IJASRM International Journal of Advanced Scientific Research and Management, Volume 4 Issue 1, Jan 2019
www.ijasrm.com
ISSN 2455-6378

Investigation on MHD MicropolarFluid flow over an exponentially Stretching Surface

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Abstract

In this Investigation, MHD micropolar fluid flow through an exponentially stretching sheet with heat and mass transfer has been considered. The steady two dimensional incompressible flows are taken into account. A mathematical governing model has developed for the continuity equation, momentum, temperature and concentration boundary layer equations. The governing partial differential equations are transformed by using similarity transformation and then the resulted set of system of nonlinear ordinary coupled differential equations with fitting boundary conditions are solved numerically by fourth order Runge- kutta method with shooting techniques. To study the flow characteristics,the behavior of various non-dimensional parameters which is involved in this problem on the dimensionless velocity, temperature and concentrationare studied numerically with the help of graphs.

Keywords: *Micropolar fluid, Stretching sheet, Boundary layer flow, Shooting technique, Runge-kutta method*

1.Introduction

Magneto hydro dynamics (MHD) stagnation point flow of micropolar fluid and heat transfer has received a lot of attention in the field of engineering, scientific and industries in recent years. Initially, it is well known; Eringen established the Micropolar fluid theory from the theory of fluids with microstructures. Later on, Eringen(1967) also developed an article based on a theory of micropolar plates from micropolar fluids theory. Raptieset.al(1998) obtained the flow analysis of a micropolar stationary fluid past in a continuously moving plate in presence of radiation effect. Kim et.al(1999) investigated micropolar fluids of steady laminar flow move in a wedge with constant surface temperature. Papaustyet.al(1999) studied the Laminar fluid behavior in microchannels by using micropolar fluid theory. El.aminet.al(2001) examined MHD free convective flow and mass transfer in a micropolar fluid with constant suction. Chi. Chang Wanget.al(2001) investigated free convective flow along a vertical wavy surface in micropolar fluids. Kim(2003) studied the convective boundary layer flow of micropolar fluid flows over a wedge with constant surface heat flux. Rahmanet.al(2006) analyzed MHD convective heat transfer of Micropolar fluid past a continuously moving vertical porous plate with heat generation/absorption and constant suction by using numerical approach. AnuarIshaket.al(2008) reported the similarity solutions for the steady MHD flow past towards a stagnation point flow on a vertical surface which is immersed in an incompressible micropolar fluid. Muthuet.al(2008) reported the study analysis of micropolar fluid in an annular tube with application to Blood flow.

Further,Bachoket.al(2009) investigated stagnation point flow of steady MHD mixed convective micropolar fluid towards a vertical surface with prescribed wall heat flux. Abdel Rahamnet.al(2009) discussed the influence of a magnetic field in a micropolar fluid flow in the vicinity of an axisymmetric stagnation point on a circular cylinder. Mohamed Abd El-Aziz (2009) examined the boundary layer flow and heat transfer processes of micropolar fluid associated with a heated exponential stretching continuous sheet being cooled by mixed convection flow. AnuarIshaket.al(2010) discussed a micropolar fluid in a thermal boundary layer flow over a stretching sheet in presence of radiation effect. Bakret.al(2011) investigated MHD mass transfer micropolar fluid flow with the constant heat source in a rotating frame of reference with the chemical reaction of the first-order, taking into account of an oscillatory plate velocity and a constant suction velocity at the plate by using the perturbation method Hayatet.al(2011) discussed the soret and Dufour effect on the stagnation point flow of a micropolar fluid towards a stretching sheet.Olanrewajuet.al(2011) examined steady MHD mixed convective stagnation point flow past in a vertical surface with the influence of thermal radiation.

Yacobet.al(2011) investigated Melting heat transfer analysis in boundary layer stagnation-point flow towards a stretching/shrinking sheet in the micropolar fluid by using Runge-KuttaFehlberg method with shooting Technique. Mahmoodet.al(2012) reported the influence of slip velocity on the flow and heat transfer techniques for an electrically conducting micropolar fluid over a permeable stretching surface with variable heat flux, heat generation/ absorption, and a transverse magnetic field. ZiaualHaqueaet.al(2012) studied MHD free convectivemicropolar fluid flow through a porous medium with constant heat and mass flux numerically. Adhikari(2013) discussed stagnation point flow of MHD micropolar fluid on a vertical surface under induced magnetic field with radiative heat flux. Loganathanet.al(2013) investigated the effectof a chemically reacting micropolar fluid on thermophoresis particle deposition through moving porous plate in presence of heat generation/absorption and variable viscosity.

Baag.et.al(2014) investigated the variation in a magnetic field, heat generation/absorption and chemical reaction for steady MHD mixed convective stagnation point flow of an incompressible micropolar fluid past in a vertical flat plate. Bariket.al(2015) studied the effect of heat absorption and chemical reaction with the magnetic field of an incompressible micropolar fluid through a porous medium in a two-dimensional symmetrical channel. Haqet.al (2015) investigated two dimensional boundary layer flow of natural convective micropolarnanofluid along a vertical stretching sheet with an effect of radiation. Mohammed Shafiqueet.al(2015) obtained the numerical solution for axisymmetric stagnation flows of micropolar fluids flow towards a shrinking sheet by using SOR Iterative procedure. Kalidas Daset.al(2016) analyzed boundary layer flow of an incompressible electrically conducting MHD micropolar fluid over a moving vertical plate with slip velocity and temperature jump at the boundary surface in presence of first-order chemical reaction by using Lie group analysis to reduce a couple of ordinary differential equation. Naveedet.al (2016) investigated the two-dimensional MHD flow of micropolar fluid due to a curved stretching sheet in presence of thermal radiation. Khilapsinghet.al(2016) studied the micropolar fluid flow with heat transfer during the melting processes towards a stretching sheet by RungeKutta- Fehlberg Method. Majidianet.al (2016) analyzed MHD micropolar fluid transport over a permeable flat plate by homotopy analysis method. Rawatet.al(2016) investigated two-dimensional flow MHD micropolar fluid flow over a nonlinear stretching sheet with variable micro inertia density, heat flux and chemical reaction.Sunday Kolawoleet.al(2016) studied two-dimensional boundary layer flow of micropolar fluid towards stagnation point formed on a horizontal linearly stretching surface. Xinhuisiet.al(2016) investigated an unsteady two-dimensional laminar flow of an incompressible micropolar fluid in a channel with expanding or contracting porous wall. Dohet.al(2017) presented the influence of heat generation on a fully developed flow and heat transfer processes of micropolar fluid between two parallel vertical plates. Animasaunet. al(2017) investigated stagnation point micropolar fluid flow of temperature dependent fluid viscosity and thermal conductivity at constant vortex viscosity. BalaAnki Reddyet.al (2017) analyzed a mathematical model for the effects of homogeneous and heterogeneous chemical reaction and slip velocity on the MHD Stagnation point flow of electrically conducting micropolar fluid past over a stretching/shrinking surface which is embedded in a porous medium. Khanet.al(2017) discussed the dual solution for the MHD micropolar fluid flow over a stretching/shrinking sheet with heat transfer processes. OlubodeKoladeKorikoet.al (2017) obtained similarity solutions for micropolar fluid flow over a UHSPR with quartic kind of autocatalytic chemical reaction. Reza Keimasneshet.al (2017) examined the effect of magnetic field, radiation heat flux ofmicropolar fluid flow over a stretching sheet.Anuradhaet.al (2017) studied MHD flow over a stretching convective surface with dufour effect, slip and radiative.Sasikalaet.al (2017) investigated MHD Mixed Convection Stagnation Point Flow with Binary Chemical Reaction and Activation Energy numerically. Punithavalli et al(2018) studied the effect of chemical reaction on Micropolar fluid over an expontially stretching sheet. Anuradhaet.al(2018) discussed the effect of binary chemical reaction onMicropolarStagantion point fluid flow throughexponentially stretching surface. Shaik Mohammed Ibrahim.et.al (2018) presented heat and mass transfer of unsteady MHD flow of a viscous, incompressible and electrically conducting micropolar fluid in the presence of viscous dissipation and radiation over a porous stretching sheet in presence of chemical reaction and solved by fourth order RungeKutta method to get the numerical solution. By motivation of the above studies and important application towards

IJASRM International Journal of Advanced Scientific Research and Management, Volume 4 Issue 1, Jan 2019
www.ijasrm.com
ISSN 2455-6378

micropolar fluid with the effect of magnetic field, this research extends the work of Anuradha et al(2018) to study the effect of steady MHD boundary layer flow of heat and mass transfer of a micro polar fluid flowing over an exponentially stretching sheet. The main objective of this article is to discuss the characteristics of magnetic field parameters numerically with the help of graphs.

2. Mathematical formulation

MHD micropolar fluid flow through an exponentially stretching sheet with heat and mass transfer has been considered. The steady two dimensional incompressible flows are taken into account. Let us consider the Cartesian coordinate axes as (*x, y, z*) with corresponding velocities (*u, v, 0*) and the origin has located at the leading edge of the sheet. The *x* axis is along the stretching sheet and y axis is normal to it in which uniform magnetic field B_0 is applied towards the positive direction of y axis. Assume that the stretching velocity is in exponential form with velocity $U_w = ae^{x/L}$ with a>0 which *a* is a stretching constant. Under the boundary layer approximation, the governing equations are as follows

Continuity Equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

Momentum Equation:

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

Angular momentum Equation:

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

Energy Equation:

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

Concentration Equation:

$$u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=D_m\frac{\partial^2 c}{\partial y^2}-K_r(C-C_\infty) \quad (5)$$

The associated boundary conditions are

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

whereυ = the kinematic viscosity, μ= the dynamic viscosity, ρ = the density,N= the microrotation,j = the micro inertia per unit mass, γ = the spin gradient viscosity, k = the vortex viscosity, T = the temperature, L = the reference length, D_m = modular diffusivity,

The exponential stretching sheet expression for U_∞, U_w , T_w and $C_w$are defined as

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

The continuity equation is satisfied byCauchy Riemann equations

$$u=\frac{\partial\psi}{\partial y}, v=-\frac{\partial\psi}{\partial x} \quad (8)$$

where ψ(x,y) = the stream function.

The following similarity transformation is introduced to get the set of ordinary differential equations in terms of non-dimensional variables

$$\begin{aligned} &u = ae^{\frac{x}{L}} f'(\eta), v=-(\frac{\upsilon a}{2L})^{1/2} e^{\frac{x}{2L}}(f(\eta)+\eta f'(\eta)), N = a(\frac{a}{2\upsilon L})^{1/2} e^{\frac{3x}{2L}} M(\eta)\\ &\theta=\frac{T-T_\infty}{T_W-T_\infty}, \eta=(\frac{a}{2\upsilon L})^{1/2} e^{\frac{x}{2L}} y, \varphi=\frac{C-C_\infty}{C_w-C_\infty} \end{aligned} \quad (9)$$

By using equation(9),the nonlinear partial differential equation(2) to (5) becomes

$$f'''+\frac{1}{1+K}(ff''-2f'^2+2)+\frac{K}{1+K}g'+M(1-f')=0 \quad (10)$$

$$g''+\frac{1}{\Lambda}(fg'-2f'g)-\frac{K\chi}{\Lambda \mathrm{Re}}(2g+f'')=0 \quad (11)$$

$$\theta''+\Pr(f\theta'-2f'\theta)+\Pr EcMf'^2+\Pr\theta=0 \quad (12)$$

$$\varphi''-Scf'\varphi+Scf\varphi'-Sc\gamma\varphi=0 \quad (13)$$

The boundary conditions are

$$\begin{aligned} &f(0)=0,\quad f'(0)=\varepsilon,\quad f'\to 1 \quad as \quad \eta\to\infty\\ &M(0)=-nf''(0),\quad M\to 0 \quad as \quad \eta\to\infty\\ &\theta(0)=1,\quad \theta\to 0 \quad as \quad \eta\to\infty\\ &\varphi(0)=1,\quad \varphi\to 0 \quad as \quad \eta\to\infty \end{aligned} \quad (14)$$

From the equations (10)-(13), the non-dimensional parameters are found to analyze the characteristics of velocity, concentration and temperature profiles. Where *f* = the dimensionless stream function, θ= the dimensionless temperature, Φ= the dimensional concentration, *g*= the angular velocity, M= Magnetic parameter. Pr= Prandtl number, Sc=Schmidt number, Re= non-linear Reynolds number, K= Micropolar parameter, γ=non-dimensional chemical reaction parameter, Ec=Eckert number

3. Numerical Solution

The governing equations of this problem had been transformed into set of couplednon-linear boundary layer equations (10) – (13) with the boundary conditions (14) and then solved by using Runge-Kutta method along with the shooting technique. To study the flow characteristics,the behavior of various non-dimensional parameters which is involved in this problem on the dimensionless velocity, temperature and concentrationare studied numerically with the help of graphs.

4. Results and Discussions

Numerical computation is carried out to get clear insight of physical problem for MHD boundary layer micropolar fluid flow through exponentially stretching sheet. The impact of various flow controlling parameters like Magnetic parameter,Prandtl number,Eckert number, Schmidt number and chemical reaction parameter on velocity, temperature and concentration profiles analyzed numerically and graphically.

Figures1illustrates the effect of the Magnetic parameter M on velocity profile, temperature profile and concentration profile.Increasing values of Magnetic parameter M decreases the velocity profile which produces the Lorenz force to the flow.Due to Lorenz force, fluid motion and thickness of boundary layer reduced. Increasing values of Magnetic parameter M increase the profiles of temperature and concentration.

Figures 2 demonstrate the influence ofPrandtl Number (Pr) on the temperature profile and concentration profile. It is observedthat smaller values of Prandtlnumber larger thermal diffusivity.Concentration profile decreases with an increasing value of Prandtl number (Pr)

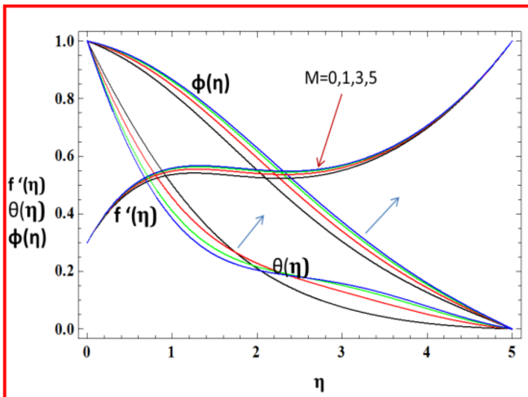

Figure.1.Influence of Magnetic parameter (M) on Velocity Profile, Temperature profile and concentration profile ε = 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, γ=1

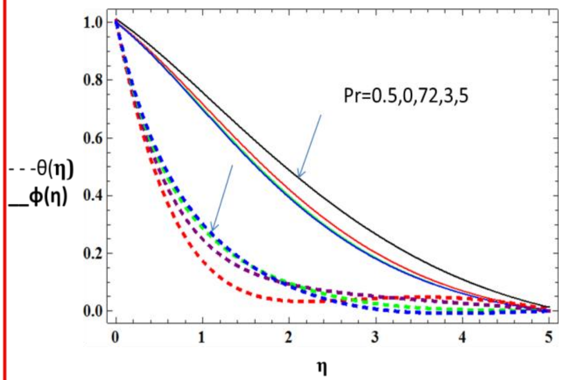

Figure.2.Influence of Prandtl number (Pr) on Velocity Profile, Temperature profile and concentration profile ε = 0.5, M =1, Re = 1, K=1, Sc=0.62, γ=1

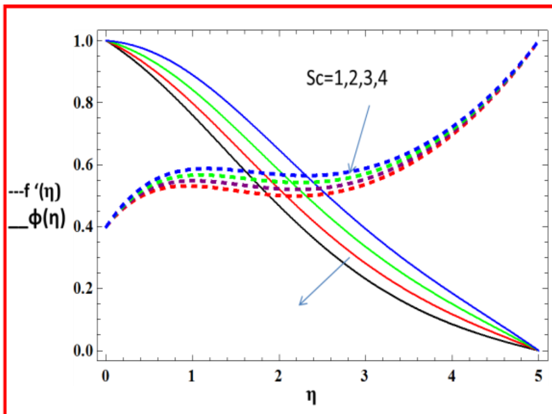

Figure.3.Influence of Schmidt number (Sc) on Velocity Profile, Concentration profile ε = 0.5, Pr =0.72, Re = 1, K=1, Pr=0.72, γ=1

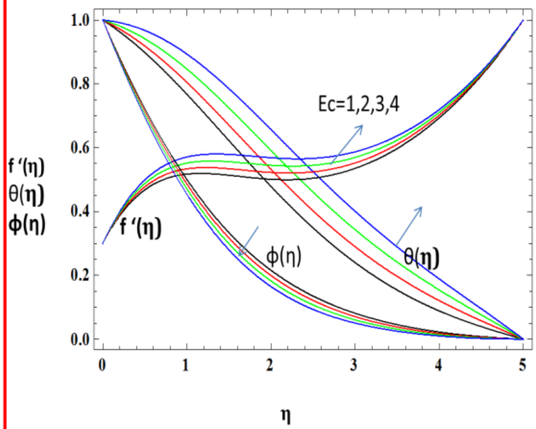

Figure.4.Influence of Eckert number (Ec) on Velocity Profile, Temperature profile and concentration profile ε = 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, γ=1,M=1

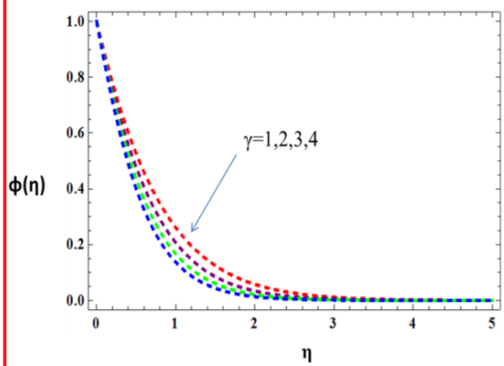

Figure.5.Influence of Chemical reaction parameter (γ) on concentration profile ε = 0.5, Pr =0.72, Re = 1, K=1, Sc=0.62, M=1

The effect of Schmidt number (Sc) on velocity profile and concentration profile are presented in the figure 3. An enhancement in Schmidt number reduce both profiles which impactthat diffusional effects dominate the viscous force and hence causes the slower movement of fluid. Figures 4 portrayed the behavior of the non-dimensional parameter Eckert number (Ec) on velocity profile, temperature profile and concentration profile respectively. Rising values of Eckert number (Ec) enhance both velocity profile and temperature profile but it decreases the concentration profile. The viscous dissipation produces the heat due to the presence of Eckert number in energy equation. Figure 5 depict the effect of chemical reaction parameter (γ) on concentration profile. Larger values of chemical reaction parameter (γ) decrease the concentration profile.

5. Conclusion

In this present investigation, MHD micropolar fluid flow through an exponentially stretching sheet with heat and mass transfer has been examined. Mathematical model formulated for the fluid flow.The resulting governing boundary layer non-linear equations are solvednumerically by shooting method along with fourth order Runge-Kuttamethod and the impact of various flow controlling parameters like Magnetic parameter, Prandtl number, Eckert number, Schmidt number and chemical reaction parameter on velocity, temperature and concentration profiles analyzed with the help of graphs. The conclusions are as follows:

- Increasing values of Magnetic parameter M decreases the velocity profile which produces the Lorenz force to the flow. Due to Lorenz force, fluid motion and thickness of boundary layer reduced.
- Increasing values of Magnetic parameter M increase the profiles of temperature and concentration.
- It is observed that smaller values of Prandtl number larger thermal diffusivity. Concentration profile decreases with an increasing value of Prandtl number (Pr)
- An enhancement in Schmidt number reduce velocity profile and concentration profile which impact that diffusional effects dominate the viscous force and hence causes the slower movement of fluid.
- Rising values of Eckert number (Ec) enhance both velocity profile and temperature profile but it decreases the concentration profile. The viscous dissipation produces the heat due to the presence of Eckert number in energy equation.
- Larger values of chemical reaction parameter (γ) decrease the concentration profile.

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