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MHD Boundary Layer Flow of a Steady Micro polar Fluid along a Stretching Sheet with Binary Chemical Reaction

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Abstract

A mathematical analysis has been done to investigate the effect of MHD boundary layer flow of a steady micropolar fluid along Stretching sheet with Arrhenius equation. Using the similarity transformation, the governed partial differential equations for continuity, momentum, temperature and concentration are transformed into ordinary differential equation and then solved numerically by using NDsolve in Mathematica. The effect of various parameters on the dimensionless velocity, temperature, Micro rotation and concentration are discussed graphically. We also discussed about the variation of temperature difference parameter for local Sherwood Number versus non-dimensional activation energy E . Comparisons are made with all the parameters for a special case and found a very good agreement.

Keyword: MHD, Micro polar fluids, Stretching sheet, Arrhenius Energy, Sherwood number

INTRODUCTION

Non Newtonian fluids have significant role and importance in the engineering and manufacturing processes such as crude oil extraction Polymer and food processing. Non Newtonian fluid models, depending upon different physical characteristics are classified as Casson fluid, Jeffrey fluid, Maxwell fluid, Johnson-segalman fluid, Ostwald-Waele Power law fluid, Micropolar fluid. Any fluid with or without external impact force undergoing microscopic transformation from its original structure with micro motion under various conditions is studied as Micropolar Fluid Dynamics. Some of the common MPFs are paints, vaccine suspension, animal blood colloidal fluids, liquid crystals, dialysis of Human blood, and cloud with dust. Allen et.al (1971) discussed a lubrication theory for micropolar fluids. McCormack(1973) had given explanation for the physical fluid dynamics with its origin and future development of fluid dynamics. It reveals the Newtonian fluid which is applied in Physics and Engineering science and also the physical properties of fluid, vortex dynamics, Slow Viscous flow and particulate fluid dynamics. Sastry.et.al (1982) investigated numerical solution for micropolar fluid flow in a channel with porous walls. Hassanien.et.al (1998) studied boundary layer flow and heat transfer processes on a continuous accelerated sheet extruded in a stationary ambient micropolar fluid. Kelson(2001) discussed the influence of surface conditions on flow processes of a micropolar fluid driven by a porous stretching sheet. Kelson(2001) also explained a self-similar boundary layer flow analysis of a micropolar fluid which was driven by the porous stretching sheet. Mohammadein et.al (2001) reported a boundary layer analysis of heat transfer processes of a laminar micropolar fluid over a linearly stretching continuous surface with viscous dissipation and internal heat generation. Nazar et.al (2002) investigated the steady laminar free convective boundary layer flow over a sphere with the presence of surface heat flux placed in a micropolar fluid. Ali. J.Chamkha et.al (2003) obtained a numerical approach for the steady boundary layer equation for the three-dimensional flow of the micropolar fluid. Lok et.al(2003) investigated an unsteady boundary layer flow of a micropolar fluid near stagnation point of a plane surface. Magdy.A.Ezzat (2004) reported a free convection flow of conducting micropolar fluid with thermal relaxation including heat sources.

Meanwhile, Heat transfer processes from a stretching iso-thermal surface embedded in a Non-Darician porous medium with uniform transverse magnetic field was analyzed by Abo-Eldahab et.al(2005). Lok et.al (2005) investigated the steady mixed convective boundary layer flow of a micropolar fluid past near the stagnation point on a double-infinite vertical flat plate and solved numerically by using Kellar-box method. Ishak et.al(2006) discussed steady boundary layer flow and heat transfer analysis of a micropolar fluid on an Isothermal continuously moving plane surface taking into account of viscous dissipation . Rafael Cortell.et.al (2007) analyzed MHD flow of an electrically conducting fluid of second grade in a porous medium over a stretching sheet with chemically reactive species. Ishak et.al (2008) studied heat transfer analysis over a stretching surface in presence of variable heat flux of micropolar fluids. The above paper was solved numerically by finite difference Method. Rahmann et.al.(2010) reported the influence of higher-order chemical reaction on micropolar fluid flow in a power-law permeable stretching sheet in presence of variable concentration in a porous medium. The result of the above article show that the effect of some parameters on the micropolar fluids less compared to the Newtonian fluids.

Further in literature, Baker et.al (2011) analyzed for the steady thermal convective heat and mass transfer in a micropolar fluid saturated by Non- darcian porous medium in the presence of radiation and thermophoresis effects. Olanrewaju et.al (2011) had investigated the influence of thermal radiation of magnetohydrodynamics flow of a micropolar fluid past towards a stagnation point on a vertical plate. Modather et.al (2012) investigated unsteady boundary layer flow and heat transfer of a viscous, incompressible micropolar fluid having temperature dependent viscosity and thermal conductivity over a non-isothermal horizontal stretching sheet. Bhattacharyya et.al (2012) studied the variation of thermal radiation on micropolar fluid flow and heat transfer processes in a porous shrinking sheet. The governing partial differential equation was solved by an efficient shooting method. Mohammed et.al (2013) studied thermal radiation effect on MHD free convective flow of a micropolar fluid past in a stretching surface embedded in a Non-darician porous medium. Uddin et.al (2014) discussed the influence of thermal radiation and heat generation/Absorption of MHD heat transfer flow of a micropolar fluid past in a wedge with hall and ion slip currents. Isaac Lare Animasuan.et.al (2015) analyzed an unsteady convective heat transfer in micropolar fluid flow with thermophoresis, chemical reaction and radioactive past in a vertical porous surface moving through binary mixture with an effect of temperature dependent dynamic viscosity and constant vortex viscosity. Mekonnen.et.al (2015) discussed the hall Effect and temperature distribution of an unsteady incompressible electrically conducting micropolar fluid between parallel plates . Mohammed Shafique et.al (2015) investigated numerical solution for MHD viscous flow of micropolar fluid over a shrinking sheet. Here the resulting partial differential equation was solved by using successive over-relaxation (SOR) iterative procedure. Lakshmi et.al (2015) discussed an unsteady, two dimensional, mixed convective flow of a viscous incompressible electrically conducting micropolar fluid over a vertical and impermeable stretching surface with MHD and second order slip flow. Sajjad Hussain.et.al (2015) investigated the MHD boundary layer flow and heat transfer processes for micropolar fluid over a shrinking sheet. Haritha et.al (2016) discussed MHD mixed convection flow of micropolar fluids through a porous medium past towards a stagnation point on a vertical surface. Khairy Zaimi et.al (2016) studied the influence of partial slip on stagnation point flow and heat transfer analysis to a stretching vertical sheet. In the above article, the Dual solution was obtained for a certain range of slip and buoyancy parameters. Mishra et.al (2016) analyzed chemical reaction and soret effect on hydrodynamics micropolar fluid past over a stretching sheet in presence of volumetric non-uniform heat source. Prasad.et.al (2016) investigated a boundary layer free convective flow of an unsteady viscous incompressible micropolar fluid and its heat transfer characteristics past over a vertical stretching sheet. Rajesh Sharma.et.al (2016) studied the steady stagnation point flow of a micropolar fluid over a stretching/shrinking sheet with second-order velocity slip. Similarity equation was solved by using MATLAB(bvp4c) based on the finite difference method. An unsteady transition thermophoretic particle deposition of forced convective heat and mass transfer processes of micropolar fluid flow with uniform magnetic field was discussed by Doh.et.al (2017). Indira Baruah.et.al (2017) investigated the influence of variable viscosity and thermal conductivity of the unsteady micropolar fluid in a permeable cylinder with moving boundaries. Koriko.et.al (2017) studied two-dimensional boundary layer flow of micropolar fluids past towards a stagnation point formed on a horizontal melting surface. Koriko et.al (2017) obtained Boundary layer analysis theory in the flow of micropolar fluid with exothermic and endothermic kind of chemical reaction and thermal radiation. Anuradha et.al (2017) investigated MHD flow over a convective stretching surface with dufour effect, slip and radiative. Subhani.et.al (2017) studied the three-dimensional micropolar nanofluids over an exponentially stretching surface in a porous medium.BVP-4c technique along with the shooting method were used to solve a partial differential equation. Vijayalakshmi.et.al (2017) investigated the flow of upper-convected Maxwell micropolar fluid over a steady stretching sheet with slip effect. Sasikala et.al (2017) studied the effect of binary chemical reaction and activation energy on MHD Mixed Convection Stagnation Point Flow numerically. Fatunmbi.et.al (2018) examined the steady two-dimensional, stagnation point, heat and mass transfer processes of an incompressible, electrically conducting micropolar fluid flow in a permeable stretching plate with presence of thermal radiation, chemical reaction, viscous dissipation, heat source/sink, and variable thermal conductivity. Punithavalli et al(2018) discussed the effect of Micropolar fluid over an expontially stretching sheet with chemical reaction. Anuradha et.al(2018) investigated on Micropolar Stagantion point fluid flow through exponentially stretching surface with binary chemical reaction. The purpose of present study is to extend the work of Anuradha et al(2018) to investigate the effect of binary chemical reaction on MHD boundary layer flow of micro polar fluid flow over an exponentially stretching sheet. The main goal of this article is to discuss the characteristics of non-dimensional binary chemical reaction parameters numerically with the help of graphs.

2. MATHEMATICAL FORMULATION

MHD micropolar fluid flow over an exponentially stretching sheet with binary chemical reaction and activation energy has been considered in this model. Assume that the sheet is vertically stretched along *x* axis and *y* axis is perpendicular to the stretching sheet. The Cartesian coordinate axes are (*x, y, z*) with corresponding velocities (*u, v, 0*) in which uniform magnetic field B_0 is applied towards the positive direction of y axis. The stretching velocity is taken in exponential form with velocity $U_w = ae^{\frac{x}{L}}$; a>0 which *a* is a stretching constant. Applying boundary layer approximation, the governing equations for continuity, Momentum and Angular momentum, temperature and Concentration are as follows

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} = U_\infty \frac{dU_\infty}{dx} + (\upsilon + \frac{k}{\rho})\frac{\partial^2 u}{\partial y^2} + \frac{k}{\rho}\frac{\partial N}{\partial y} + \frac{\sigma B_0^2}{\rho}(U - u) \tag{2}$$

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

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial x}=\gamma\frac{\partial^2 T}{\partial y^2}+(\upsilon+\frac{k}{\rho})\frac{\partial^2 u}{\partial y^2}+\frac{\sigma B_0^2}{\rho}(U-u)+\frac{Q_0}{\rho}(T-T_\infty) \quad (4)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}-K_r^2(\frac{T}{T_\infty})^n Exp(\frac{-Ea}{K_T})(C-C_\infty) \quad (5)$$

Where u and v are the velocity component parallel to the x and y-axes respectively, ρ is the fluid density, θ is the kinematic viscosity, N is the micro rotation or angular velocity, k is the thermal conductivity of the fluid, j= (υ/c) is the micro inertia per unit mass, T is temperature, C is concentration of the fluid, D_m is the coefficient of mass diffusivity, $K_r^2(\frac{T}{T_\infty})^n Exp(\frac{-Ea}{K_T})(C-C_\infty)$ represents the modified Arrhenius equation in which K_r^2 = the reaction rate, E_a =Activation energy, κ = 8.61x10^{-5} eV/K = the Boltzmann constant and n= fitted rate constant ; -1 < n < 1.

The associated initial and boundary conditions for the problem are

$$u=U_w,\ v=0,\ N=n(\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}),\ T=T_w(x),\ C=C_w(x)\quad at\quad y=0 \quad (6)$$
$$u\to U_\infty,\ N\to 0,\quad T\to T_\infty,\quad C\to C_\infty\quad as\quad y\to\infty$$

The stretching velocity U_w ,surface temperature T_w and surface concentration C_w are defined as

$$U_\infty=ae^{\frac{x}{L}},\ U_W=be^{\frac{x}{L}},\quad T_w=T_\infty+ce^{\frac{x}{L}},\quad C_w=C_\infty+de^{\frac{x}{L}} \quad (7)$$

Since our goal is to find the numerical solution of the governing problem,the governing partial differential equations is transformed into a system of non- linear ordinary differential equation, we introduce the following dimensionless and similarity variable into Equation (2) - (5)

$$u=ae^{\frac{x}{L}}f'(\eta),v=-(\frac{\upsilon a}{2L})^{1/2}e^{\frac{x}{2L}}(f(\eta)+\eta f'(\eta)),N=a(\frac{a}{2\upsilon L})^{1/2}e^{\frac{3x}{2L}}M(\eta) \quad (8)$$
$$\theta=\frac{T-T_\infty}{T_W-T_\infty},\eta=(\frac{a}{2\upsilon L})^{1/2}e^{\frac{x}{2L}}y,\varphi=\frac{C-C_\infty}{C_w-C_\infty},u=\frac{\partial\psi}{\partial y},v=-\frac{\partial\psi}{\partial x}$$

using the transformation in Equation (8) ,the governing boundary layer equation can be written as

$$f'''+\frac{1}{1+K}(ff''-2f'^2+2)+\frac{K}{1+K}g'+M(1-f')=0 \quad (9)$$

$$g''+\frac{1}{\Lambda}(fg'-2f'g)-\frac{K\chi}{\Lambda\,\mathrm{Re}}(2g+f'')=0 \quad (10)$$

$$\theta''+\Pr(f\theta'-2f'\theta)+\Pr EcMf'^2+\Pr\theta=0 \quad (11)$$

$$\phi''(\eta)+\mathrm{Sc}\,f\phi'-Sc\sigma(1+\delta\theta)^n\phi e^{\left(-\frac{E}{1+\delta\theta}\right)}=0 \quad (12)$$

Where primes denote differentiation with respect to η, K = micro rotation parameter, Pr=the prandtl number, M = Hartman number, Sc=Schmidt number, E=Non-dimensional Activation energy, σ= non-dimensional chemical reaction rate,δ= temperature relative parameter, Ec = Eckert number.

The transformed boundary conditions are as follows

$$\begin{aligned}&f(0)=0,\quad f'(0)=\varepsilon,\quad f'\to 1\quad as\quad \eta\to\infty\\&M(0)=-nf''(0),\quad M\to 0\quad as\quad \eta\to\infty\\&\theta(0)=1,\quad \theta\to 0\quad as\quad \eta\to\infty\\&\varphi(0)=1,\quad \varphi\to 0\quad as\quad \eta\to\infty\end{aligned} \quad (13)$$

The quantities of physical interest, the non-dimensional local skin friction coefficient, the local couple stress,the local Nusselt number and the local Sherwood number are defined as follows;

$$\begin{aligned}&\mathrm{Re}_x^{1/2}C_f=\frac{1}{\varepsilon^2}(1+(1-n)K)f''(0)\\&M_x\,\mathrm{Re}_x=(1+\frac{K}{2})M'(0)\\&Nu_x\,\mathrm{Re}_x^{-1/2}=-\theta'(0)\\&Sh_x\,\mathrm{Re}_x^{-1/2}=-\phi'(0)\end{aligned} \quad (14)$$

Where Re_x= Local Reynolds number

3. RESULTS AND DISCUSSIONS

For the purpose of this mathematical model, the transformed set of coupled non-linear boundary layer equations with dimensionless varibles can be solved numerically by NSolve Mathematica procedure. To investigate the physical characteristics of non-dimensional parameters, velocity, temperature and concentration profiles are presented graphically by using numerical values. This paper extends the study of Anuradha(2018) for the effect of MHD boundary layer flow of an unsteady micropolar fluid along Stretching sheet with Arrhenius equation. The non-dimensional parameters such as Temperature difference parameter δ , Dimensionless reaction rate σ , Non-dimensional energy E on velocity, temperature and concentration profiles are analyzed by plotting numerical values in the graph.

The influence of Activation Energy E on velocity, temperature and concentration profiles are shown in the figures 1 and we conclude that higher values of E elevate the momentum thickness and reduce the thermal flow field. The Activation energy E simply defined as, the ration of reaction rate co-efficient to the constant temperature. Generally weaker rate of chemical reaction is occurred due to higher energy activation and weaker temperature resists chemical reaction.

Figures 2 is drawn to look into the velocity, temperature and concentration profiles for different values of Temperature difference parameter δ. We see that higher values of δ reduced the concentration flow field and associated the boundary layer thickness. Meanwhile, an opposite reaction obtained in velocity and temperature flow field.

Figures 3 represents the variation of velocity, temperature and concentration profiles with chemical reaction rate constant σ. It is found that chemical reaction rate constant reduces the momentum boundary layer thickness and increases the thermal and concentration flow field.

Figure 4 portrays the behavior of Schmidt number Sc on velocity, temperature and concentration profiles. It is concluded that the larger values of Schmidt number reduces velocity, and concentration profiles. Figure 5 depict the plot of local Sherwood number versus activation energy for different values of chemical reaction rate constant σ . Increasing values of chemical reaction rate constant σ decreases activation energy E. From this, we conclude that mass flux from the sheet is smaller when chemical reaction requires larger activation energy.

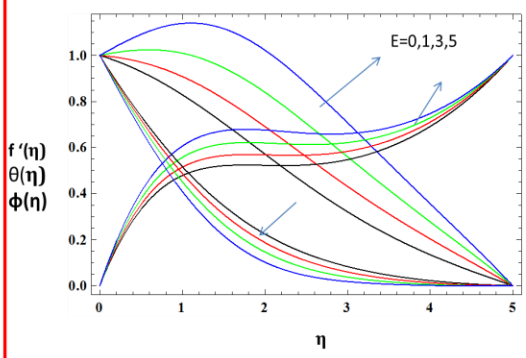

Figure.1. Effect of Non-dimensional Energy (E) on Velocity Profile, Temperature profile and concentration profile n= 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, γ=1,δ=1

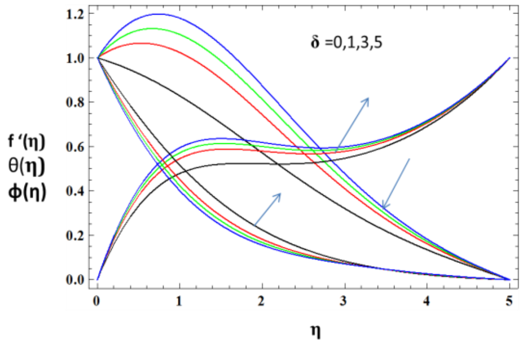

Figure.2. Effect of temperature parameter (δ) on Velocity Profile, Temperature profile and concentration profile n= 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, γ=1, E =1

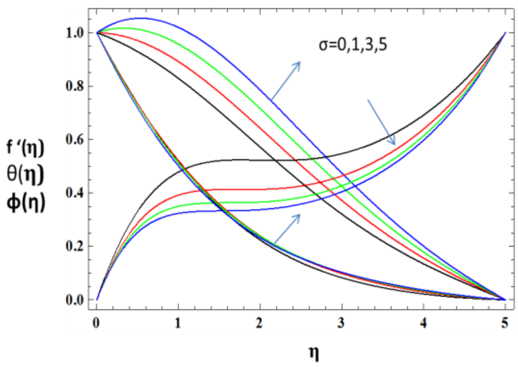

Figure.3. Effect of chemical reaction rate (σ) on Velocity Profile, Temperature profile and concentration profile n= 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, γ=1,δ=1,E=1

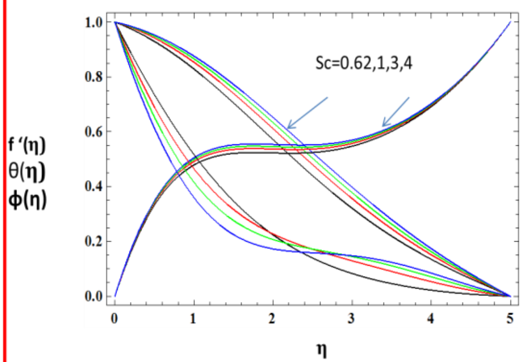

Figure.4. Effect of Non-dimensional Energy (Sc) on Velocity Profile, Temperature profile and concentration profile n= 0.5, Pr =0.72, Re = 1, K=1,σ=1, γ=1,δ=1

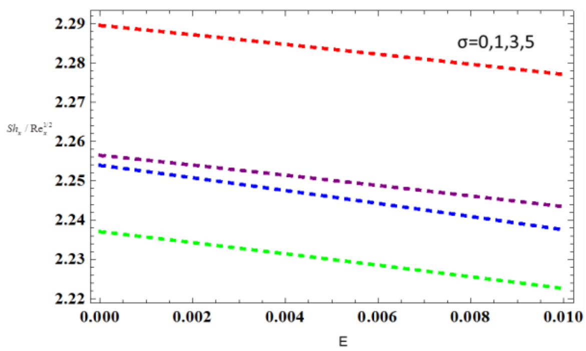

Figure.5. Effect of Local Sherwood number verus activation Energy E for different values of temperature difference parameter n= 0.5, Pr =0.72, Re = 1, K=1,σ=1, γ=1,δ=1

4. CONCLUSION

In this present study, a mathematical analysis has been done to investigate the effect of MHD boundary layer flow of a steady micropolar fluid along Stretching sheet with Arrhenius equation. Using the similarity transformation, the governed partial differential equations for continuity, momentum, temperature and concentration are transformed into ordinary differential equation and then solved numerically by using NDsolve in Mathematica. The conclusions are as follows:

- Higher values of E elevate the momentum thickness and reduce the thermal flow field. The Activation energy E simply defined as, the ration of reaction rate co-efficient to the constant temperature. Generally weaker rate of chemical reaction is occurred due to higher energy activation and weaker temperature resists chemical reaction.
- Increasing values of δ are to heighten the concentration flow field and associated the boundary layer thickness. Meanwhile, an opposite reaction obtained in velocity and temperature flow field.
- It is found that chemical reaction rate constant reduces the momentum boundary layer thickness and increases the thermal and concentration flow field.
- Larger values of Schmidt number reduce velocity, and concentration profiles.
- Increasing values of chemical reaction rate constant σ decreases activation energy E. From this, we conclude that mass flux from the sheet is smaller when chemical reaction requires larger activation energy.

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