhagya Lakshmi et.al [13] justified the thermal radiation and heat transfer effects on MHD Micro polar fluid flow past a vertical plate with chemical reaction. Sheeba Juliet et.al [14] described the effect of mass transfer with chemical reactions on MHD free convective flow of dissipative and radiative fluid past an infinite vertical plate. Priyajit Mondal et.al [15] studied the entropy generation in nanofluid flow due to double diffusive MHD mixed convection. Kiran Kumar et.al [16] discussed heat and mass transfer in MHD micropolar fluid in the presence of diffusion thermo and chemical reaction. Mohammed Ibrahim et.al [17] explained the radiation and mass transfer effects on MHD free convection flow of a micropolar fluid past a stretching surface embedded in a non-Darcian porous medium with heat generation. Ojjela and Naresh Kumar [18] found the unsteady MHD mixed convection flow of chemically reacting micropolar fluid between porous parallel plates with Soret and Dufour effects. Arifuzzaman et.al [19] explained the numerical study about the magneto hydrodynamic micropolar fluid flow in presence of nano particles through porous plate. Somasekhara Reddy and Prasada Rao [20] obtained the effect of thermal radiation, Joule heating, heat sources on hydro magnetic flow of micro polar fluid past a stretching surface with convective boundary condition. M.Vidhya et.al [21] explained the effect of radiation and heat source on unsteady MHD free convective flow past a vertical porous plate. Hassanien et.al [22] discussed the thermal radiation effect on flow and heat transfer of unsteady MHD micropolar fluid over vertical Heated non isothermal stretching surface using group analysis. Prameela et.al [23] explained the influence of thermal radiation on MHD fluid flow over a sphere. Ganesh Kumar et.al [24] researched the double-diffusive convection flow of Casson fluid with nonlinear thermal internal heat generation effect on radiation heat transfer mhd dissipating flow of a micropolar fluid with variable wall heat flux radiation and convective condition. Sreenivasulu et.al [25] demonstrated the internal heat generation effect on radiation heat transfer MHD dissipating flow of a micropolar fluid with variable wall heat flux. Prakash and Muthtamilselvan [26] researched the effect of radiation on transient MHD flow of micropolar fluid between porous vertical channel with boundary conditions of the third kind. Satya Narayana et.al [27] analyzed the effects of hall current and radiation absorption on MHD micropolar fluid in a rotating system. S.Sheeba Juliet et.al [28] explained the effect of chemical reaction on oscillatory flow through porous medium with mass transfer and heat source.K.D. Singh [29] found the exact solution of MHD mixed convection periodic flow in a rotating vertical channel with heat radiation. B.K Sharma et.al [30] demonstrated the heat source and Soret effects on magneto micropolar fluid flow with variable permeability and chemical reaction. Ravichandra babu et.al [31] discussed the effect of magnetic field and radiation on MHD heat and mass transfer of micropolar fluid over stretching sheet with Soret and Dufour effects. Sharma et.al [32] explained the effects of chemical reaction on magneto-micropolar fluid flow from a radiative surface with variable permeability. Mamtha et.al [33] researched the unsteady MHD mixed convection, radiative boundary layer flow of a micro polar fluid past a semi-infinite vertical porous plate with suction. Shamshuddin et.al [34] explained the micropolar fluid flow induced due to a stretching sheet with heat source/sink and surface heat flux boundary condition effects. Debasish Dey [35] point out the mixed convective MHD micro-polar fluid flow in a porous medium with radiation absorption. Basant K Jha and Babatunde Aina [36] found the MHD mixed convection flow in an inclined porous channel having time-periodic boundary condition. Umadevi K B and Patil Mallikarjun [37] discussed the effects of thermal radiation and suction/injection on magneto-hydrodynamic boundary layer flow of a micropolar fluid past a wedge embedded in a porous stratum. Sailaja et.al [38] applied the finite element technique to find the double diffusive effects on MHD mixed convection Casson fluid flow towards a vertically inclined plate filled in porous medium in presence of biot number. Bilal et.al [39] discussed about the parametric simulation of micropolar fluid with thermal radiation across a porous stretching surface. Hari R.Kataria and Akhil S Mittal [40] explained the Soret and radiation effects on MHD chemically reactive Nano fluid over an exponentially accelerated vertical plane with ramped wall temperature and ramped surface concentration through porous medium. Hari

R.Kataria and Harshad R Patel [41] studied about the radiation, reaction and parabolic motion effects on MHD Casson fluid flow with ramped wall temperature. Lavanya and Leela Ratnam [42] researched the effects of thermal radiation, heat generation, viscous dissipation and chemical reaction on mhd micropolar fluid past a stretching surface in a non-Darcian porous medium. Roja et.al [43] explained the thermal radiation and chemical reaction effects on mhd mixed convection flow of a micro-polar fluid past a continuous surface in a parallel moving stream with viscous dissipation. This study devoted to investigate the effect of Soret and electro-magnetic radiation power in the presence of chemical reaction of MHD micro-polar fluid past a porous medium. In the energy equation the applied magnetic field strength and in the concentration equation the Soret effect are incorporated. The electro-magnetic radiation effect on the fluid flow and the radiation parameters are analyzed in this study. We also consider the effect of heat and mass transfer with first order chemical reaction and thermal radiation. The magnetic field presence here is in transverse direction. The vertical porous plate is considered here and the micro-polar fluid past the vertical plate with slip boundary conditions at the porous boundary. The velocity of the fluid varies exponentially with time t and the flow is considered as free stream. This study would find applications in aerodynamic heating, cochlea in human ear, flow of blood in the arteries etc in various science and technology fields

2. Related works

Consider an unsteady laminar, two-dimensional, MHD convective heat and mass transfer characteristics, incompressible, electrically conducting, chemically reactive, and thermal radiative micro polar fluid past a porous plate. The constant permeability porous medium and the fluid are in a thermal equilibrium state. The fluid is assumed to be a gray, absorbing, emitting, and non-scattering medium. The X-axis is considered horizontally along the plane surface, and Y-axis is perpendicular to the plane surface. The thermo-physical properties remain constant except for the influence of density variation with temperature and neglecting the viscous dissipation. T_w is the wall temperature of the plane, T_∞ the ambient temperature of the fluid and T is the temperature of the fluid in the boundary layer. C is the fluid concentration, C_w is the surface concentration, and C_∞ is the ambient concentration of the fluid. The physical model of the problem is shown in Figure:1. The governing equations for the micropolar fluid boundary layer flow through porous medium with chemical reaction, Electro-magnetic radiation effect, and Soret effect along with Boussinesq approximation subject to transverse uniform magnetic field B_0 in the presence of pressure gradient and buoyancy forces can be written as follows :

Continuity Equation

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

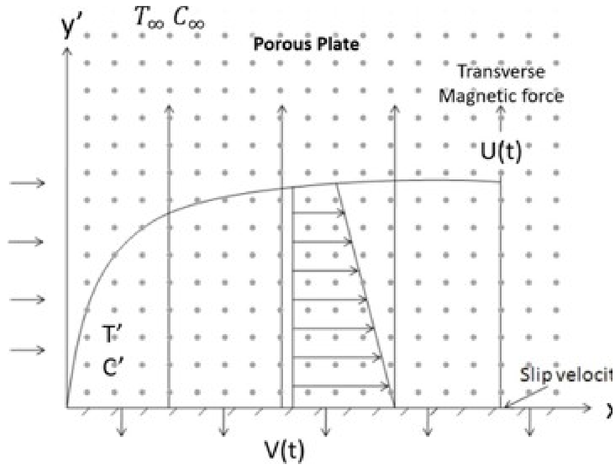

FIGURE 1. Fluid flow configuration

Momentum equation

$$\frac{\partial u'}{\partial t'}+v'\frac{\partial u'}{\partial y'}$$
$$=-\frac{1}{\rho}\frac{\partial p'}{\partial x'}+(v+v_r)\frac{\partial^2 u'}{\partial y'^2}-\frac{\sigma_{B_0}^2 u'}{\rho}+2v_r\frac{\partial w'}{\partial y'}+g\beta_T(T'-T_\infty)+g\beta_C(C'-C_\infty). \tag{2}$$

Angular Momentum Equation

$$\rho j'\left(\frac{\partial w'}{\partial t'}+v'\frac{\partial w'}{\partial y'}\right)=\gamma\frac{\partial^2 w'}{\partial y'^2}. \tag{3}$$

Energy Equation

$$\frac{\partial T^{'}}{\partial t'}+v^{'}\frac{\partial T^{'}}{\partial y'}=\frac{k}{\rho c_p}\frac{\partial^2 T^{'}}{\partial {y'}^2}-\frac{1}{\rho c_p}\frac{\partial {q_r}^{'}}{\partial y^{'}}-\frac{Q_0}{\rho c_p}(T^{'}-T\infty)+{Q_1}^{'}(C^{'}-C\infty)+\frac{\sigma {B_0}^2 {u^{'}}^2}{\rho c_p}. \tag{4}$$

Species Equation

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=\frac{D_m\partial^2 C'}{\partial y'^2}-R'(C'-C_\infty)+\frac{D_m K_T}{T_m}\frac{\partial^2 T'}{\partial y'^2}. \tag{5}$$

Boundary conditions are:

$$U'=U_s'=\sqrt{\frac{k}{\alpha}}\frac{\partial u'}{\partial y'}.$$

$$T'=T_w+\varepsilon(T_w-T_\infty)e^{n't'}W'=-\delta\frac{\partial u'}{\partial y'}.$$

$$C' = C_w + \varepsilon(C_w - C_\infty)e^{n't'} \quad \text{at } y' = 0. \tag{6}$$

$$U' \to U_\infty = U_0(1 + \varepsilon e^{n't'}) \quad T' \to T_\infty,$$
$$W' \to 0, \quad C' \to C_\infty \quad \text{at} \quad y' \to \infty \quad . \tag{7}$$

The boundary condition for the micro rotation variable w' denotes the surface stress in the presence of the surface. The velocity normal to the plate can be described as

$$v' = -V_0(1 + \epsilon A e^{n't'}). \tag{8}$$

Where A and V_0 are constants , ϵ and ϵ A are small.
Beyond the boundary layer the momentum equation becomes

$$-\frac{1}{\rho}\frac{\partial p'}{\partial x'} = \frac{\partial U'_\infty}{\partial t'} - \frac{\sigma B_0^2 U'_\infty}{\rho}. \tag{9}$$

According to Rosseland approximation the radiative heat flux is defined as

$$q'_r = -\frac{4\sigma'}{3k'}\frac{\partial T'^4}{\partial y'}. \tag{10}$$

Using Taylor's series expansion $T^{'4}$ can be expressed in terms of T_ϵ and omit the higher order terms. There fore

$$\mathrm{T}'^4 \approx 4\mathrm{T_\epsilon}^3\mathrm{T}' - 3\mathrm{T_\epsilon}^4. \tag{11}$$

Non dimensional quantities are

$$U = \frac{u'}{U_0}, \quad v = \frac{v'}{V_0}, \quad \eta = \frac{V_0 y'}{v}, \quad U_\infty = \frac{U'_\infty}{U_0}, \quad t = \frac{V_0^2 t'}{v}, \quad w = \frac{v w'}{U_0 V_0}, \quad j = \frac{V_0^2 j'}{v^2}.$$

$$G_r = \frac{g\beta_T v(T_w - T_\infty)}{U_0 V_0^2} \; G_c = \frac{g\beta_C v(C_w - C_\infty)}{U_0 V_0^2} \; M = \frac{\sigma B_0^2 v}{\rho V_0^2} \; P_r = \frac{\mu c_p}{K} \; \phi = \frac{Q_0 v}{\rho c_p V_0^2}.$$

$$Q_1 = \frac{Q'_1 v(C_w - C_\infty)}{V_0^2(T_w - T_\infty)} \; R = \frac{kk'}{4\sigma' {T_\infty}^3} \; S_c = \frac{v}{D} \; \xi = \frac{R' v}{V_0^2} \; \theta = \frac{T' - T_\infty}{T_w - T_\infty}.$$

$$C = \frac{C' - C_\infty}{C_w - C_\infty}, \; n = \frac{n' v}{V_0^2}, \quad S_0 = \frac{K_T(T' - T_\infty)}{T_m(C' - C_\infty)}. \tag{12}$$

Spin gradient viscosity

$$\gamma = \mu j' + \frac{K}{2}j' = \mu\left(1 + \frac{1}{2}\beta\right). \tag{13}$$

Variables are explained in nomenclature.
Substitute the above values of (8) to (13) in equations (2) to (5) and simplify we get in the non-dimensional form of the equations as follows:

$$\frac{\partial u}{\partial t} - (1 + \epsilon A e^{nt})\frac{\partial u}{\partial \eta} = \frac{dU_\infty}{dt} + M(U_\infty - U) + (1 + \beta)\frac{\partial^2 U}{\partial \eta^2} + G_r\theta + G_c C + 2\beta\frac{\partial w}{\partial \eta}. \tag{14}$$

$$\frac{\partial w}{\partial t} - (1 + \epsilon A e^{nt})\frac{\partial w}{\partial \eta} = \frac{1}{\lambda}\frac{\partial^2 w}{\partial \eta^2}. \tag{15}$$

$$\frac{\partial \theta}{\partial t} - (1+\epsilon A e^{nt})\frac{\partial \theta}{\partial \eta} = \frac{1}{\Gamma}\frac{\partial^2 \theta}{\partial \eta^2} - \phi\theta + Q_1 C + M\xi\left(\frac{\partial u}{\partial t}\right)^2. \tag{16}$$

$$\frac{\partial C}{\partial t} - (1+\epsilon A e^{nt})\frac{\partial C}{\partial \eta} = \frac{1}{S_c}\frac{\partial^2 C}{\partial \eta^2} - \xi C + S_0\frac{\partial^2 \theta}{\partial t^2}. \tag{17}$$

where

$$\lambda = \frac{\mu j'}{\gamma} = \frac{2}{2+\beta}\Gamma = \frac{3RP_r}{3R+4}. \tag{18}$$

Corresponding boundary conditions in non-dimensional form are

$$U = U_s = \phi_1\frac{\partial U}{\partial \eta}\ \theta \quad = 1+\epsilon e^{nt}\ w = -\delta\frac{\partial U}{\partial \eta}, \quad C = 1+\epsilon e^{nt} \quad \text{at} \quad \eta = 0. \tag{19}$$

$$U \to U_\infty = 1+\epsilon e^{nt}, \quad \theta \to 0, \quad w \to 0, \quad C \to 0 \quad \text{as} \quad \eta \to \infty. \tag{20}$$

where
$\phi_1 = \sqrt{\frac{K}{\alpha}\frac{V_0}{v}}$.

3. Method of Solution

To find the approximate analytical solutions of the non linear equations (14) to (17) perturbation method is applied here. The amplitude oscillation value $\epsilon \ll 1$ is very small. So the solutions of fluid velocity U, temperature θ , micro rotation W and concentration C can be assumed as.

$$U = f_0(\eta) + \epsilon e^{nt} f_1(\eta) + o(\epsilon^2). \tag{21}$$

$$\theta = g_0(\eta) + \epsilon e^{nt} g_1(\eta) + o(\epsilon^2). \tag{22}$$

$$W = w_0(\eta) + \epsilon e^{nt} w_1(\eta) + o(\epsilon^2). \tag{23}$$

$$C = h_0(\eta) + \epsilon e^{nt} h_1(\eta) + o(\epsilon^2). \tag{24}$$

Substitute (21) to (24) into the equations (14) to (17) and equating harmonic, non-harmonic terms and neglect higher order of $o(\epsilon^2)$ and simplifying the following pairs of zeroth order and first order equations obtained.

Zeroth order

$$\begin{aligned}&\frac{d^2 f_0(\eta)}{d\eta^2}(1+\beta) + \frac{df_0(\eta)}{d\eta}(1+A\epsilon e^{nt}) - Mf_0(\eta)\\ &= -G_r g_0(\eta) - 2\beta\frac{dw_0(\eta)}{d\eta} - G_c h_0(\eta) - M.\end{aligned} \tag{25}$$

First order

$$\begin{aligned}&\epsilon e^{nt}\left(\epsilon e^{nt} + \beta\right)\frac{d^2 f_1}{d\eta^2} + \left(\epsilon e^{nt} + \epsilon^2 A e^{2nt}\right)\frac{df_1}{d\eta} - M\epsilon e^{nt} f_1(\eta)\\ &= -2\beta\epsilon e^{nt}\frac{dw_1}{d\eta} - G_r\epsilon e^{nt} g_1(\eta) - G_c\epsilon e^{nt} h_1(\eta) - M\epsilon e^{nt}.\end{aligned} \tag{26}$$

Zeroth order

$$\frac{1}{\lambda}w_0''(\eta) + w_0'(\eta)(1+A\epsilon e^{nt}) = 0. \tag{27}$$

First order

$$\frac{1}{\lambda}\epsilon e^{nt}\frac{d^2w_1(\eta)}{d\eta^2}+\frac{dw_1(\eta)}{d\eta}\left(\epsilon e^{nt}+A\epsilon^2e^{2nt}\right)-n\epsilon e^{nt}w_1(\eta)=0. \tag{28}$$

Zeroth order

$$\frac{1}{\Gamma}\frac{d^2g_0(\eta)}{d\eta^2}+\frac{dg_0(\eta)}{d\eta}\left(1+A\epsilon e^{nt}\right)-\phi g_0(\eta)=Q_1h_0(\eta). \tag{29}$$

First order

$$\frac{1}{\Gamma}\epsilon e^{nt}\frac{d^2g_1(\eta)}{d\eta^2}+\frac{dg_1(\eta)}{d\eta}(\epsilon e^{nt}+A\epsilon^2e^{2nt})-(\phi\epsilon e^{nt}+n\epsilon e^{nt})g_1(\eta)$$
$$=Q_1\epsilon e^{nt}h_1(\eta)+M\xi n^2\epsilon^2e^{2nt}. \tag{30}$$

$$\frac{1}{S_c}\frac{d^2h_0}{d\eta^2}+\frac{dh_0}{d\eta}\left(1+A\epsilon e^{nt}\right)-\xi h_0(\eta)=0. \tag{31}$$

$$\frac{1}{S_c}\epsilon e^{nt}\frac{d^2h_1}{d\eta^2}+\frac{dh_1}{d\eta}(\epsilon e^{nt}+A\epsilon^2e^{2nt})+(\xi\epsilon e^{nt}-n\epsilon e^{nt})h_1=-S_0n^2\epsilon e^{nt}g_1(\eta). \tag{32}$$

Here the prime ’ denotes the differentiation of the function with respect to n. The boundary conditions are

$$f_0=\varphi_1f_0',\quad f_1=\varphi_1f_1',\quad g_0=1,\quad g_1=1.$$

$$\omega_0=-\delta f_0',\quad \omega_1=-\delta f_1',\quad h_0=1,\quad h_1=1\quad \text{at } \eta=0 \tag{33}$$

,$f_0=1,\ f_1=1,\ g_0=0,\ g_1=0,\ \omega_0=0,\ \omega_1=0.$

$$h_0=0,\quad h_1=0\quad \text{as}\quad \eta\to\infty. \tag{34}$$

Apply the boundary conditions (33) and (34) on the solutions of the equations (25) to (32) . The solutions of the equations (25) to (32) are as follows:

$$f_0(\eta)=e^{m_9\eta}+e^{m_{10}\eta}\left(X_8-\frac{G_rX_9}{X_1}\right)+\frac{G_rX_{10}}{X_1}-X_{11}-X_{12}. \tag{35}$$

$$f_1(\eta)$$
$$=e^{m_{15}\eta}\left[1+\frac{G_rL_{38}}{(1+\beta)}+\frac{G_cL_{39}}{(1+\beta)}+L_{40}\right]$$
$$+e^{m_{16}\eta}\Bigg[-1-\frac{G_rL_{38}}{(1+\beta)}-\frac{G_cL_{39}}{(1+\beta)}-L_{40}-L_{32}+\frac{G_r(L_{38}+L_{41})}{(1+\beta)}$$
$$+\frac{G_c(L_{39}+L_{42})}{(1+\beta)}-L_{40}\Bigg]+L_{32}e^{m_6\eta}$$

$$-G_r\frac{1}{(1+\beta)}\Bigg[\frac{L_{29}}{L_{33}}e^{m_{11}\eta}+\frac{L_{30}}{L_{34}}e^{m_{12}\eta}+\frac{L_{31}}{L_{35}}e^{m_{13}\eta}-\frac{(L_{14}L_{23})}{L_{36}}e^{m_{14}\eta}$$

$$+\frac{L_{13}}{(\phi+n)L_{27}}+\frac{L_{25}}{L_{27}}\Bigg]$$

$$-G_c\frac{1}{(1+\beta)}\Bigg[-\frac{L_{21}}{L_{33}}e^{m_{11}\eta}-\frac{L_{24}}{L_{34}}e^{m_{12}\eta}+\frac{(L_{21}-L_{19})}{L_{35}}e^{m_{13}\eta}$$

$$+\frac{L_{23}}{L_{36}}e^{m_{14}\eta}-L_{37}\Bigg]+L_{40}. \tag{36}$$

$$g_0(\eta)=1-\frac{\Gamma Q_1}{L_6}e^{m_8\eta}+\frac{\Gamma Q_1}{L_6}e^{L_5\eta}. \tag{37}$$

$$g_1(\eta)=(1+L_{14})e^{m_{12}\eta}-L_{14}h_1(\eta)-\frac{L_{13}}{\phi+n}\left[1-e^{m_{11}\eta}\right]. \tag{38}$$

$$w_0(\eta)=-\delta f_0{}'e^{-\lambda(1+A\varepsilon e^{nt})\eta}. \tag{39}$$

$$w_1(\eta)=e^{\left(-\frac{L_3-\sqrt{L_3^2-4\lambda n}}{2}\right)\eta}. \tag{40}$$

$$h_0(\eta)=e^{\left(-\frac{L_1-\sqrt{L_1^2+4\xi}}{2}\right)\eta}. \tag{41}$$

$$h_1(\eta)=\left(\frac{L_{19}}{L_{17}}-L_{19}\right)e^{m_{13}\eta}+\left[1+L_{19}+\frac{L_{18}}{L_{16}}(1+L_{14})-\frac{L_{19}}{L_{15}}\right]e^{m_{14}\eta}$$

$$-\frac{L_{18}}{L_{16}}(1+L_{14})e^{m_{12}\eta}+\frac{L_{19}}{L_{15}}\ -\frac{L_{19}}{L_{17}}e^{m_{11}\eta}. \tag{42}$$

The solutions in the boundary layer are Velocity, Temperature, Micro rotation and Concentration becomes

$$U(\eta,t)=f_0(\eta)+\epsilon e^{nt}f_1(\eta)$$

$$\theta(\eta,t)=g_0(\eta)+\epsilon e^{nt}g_1(\eta)$$

$$\omega(\eta,t)=\omega_0(\eta)+\epsilon e^{nt}\omega_1(\eta)$$

$$C(\eta,t)=h_0(\eta)+\epsilon e^{nt}h_1(\eta)$$

$$U(\eta,t)=\left(e^{m_9\eta}+e^{m_{10}\eta}\left(X_8-\frac{G_rX_9}{X_1}\right)+\frac{G_rX_{10}}{X_1}-X_{11}-X_{12}\right)$$

$$+\epsilon e^{nt}\Bigg[e^{m_{15}\eta}\left(1+\frac{G_rL_{38}}{(1+\beta)}+\frac{G_cL_{39}}{(1+\beta)}+L_{40}\right)$$

$$+e^{m_{16}\eta}\Bigg(-1-\frac{G_rL_{38}}{(1+\beta)}-\frac{G_cL_{39}}{(1+\beta)}-L_{40}-L_{32}$$

$$+\frac{G_r(L_{38}+L_{41})}{(1+\beta)}+\frac{G_c(L_{39}+L_{42})}{(1+\beta)}-L_{40}\Big)+L_{32}e^{m_6\eta}$$
$$-\frac{G_r}{(1+\beta)}\Bigg(\frac{L_{29}}{L_{33}}e^{m_{11}\eta}+\frac{L_{30}}{L_{34}}e^{m_{12}\eta}+\frac{L_{31}}{L_{35}}e^{m_{13}\eta}-\frac{L_{14}L_{23}}{L_{36}}e^{m_{14}\eta}$$
$$+\frac{L_{13}}{(\phi+n)L_{27}}+\frac{L_{25}}{L_{27}}\Bigg)$$
$$-\frac{G_c}{(1+\beta)}\Bigg(-\frac{L_{21}}{L_{33}}e^{m_{11}\eta}-\frac{L_{24}}{L_{34}}e^{m_{12}\eta}+\frac{(L_{21}-L_{19})}{L_{35}}e^{m_{13}\eta}$$
$$+\frac{L_{23}}{L_{36}}e^{m_{14}\eta}-L_{37}\Bigg)+L_{40}\Bigg]. \tag{43}$$

$$\theta(\eta,t)$$
$$=1-\frac{\Gamma Q_1}{L_6}e^{m_8\eta}+\frac{\Gamma Q_1}{L_6}e^{L_5\eta}+\epsilon e^{nt}\Bigg[L_{20}e^{m_{12}\eta}-\frac{L_{13}}{\phi+n}\left(1-e^{m_{11}\eta}\right)$$
$$-L_{14}\left[\left(L_{21}-L_{19}\right)e^{m_{13}\eta}+e^{m_{14}\eta}L_{23}-e^{m_{12}\eta}L_{22}+\frac{L_{19}}{L_{15}}-L_{21}e^{m_{11}\eta}\right]\Bigg]. \tag{44}$$

$$\omega(\eta,t)$$
$$=-\delta e^{-\lambda(1+A\epsilon e^{nt})\eta}\Bigg(m_9e^{m_9\eta}+m_{10}e^{m_{10}\eta}\left(X_8-\frac{G_rX_9}{X_1}\right)$$
$$+\frac{G_r}{X_1}\left(\frac{L_9L_7}{X_4}e^{L_9\eta}-\frac{L_3e^{L_3\eta}}{X_5}-\frac{L_{10}L_7}{X_6}e^{L_{10}\eta}\right)-\frac{L_{11}G_ce^{L_{11}\eta}}{X_1X_7}-\frac{L_3Me^{L_3\eta}}{X_1X_5}\Bigg)$$
$$+\epsilon e^{nt}e^{-\frac{L_3+\sqrt{L_3^2-4\lambda n}}{2}\eta}. \tag{45}$$

$$C(\eta,t)$$
$$=e^{-\frac{L_1-\sqrt{L_1^2+4\xi}}{2}\eta}+\epsilon e^{nt}\Bigg(\frac{L_{19}}{L_{17}-L_{19}}e^{m_{13}\eta}+\left[1+\frac{L_{19}+L_{18}/L_{16}}{1+L_{14}}-\frac{L_{19}}{L_{15}}\right]e^{m_{14}\eta}$$
$$-\frac{L_{18}/L_{16}}{1+L_{14}}e^{m_{12}\eta}+\frac{L_{19}}{L_{15}}-\frac{L_{19}}{L_{17}}e^{m_{11}\eta}\Bigg). \tag{46}$$

The exponential indices and coefficients are explained in Appendix. Skin friction coefficient C_f at the wall

$$C_f=\Big(\frac{\partial U}{\partial\eta}\Big)_{\eta=0}=m_9+m10(X_8-\frac{G_rX_9}{X_1})+\epsilon e^{nt}$$
$$\times\Bigg[m_{15}\Big(1+\frac{G_rL_{38}}{(1+\beta)}+\frac{G_cL_{39}}{(1+\beta)}+L_{40}\Big)+m_{16}\Big(-1-\frac{G_rL_{38}}{(1+\beta)}-\frac{G_cL_{39}}{(1+\beta)}$$

$$- L_{40} - L_{32} + \frac{G_r(L_{38}+L_{41})}{(1+\beta)} + \frac{G_c(L_{39}+L_{42})}{(1+\beta)} - L_{40}\Big) + L_{32}m_6$$
$$- \frac{G_r}{(1+\beta)}\Big(\frac{L_{29}}{L_{33}}m_{11} + \frac{L_{30}}{L_{34}}m_{12} + \frac{L_{31}}{L_{35}}m_{13} - \frac{L_{14}L_{23}}{L_{36}}m_{14}\Big)$$
$$- \frac{G_c}{(1+\beta)}\Big(- \frac{L_{21}}{L_{33}}m_{11} - \frac{L_{24}}{L_{34}}m_{12} + \frac{(L_{21}-L_{19})}{L_{35}}m_{13} + \frac{L_{23}}{L_{36}}m_{14}\Big)\Big]. \quad (47)$$

Couple stress coefficient at the plate

$$C_m = (1+\frac{\beta}{2})\left(\frac{\partial w}{\partial \eta}\right)_{\eta=0}$$
$$= \Bigg(1 + \frac{\beta}{2} - \delta L_3\Big(m_9^2 + m10^2\Big(X_8 - \frac{G_rX_9}{X_1}\Big)$$
$$+ \frac{G_r}{X_1}\Big(\frac{L_9^2L_7}{X_4} - \frac{L_3^2}{X_5} - \frac{L_{10}^2L_7}{X_6}\Big) - \frac{L_{11}^2G_c}{X_1X_7} - \frac{L_3^2M}{X_1X_5}\Big)\Bigg) + \epsilon e^{nt}m_6. \quad (48)$$

Local Surface heat flux (Nusselt number) $N_u = -(1+\frac{4}{3}R)\left(\frac{\partial\theta}{\partial\eta}\right)_{\eta=0}$.

$$N_u = -(1+\frac{4}{3}R)\Bigg(\frac{\Gamma Q_1}{L_6}m_8 + \frac{\Gamma Q_1}{L_6}L_5 \qquad +\epsilon e^{nt}\Big(L_{20}m_{12} + \frac{L_{13}m_{11}}{\phi+n}$$
$$- L_{14}\Big((L_{21}-L_{19})m_{13} + m_{14}L_{23} - m_{12}L_{22} - L_{21}m_{11}\Big)\Big)\Bigg). \quad (49)$$

4. Results and Discussion

The fluid flow equations (14) to (17) are solved by Perturbation method to discuss the Soret effects and EMR (Electromagnetic Radiation) effects in the presence of chemical reaction of a MHD micro polar fluid past a porous medium. The analytical solutions of the equations obtained to analyze the velocity, temperature, micro rotation and concentration of the fluid flow. The graphical solutions are found using MATLAB R2019b. Figure 2 illustrates the velocity profile U for different magnetic force parameter values M. It explains that when the magnetic force parameter value increases the Lorentz's force is developed which is in the opposite direction of the fluid flow and it depreciates the velocity of the fluid. Hence the velocity of the fluid decreases. Figure 3 shows the velocity graph U for different chemical reaction parameter values ξ within the boundary layer. Inside the boundary layer the velocity of the fluid increase as the chemical reaction parameter ξ increase. Physically the fluid motion increase as ξ increase.

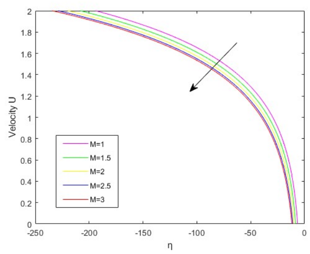

FIGURE 2. Velocity graph for different M values with $Gr = 4$, $Gc = 2$, $\beta = 2$, $\xi = 1$, $Q_1 = 2$, $\phi = 2$, $Q1 = 2$, $\delta = 2$, $\Gamma = 2$, $\xi = 1$, $\lambda = 1$, $n = 1$, $\epsilon = 0.5$, $A = 2$, $S_0 = 4$, $Sc = 2$.

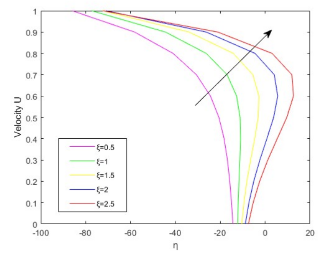

FIGURE 3. Velocity graph for different ξ values with $Gr = 4$, $Gc = 4$, $\beta = 0.5$, $M = 2$, Q_1=2, $\varphi = 2$, Q_1=2, δ=2, Γ=2, ξ=1, λ=1, n=2, ϵ=0.2, A=2, S_0=4, Sc=2.

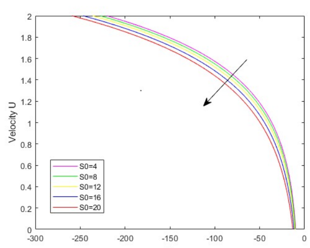

FIGURE 4. Velocity graph for different ξ values with Gr=4, Gc=4, β=0.5, M=2, Q_1=2, φ=2, Q_1=2, δ=2, Γ=2, ξ=1, λ=1, n=2, ϵ=0.2, A=2, S_0=4, Sc=2.

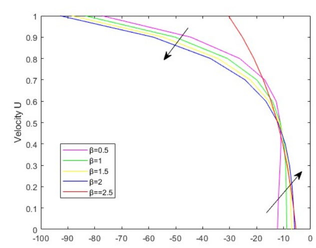

FIGURE 5. Velocity graph for different β values with Gr=4, Gc=4, $M = 2$, $Q_1 = 2$, $\varphi = 2$, $\delta = 2$, $\Gamma = 2$, $\xi = 1$, $\lambda = 2$, $n = 2$, $\epsilon = 0.2$, $A = 2$, $S_0 = 4$, $Sc = 2$.

Figure 4 explains the influence of Soret number S0 over the velocity graph U. The velocity increases while Soret parameters increases. That is, due to the effect of thermal diffusion the fluid flow move faster. Figure 5 demonstrates the velocity graph U for different viscosity ratio values β It is noted from the graph that the velocity increases when the viscosity ratio value β increases and at a particular stage it has an opposite behaviour and the velocity work as in an inverse manner. That is the velocity of the fluid decreases when the viscosity ratio increases.

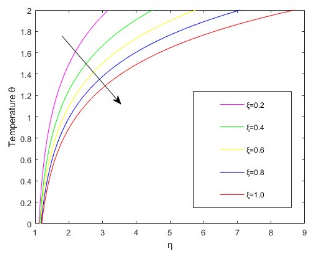

FIGURE 6. Temperature graph for different ξ values with Gr=4, Gc=2, M=2, β=2, Q_1=1, ϕ=1, δ=1, Γ=0.2, λ=1, n=1, ϵ=0.2, A=0.5, S_0=1, Sc=2.

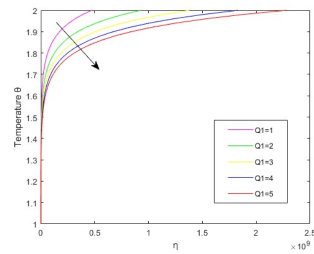

FIGURE 7. Temperature graph for different Q_1 values with $Gr = 2$, $Gc = 2$, $M = 2$, $\beta = 2$, $\phi = 2$, $\xi = 0.2$, $\delta = 1$, $\Gamma = 1$, $\lambda = 1$, $n = 5$, $\epsilon = 0.3$, $A = 2$, $S0 = 1$, $Sc = 2$.

Figure 6 has been plotted to depict the temperature profile for different chemical reaction parameter values ξ and all other parameter values fixed. This graph shows that the temperature profile decreases with increase in chemical reaction parameter. Figure 7 illustrates the temperature graph for different absorption radiation parameter values Q_1. This figure clearly indicates when the absorption radiation parameter values increase the temperature of the fluid decrease. Figure 8 illustrates the micro rotation profile for different values of thermal Grashof number Gr. Clearly the graph indicates the micro-rotation of the fluid increase if the thermal Grashof value increase. Figure 9 depicts the micro-rotation profile for different solutal Grashof Gc values. The graph clearly explains when the solutal Grashof value increase the micro-rotation of the fluid increase. Figure 10 depicts micro-rotation graph for different δ values. It clearly shows as the δ value increases the micro-rotation of the fluid also increases.

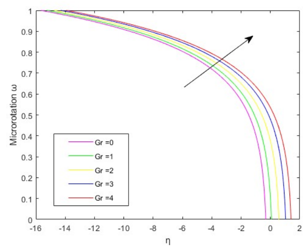

FIGURE 8. Microrotation graph for different Gr values with $Gc = 2$, $M = 2$, $\beta = 2$, $\varphi = 2$, $Q_1 = 1$, $\xi = 0.2$, $\delta = 0.5$, $\Gamma = 1$, $\lambda = 1$, $n = 5$, $\varepsilon = 0.3$, $A = 0$, $S_0 = 1$, $Sc = 2$.

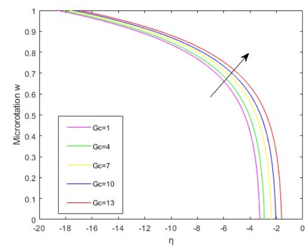

FIGURE 9. Microrotation graph for different Gc values with $Gr = 2$, $M = 2$, $\beta = 2$, $\phi = 2$, $Q_1 = 1$, $\xi = 0.2$, $\delta = 1$, $\Gamma = 1$, $\lambda = 1$, $n = 5$, $\varepsilon = 0.3$, $A = 0$, $S0 = 1$, $Sc = 2$.

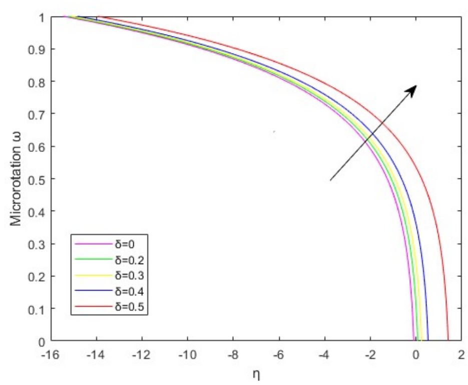

FIGURE 10. Microrotation graph for different δ values with $Gr = 4$, $Gc = 2$, $M = 2$, $\beta = 2$, $\phi = 2$, $Q_1 = 1$, $\xi = 0.2$, $\Gamma = 1$, $\lambda = 1$, $n = 5$, $\varepsilon = 0.3$, $A = 0$, $S0 = 1$, $Sc = 2$.

5. Conclusion

In this article the perturbation method is applied to investigate the effects of Soret and electro-magnetic radiation of MHD micro-polar fluid past a porous medium in the presence of chemical reaction. From the computed results the following conclusions are made:

The velocity profile increases as the Soret value and the chemical reaction parameter increases. Also it decreases when the magnetic parameter value increases. But as the viscosity parameter increases the velocity profile is in upward direction and increased first then it is in downward direction and the velocity decreases.
The temperature profile decreases as the chemical reaction parameter and the absorption parameter values increases.
The micro-rotation profile increases when the thermal Grashof number , the solutal Grashof number and the micro gyration vector values increases.The micro-rotation is first decreasing and then increasing if A value increases. Concentration profile increases if γ value, A value increases and it decreases if the chemical reaction parameter value, Soret number values increases.
Skin friction coefficient Cf increases if Gr value, Gc value increases and Cf value decreases when M value increases.
Couple stress coefficient Cm values increases if β value, A value increases and Cm value decreases if λvalue increases.
Nusselt number Nu increases when ϕvalue, M value increases and Nu decreases if R value increases.

Conflicts of interest : The authors declare no conflict of interest.

Data availability : Not applicable

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