Micropolar Stagnation point fluid flow over steady exponetially stretching surface with binary chemical reaction

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Abstract **In this investigation, boundary layer stagnation point flow of Micropolar fluid with binary chemical reaction has considered. A mathematical governing model has developed for the momentum, temperature and concentration boundary layer. Whereas this prominent transformation are used to transform the principal nonlinear boundary layer equations for momentum, thermal energy and concentration to a system of nonlinear ordinary coupled differential equations with fitting boundary conditions and are solved numerically by using finite difference method.**

Keywords: Micropolar fluid, Binary chemical reaction,Boundary layer flow, finite difference method

I. INTRODUCTION

In areas such as geothermal or oil reservoir engineering, the above phenomenon is usually applicable. Apart from experimental works in these areas, it is also important to make some theoretical efforts to predict the effects of the activation energy in flows mentioned above. The Chemical reaction processes in mass transfer is quite complex for all the required reactions. Theoretically such an equation is rather impossible to tackle. Form chemical kinetic viewpoint this is a very difficult problem, but if the reaction is restricted to binary type a lot of progress can be made. A balance in the thermo-mechanical equations for a mixture of general materials were first formulated by Truesdell (1954). There after Mills (1966) and Beevers (1982) have obtained some exact solutions for the boundary layer flow of a binary mixture of incompressible Newtonian fluids. The problems facing in the oil and water emulsions mechanism and in the application of lubrication practices are considered within the context of a binary mixture theory by Al.Sharif (1976) and Wang (1993).

The study of binary chemical reaction in a Micropolar fluid plays important role in nature and industrial applications. The theory of micro polar fluids has been an active area of research for several decades, because of its wide range of application in analyzing fluid flow in brain, exotic lubricants, blood flow in animals, cooling of metallic plate in a bath, solidification of liquid crystals, colloidal suspensions etc.Peddieson.et.al (1970) has investigated boundary layer theory for micropolar fluids. Peddieson.et.al (1972) has investigated the problem of plane or axisymmetric stagnation point flow of a micropolar fluid over a flat plate. Ariman et.al (1974) had given a comprehensive review of the existing theories of micro continuum fluid mechanics. Maiti(1975) reported convective heat transfer in micropolar fluid flow through a horizontal parallel plate channel. Ahmad (1976) investigated the boundary layer flow over a semi-infinite plate. Guram et.al(1979) investigated about three dimensional and axially symmetric steady flow of a micropolar fluid due to a rotating disc.Kummerer.et.al (1977) analyzed about similar laminar boundary layers incompressible micropolar fluids flow near a stagnation point. Guram et.al (1980) explained the plane and axially symmetric flow of micropolar fluids in contact with an infinite plate and tending to potential flow at infinity with a stagnation point on the plate. Guram et.al (1981) considered the steady laminar and incompressible flow of micropolar fluid due to a rotating disc with uniform suction and injection. Kumari et.al (1984) studied unsteady incompressible fluid at a stagnation point. Sankara (1985) studied the flow of an incompressible, constant density micropolar fluid past a stretching sheet and solved by globally convergent homotopy method. Heruska et.al (1986) discussed the incompressible micropolar fluid flow past a porous stretching sheet. In which, numerical solution are obtained from quasi-Newton Algorithm and solved by homotopy method. Jena.et.al (1987) investigated laminar free convective boundary layer flow of a thermo micropolar fluid past a non-isothermal vertical flat plate. It is noticed that the similarity solution are obtain when the variation in the temperature of the plate is a linear function of the distance from the leading edge measured along the plate.

 DOI : 10.18231/2454-9150.2018.1100

Siddheshwar et.al (1999) examined the influence of heterogeneous chemical reaction on the exchange coefficient, convective coefficient and diffusive coefficient arising in the study of dispersion in a micropolar fluid flow. Bhargava et.al (2003) presented finite element solutions for mixed convection micropolar flow drives by a porous stretching sheet with uniform suction. It is noticed from the graphical representation of velocity, microrotation and temperature that the micropolar fluids helps in the reduction of drag force and also act as a cooling agent. Kucaba-Pietal et.al (2004) studied the applicability of the theory of micropolar fluid to modelling and calculating flows in micro channels depending on the geometrical dimension to the flow field and poiseuille flows in a micro channel is discussed. Nazar et.al (2004) discussed steady two dimensional stagnation point flow of an incompressible micropolar fluid over a stretching sheet when the sheet is stretching in its own plate with the velocity proportional to distance from the stagnation point. Comparisons with previous results are made for viscous fluid. Seddeek et.al (2004) had examined the effect of various parameters of the problem for the boundary layer analysis of the hall and ion-slip currents on the steady magneto-micropolar of a viscous incompressible and electrically conducting fluid over a horizontal plate. The numerical solutions are obtained by shooting method. Hazem (2006) studied laminar flow in a porous medium of an incompressible non Newtonian micropolar fluid of an incompressible non permeable flat plate with heat transfer analysis. The variation of porosity medium is presented graphically. Rahman et.al (2009) investigated the effect of the fluid electric conductivity and non-uniform heat source(or sink) on two dimensional steady hydromagnetic convective flow of a micropolar fluid with comparison of Newtonian fluid flowing along an inclined flat plate with a uniform surface heat flux. Ishak et.al (2009) analysed a steady laminar magneto hydrodynamics boundary layer flow past a wedge with constant surface heat flux immersed in an incompressible micropolar fluid in the presence of a variable magnetic field. Khedr et.al (2009) investigated in the presence of temperature dependent heat generation or absorption, magnetic field and thermal radiation effects. Chen.et.al (2010) formulated MHD fundamentals and proposes a numerical scheme integrating chorins projection method and time centred split method (TCSM) for solving unsteady forms of MHD equations. Pal.et.al (2010) studied a mathematical analysis for a MHD boundary layer flow heat and mass transfer characteristic on steady two dimensional flow of a micropolar fluid over a stretching sheet embedded in a non-Darician porous medium with uniform magnetic field.

Nadeem et.al(2010) investigated the effect of MHD and porous medium, non-dimensional velocity and micro rotation for unsteady MHD boundary layer flow of a micropolar fluid near the forward stagnation point of a two dimensional plane surface using similarity transformation. Ariful.et.al (2011) has performed to evaluate the MHD micropolar fluid flow through a vertical porous plate. Finite difference technique is used as a tool for numerical approach. Islam.et.al (2011) examined MHD micropolar fluid flow through a vertical porous plate. Finite difference technique is as a tool for the numerical approach. The influence on the velocity, micro rotation the spin gradient viscosity and vortex viscosity of various parameters are discussed graphically. Jain (2011) presented on micropolar fluid flow on heat transfer fluid mechanics and thermodynamics. Jat et.al (2012) studied MHD stagnation point flow and heat transfer of a micropolar fluid in a porous medium. Asraf et .al(2012) analyzed MHD flow heat transfer of micropolar fluid between two porous disk. The influence of the Reynolds number, the magnetic parameter, the micropolar parameter and the prandtl number in the flow of velocity and temperature distribution are discussed. Muhammad Qasim.et.al(2013) discussed the steady flow of micropolar fluid over a stretching surface with heat transfer in the presence of Newtonian heating. Ayano(2013) presented mixed convection flow of an incompressible micropolar fluid along a semi-infinite vertical plate with uniform heat and mass flux in presence of transverse magnetic field. An investigation on chemical reaction and Arrhenius energy of unsteady MHD free convection heat and mass transfer boundary layer incompressible fluid flow past a vertical porous plate in the presence of viscous dissipation, heat generation/absorption presented by Abdul Maleque et al(2013). Mekheimer et.al (2014) had carried out the variation of the pulsatile flow on peristaltic motion of an incompressible conducting micropolar fluid through porous medium in a channel bounded by flexible walls. Numerical calculations are done for the pressure rise and friction force on the wall. Ojjela.et.al (2014) investigated an incompressible two dimensional heat and mass transfer of an electrically conducting micropolar fluid flow in a porous medium between two parallel plates with chemical reaction. Olajuwon.et.al (2014) discussed the convective heat and mass transfer in a hydromagnetic flow of a micropolar fluid over a porous medium by using Perturbation. An unsteady flow over a stretching surface in an incompressible rotating viscous fluid in presence of binary chemical reaction and Arrhenius activation energy had presented by Faiz.et al (2014). Ojjela.et.al(2015) investigated an incompressible two dimensional MHD flow and heat transfer of an electrically conducting micropolar fluid between parallel porous plates. Mekonnen.et.al(2015) discussed unsteady in compressible electrically conducting micropolar fluid between parallel plates when one plate is moving with constant velocity in the presence of transverse magnetic field. Rout et.al(2016) has studied the analysis of the chemical reaction on a boundary layer flow of an electrically conducting micropolar fluid subject to

 DOI : 10.18231/2454-9150.2018.1100

transverse magnetic field along a vertical plate with variable wall temperature and concentration. Muhammad Ramzan.et.al(2017) studied the flow of micropolar nanofluid due to a rotating disk in the presence of magnetic field and partial slip condition. Ordinary differential equations are numerically solved by using maple Dsolve command and Runge Kutta fourth-fifth Fehlberg techniques. A comparison with previous study is made for different values of parameters. Dar.et.al(2017) presented the effect of magnetic field ,thermal radiation and joule heating the on the momentum and thermal transport characteristic of the steady electro-osmotic flow of micropolar fluid through the porous micro channel of constant heat flux at the wall. Analytical solutions are obtained for micro rotation, temperature profiles mean fluid temperature and fully developed Nusselt number. The Variation in internal heat generation/absorption, viscous and ohmic dissipations, effects of binary chemical reaction and activation energy on steady two-dimensional radiative MHD boundary-layer flow of a viscous, incompressible, electrically conducting nanofluid over a vertical plate is discussed by Anuradha.et al(2017). A two dimensional convection slip flow of nanofluid over a stretching sheet with binary chemical reaction and activation energy had analyzed by Anuradha et al(2017). Analysis of Arrhenius activation energy in MHD carreau fluid flow through improved theory of heat diffusion and binary chemical reaction is studied by Kiran Kumar et al (2018).By motivation the above studies, boundary layer stagnation point flow of Micropolar fluid with binary chemical reaction have investigated in this paper.

II. MATHEMATICAL FORMULATION

The steady two dimensional incompressible flows on a micro polar fluid with binary chemical reaction over an exponentially stretching sheet has considered in this paper. Assume that the stretching velocity is in exponential form as $U_w = ae^{x/L}$ with a>0 where a is a stretching constant. The equation of continuity, Momentum equation, Angular Momentum equation, Energy equation and Concentration equation for the micro polar fluid can be written as by using the boundary layer approximation.

Continuity Equation:

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

Momentum Equation:

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

Angular momentum Equation:

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

Energy Equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial x}=\frac{k^*}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{\rho c_p}{\rho c_f}\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] \tag{4}$$

Concentration Equation:

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}+w\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial z^2}-k_r^2(\frac{T}{T_\infty})^n Exp(\frac{-Ea}{kT})(C-C_\infty) \tag{5}$$

Subject to the boundary condition

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

In this mathematical formulation, u and v denote the velocity components in x and y directions respectively. υ, μ, ρ , N, j , γ , k, k^* , c_p , T_0, T_∞ k_r^2 , E_a , κ = 8.61x10^{-5}eV/K are the variables which denote kinematic viscosity, dynamic viscosity, density, micro-rotation, micro inertia per unit mass, spin gradient viscosity, vortex viscosity, thermal conductivity of the fluid, the specific heat, constant temperature increment along the sheet, free stream temperature assumed to be constant, the reaction rate, the activation energy , Boltzmann constant and n fitted rate constant which generally lies in the range -1 < n < 1 respectively.

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

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

The Cauchy Riemann equations with following similarity transformation are introduced.

$$u=\frac{\partial\psi}{\partial y},v=-\frac{\partial\psi}{\partial x} \tag{8}$$

$$u=ae^{\frac{x}{L}}f'(\eta),v=-(\frac{\upsilon a}{2L})^{1/2}e^{\frac{x}{2L}}(f(\eta)+\eta f'(\eta)),N=a(\frac{a}{2\upsilon L})^{1/2}e^{\frac{3x}{2L}}M(\eta)$$

$$\theta=\frac{T-T_\infty}{T_W-T_\infty},\eta=(\frac{a}{2\upsilon L})^{1/2}e^{\frac{x}{2L}}y,\varphi=\frac{C-C_\infty}{C_w-C_\infty} \tag{9}$$

By using equations (8) and (9), the nonlinear partial differential equations (2) to (5) had transformed into the following ordinary differential equation with non-dimensional variables are as follows:

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

$$M''+\frac{1}{\Lambda}(fM'-3f'M)-\frac{K\chi}{\Lambda\,\mathrm{Re}}(2M+f'')=0 \tag{11}$$

$$\theta''+\Pr(f\theta'-2f'\theta)+Nb\theta'\phi'+Nt\theta'^2=0 \tag{12}$$

$$\phi''+\Pr Le\left(-2f'\varphi+f\varphi'\right)+\frac{Nt}{Nb}\theta''-Le\sigma(1+\delta\theta)^n\varphi e^{\left(-\frac{E}{1+\delta\theta}\right)}=0 \tag{13}$$

And the reduced boundary conditions becomes

 DOI : 10.18231/2454-9150.2018.1100

ISSN : 2454-9150 Vol-04, Issue-08, Nov 2018

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

Where non-dimensional parameters with respect to η are

$K=\dfrac{k}{\mu}$ = Micropolar parameter, $\Pr=\dfrac{\upsilon}{\alpha}$ = Prandtl number, $\mathrm{Re}=\dfrac{LU_\infty}{2\upsilon}$ = Non-similar Reynolds number, $Le=\upsilon/D_B$ = the Lewis number,

$Nb=D_B\dfrac{\rho c_p}{\rho c_f}\dfrac{(C_w-C_\infty)}{\upsilon}$ = Brownian motion parameter , $Nt=\dfrac{D_T}{T_\infty}\dfrac{\rho c_p}{\rho c_f}\dfrac{(T_w-T_\infty)}{\upsilon}$ = thermophoresis parameter, Temperature difference parameter= $\delta=\dfrac{T_w-T\infty}{T\infty}$, Dimensionless reaction rate $=\sigma=\dfrac{K_r^2}{c}$, Non-dimensional energy = $E=\dfrac{E_a}{\kappa T}$

III. RESULTS AND DISCUSSION

In this paper, mathematical equations have formulated for continuity, momentum, angular momentum, temperature and concentrations profiles and the similarity transformation has applied to transform the governing partial differential equations into system of boundary layer equations and then solved numerically by Mathematica software. In order to study the physical characteristics of non-dimensional parameters such as Micropolar parameter K, Prandtl number Pr, Non-similar Reynolds number Re, Lewis number Le, Brownian motion parameter Nb, thermophoresis parameter Nt, Temperature difference parameter δ , Dimensionless reaction rate σ , Non-dimensional energy E on velocity, microrotation, temperature and concentration profiles analyzed with the help of graphs.

Figures.1 and 2 illustrate the effect of the Micro polar parameter (K) on the velocity profile and microrotation profile. Increasing values of Micro polar parameter (K) decrease the velocity profile, whereas the microrotation profile increases with an increasing value of Micropolar parameter (K). Figure 3 captured the effect of Non-similar Reynolds number (Re) on microrotation profile. It is observed that increasing values of Non-similar Reynolds number Re enhances the microrotation profile. The behavior of temperature profile of micropolar fluid against the Prandtl number has been demonstrated in the figure 4.

Figure 5 and 6 presented the effect of Brownian parameter (Nb) on temperature profile and concentration profile respectively. Increasing Brownian parameter increase temperature profile which thickens the boundary layer and it decreases the concentration profile.

The influence of thermophoresis parameter (Nt) on the temperature profile and concentration profile are displayed in Figure 7 and 8. It is observed that enhancement in thermophoresis parameter (Nt) increase temperature profile and concentration profile.

Figures 9 to 12 demonstrate the effect of different non-dimensional binary chemical parameters on concentration profile. Activation Energy E increases the concentration profile. The increasing non-dimensional parameters Lewis number Le, Temperature difference parameter δ , Dimensionless reaction rate σ decrease the concentration profile.

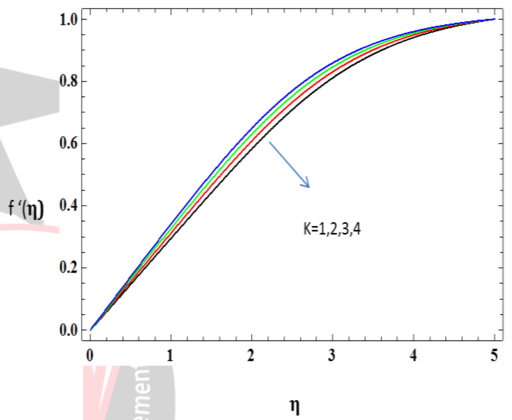

Figure.1.Influence of Micropolar parameter (K) on Velocity Profile ε = 0.5, Λ =1, Re = 1, n = 0.5, ξ = 1,Nt= 0.2,Nb=0.7,E=0.25,Le =1, δ=0.1

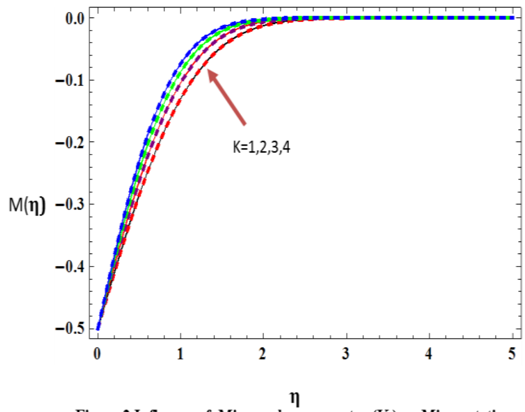

Figure.2.Influence of Micro polar parameter (K) on Microrotation Profile ε = 0.5, Λ =1, Re = 1, n = 0.5, ξ = 1,Nt= .2,Nb=0.7,E=0.25, Le =1, δ=0.1

DOI : 10.18231/2454-9150.2018.1100

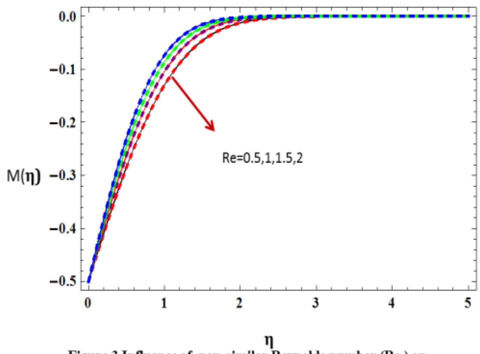

Figure.3.Influence of non-similar Reynolds number (Re) on Microrotation Profile ε = 0.5, K = 1, n = 0.5, ξ = 1, Nt=0.2,Nb=0.7,E=0.25, Le =1, δ=0.1, Λ =1

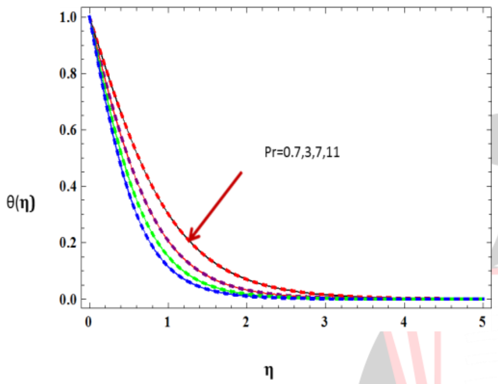

Figure.4.Influence of Prandtl number (Pr) on Temperature Profile ε = 0.5, Λ =1, Re = 1, n = 0.5, ξ = 1, Nt=0.2,Nb=0.7,E=0.25, Le =1, δ=0.1

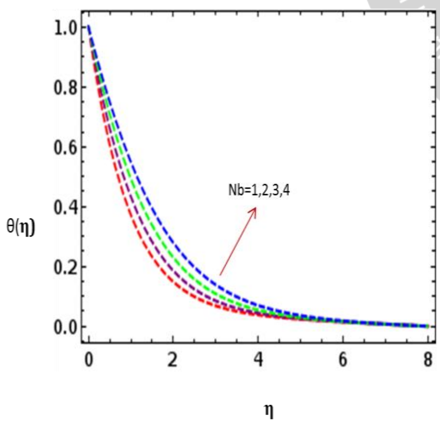

Figure.5.Influence of Brownian parameter (Nb) on Temperature Profile ε = 0.5, Λ =1, Re = 1, n = 0.5, ξ = 1, Nt=0.2,Pr=0.7,E=0.25, Le =1, δ=0.1

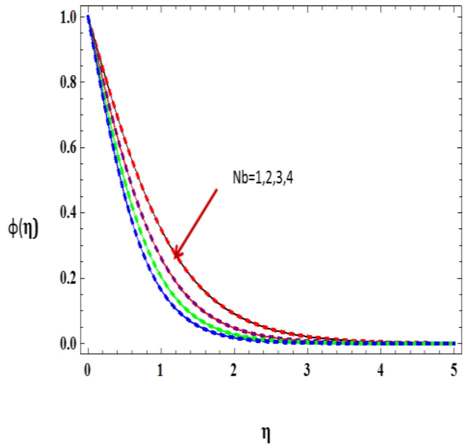

Figure.6.Influence of Brownian parameter (Nb) on Concentration Profile ε = 0.5, Λ =1, Re = 1, n = 0.5, ξ = 1, Nt=0.2,Pr=0.7,E=0.25, Le =1, δ=0.1

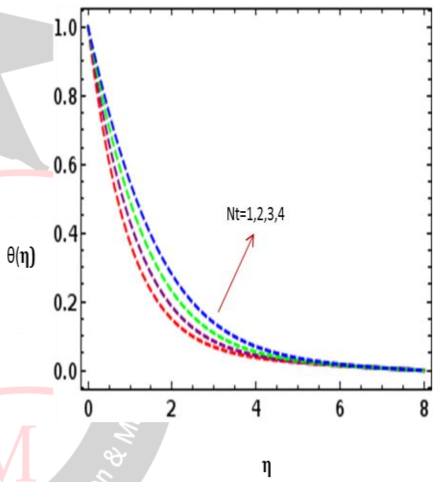

Figure.7.Influence of Thermophoresis parameter (Nt) on Temperature Profile ε = 0.5, Λ=1, Re = 1, n = 0.5, ξ = 1, Nt=0.2,Pr=0.7,E=0.25, Le =1, δ=0.1

 DOI : 10.18231/2454-9150.2018.1100

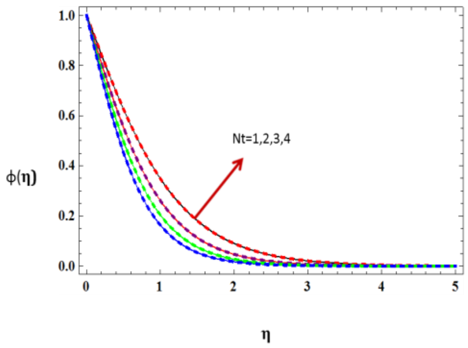

Figure.8.Influence of Thermophorsis parameter (Nt) on Concentration Profile $\varepsilon = 0.5$, $\Lambda = 1$, Re = 1, n = 0.5, $\xi = 1$, Nt=0.2,Pr=0.7,E=0.25, Le =1, δ=0.1

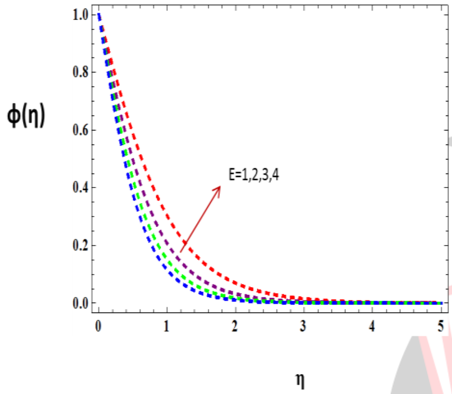

Figure.9.Influence of non-dimensional energy (E) on concentration Profile $\varepsilon = 0.5$, =1, Re = 1, n = 0.5, Nt=0.2,Pr=0.7, Le =1, δ=0.1

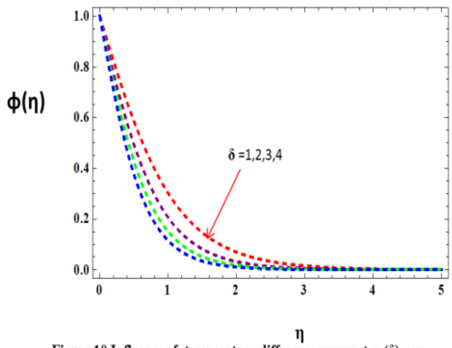

Figure.10.Influence of temperature difference parameter (δ) on concentration Profile $\varepsilon = 0.5$, =1, Re = 1, n = 0.5, Nt=0.2,Pr=0.7, Le =1, Nb=0.1

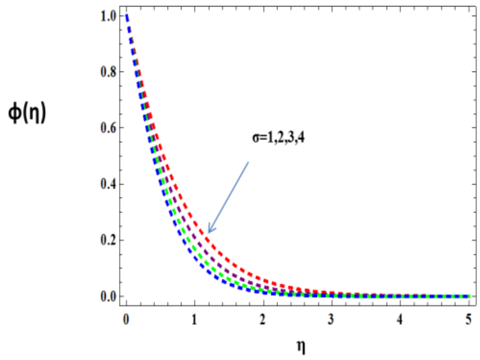

Figure.11.Influence of reaction rate (σ) on concentration Profile $\varepsilon = 0.5$, Λ =1, Re = 1, n = 0.5, Nt=0.2,Pr=0.7, Le =1, Nb=0.1

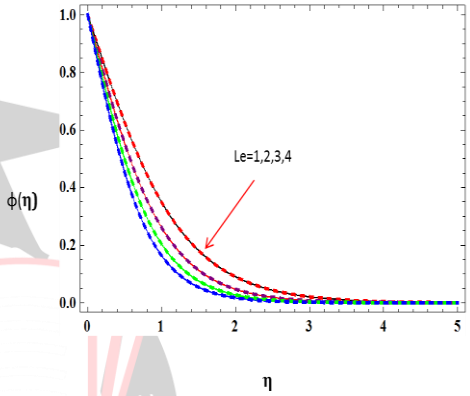

Figure.12.Influence of Lewis number (Le) on Concentration Profile $\varepsilon = 0.5$, Re = 1, n = 0.5, Λ= 1, Nt=0.2,Pr=0.7,E=0.25, Le =1, δ=0.1, ξ=1,

IV. CONCLUSION

In the present study, we have considered the problem of Micropolar fluid stagnation point flow through an exponentially stretching sheet with binary chemical reaction and the effect of non-dimensional parameters involved in the problem has investigated through graphs numerically. The conclusions are as follows:

- Increasing values of Micro polar parameter (K) decrease the velocity profile, whereas the microrotation profile increases with an increasing value of Micropolar parameter (K).
- Increasing values of Non-similar Reynolds number Re enhances the microrotation profile.
- Increasing Brownian parameter increase temperature profile which thickens the boundary layer and it decreases the concentration profile.
- Enhancement in thermophoresis parameter (Nt) increase temperature profile and concentration profile.

 DOI : 10.18231/2454-9150.2018.1100

- Activation Energy E increases the concentration profile. The increasing non-dimensional parameters Lewis number Le, Temperature difference parameter δ , Dimensionless reaction rate σ decrease the concentration profile.

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