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Investigation on MHD radiative flow of Powell-Eyring Nanofluid through non-linear stretching sheet

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Abstract

In this Article, We have considered the Powell-Eyring nanofluid over a nonlinear stretching sheet with variable thickness. Powell-Eyring nanofluid MHD boundary layer system has been modelled to form continuity equation, momentum equation, energy equation and concentration equation. The governing boundary layer Powell-Eyring flow equations can be transformed into ordinary differential equations by similarity transformations. Then reduced ODE equations under the boundary condition are solved by implicit finite difference scheme. In order to study the physical characteristics of non-dimensional parameters such as Magnetic parameter (M), thickness parameter (α), fluid parameters (λ) and (N), Thermophoresis parameter (Nt), Brownian motion parameter (Nb), Radiation parameter (R), Prandtl number (Pr), Lewis number (Le), nonlinear stretching parameter (n) on the velocity, temperature and concentration profiles of Powell-Eyring nanofluid analyzed and discussed with the help of graphical results.
Keywords - MHD, Nanoparticle, Powell- Eyring fluid, stretching sheet, Variable thickness.

1.Introduction

MHD boundary layer flow of Powell-Eyring nanofluid in a stretching sheet have been investigated by many researchers during the past few decades owing their numerous applications in industrial manufacturing, for example, drawing of plastic films, artificial fibres, wire drawing, glass fibre, and so on. With attention to the many more application of nanofluids, the researchers have been regard to improve heat transfer using nanofluids.

Patel and Timol (2009) investigated themethod of asymptotic boundary conditions for Powell-Eyring fluid. Nadeem et al.(2013) examined the boundary layer flow and heat transfer of oldroyd-B nanofluid towards a stretching sheet by the solution of numerical study. Anwar et al. (2013) explored the MHD stagnation-point flow of a nanofluid over a porous sheeton chemical reaction and uniform heat generation or absorption effects. Jalil et al. (2013) discussed the heat transfer flow of Powell-Eyring fluid over a moving surface in a parallel free stream. Ganesh et al.(2014) analysed the magnetic field effects on free convective flow of a nanofluid over a semi-infinite stretching sheet. Araa et al.(2014) studied theEyring-Powell fluid over an exponentially shrinking sheeton boundary layer flow of Radiative effect. Numerical and analytical solution for the MHD Eyring-Powell nanofluid flow of mixed convection boundary layer flow and axisymmetric flow of nanofluid due to non-linearly stretching sheet can be found in (2015). Das (2015) studied the Nanofluid flow over a non-linear permeable stretching sheet with partial slip. Govindaraju et al. (2015) examined the Entropy generation analysis of MHD flow of a nanofluid over a stretching sheet. Ali et al.(2015) explored the heat and mass transfer flow over an inclined stretching sheet with viscous flux dissipation and constant heat flux in presence of magnetic field. Raju et al.(2015) presented the Radiation, inclined magnetic field and cross-diffusion effects on flow over a stretching surface. Gireesha et al.(2015) analysed the three-dimensional MHD Eyring- Powell fluid flow of heat and mass transfer forradiating effectsuspended nanoparticles over a stretching sheet. Akbar et al.(2015) examined the Eyring-Powell fluid flow on magnetic field effect towards

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a stretching sheet. Ibrahim (2015) presented the convective boundary condition for a nonlinear radiative heat transfer in MHD stagnation point flow of nanofluid past a stretching sheet. Daniel (2015) analysed the MHD flow over a stretching porous sheet of buoyancy effect and thermal radiation by using the method of homotopy analysis. Ravindran et al. (2015) investigated the chemical reaction and heat generation of unsteady mixed convection flow over a stretching sheet in presences of absorption with non-uniform slot suction or injection. Hayat et al.(2015) presented the comparison of series of Eyring-Powell fluid with Newtonian heating and internal heat generation and it is solved numerically. Sulochana et al.(2016) studied the three dimensional Cassonnanofluid flow over a stretching sheet with convective boundary conditions. Sandeep et al.(2016) analysed the MHD dusty nanofluid radiative flow and unsteady heat transfer over an exponentially stretching surface. Naramgari et al. (2016) presented the MHD flow over a permeable stretching/shrinking sheet of a nanofluid with suction. Dhanai et al. (2016) explored MHD mixed convection nanofluid flow and heat transfer over an inclined cylinder due to velocity and thermal slip effects. Hayat et al.(2016) studied the Eyring-Powell fluid flow with the soret and dufour effects in the influence of thermal radiation and joule heating. Rehman et al.(2016) presented the Eyring-Powell fluid over an inclined stretching cylinder with heat generation effecton dual stratified mixed convection flow. Malik et al. (2016) analysed the MHD flow in variable and viscosity of Casson fluid with Cattaneo-Christov heat flux model by using Keller box method.Khan et al.(2016) numerically investigated the squeezed flow of Carreau fluid with heat transfer variable on thermal conductivity over a sensor surface. Nayak et al.(2016) explores MHD viscoelastic fluid over a stretching sheet through porous medium of heat and mass transfer effects in presence of chemical reaction. Reddy (2016) studied the thermal radiation and chemical reaction on MHD flow of a Casson fluid over an exponentially inclined permeable stretching surface. Malik and Rehman (2016) discussed the MHD free convection dissipative fluid flow past an inclined porous surface by way of heat generationeffects on second order chemical reaction. Rehman et al.(2017) presented the dual stratified stagnation point MHD mixed convection flow of Eyring-Powell fluid induced by an inclined cylindrical stretching surface of Logarithmic and parabolic curve fitting analysis. Khan et al.(2017) analysed the MHD flow of Powell-Eyring fluid over a stretching sheet with Newtonian heating homogenousheterogeneous reactions. Rehman and Malik (2017) examined the MHD mixed convection flow of non-Newtonian fluid over an inclined stretching cylinder which is thermally stratified. Khan et al.(2017)presented the physical study of nanoparticles in non-Newtonian liquid in the presence of chemically reactive species through parabolic approach. Rehman et al. (2017) investigated the non-Newtonian fluid model of Thermo physical aspects of stagnation point magneto nanofluid flow yields by an inclined stretching cylindrical surface and parabolic curve fitting study of Joule heating in MHD mixed convection stagnation point flow of Eyring-Powell fluid induced by an inclined cylindrical. Salahuddin et al. (2017) examined the nanofluid impinging on a stretching cylinder near the stagnation pointanalysis of tangent hyperbolic. The main motivation of present investigation is to analyze the characteristics of MHD flow of Powell-Eyring nanofluid through stretching sheet with variable thickness, Radiative heat flux and nth order chemical reaction.

2. Mathematical Formulation

Let us consider the Powell-Eyring nanofluid over a nonlinear stretching sheet with variable thickness. Powell-Eyring nanofluid MHD boundary layer system has been modeled to form continuity equation, momentum equation, energy equation and concentration equation. A Cartesian coordinate system is chosen that x-axis is considered along the direction of the sheet and y-axis is considered along normal to it. Assume non-linear stretching surface velocity is $U_w = U_0(x+b)^n$ where U_0 = initial velocity and b = constant, and nonlinear stretching surface variable is at $y = A(x+b)^{\frac{1-n}{2}}$. If n=1, stretching surface has the same thickness.A non-uniform magnetic field is as $B(x) = B_0(x+b)^{\frac{n-1}{2}}$. Induced magnetic and electric field are not taken into account.

The governing equations are given as follows

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \left(\nu + \frac{1}{\rho\beta d}\right)\frac{\partial^2 u}{\partial y^2} - \frac{1}{2\rho\beta d^3}\left(\frac{\partial u}{\partial y}\right)^2\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B^2(x)}{\rho}u \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_{nf}\frac{\partial^2 T}{\partial y^2} + \tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) - \frac{\partial q_r}{\partial y}\frac{1}{\rho c_p} + \frac{Q_0}{\rho c_p}(T - T_\infty) \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}-Kr(C-C_\infty)^n \quad (4)$$

By Rosseland approximation, the Radiative flux is follows

$$q_r=\frac{-4\sigma}{3k^*}\left(\frac{\partial T^4}{\partial y}\right) \quad (5)$$

By assuming very small temperature differences within the flow, T^4 expressed in terms of linear combination of temperature and expand T^4 about T_∞ in Taylor's series and neglecting higher order terms yields:

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \quad (6)$$

By (6),

$$\frac{\partial q_r}{\partial y}=-\frac{16\sigma^*T_\infty^3}{3k_0}\frac{\partial^2 T}{\partial y^2} \quad (7)$$

Using the equations (5) and (6), the equation (3) can be written as follows

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}+\tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right)+\frac{16\sigma^*T_\infty^3}{3k_0\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{Q_0}{\rho c_p}(T-T_\infty) \quad (8)$$

Follow with the boundary conditions:

$$u=U_w(x)=U_0(x+b)^n, v=0, T=T_w, D_B\frac{\partial C}{\partial y}+\frac{D_T}{T_\infty}\frac{\partial T}{\partial y}=0 \text{ at}$$

$$y=A(x+b)^{\frac{1-n}{2}} \quad (9)$$

$$u\to 0, v\to 0, T\to T_\infty, C\to C_\infty \text{ as } y\to\infty \quad (10)$$

Where k = thermal conductivity, $\alpha_{nf}=\frac{k}{(\rho c)_f}$ the thermal diffusivity of liquid, μ = Dynamic viscosity, $v=\frac{\mu}{\rho}$ =kinematic viscosity, ρ = the fluid density, τ =Ratio of the heat capacity of fluid of the nanoparticles material to the effective heat capacity of the base fluid,

D_B = Brownian diffusion coefficient, D_T = Thermophoretic Diffusion

The corresponding similarity transformations are as follows:

$$u=U_0(x+b)^nF'(\eta), v=-\sqrt{\left(\frac{n+1}{2}\right)vU_0(x+b)^{n-1}}\left[F(\eta)+\eta F'(\eta)\left(\frac{n-1}{n+1}\right)\right]$$

$$\eta=y\sqrt{\left(\frac{n+1}{2}\right)\frac{U_0(x+b)^{n-1}}{v}}, \Theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}, \Phi(\eta)=\frac{C-C_\infty}{C_\infty} \quad (11)$$

Using (7), the equations (2), (8), (6) becomes

$$(1+N)F'''+FF''-\left(\frac{2n}{n+1}\right)F'^2-N\left(\frac{n+1}{2}\right)\lambda F''^2F'''-\left(\frac{2n}{n+1}\right)M^2F'=0 \quad (12)$$

$$\frac{1}{\Pr_{eff}}\Theta''+F\Theta'+N_b\Theta'\Phi'+N_t\Theta'^2+Q\Theta=0 \quad (13)$$

$$\Phi''+\Pr LeF\Phi'+\left(\frac{N_t}{N_b}\right)\Theta''-K\Phi^n=0 \quad (14)$$

By using (7), reduced boundary conditions are

$$F(\alpha)=\alpha\left(\frac{1-n}{1+n}\right), F'(\alpha)=1, \Theta(\alpha)=1, \Phi'(\alpha)+\left(\frac{N_t}{N_b}\right)\Theta'(\alpha)=0 \quad (15)$$

$$F'(\infty)\to 0, \Theta(\infty)\to 0, \Phi(\infty)\to 0 \quad (16)$$

Where $\alpha=A\sqrt{\left(\frac{n+1}{2}\right)\frac{U_0}{v}}$ = wall thickness parameter= the plate surface.

Taking

$F(\eta)=f(\eta-\alpha)=f(\zeta), \Theta(\eta)=\theta(\eta-\alpha)=\theta(\zeta)$,

$\Phi(\eta)=\phi(\eta-\alpha)=\phi(\zeta)$.

Equations (12) -(16) are as follows:

$$(1+N)f'''+ff''-\left(\frac{2n}{n+1}\right)f'^2-N\left(\frac{n+1}{2}\right)\lambda f''^2f'''-\left(\frac{2n}{n+1}\right)M^2f'=0 \quad (13)$$

$$\frac{1}{\Pr_{eff}}\theta''+f\theta'+N_b\theta'\phi'+N_t(\theta')^2+Q\theta=0 \quad (14)$$

$$\phi''+\Pr Lef\phi'+\left(\frac{N_t}{N_b}\right)\theta''-K\phi^n=0 \quad (15)$$

$$f(0)=\alpha\left(\frac{1-n}{1+n}\right), f'(0)=1, \theta(0)=1, \phi'(0)+\left(\frac{N_t}{N_b}\right)\theta'(0)=0$$

$$f'(\infty)=0, \theta(\infty)=0, \phi(\infty)=0 \quad (16)$$

The dimensionless parameters are

$$\Pr=\frac{v}{\alpha_f}, M^2=\frac{\sigma B_0^2}{\rho U_0}, N=\frac{1}{d\beta\mu}, \lambda=\frac{U_0^3}{4d^2v}(x+b)^{3n-1},$$

$$Le=\frac{\alpha_f}{D_B}, N_b=\tau\frac{D_BC_\infty}{v}, N_t=\tau\frac{D_T(T_w-T_\infty)}{vT_\infty}, \Pr_{eff}=\frac{\Pr}{\left(1+\frac{16R}{3}\right)} \quad (17)$$

Where Pr= Prandtl number, M =Magnetic parameter, N and λ = fluid parameters,

Le = Lewis number, N_b = Brownian motion parameter, N_t = thermophoresis parameter

3.Results and Discussions

The governing boundary layer Powell-Eyring flow equations can be transformed into ordinary differential equations by similarity transformations. Then the equations (13) to (15) under the boundary condition (16) solved by implicit finite difference scheme. In order to study the physical characteristics of non-dimensional parameters such as Magnetic parameter (M), thickness parameter (α),fluid parameters(λ) and (N), Thermophoresis parameter (Nt), Brownian motion parameter (Nb), Radiation parameter (R),

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Prandtl number(Pr), Lewis number(Le), nonlinear stretching parameter(n) on the velocity, temperature and concentration profiles of Powell-Eyring nanofluid analyzed and discussed with the help of graphical results.

Figures 1-15 investigated the novel characteristics of non-dimensional parameters on velocity profile, concentration profile and temperature profile respectively. Figure 1 demonstrates the behaviour of velocity profile for various values of Magnetic parameter M. Increasing values of magnetic parameter M decrease the velocity profile. Figure 2 explores the effect of thickness parameter α on velocity profile. Enhancing the values of thickness parameter reduces the velocity profile. Figure 3 and 4 show the characteristic of fluid parameters λ and N. Larger values of fluid parameter λ diminishes the velocity profile and velocity profile enhances by increasing values of fluid parameter N. Figure 5 examined the characteristics of non-linear stretching sheet parameter n. Increasing values of n increase the velocity profile.

Figures 6-11 display the dimensionless temperature field for different non-dimensional parameters Magnetic parameter M, thickness parameter α, Thermophoresis parameter Nt, Brownian motion parameter Nb, Radiation parameter R, Prandtl number Pr. Figure 6 depicts that temperature profile increases by increasing values of magnetic parameter. It canbe noticed that increasing values of thickness parameter α diminishes the temperature profile in figure 7. Also figures 8 and 9 explain the variations of Thermophoresis parameter Nt and Brownian motion parameter Nb. The influence of Thermophoresis parameter Nt on temperature distribution increases when it rises and vice versa for the Brownian motion parameter Nb. In Figure 10, thermal boundary layer diminishes when Prandtl number increases. Increasing values of radiation parameter R increase the temperature distribution as shown in the figure 11.

Figures 12-16 demonstrates the behaviour of Concentration profile. Figure 12 explains that increment in magnetic parameter M increases the concentration profile. Figure 13 explores the influence of increasing Brownian motion parameter Nb on concentration profile. The concentration profile reduces with an increasing value of Brownian motion parameter Nb. An enhancing value of Thermophoresis parameter Nt increase the concentration profile in figure 14. Figure 15-16 display the concentration profile for various values of Prandtl number and Lewis number. Both non-dimensional parameters decrease the concentration distribution.

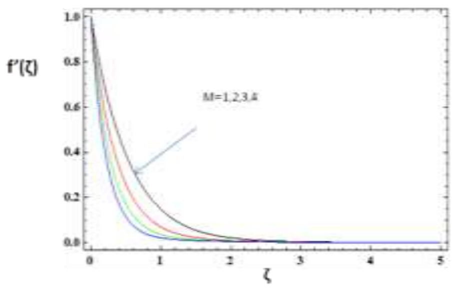

Figure.1.Influence of Magnetic parameter M on Velocity Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2, R=1

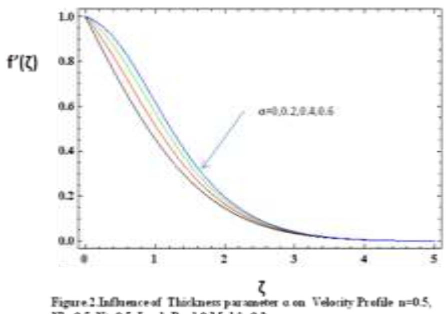

Figure.2.Influence of Thickness parameter α on Velocity Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, M=1, λ=0.2

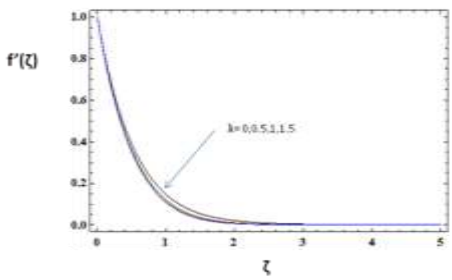

Figure.3.Influence of fluid parameter λ on Velocity Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, α=0.2

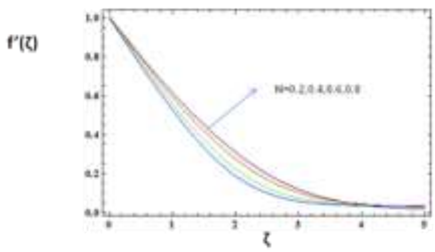

Figure.4.Influence of Fluid parameter N on Velocity Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

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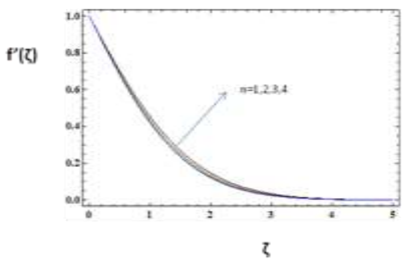

Figure.5.Influence of non-linear stretching parameter n on velocity Profile N=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

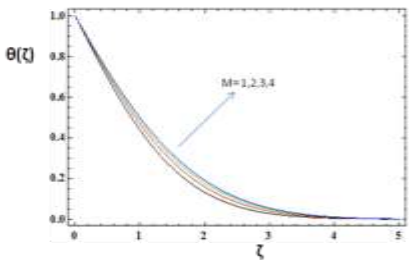

Figure.6.Influence of Magnetic parameter M on Temperature Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

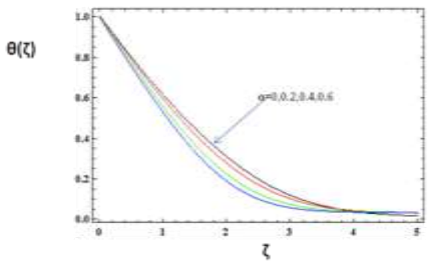

Figure.7.Influence of Thickness parameter λ on Temperature Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, M=0.2

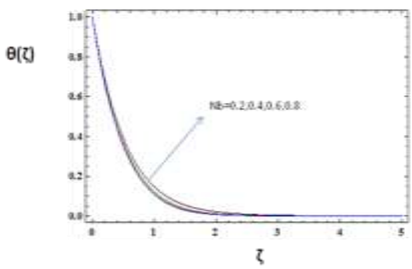

Figure.8.Influence of Brownian parameter Nb on temperature Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

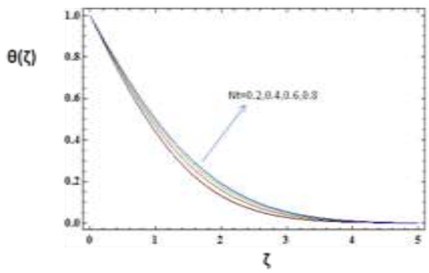

Figure.9.Influence of Thermophoresis parameter Nt on temperature Profile n=0.5, Nb=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

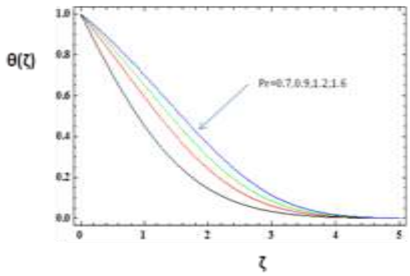

Figure.10.Influence of Prandtl number Pr on temperature Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, α=0.3, λ=0.2

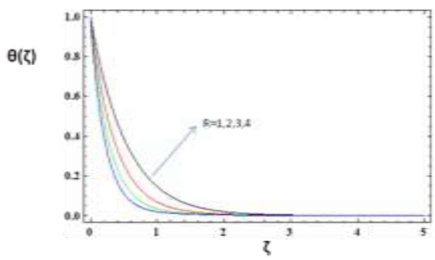

Figure.11.Influence of Radiation parameter R on temperature Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

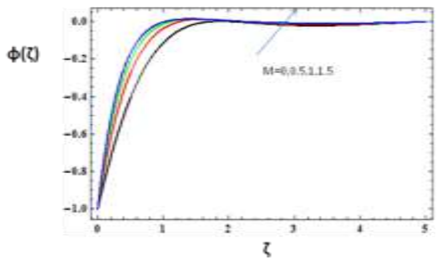

Figure.12.Influence of Magnetic parameter Nt on Concentration Profile n=0.5, Nb=0.5, Nt=0.5, Le=1, Pr=1.0, α=0.3, λ=0.2

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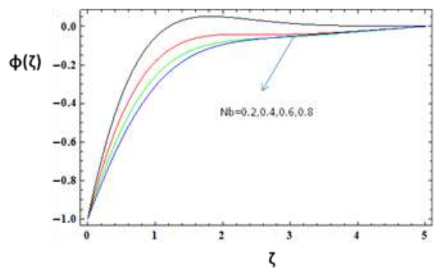

Figure.13.Influence of Brownian parameter Nb on Concentration Profile n=0.5, M=0.2,Nt=0.5, Le=1,,Pr=1.0,α=0.3,λ=0.2

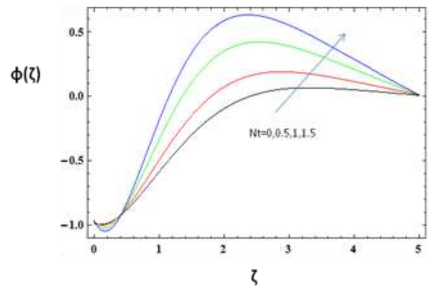

Figure.14.Influence of Thermophoresis parameter Nt on Concentration Profile n=0.5, Nb=0.5, Nt=0.5, Le=1,,Pr=1.0,α=0.3,λ=0.2

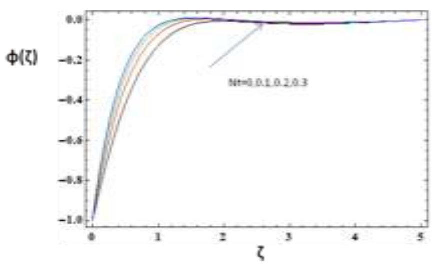

Figure.15.Influence of Thermophoresis parameter Nt on Concentration Profile n=0.5, Nb=0.5, Le=1,,Pr=1.0,α=0.3,λ=0.2

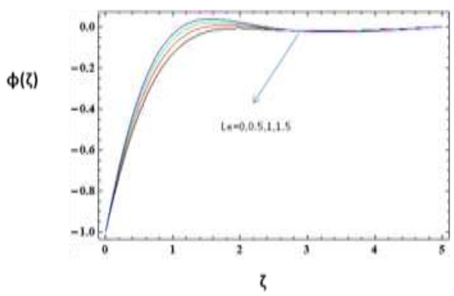

Figure.16.Influence of Lewis number on Concentration Profile n=0.5, Nb=0.5, Nt=0.5, Le=1,,Pr=1.0,α=0.3,λ=0.2

4.Conclusion

The impact of thermal radiation and nth order chemical reaction due to MHD Radiative Powell-Eyring fluid flow through non-linear stretching sheet with variable thickness have investigated in this Article. We conclude the main outcome of this investigation as follows:

- Increasing values of magnetic parameter M decrease the velocity profile.
- Enhancing the values of thickness parameter reduces the velocity profile.
- Larger values of fluid parameter λ diminish the velocity profile and velocity profile enhances by increasing values of fluid parameter N.
- Increasing values of n increase the velocity profile.
- It can be noticed that increasing values of thickness parameter α diminishes the temperature profile
- The influence of Thermophoresis parameter Nt on temperature distribution increases when it rises and vice versa for the Brownian motion parameter Nb.
- Increasing values of radiation parameter R increase the temperature distribution.
- Increment in magnetic parameter M increases the concentration profile.
- The influence of increasing Brownian motion parameter Nb on concentration profile.
- The concentration profile reduces with an increasing value of Brownian motion parameter Nb.
- An enhancing value of Thermophoresis parameter Nt increase the concentration profile
- Both non-dimensional parameters Prandtl number and Lewis number decrease the concentration distribution.

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