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Non –Darcian Soret effects on MHD convective flow over a stretching sheet in a micropolar fluid with radiation in the presence of chemical reaction

[1]Fatin NurFatiha Binti Jaafar, [1]R. Kandasamy, [1]Natasha Amira Binti Mohd Zailani

[1]Research Centre for Computational Mathematics, Faculty of Science, Technology and Human Development, Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, Malaysia

Email： fatinurfatiha93@gmail.com

Abstract

The presence of chemical reaction in a non –Darcian permeable plate with thermal radiation which effect by certain works from Soret effects and non-uniform heat sources in convection of heat and mass transfer flow of a micropolar liquid with radiation over a stretching sheet are studied. The Runge-Kutta-Fehlberg method with shooting technique are using to solve governing non-linear partial differential equations revolutionized into a class of non-linear coupled ordinary differential equations by numerical method. Then, numerical results are acquired and proceed to investigate more for velocity, angular velocity, temperature and concentration including the local Nusselt number, Sherwood number, and skin-friction coefficient.

The acquired results are displayed graphically to represent the effect of governing parameter on dimensionless velocity, angular velocity, temperature and also concentration. Next, the

numerical results are compared graphically and found to be in good agreement with preceding published result in certain cases of the problem.

Key words: Non-uniform heat source/sink, Thermal radiation, Non-Darcian, Soret number, Chemical Reaction.

1.Introduction

Heat and mass transfer are kinetic mechanisms that may happen and be investigate conjointly and severally. They are simple to study but both processes are created by identical mathematical equations in the special cases which are diffusion and convection and it is more capable of united. Besides, heat and mass transfer should unite several cases such as ablation and evaporative cooling. Many applications obtained in heat and mass transfer past a stretching sheet such as glass fibre production, metal spinning, glass blowing and hot rolling wire drawing. According to applications, the rate of heat transfer at the stretching sheet depend on the quality of the last result necessarily. McCormack and Crane [1] investigated the overall study on boundary layer flow generated by the stretching of an elastic flat surface. The flow caused by a stretching sheet was studied by Crane [2] and there are many authors continued the investigation of Crane which is Gupta [6], Chen and Char [11] and Dutta et al. [10] in the effects of heat and mass transfer in assorted cases.

Micropolar fluids are fluids which have microstructure. The polar fluids are groups of fluids in the presence of non-symmetric stress tensor, and the ordinary fluids are classical fluids where some special case on established Navier-Stokes model. Physically, non-Newtonian fluid models represented by micropolar fluids, which this model can be used to evaluate the nature of exotic lubricants colloidal suspensions or liquid crystals. The overall discussion of micropolar fluids and also applications in fluid mechanics has presented by some authors which are Ariman et al. [3-4], Lukaszewicz [5], and Eringen [7-9]. Mansour et al. [15] proposed the heat and mass transfer effects on the magnetohydrodynamic (MHD) flow of a micropolar fluid over a circular cylinder. The dissipation effects on the MHD convective flow past a non-isothermal sheet in micropolar fluids was studied by El-Hakiem [13]. Both authors, El-Hakiem et al. [12] and El-Amin [14] presented heat and mass transfer in a micropolar fluid which effects on the MHD convective flow. The unstable MHD convection flow of a micropolar fluid over a vertical surface moving the porous plate in a porous medium was derived by Kim [20]. However, this studied which is the effect of heat transfer and a side effect of radiation on the flow has not been considered.

Thermal radiation is the process energy which is emitted in the form of electromagnetic radiation from heated surfaces in all directions. It is becoming important in many industries when the effect of thermal radiation on MHD flow and heat transfer cases is increasing. The temperature distribution of a micropolar fluid over distinct medium and thermal radiation can be affected the heat transfer at high temperature. The thermal radiation effects on heat transfer of a micropolar fluid past a porous medium were investigated Abo-Eldohad and Ghonaim [16]. The thermal radiation effects on the stable convective flow of a micropolar fluid through a vertical porous flat plate with variable heat flux in a porous medium was proposed by Rahman and Sultana [19]. The effect of dust particles suspended in a nanofluid flow through a stretching surface with thermal radiation was presented by Krishnamurthy et al. [17]. Prasanna Kumar et al. [21] investigated magnetohydrodynamics stagnation-point flow of a viscous fluid against a stretching sheet with variable thickness and thermal radiation.

In view of some physical problems, there is another important case which are the effects on heat transfer of heat source/sink. The backlash of uniform heat source/sink especially in temperature reliant heat source/sink on heat transfer was included in aforesaid studies. Several authors, Pal and Chatterjee [22-23], Subhas and Mahesha [18], Rahman et al. [24] and Battaller [25] also studied the side effect of non-uniform heat source but only limited in the viscous fluid cases.

The important of Soret number affected in engineering process especially in the chemical is between molecular weight gasses in heat and mass transfer (fluid binary systems). Many researchers, Jha and Singh [26], Kafoussias [27], Alam and Sattar [28], and Alam et al. [29] were explained the necessary of Soret number effect in the distinct convective flow. The combination of Soret number effect, thermal conductivity, and non-uniform heat source/sink are not stated in study works above.

Chemical reaction is a process where the rearrangement of the ionic or molecular structure of substance. In addition, chemical reaction reacts at temperature and chemical concentration which are characteristics of reaction rate and there are some examples in chemical reaction likes burning fuels, smelting iron, and making glass.

This present study is to explore the presence of chemical reaction in the problem of MHD non-Darcian with the effect of Soret number and non-uniform heat source/sink convective flow in a micropolar fluid through a stretching sheet with thermal radiation. The using of a numerical method when the non-linear of equations correlated with mathematical difficulties. Then, the governing parameters are solved by using numerical which the fifth order Runge-Kutta-Fehlberg method with shooting technique and the result acquired from the present study will contribute advantageous information for the distinct industrial application.

2.Formulation of the problem

Consider a steady state of two-dimensional which is incompressible in flow micropolar fluids towards the surface with the plane of y=0 and y > 0. Along with direction and perpendicular to the fluid motion, x-axis and y-axis are taken respectively. The two equal and opposites forces with the x-axis are reacted and goes to generated the flow. Besides, from the origin x=0, the surfaces are stretched and it makes velocity is proportional to the distance at any prompt. Further, an external transverse magnetic field ($\vec{B}$=0,B_0,0) responded to the exposed from the flow field. In this present model, there are considered the application of magnetic field (Ohmic heating) and the Soret effects due to frictional heating. The governing equations of conservation of momentum, angular momentum, energy and mass diffusion are written as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\left(v+\frac{k_1}{\rho}\right)\frac{\partial^2 u}{\partial y^2}+\frac{k_1}{\rho}\frac{\partial N}{\partial y}-\frac{v\varphi}{k}u-\frac{C_b}{\sqrt{k}}\varphi u^2-\frac{\sigma B_0^2}{\rho}u+$$

$$g\beta(T-T_\infty)+g\beta^*(C-C_\infty), \tag{2}$$

$$\rho j\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=\gamma\frac{\partial^2 N}{\partial y^2}-k_1\left(2N+\frac{\partial u}{\partial x}\right), \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial x}=\frac{1}{\rho C_p}\frac{\partial}{\partial y}\left(\kappa\frac{\partial T}{\partial y}\right)-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}+\frac{\sigma B_0^2}{\rho C_p}u^2+\frac{q'''}{\rho C_p}+\frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2, \tag{4}$$

$$u\frac{\partial C}{\partial x}+\frac{\partial u}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2}-K_1 C, \tag{5}$$

The following boundary condition for the given problem can be written as follow:

At y=0:

$u=u_W=bx,\qquad v=0,\qquad N=-m_0\frac{\partial u}{\partial y},\qquad T=T_W=T_\infty+A_0(\frac{x}{l})^2,$

$C=C_W=C_\infty+A_1(\frac{x}{l})^2,$

At y→ ∞:

u→ 0, N→ 0, T→ T_∞, C→ C_∞. (6)

where u and v are the velocity components along the x and y axis directions respectively, μ - the dynamic viscosity, ρ - the density of the fluid, v - the kinematic viscosity, T - the temperature of the fluid, C - the concentration of the fluid, C_b - the form of the drag coefficient which is independent of viscosity, k - permeability of the porous medium, σ - the electrical conductivity of the fluid, φ - the porosity of the porous medium, β - the coefficient of the thermal expansion, β^* - the coefficient of concentration expansion, c_p - the specific at constant pressure, N - the components of micro-rotation or angular velocity which is rotation is in the direction of the x and y plane. Then j, γ and k_1 are the spin gradient viscosity, micro-inertia per unit mass, and also vortex viscosity. The spin gradient viscosity of γ is the relationship between the coefficient of viscosity and micro-inertia j, means as $\gamma = \mu(1 + K/2)j$ [28], and where $K = k_1/\mu(> 0)$ defined as the material parameter. There are the material constants which γ, μ, K and j are non-negative and then, $j = v/b$ are taken as a reference length. Besides, T_m - the mean fluid temperature, k_1- the rate of chemical reaction, k_T - the thermal diffusion ratio, l - the characteristic length, T_W - the wall temperature of the fluid, T_∞ - the temperature of the fluid far away from the sheet, C_W - the wall concentration of the solute and C_∞ - the concentration of the solute far away from the sheet, D_m - the mass diffusivity, m_0 - a constant such that $0 \leq m_0 \leq 1$, and A_0, A_1 are constants.

q''' is the non-uniform heat generation or absorption and also defined as:

$$q''' = \frac{\kappa u_w}{xv}(Q_0(T_w - T_\infty)e^{-\eta} + Q_1(T - T_\infty)),$$

Where Q_0 and Q_1 are defined as the coefficient of space and temperature- dependent heat source/sink. The internal heat generation are group of corresponding cases Q_0>0 and Q_1>0 while the internal heat absorption are corresponding to the Q_0<0 and Q_1<1 cases.

Here is the radiative heat flux, q_r is defined as:

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y},$$

Where κ is defined as differ continuously with temperature and $\kappa = \kappa_\infty(1 + \varepsilon\theta(\eta))$ are formed. Then $\theta(\eta) = (T - T_\infty)/(T_w - T_\infty)$ and $\varepsilon = (\kappa_w - \kappa_\infty)/\kappa_\infty$ are depends on the nature of the fluids. Other than that, σ^*- the Stefan –Boltzmann constant, k^* - absorption coefficient and T^4 can be declared by using Taylor's series which is modelled as:

$T^4 \cong 4T_\infty^3 T - 3T_\infty^4,$

So, we have eq.(4) as:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial x} = \frac{1}{\rho C_p}\frac{\partial}{\partial y}\left((\kappa + \frac{16T_\infty^3\sigma^*}{3k^*})\frac{\partial T}{\partial y}\right) + \frac{\sigma B_0^2}{\rho C_p}u^2 + \frac{q'''}{\rho C_p} + \frac{\mu}{\rho C_p}(\frac{\partial u}{\partial y})^2, \quad (7)$$

We defined the following transformation for dimensionless variables:

$$\eta = \sqrt{\frac{b}{v}}y, \quad N = bx\sqrt{\frac{b}{v}}\mathrm{g}(\eta), \quad u = bxf'(\eta), \quad v = -\sqrt{bv}f(\eta),$$

$$\theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}, \quad \phi(\eta) = \frac{C-C_\infty}{C_w-C_\infty}, \quad T - T_\infty = A_0\left(\frac{x}{l}\right)^2\theta(\eta),$$

$$T_w - T_\infty = A_0\left(\frac{x}{l}\right)^2, \quad C - C_\infty = A_1\left(\frac{x}{l}\right)^2\phi(\eta), \quad C_w - C_\infty = A_1\left(\frac{x}{l}\right)^2, \quad (8)$$

Where f – the dimensionless stream function, g-the dimensionless micro- rotation function, η-the similarity variable, and l- the characteristic length.

The governing equations conservation of momentum, angular momentum, energy and mass diffusion with boundary conditions (6) are transformed into equations:

$$(1+K)f''' + ff'' - f'^2 - Da^{-1}f' - \alpha f'^2 + kg' - Mf' + Gr\theta + Gm\phi = 0, \quad (9)$$

$$\left(1+\frac{K}{2}\right)g'' - K(2g + f'') - f'g + fg' = 0, \quad (10)$$

$$(1+R+\varepsilon\theta)\theta'' + \mathrm{Pr}(f\theta' - 2f'\theta) + \varepsilon\theta'^2 + PrMEcf'^2 + PrEcf''^2$$

$$+(1+\varepsilon\theta)(Q_0 f' + Q_1\theta) = 0, \quad (11)$$

$$\phi'' + Sc(\phi' f - 2\phi f') + ScSo\theta'' - Sc\gamma\phi(\eta) = 0, \quad (12)$$

The following boundary conditions (6) are becomes

For $\eta = 0$:

$$f(\eta) = 0, \quad f'(\eta) = 1, \quad g = -m_0 f''(\eta), \quad \theta(\eta) = 1, \quad \phi(\eta) = 1, \quad (13)$$

For $\eta \longrightarrow \infty$:

$$f'(\eta) \longrightarrow 0, \quad g(\eta) \longrightarrow 0, \quad \theta(\eta) \longrightarrow 0, \quad \phi(\eta) \longrightarrow 0, \quad (14)$$

Where $Da^{-1} = \frac{\varphi v}{kb}$(inverse Darcy number), $M = \frac{\sigma}{b\rho}B_0^2$(Magnetic field parameter),

$Gr = \frac{g\beta(T-T_\infty)}{b^2 t}$ (Grashof number), $Gm = \frac{g\beta(C-C_\infty)}{b^2 t}$ (modified Grashof number), $K = \frac{k_1}{\mu}$ (material parameter), $Pr = \frac{\mu C_p}{K_\infty}$ (Prandtl number), $Ec = \frac{b^2 l^2}{A_0 C_p}$ (Eckert number), $R = \frac{16T_\infty^3\sigma^*}{3k^* k_\infty}$ (thermal radiation parameter), $Sc = \frac{V}{D_m}$(Schmidt number), $So = \frac{k_T(T_w-T_\infty)}{T_m(C_w-C_\infty)}$ (Soret number).

The physical quantities which are important in this cases are defined $C_f = \frac{\tau_w}{\rho u_w^2/2}$ (skin-friction coefficient), $Nu_x = \frac{xq_w}{\kappa(T_w-T_\infty)}$ (local Nusselt number), $Sh_x = \frac{xm_w}{D_m(C_W-C_\infty)}$ (Sherwood number).

3.Result and Discussions

To verify the presents results, comparison for the material parameter with the published result are presented in figure 1 and figure 2. From these graph, it found that the present result are in good agreement with previously published graph. It shows that velocity profiles for both graph, current and published are increasing when η>1.

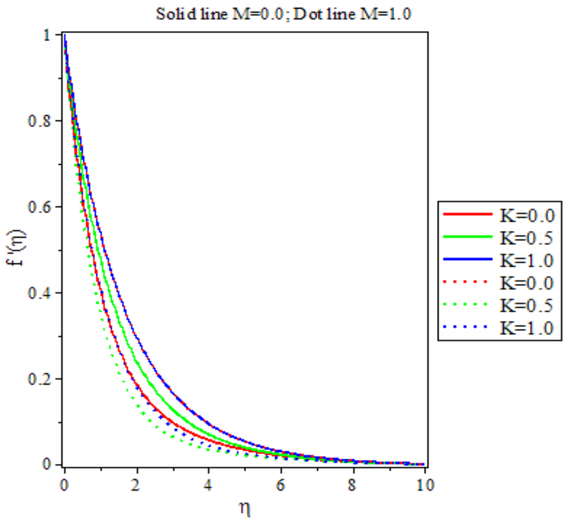


Fig. 1. Comparison of velocity for different values of material parameters and Pr=0.71, S_0=m_0=Gr=Gm=α=M=Ec=R=Da^{-1}=0.1, Sc=0.22, ε=0.01, Q_0=0.02, Q_1=-0.01, A=0.0.

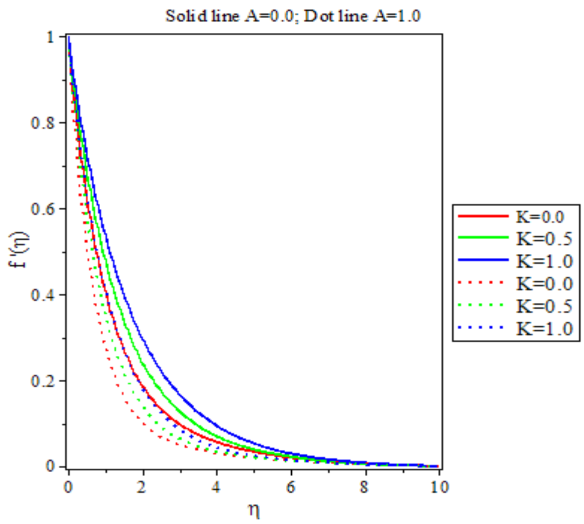
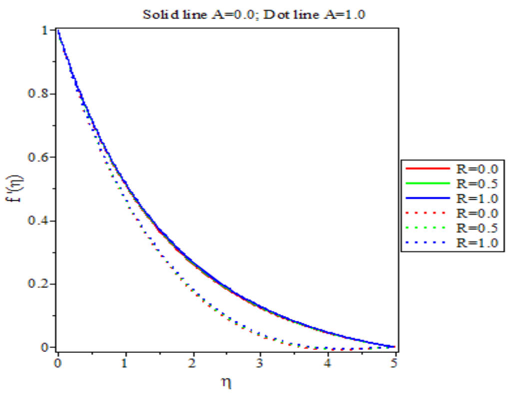
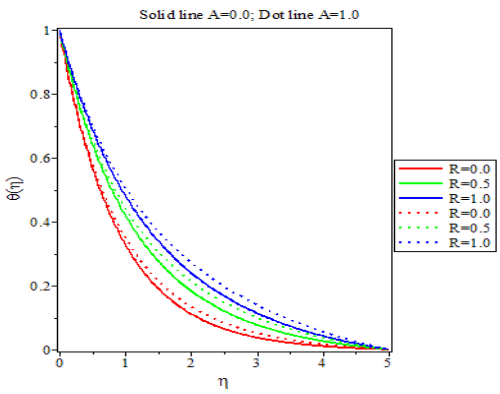


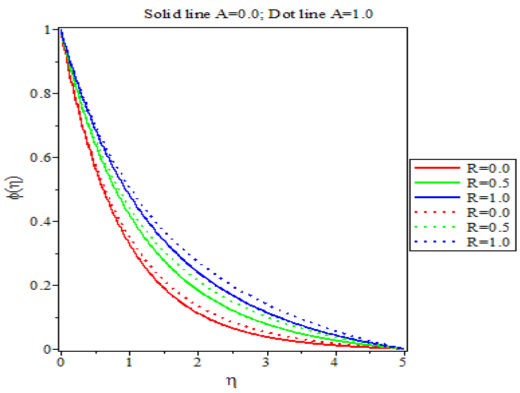
Fig.2. Velocity graph by S.M Ibrahim and et. al. (2015) for different values of material parameters and other parameters are same with above.



(a) Velocity



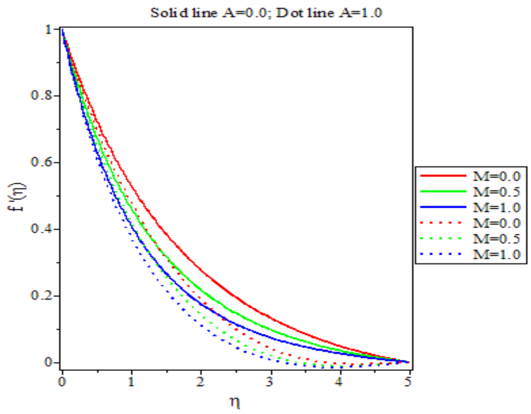
(b) Temperature



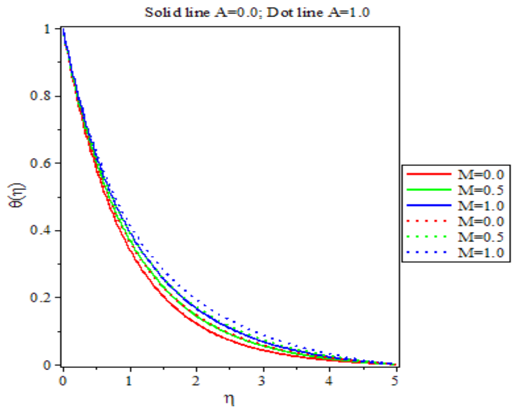
(c) Concentration

Fig. 3. Effects of Thermal Radiation parameter on velocity, temperature and concentration when $Pr=0.71$, $S_0=m_0=Gr=M=Gm=\alpha=Ec= Da^{-1}=0.1$, $Sc=0.22$, $\varepsilon=0.01$, $Q_0=0.02$, $Q_1=-0.01$, $A=0.0$, $K=1.0$.

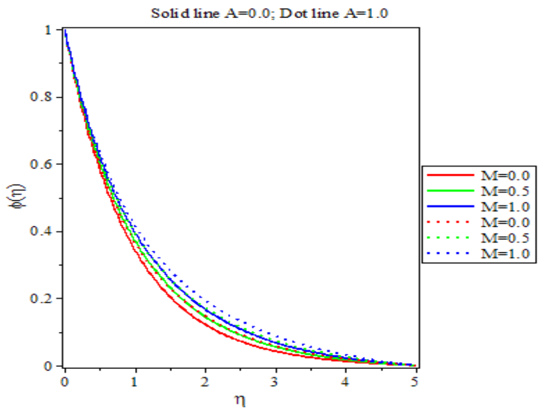
Figures 3 display the effect of Thermal radiation parameter on velocity, temperature and concentration profiles, respectively in the presence of chemical reaction, *A*=0.0 and *A*=1.0. With the existence of chemical reaction, there are reaction on temperature and concentration profiles, which it is clear that an increase thermal radiation parameter leads to increase both, temperature and concentration when the others parameter are remain constant. But for velocity, chemical reaction is not acting on this profile for both *A*=0.0 and *A*=1.0.



(a) Velocity



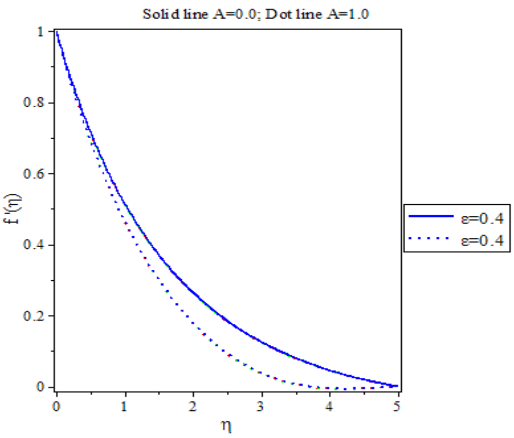
(b) Temperature



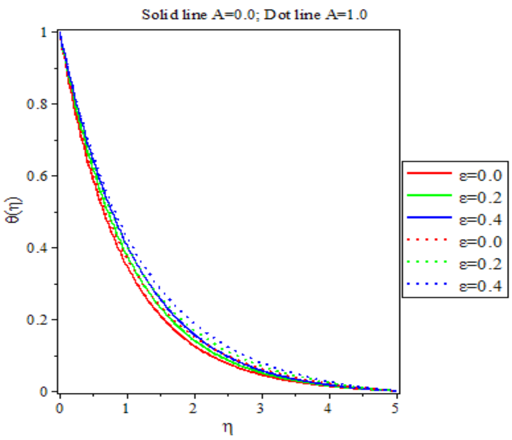
(c) Concentration

Fig. 4. Effects of Magnetic field parameter on velocity, temperature and concentration when Pr=0.71, $S_0=m_0=Gr=Gm=\alpha=Ec=R=Da^{-1}=0.1$, Sc=0.22, ε=0.01, $Q_0=0.02$, $Q_1=-0.01$, A=0.0, K=1.0.

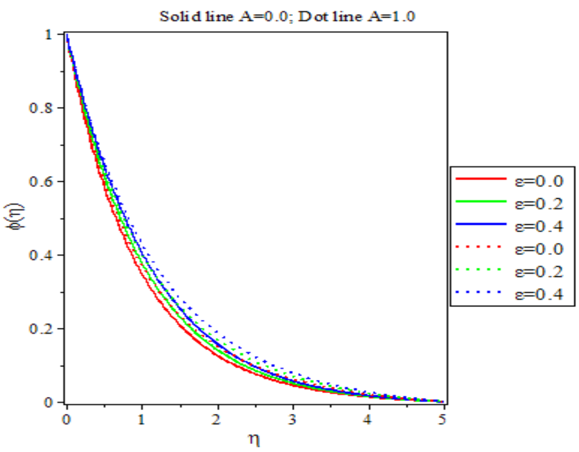
In figure 4, Magnetic field parameter plays an essential role on these three profiles which are velocity, temperature and concentration when the other parameters such as porous ε, Grashof number *Gr*, local inertia-coefficient α, and so on so forth are remain constant with the presence of chemical reaction. There are an active reaction of chemical reaction on velocity, temperature and concentration profiles as the magnetic field parameter is increasing for both *A*=0.0 and *A*=1.0. As we conclude, the velocity profile is decreasing while the other profiles which are temperature and concentration are increasing when the magnetic field parameter increase.



(a) Velocity



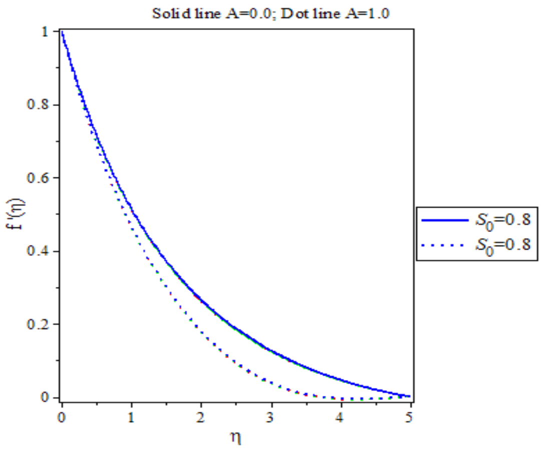
(b) Temperature



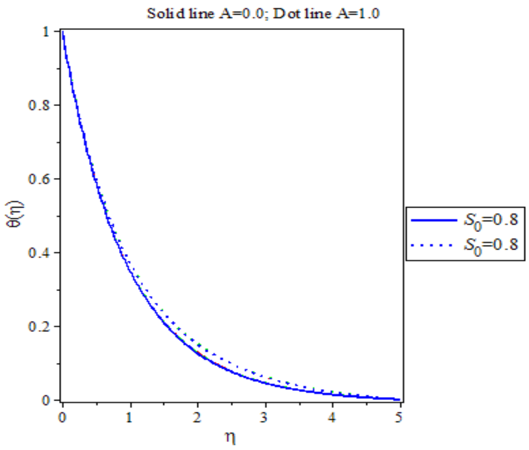
(c) Concentration

Fig. 5. Effects of porous media on velocity, temperature and concentration when Pr=0.71, S_0=m_0=Gr=Gm=α=M=Ec=R=Da^{-1}=0.1, Sc=0.22, Q_0=0.02, Q_1=-0.01, A=0.0, K=1.0.

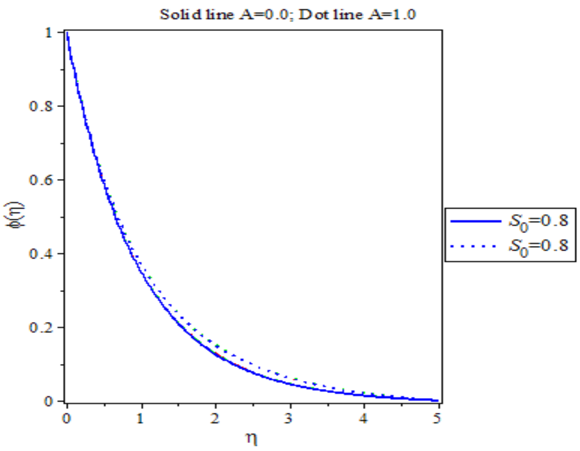
Figure 5 show the effect of porous media on three profiles which are velocity, temperature and concentration with the presence of chemical reaction. It is observed that when the porous media increase, the both profiles, temperature and concentration also increase but for velocity profile, there is remain constant for both A=0.0 and A=1.0. The presence of chemical reaction has been change the temperature and concentration profiles which mean there are reaction on both profiles difference with velocity profiles which no react with chemical reaction. The other properties exposed by graph are when the porous media is increasing, the boundary layer thickness for velocity, temperature and concentration profiles, respectively are decreasing.



(a) Velocity



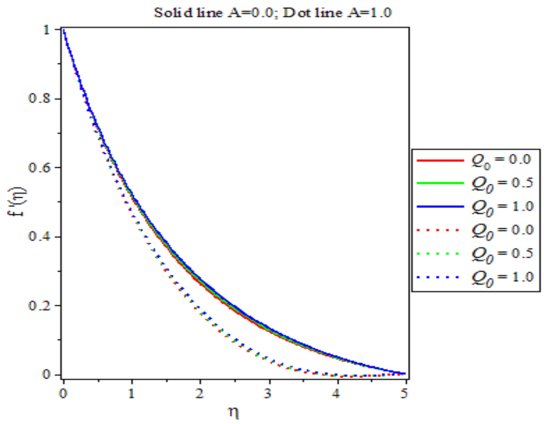
(b) Temperature



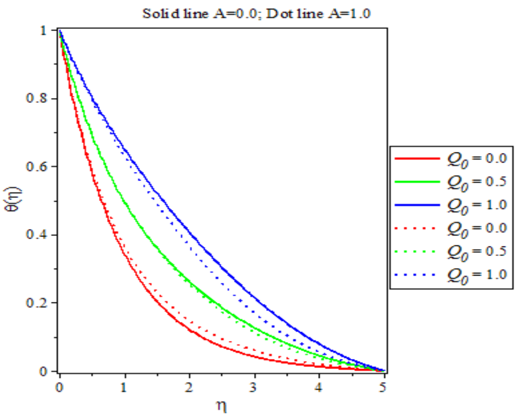
(c) Concentration

Fig.6. Effects of Soret number on velocity, temperature and concentration when Pr=0.71, $m_0=Gr=Gm=\alpha=M=Ec=R=Da^{-1}$=0.1, Sc=0.22, ε=0.01, Q_0=0.02, Q_1=-0.01, A=0.0, K=1.0.

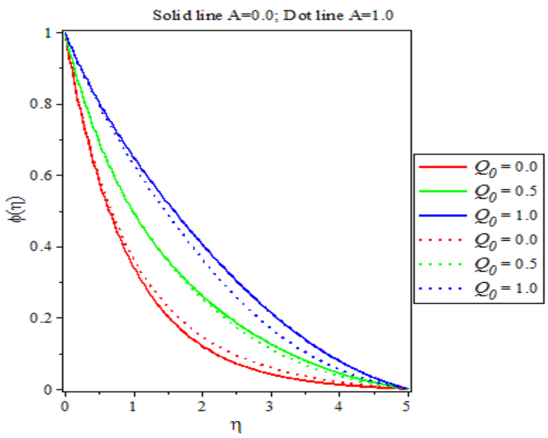
Figure 6 represent the effect of Soret number on velocity, temperature and concentration profiles, respectively with the existence of chemical reaction. Here, it explain chemical reaction are not effect on three profiles which are velocity, temperature and concentration as the Soret number is increasing for both A=0.0 and A=1.0 while the other parameters are remains constant.



(a) Velocity



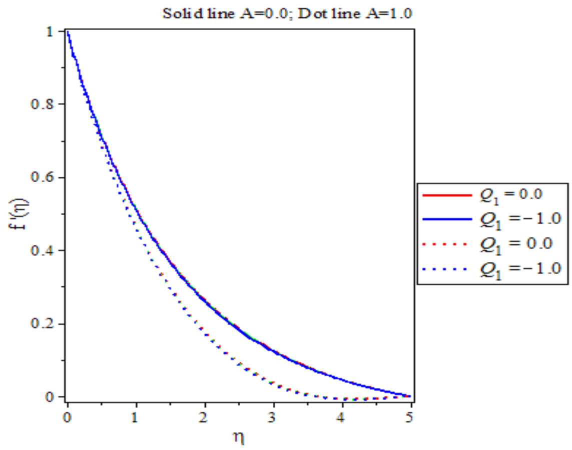
(b) Temperature



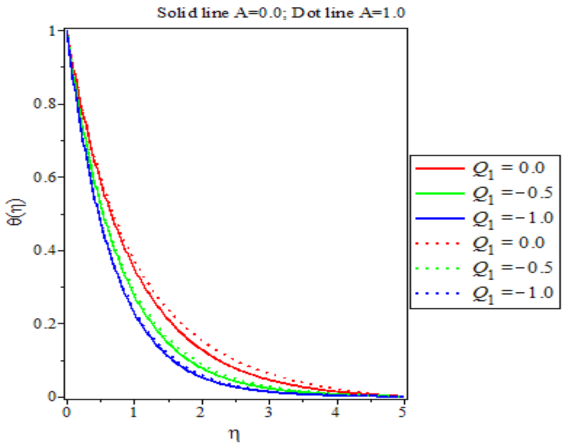
(c) Concentration

Fig.7. Effects of Coefficient of Space-dependent heat source/sink on velocity, temperature and concentration when Pr=0.71, S_0=m_0=Gr=Gm=α=M=Ec=R=Da^{-1}=0.1, Sc=0.22, ε=0.01, Q_1=-0.01, A=0.0, K=1.0.

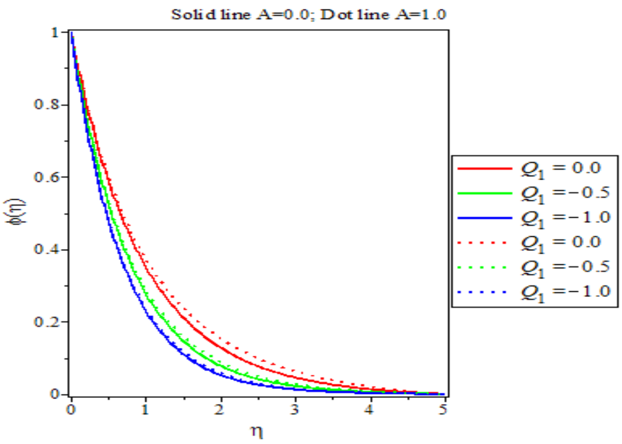
The effect of Coefficient space-dependent heat source/sink is presented for different parameters in figure 7. In this figure, there is presence of chemical reaction on three profiles which are velocity, temperature and concentration, respectively. For both profiles, temperature and concentration, they are increasing as the coefficient space-dependent heat source/sink is increasing for both A=0.0 and A=1.0. The others properties declared by graph is the chemical reaction effect on both profiles, temperature and concentration while velocity profiles no change eventhough the coefficient space-dependent heat source/sink is increasing. Next, we can conclude that the boundary layer thickness decrease for velocity, temperature and concentration profiles, respectively.



(a) Velocity



(b) Temperature



(c) Concentration

Fig.8. Effects of Coefficient of Temperature-dependent heat source/sink on velocity, temperature and concentration when Pr=0.71, $S_0=m_0=Gr=Gm=\alpha=M=Ec=R=Da^{-1}$=0.1, Sc=0.22, ε=0.01, Q_0=0.02, A=0.0, K=1.0.

Figure 8 elucidate the reaction of coefficient temperature-dependent heat source/sink for different values of appropriate parameters on velocity, temperature, and concentration profiles, respectively with presence of chemical reaction. It is clearly shown the velocity profiles is not affected with the chemical reaction. Besides, as the coefficient temperature-dependent heat source/sink is increasing lead to both profiles, temperature and concentration are decreasing for both A=0.0 and A=1.0. Further, the chemical reaction react on both profiles, temperature and concentration, respectively.

4.Conclusions

This present work collaboration with numerical analysis of combination heat and mass with joined Soret effect on MHD non-Darcian convective flow in a micropolar fluid over a stretching sheet with the presence of chemical reaction. The outcomes non-linear partial differential equations which transform to a set of ordinary differential equations are solved numerically by applying the Runge-Kutta-Felhberg method and joined with shooting method. Further, the analysis represent that velocity, temperature and concentration profiles in the boundary layer depends on fifteen dimensionless parameters, namely Material parameter K, Inverse Darcy number Da^{-1}, Local inertia-coefficient α, Thermal radiation parameter R, Magnetic field parameter M, Porous media ε, Soret number S_o, Schmidt number Sc, Eckert number Ec, Prandtl number Pr, Grashof number Gr, Modified grashof number Gm, Chemical reaction A, Coefficient of space-dependent heat source/sink Q_o, and Coefficient of temperature-dependent heat source/sink Q_1. Then, the chemical reaction also plays an important role on this three profile, which are velocity, temperature and concentration and from regression analysis of the data, Nusselt and Sherwood number are developed by algebraic correlations.

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