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Research Article

Heat Generation/Absorption Along With Suction/Injection Effects on Powell- Eyring Nanofluid Flow

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Abstract— In this study we investigated the magnetohydrodynamic (MHD) boundary layer flow of Powell-Eyring nanofluid over a non-linear stretched surface of adjustable viscosity. We considered an electrically conducting fluid with magnetic field applied transverse to the surface. The mathematical expressions are obtained by the boundary layer approximation with the help of the non- dimensional quantities. The flow exploration is exposed to a newly conventional boundary conditions which require zero nanoparticles mass flux. Acceptable transformations were employed to reduce the partial differential equations to some ordinary differential equations. Solutions of the governing non- linear flow of momentum, temperature and nanoparticles concentration have been executed in maple. Visual analysis of pertinent parameters is dispersed by graphical illustrations and tabular values. It is investigated that higher values of the suction and injection parameter results in the increase of Sherwood number distribution, which on the other hand decreases the temperature of the fluid. Effects of heat generation/ absorption parameter on temperature and concentration profiles are qualitatively similar. Both the temperature and concentration profiles are enhanced for higher values of the fluid parameter.

Keywords— Heat generation/absorption, Powell- Eyring, Variable thickness surface, Suction/injection.

1. Introduction

Nanofluids are the materials that consist of small quantities of nanometer-size particles, known as nanoparticles. Typically the nanoparticles are made of oxides like alumina, Titanium and copper oxide, carbides and metals including copper and gold. Diamond and Carbon nanotubes have also been utilized in nanofluids. These particles have ability to increase thermophysical properties of the base liquids. The base fluids include oil, ethylene glycol, water, bio fluids, polymer solutions and some lubricants. Furthermore, magnetic nanofluid is a single material having both the magnetic and liquid properties. Magnetic field interaction with nanofluids is useful to deal with the situations such as cooling of nuclear reactors via liquid sodium. The magneto nanofluids have remarkable involvement in nonlinear optical materials, optical switches, optical modulators, tunable optical fiber filters, magnetic resonance imaging, optical grating, blockage removal in the arteries, drug delivery and hyperthermia etc. Choi [1] was the first one who introduced this colloidal suspension. Buongiorno [2] studied the convective transport phenomena in nanofluid. He constructed a mathematical model to study the nanofluid flow comprising Brownian motion and thermophoretic dispersion of nanoparticles. The two dimensional stretched flow of nanofluid is conducted by Khan and Pop [3]. Makinde and Aziz [4] extended this analysis by considering convective boundary conditions. They demonstrated that convective heating significantly affects the thermal boundary layer. Having such facts in mind, many engineers and scientists are busy in the investigations of flows of nanofluid via various aspects. Few representative studies in this direction can be seen in the attempts (see [5- 13]. In real world, most of the fluids such as water, kerosene oil, ethylene, glycol, and others are poor conductors of heat due to their lower values of thermal conductivity. To cope up with this problem and to enhance the thermal conductivity or other thermal properties of these fluids, a newly developed technique is used which includes, addition of Nano-sized particles of good conductors such as copper, aluminum, Titanium, iron and other oxides to the fluids. (See [14, 15, and 16]). Here are some of the studies which are used in the applications of magneto-physiological flow devices and manufacture of electrically conducting bio-polymeric fluids. The Buongiorno's nanofluid flow with thermal radiation effect was presented by Tarakaramu et al. [17], Sudarsana et al [18]. The non-newtonian fluid flow over different physical aspects was developed by Hayat et al. [19], Sarojamma et al. [20], Mabood et al [21] and Hassan [22]. The non-newtonian fluid flow over a rotating disk was developed by Uma Devi and Mabood [23], Shehzad et al.

[24], Naz et al [25], Yadav [26]**.** The prime goal of Hussaini et al. [27] was to analyze the effect of Heat generation/absorption on an existing mathematical model.

Asghar et al. [28] analyzed the effects of heat generation and absorption, and the slip velocity through a vertically shrinking sheet. A two-dimensional magnetic nanofluid is numerically considered for convection. They considered Al_2O_3–Cu/water composite nanofluid, where water is deemed the base liquid and copper (Cu) and alumina (Al_2O_3) are the solid nanoparticles. Modern composite nanofluids improve heat transfer efficiency. Using the Tiwari-Das model, they examined the effects of the solid volume fraction of copper, heat generation/absorption, MHD, mixed convection, and velocity slip parameters on velocity and temperature distributions. Soliman et al. [29], studied a numerical estimation of the double-diffusive peristaltic flow of a non-Newtonian Sisko nanofluid through a porous medium inside a horizontal symmetric flexible channel under the impact of Joule heating, non- linear thermal radiation, viscous dissipation, and heat generation/ absorption in the presence of heat and mass convection, considering effects of the Brownian motion and the thermophoresis coefficients.

El-Arabawy [30] conducted an analysis to study the effect of suction and injection on the flow and heat transfer characteristics for a continuous moving plate in a micro polar fluid in the presence of radiation. The boundary layer equations are transformed to non-linear ordinary differential equations. Numerical results are presented for the distribution of velocity, micro rotation and temperature profiles within the boundary layer. The effects of varying the Prandtl number, the radiation parameter and porosity parameter are determined. The heat and mass transfer characteristics in boundary layer flow about a stretching sheet in a porous medium filled with TiO_2- water and Al_2O_3- water- based nanofluids, in the presence of internal heat generation or absorption and viscous dissipation with variable suction or injection effects is numerically studied by Kannan et al. [31]. The analysis of the features of nanoparticles in MHD flow of Powell-Eyring fluid over a stretching sheet with variable thickness, in which they considered the influences of Brownian motion and thermophoresis together with more realistic boundary conditions imposed at the boundary, the relevant mathematical formulation is established under boundary layer approach. They applied Homotopic technique for the convergent series solutions, Hayat et al. [32]. Alkinidri et al. [33] described the influence of mass and heat transfer on magnetohydrodynamic (MHD) bioconvective peristaltic transport of Powell- Eyring nanofluid through a curved channel with radius dependent magnetic field. Modified Darcy's, Ohmic heating, motile gyrotactic microorganism, thermal radiation, variable properties, Brownian and thermophoresis motion are also considered. Hussaini [34] discussed the effects of heat generation/absorption on MHD nanfluid flow over a stretching surface. He also discussed extensively on the influence of other parameters over the profiles of momentum, temperature, nanoparticle concentration as well as Nusselt number. He focused his study on the effects of heat generation/absorption, magnetic field, sun radiation and other parameters.

2. Methodology

We consider steady two-dimensional (2D) flow of an incompressible Powell-Eyring nanofluid over a non- linear stretchable sheet. The flow is bounded by a non- linear stretchable sheet. Brownian motion and thermophoresis effects are accounted. Convective heat and mass conditions are imposed at the boundary. It is further considered that the surface of the sheet is heated through the hot fluid having T_f, C_f as temperature and concentration respectively. Fluid is taken electrically conducted via non-uniform magnetic field B (x) in the y−direction (see Fig. 1). Effects of electric field and Hall current are neglected. Induced magnetic field is not considered subject to small magnetic Reynolds number. We adopt the Cartesian coordinate in such a manner that x−axis is taken along the stretching sheet and y−axis normal to the sheet. The sheet at y = 0 is stretched along the x−direction having velocity $u_w(x) = ax^n$ where a and n are the positive constants.

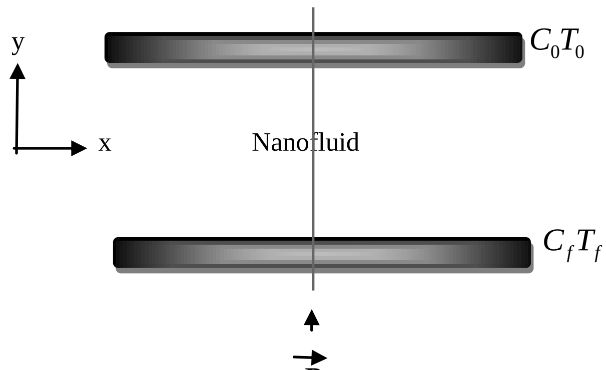

Figure 1: Geometry of the problem

The equations for two-dimensional (2D) boundary layer flow of Powell-Eyring nanofluid in the present situation are given as follows [32]:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left(v+\frac{1}{\rho\beta d}\right)\frac{\partial^2 u}{\partial y^2}-\frac{1}{2\rho\beta d^3}\left(\frac{\partial u}{\partial y}\right)^2\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2(x)}{\rho}u,=0 \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}+\tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right)+\frac{Q}{\rho_{nf}}\left(T-T_\infty\right)=0, \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial y^2}\right)=0, \quad (4)$$

Subject to the boundary conditions

$$u=U_w=U_0(x+b)^n, v=0, T=T_w, D_B\frac{\partial C}{\partial y}+\frac{D_T}{T_\infty}\frac{\partial T}{\partial y}=0, \ at \ y=A(x+b)^{\frac{1-n}{2}}, \quad (5)$$

$$u\to 0, v\to 0, T\to T_\infty, C\to C_\infty \ as\ y\to\infty, \quad (6)$$

Here u and v are the corresponding velocity components parallel to x- and y-directions respectively, $v=\frac{\mu}{\rho}$ designates the kinematic viscosity, ρ the fluid density, d and β are the material liquid parameters of Powell-Eyring model, σ is the electrical conductivity, B is the Magnetic field, ρ_{nf} is densisty of the nanofluid, α_{nf} is the for thermal diffusivity, n the thermal diffusivity of liquid, τ the ratio of the heat capacity of fluid of the nanoparticles material to the effective heat capacity of the base fluid, D_B indicates the Brownian diffusion coefficient, D_T represents the thermophoretic diffusion, Q denotes the Heat flow, T the temperature of the fluid, C the nanoparticles concentration, T_w and T_∞ are the sheet and ambient fluid temperatures and C_∞ the ambient fluid nanoparticles concentration. Transformations are expressed as follows [32]:

$$u=U_0(x+b)^n F'(\eta), v=-\sqrt{\left(\frac{n+1}{2}\right)vU_0(x+b)^{n-1}}\left[F(\eta)+\eta F'(\eta)\left(\frac{n-1}{n+1}\right)\right],$$
$$\eta=y\sqrt{\left(\frac{n+1}{2}\right)\frac{U_0(x+b)^{n-1}}{v}}, \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},$$
$$\varphi(\eta)=\frac{C-C_\infty}{C_\infty}, \quad (7)$$

Incompressibility condition is satisfied identically and Eqs. (2)- (6) take the following forms:

$$(1+N)f'''+ff''-\left(\frac{2n}{n+1}\right)f'^2-N\left(\frac{n+1}{2}\right)\lambda f''^2 f'''-\left(\frac{2}{n+1}\right)M^2 f'=0, \quad (8)$$

$$\theta''+\Pr\left(f\theta'+Nb\theta'\varphi'+Nt\theta'^2\right)+A\theta=0, \quad (9)$$

$$\varphi''+\Pr Lef\varphi'+\left(\frac{Nt}{Nb}\right)\theta''=0, \quad (10)$$

$$f(0)=S, f'(0)=\alpha\left(\frac{1-n}{n+1}\right), \theta(0)=1, \varphi'(0)+\left(\frac{Nt}{Nb}\right)\theta'(0), \quad (11)$$

Where (A > 0) is the heat generation parameter, (A < 0) is the heat absorption parameter, N is the fluid parameter, (S > 0) is the suction parameter, (S < 0) is the injection parameter, M represents the magnetic parameter, N and λ stand for the fluid parameters Nb the Brownian motion parameter, Pr the Prandtl number, Nt the thermophoresis parameter, Le presents Lewis number and prime indicates differentiation with respect to η. The non-dimensional parameters are

$$N=\frac{1}{d\beta\mu}, \lambda=\frac{U_0^3}{4d^2 v}(x+b)^{3n-1}, M^2=\frac{\sigma B_0^2}{\rho U_0}, \Pr=\frac{v}{\alpha_f},$$
$$Nb=\tau\frac{DbC_\infty}{v}, Nt=\tau\frac{D_T(T_w-T_\infty)}{vT_\infty}, Le=\frac{\alpha_f}{D_B},$$
$$A=\frac{Q}{\alpha_f T_w \rho_{nf}} \quad (12)$$

Surface drag coefficient and surface heat transfer are expressed as follows:

$$C_f=\frac{2\tau_w}{\rho_f U_w^2}, Nu_x=\frac{(x+b)q_w}{k(T_w-T_\infty)}, \tau_w=\left(\left(\mu_{nf}+\frac{1}{\beta d}\right)\frac{\partial u}{\partial y}-\frac{1}{6\beta d^3}\left(\frac{\partial u}{\partial y}\right)^3\right)_{y=A(x+b)^{\frac{1-n}{2}}}.$$
$$q_w=-k\left(\frac{\partial T}{\partial y}\right)_{y=A(x+b)^{\frac{1-n}{2}}} \quad (13)$$

These are the dimensionless quantities:

$$C_f \mathrm{Re}_x^{1/2}=\sqrt{2(n+1)}\left((1+N)f''(0)-\frac{(n+1)}{2}\frac{N\lambda}{3}\left(f'''(0)\right)^3\right),$$
$$Nu_x \mathrm{Re}_x^{-1/2}=-\sqrt{\frac{n+1}{2}}\theta'(0), \quad (14)$$

Where $\mathrm{Re}_x=U_w(x+b)/v.$ designates the local Reynolds number.

3. Results and Discussion

Figures 2- 23 are organized to discuss the features of non-dimensional momentum, temperature as well as the nanoparticles concentration for divergent values of evolving parameters such as heat generation (A > 0) and heat absorption (A < 0), the thermal conductivity k, fluid parameters N and λ, Prandtl number Pr, magnetic parameter M, Lewis number Le, velocity index parameter n, suction (S > 0) and injection (S < 0). The influence of heat generation parameter on the temperature profile is depicted on in figure1. It is clearly displayed that increasing values of the parameter results in the progression in the fluid temperature. In fact larger values of heat generation parameter correspond to temperature rise due to stretching of wall and hence the temperature profile increases. The effects of heat generation parameter over the nanoparticle concentration is depicted on figure 2. It can clearly be observed that for any increase in the parameter it also produce an increase in the nanoparticle concentration profile.

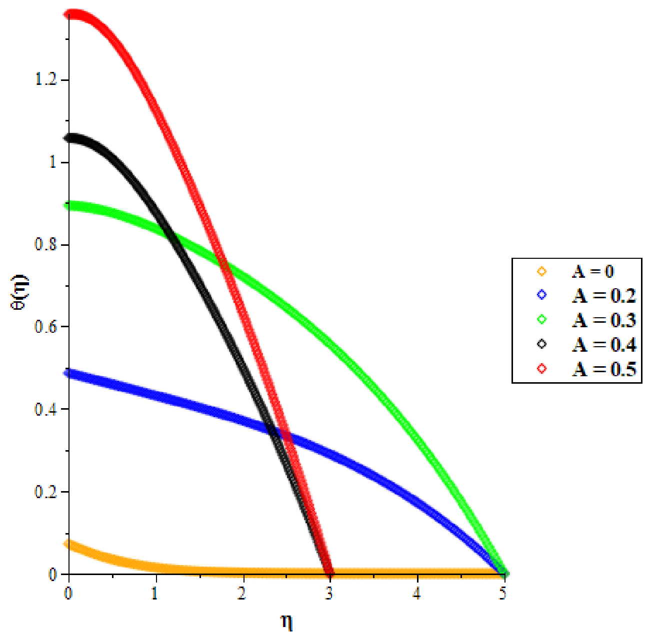

Figure1: Effect of heat generation on temperature profile.

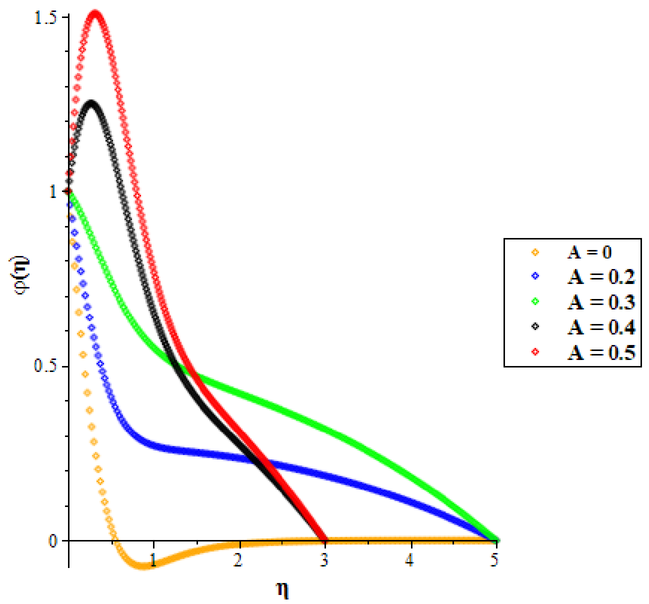

Figure2: Effect of heat generation on Concentration profile.

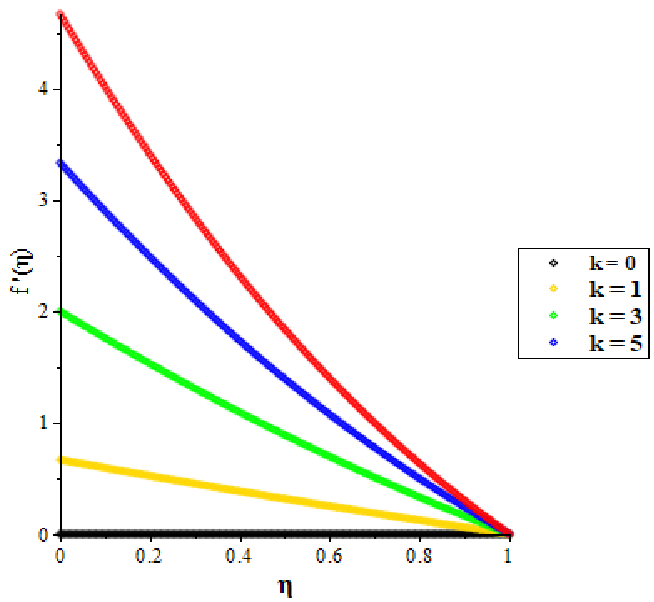

Figure3: Effect of thermal conductivity (k) on momentum profile.

Furthermore, figure3 displayed the effects of thermal conductivity k on the momentum profile. It is seen here, that for any increment in the parameter in accelerates the momentum of the fluid. Similarly, on figure 4 shows the variation of temperature solutal boundary-layer with the effects of the thermal conductivity parameter k. It is noticed that the thermal and solutal boundary layer thickness increases with an increase in the thermal conductivity parameter. Physically, this can be explained as follows, as the thermal conductivity parameter increases, this give rooms for more entrance of heat into the Casson flow. As the heat increases, the temperature profiles also become affected and tend to increase. It is worthwhile to note that the concentration and temperature increases with the increase in values of thermal conductivity parameter k as shown on figure 5.

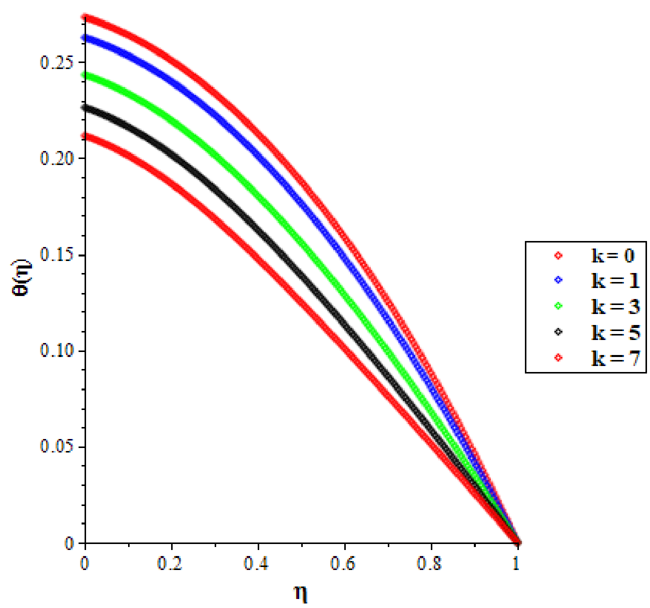

Figure4: Effect of thermal conductivity (k) on Temperature profile.

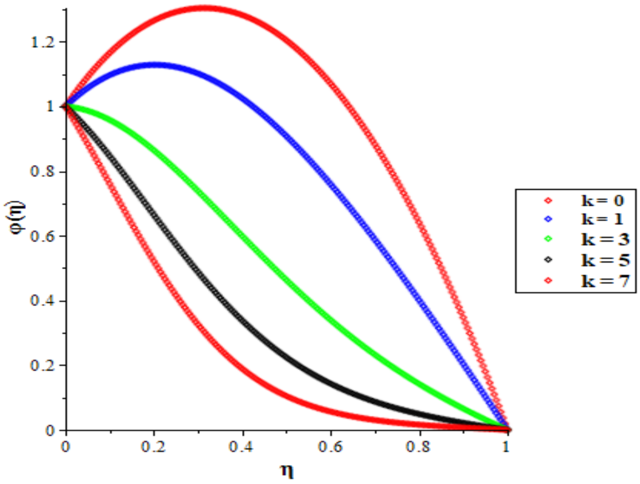

Figure5: Effect of thermal conductivity (k) on Concentration profile.

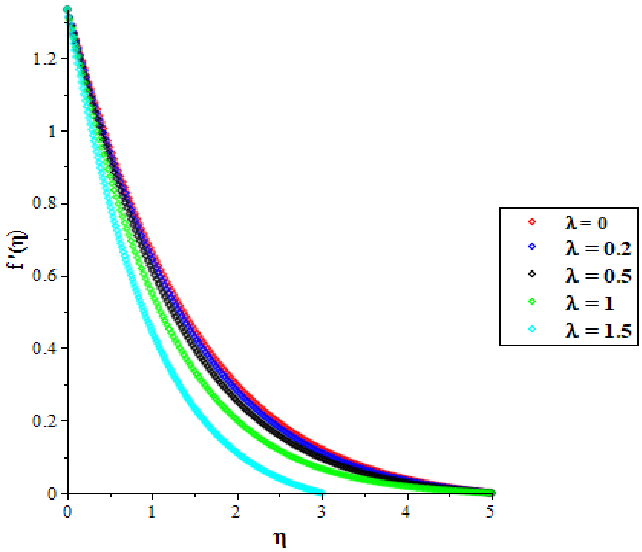

Figure6: Effect of fluid parameter (λ) on Momentum profile.

On figure 6 we have seen that the momentum profile diminishes for larger values of the fluid parameter λ, contrarily, the temperature and nanoparticle concentration profiles are observed to be increased with the increase in the fluid parameter λ, this is clearly visible on figure 7 and figure 8 respectively. The variation of Lewis number Le on nanoparticle concentration is described in Figure 9. It is perceived that the concentration of the fluid decreases with rising values of the Lewis number, hence couple stress fluid is more useful in many engineering applications such as air conditioning, food industry, waste heat recovery, refrigeration and automobile radiators due to enhanced heat transfer. Influence of various values of magnetic field parameter M on the nanoaparticle concentration is depicted on figure 10, with the higher numerical values of the magnetic parameter, it is clear that the rate of heat transfer for couple stress nanofluid motion is more than the pure fluid, the mass transfer rate is more significant in the present study while compared to the boundary layer thickness also enhances. Hence, magnetohydrodynamic couple stress fluid plays key role solicitations in engineering processes like blood pumping machines, peristaltic MHD compressor exit. Physically, the magnetic field parameter depends upon the Lorentz force and the higher values of *M* yields a stronger Lorentz force. Such stronger Lorentz force causes amplify of the nanoparticle concentration profile.

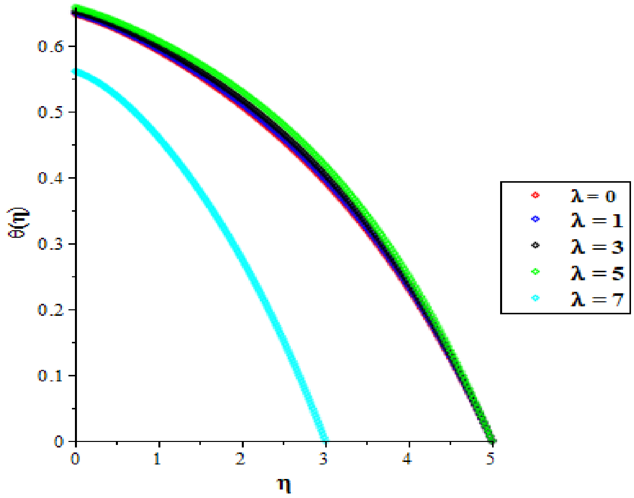

Figure7: Effect of fluid parameter (λ) on Temperature profile.

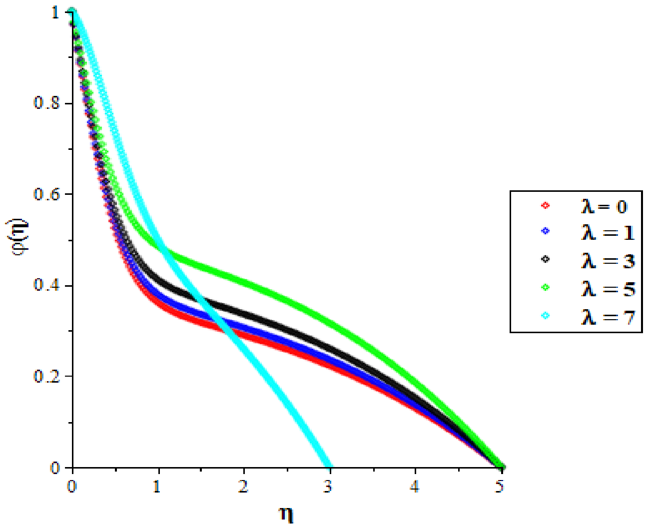

Figure8: Effect of fluid parameter (λ) on Concentration profile.

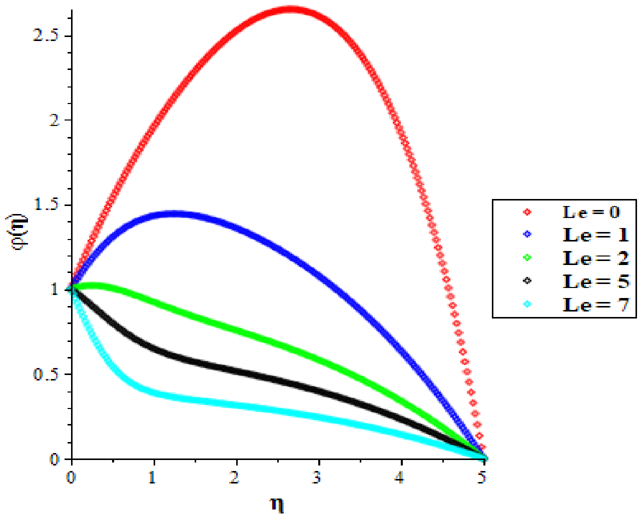

Figure9: Effect of Lewis number (Le) on Concentration profile.

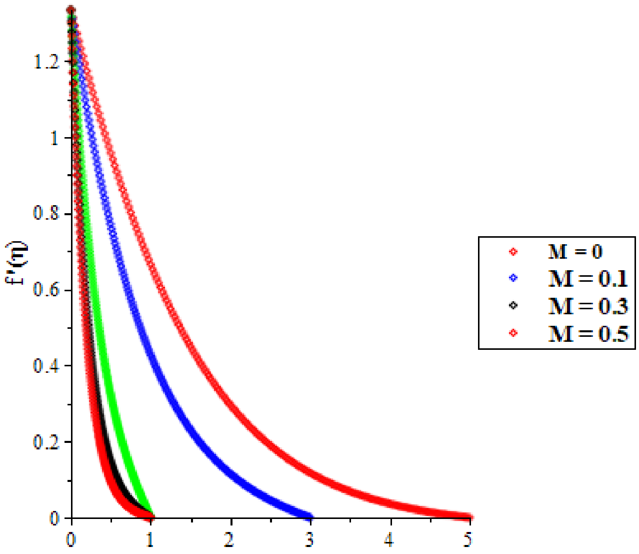

Figure10: Effect of Magnetic parameter (M) on Concentration profile.

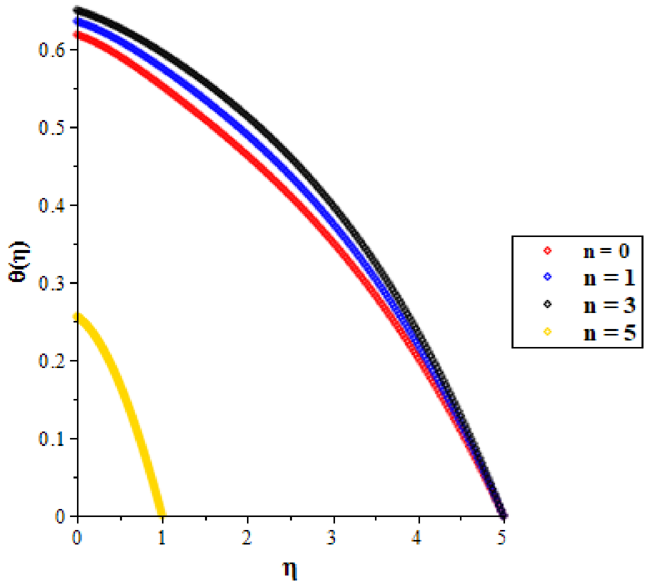

Figure12: Effect of velocity power index parameter (n) on Temperature profile.

From figure 11 it is observed that in the case of velocity power index (n) the velocity profiles and momentum boundary layer thickness decreases which is in best agreement with the previously published results. Both temperature and nanoparticle concentration profiles increases with an increase in the velocity power index (n) just as displayed on figures 12 and 13 respectively. The characteristics of momentum profile for different values of fluid parameter (N) is depicted in Figure 14. The axial velocity of the fluid hike and transverse velocity increase with rising values of (N). Also, more heat transfer is observed in the presence of couple stresses.

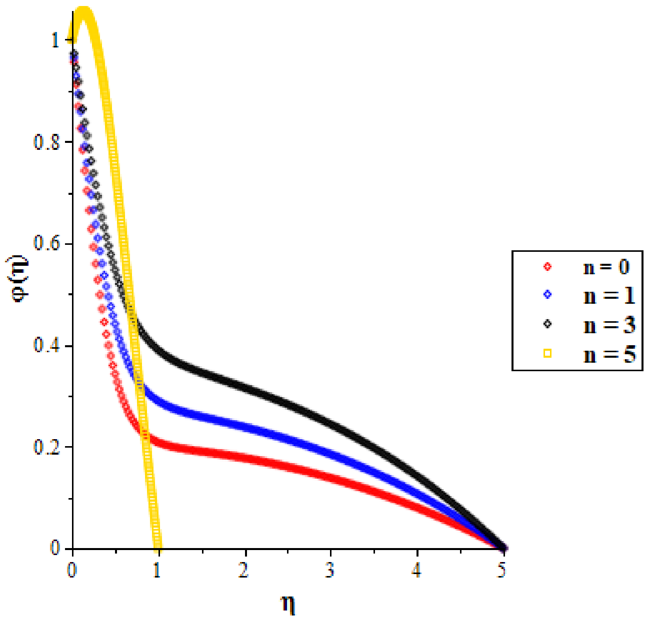

Figure13: Effect of velocity power index parameter (n) on Concentration profile.

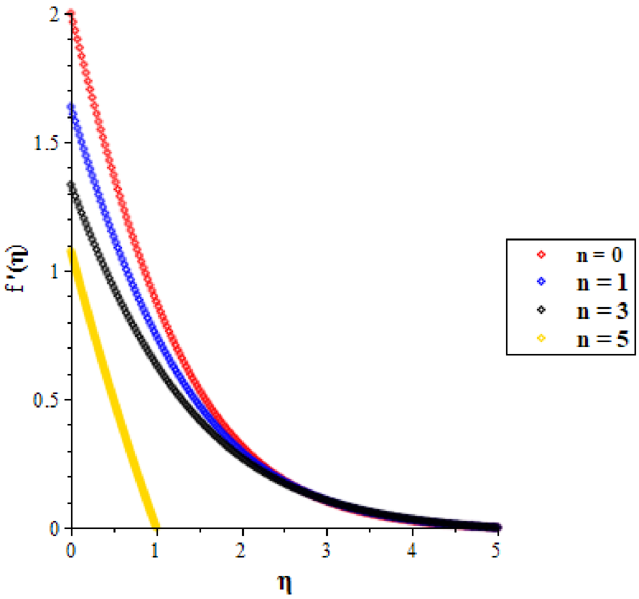

Figure11: Effect of velocity power index parameter (n) on Momentum profile.

On the other hand, figures 15 and 16 explains the effects of fluid parameter (N) on the temperature as well as the nanoparticle concentration profiles. Such that, for any increase in the fluid parameter (N) it yields an increase in both the profiles of temperature as well as the nanoparticle concentration. Figure 17 displays the characterisation of Prandtl number (Pr) for temperature profile. It is seen that, the rising values of Pr yields a deteriorated of heat transfer rate. In addition, the rate of heat transfer in presence of nanofluid is more than couple stress fluid near the stretching surface area. Physically, Pr is inversely proportional to thermal diffusivity. The greater values of Pr implies a stronger heat transfer rate which yields due to high thermal diffusivity.

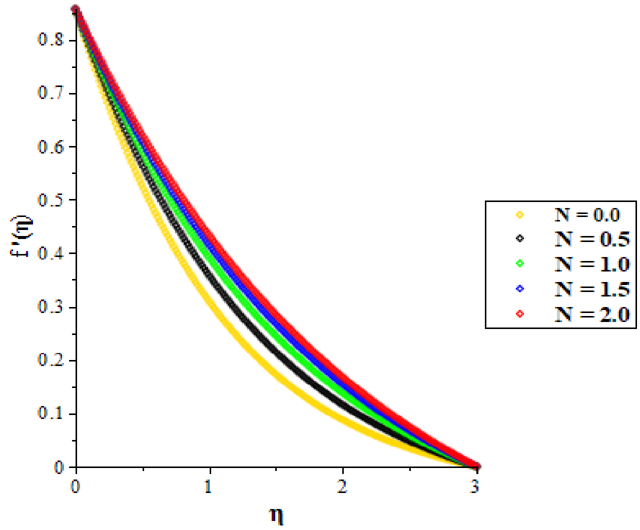

Figure14: Effect of fluid parameter (N) on Momentum profile.

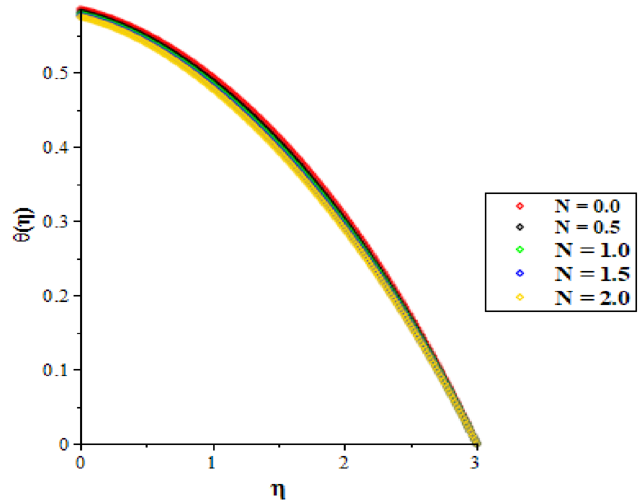

Figure15: Effect of fluid parameter (N) on Temperature profile.

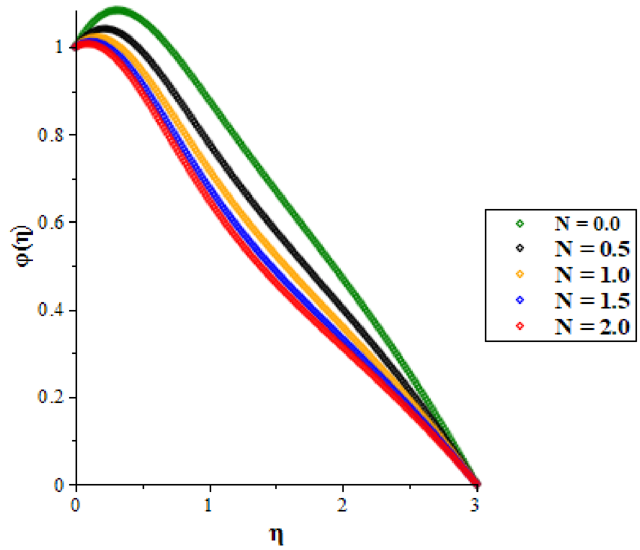

Figure16: Effect of fluid parameter (N) on Concentration profile.

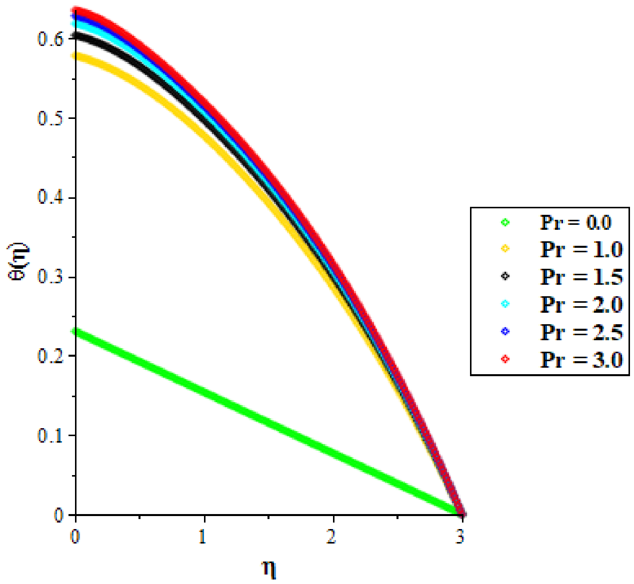

Figure17: Effect of Prandtl number (Pr) on Concentration profile.

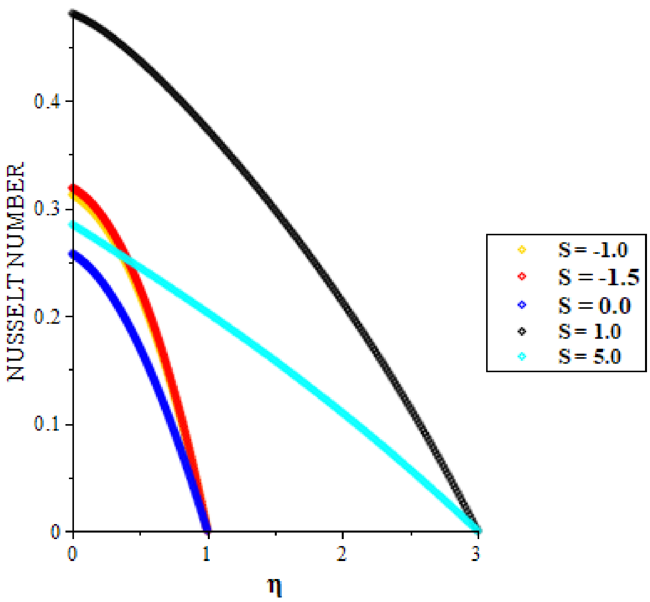

Figure19: Effect of suction/ injection parameter (S) on Nusselt number profile.

The influence of Suction (S > 0) and injection (S < 0) parameter on the Nusselt number profile is depicted on figure 19, in this case it is recorded differently, for the case of suction, any increase in the parameter produces a rise in the Nusselt number profile, It is clear that the reverse directions for the injection parameter is observed. Regardless of suction (S > 0) or injection (S < 0), increase in the parameter significantly rises the Sherwood number profile, this is depicted on figure 20, which is on the characterization of suction/injection parameter on the Sherwood number profile. Similar but reversed result is observed on figure 22, which is on the influence of suction/ injection parameter on the temperature profile. In this case, irrespective of suction/ injection parameter, an increase in the parameter decreases the temperature.

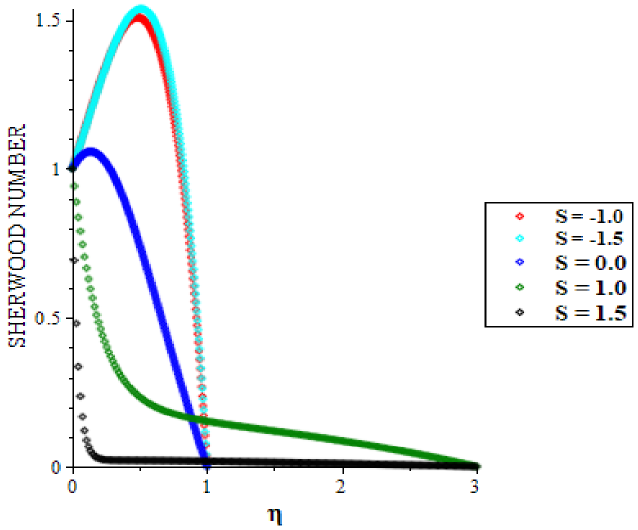

Figure20: Effect of suction/ injection parameter (S) on Sherwood number profile.

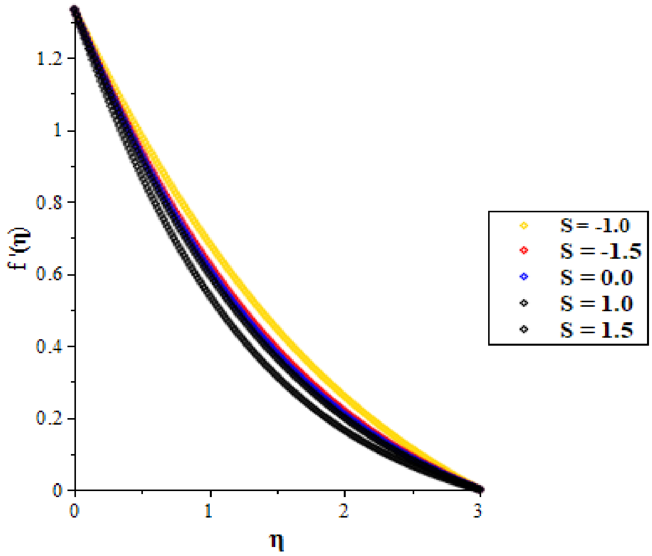

Figure21: Effect of suction/ injection parameter (S) on Momentum profile.

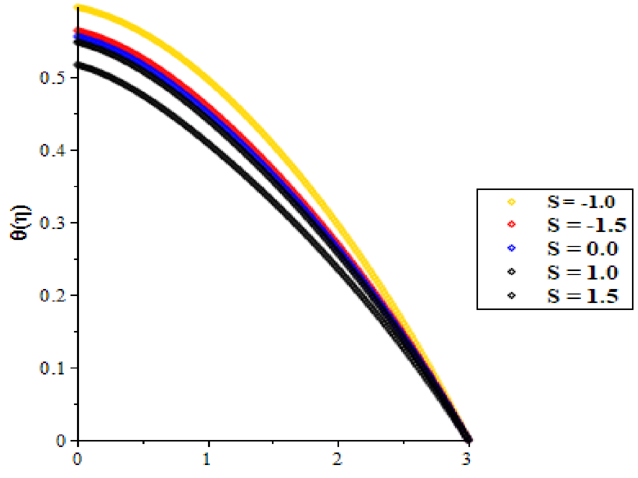

Figure22: Effect of suction/ injection parameter (S) on Temperature profile.

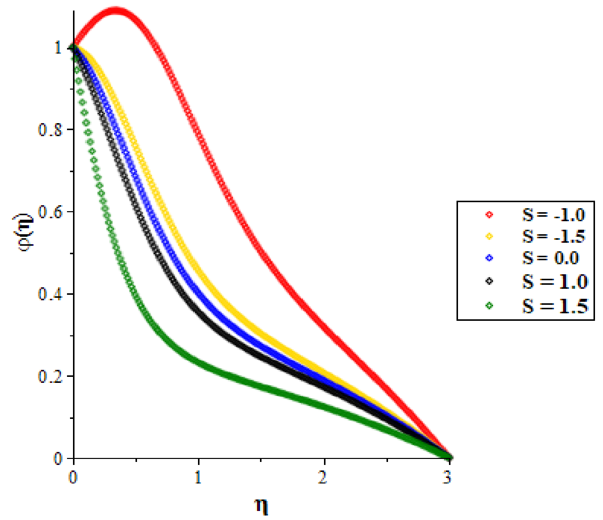

Figure23: Effect of suction/ injection parameter (S) on Concentration profile

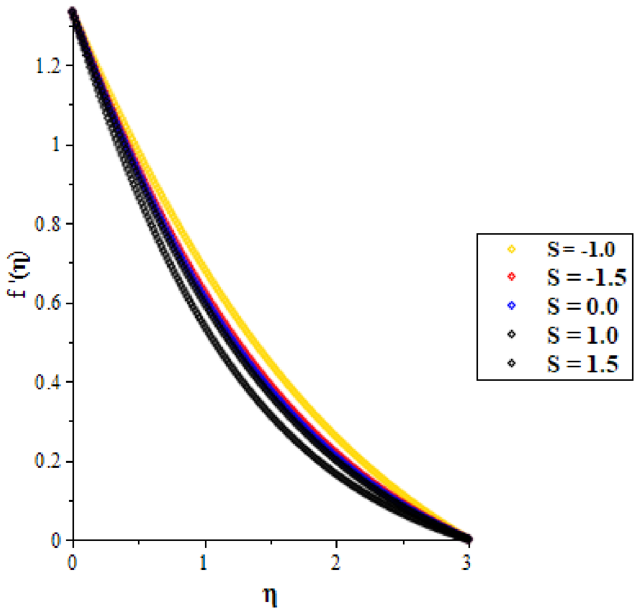

Figure21: Effect of suction/ injection parameter (S) on Momentum profile.

Additionally, figure 21, is all about the influence of suction/ injection parameter on the momentum profile, in this case, it is observed that for any increase in the parameter it slows down the fluid’s momentum regardless of suction (S > 0) or injection (S < 0). Figure 23, displays the influence of suction/ injection parameter on the concentration profile, in the same vain, its observed that the concentration profile is increased with both cases of suction (S > 0) and injection (S < 0).

4. Conclusion

We scrutinized the feature of MHD stretchable fluid flow of Powell- Eyring nanofluid over a sheet with variable thickness. Main results are unambiguously itemized underneath:

1. Momentum profile is increase with an increase in k and N parameters, while the reverse in observed with an increase in n and λ parameters.

2. The temperature profile is increased with an increase in both heat generation and heat absorption parameter (A), λ, n as well as Pr parameters. The temperature is observed to decline with an increase in k, N, as well as both suction and injection parameter (S).
3. The parameters of heat generation and heat absorption (A), λ, n, as well as suction injection parameters (S) rises the fluid's nanoparticle concentration, but it declined with an increase in k and N.
4. The Nusselt number is seen to increase with injection parameter (S < 0). While it decreases Suction parameter (S > 0).
5. Sherwood number is an increasing function with suction and injection parameter.

Data Availability (Size 10 Bold)
None.

Conflict of Interest
Author(s) declare that they do not have any conflict of interest.

Funding Source
None

Authors' Contributions
All author(s) worked harmoniously in conducting the research, drafting the first version of the manuscript as well as the Camera- Ready Copy.

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References

[1] S. U. S. Choi, "Enhancing thermal conductivity of fluids with nanoparticles, in: Developments and Applications of Non-Newtonian Flows', FED- vol. **231**/MDvol. **66**, pp. **99- 105**, **1995**.
[2] J. Buongiorno, "Convective transport in nanofluids". Journal of Heat Transfer", Vol. **128**, pp. **240**–**50**, **2006.**
[3] W.A. Khan, I. Pop, "Boundary-layer flow of a nanofluid past a stretching sheet", International Journal of Heat andMass Transfer, Vol. **53**, pp. **2477**–**2483**, **2010.**
[4] O.D. Makinde, A. Aziz, "Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition", International Journal of Thermal Science, Vol. **50**, pp. **1326–32**, **2011.**
[5] M. Turkyilmazoglu, "Exact analytical solutions for heat and mass transfer of MHD slip flow in nanofluids", Chemical and Engineering Science, Vol. **84**, pp. **182**–**197**, **2012**
[6] O.D. Makinde, W.A, Khan, Z.H. Khan, "Buoyancy effects on MHD stagnation point flow and heat transfer of a nanofluid past a convectively heated stretching/shrinking sheet", International Journal of Heat and Mass Transfer, Vol. **62**, pp. **526–533**, **2013.**,
[7] A. Zeeshan, M. Baig, R. Ellahi, T. Hayat, "Flow of viscous nanofluid between the concentric cylinders", Journal of Computational Theory of Nanoscience, Vol. **11**, **646**–**54**, **2014**.
[8] M. Sheikholeslami, S. Abelman, D.D. Ganji, "Numerical simulation of MHD nanofluid flow and heat transfer considering viscous dissipation", International Journal of Heat and Mass Transfer, Vol. **79**, pp. **212**–**22**, **2014**.
[9] T. Hayat, G. Numra, M. Farooq, B. Ahmad, "Thermal radiation effect in MHD flow of Powell– Eyring nanofluid induced by a stretching cylinder", Journal of Aerospace Engineering, Vol. **29**, No **1**, pp. **188**–**97**, **2015**.
[10] F.M, Abbasi, S.A, Shehzad, T. Hayat, B. Ahmad, "doubly stratified mixed convection flow of Maxwell nanofluid with heat generation/absorption", Journal of Magnetism and Magnetic Material, Vol. **404**, pp. **159**–**65**, **2016**.
[11] A. A, Hussaini, A. G. Madaki, S.K. Alaramma, A. Barde, "Numerical Study on the Influence of Thermophores and Magnetic Field on the Boundary Layer Flow Over a Moving Surface in a Nanofluid", *Int. Journal of Scientific Research and Modern Technology. Vol.* **2,** No **1**, pp. **4- 9, 2022.**
[12] A. G. Madaki, A.A. Hussaini, L. Philemon, "Heat and Mass Transfer in Radiant-Magnetohydrodynamics Squeeze Flow of Vanadium Pentoxide (V_2O_5)-Based Jeffrey Hybrid Nanofluid with Heat Source/Sink", *International Journal of Scientific Research in Mathematical and Statistical Sciences*, Vol. **11**, No **1**, pp.**17-23**, E-ISSN: 2348-4519, **2024.**
[13] A. G. Madaki, A.A. Hussaini, L. Philemon, "Numerical results on the radiative Mhd Squeeze flow of Vanadium Pentoxide (V_2O_5)-Based Jeffrey Hybrid Nanofluid through Porous Parallel Plates", *International Journal Scientific Research in Mathematical and Statistical Sciences*, Vol. **11**, No **1**, pp. **48-55**, E-ISSN: 2348-4519, **2024.**
[14] C.S.K. Raju, N. Sandeep, "A comparative study on heat and mass transfer of the Blasius and Falkner-Skan flow of a bioconvective Casson fluid past a wedge', European Physical Journal Plus, Vol. **131**, pp**. 1- 13**, **2016.**
[15] A. Majeed, T. Javed, A. Ghaffari, "Numerical investigation on flow of second grade fluid due to stretching cylinder with Soret and Dufour effects', Journal of Molecular Liquids Vol. **221**, pp. **878**–**884**, **2016**.
[16] A. Majeed, T. Javed, I. Mustafa, A. Ghaffari, "Heat transfer over a stretching cylinder due to variable Prandtl number influenced by internal heat generation/absorption: a numerical study', Revista Mexicana de Fı´sica, Vol. **62**, No. **4**, pp. **317**–**324**, **2016.**
[17] N. Tarakaramu, P.V. Satya Narayana, "Influence of Heat Generation/Absorption on 3D Magnetohydrodynamic Casson Fluid Flow over a Porous Stretching Surface", Advances *in Fluid Dynamics* **381-392**., **2020**.
[18] P. Sudarsana Reddy, P. Sreedevi, A .J. Chamkha, "Thermodiffusion and Diffusion- Thermo Effects on MHD Heat and Mass Transfer of Micropolar Fluid over a Stretching Sheet", *International Journal of Fluid Mechanics and Research pp.* **241-256**, **2020**. doi:10.1615/InterJFluidMechRes.2017019190
[19] T. Hayat, S. T. Hussain, A. Muhammad, M. Alsaedi Ayub, "Radiative Flow of Powell- Eyring Nanofluid with Convective Boundary Conditions", *Chinese Journal of Physics, Vol.* **55**, No. **4**, **1523-1538**, **2017.**
[20] G. Sarojamma, R. Vijaya Lakshmi, P.V. Satya Narayana, I.L. Animasaun. "Exploration of the Significance of Autocatalytic Chemical Reaction and Cattaneo-Christov Heat Flux on the Dynamic of a Micropolar Fluid", *Journal of Applied and Computational Mechanics, Vol.* **6**, No. **1**, pp. **77-89**, **2020.**
[21] F. Mabood, S.M. Ibrahim, P.V. Kumar, and G. Lorenzini. "Effects of Slip and Radiation on Convective MHD Casson Nanofluid Flow over a Stretching Sheet Influenced by Variable Viscosity", *Journal Engineering Thermo physics, Vol.* **29**, pp. **303-315**, **2020**.
[22] A.R. Hassan, "The Entropy Generation Analysis of a Reactive Hydromagnetic Couple Stress Fluid Flow through a Saturated Porous Channel", *Applied Mathematics and Computation, Vol.* **369, 1- 6, 2020.**
[23] S.S. Uma Devi, F. Mabood. "Entropy Anatomization on Marangoni Maxwell Fluid over a Rotating Disk with Nonlinear Radiative Flux and Arrhenius Activation Energy', *International Communications in Heat and Mass Transfer, Vol.* **118**, **1- 10**, **2020**.

[24] S.A. Shehzad, F. Mabood, A. Rauf, and I. Tlili, "Forced Convective Maxwell Fluid Flow through Rotating Disk under the Thermophoretic Particles Motion", *International Communications in Heat and Mass Transfer, Vol.* **116**, **2020**. doi:10.1016/j.icheatmasstransfer.2020.104693.

[25] R. Naz, F. Mabood, T. Hayat. "Inclined Magnetic Field Effects on Marangoni Flow of Carreau Liquid", *Thermal Sciences, Vol.* **24**, No **2**, pp. **131- 1141**, **2020.**

[26] D. Yadav, "The Effect of Viscosity and Darcy Number on the Start of Convective Motion in a Rotating Porous Medium Layer Saturated by a Couple-Stress Fluid', *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering and Sciences* **1-9**, **2020**, doi: 10.1177/0954406220942551.

[27] A. A. Hussaini, A. G. Madaki, A. M. Kwami, "Modified Mathematical Model on the Study of Convective MHD Nanofluid flow with Heat Generation/Absorption', *International Journal of Engineering Research & Technology, Vol.* **10**, *No 09*, **2021**.

[28] Adnan Asghar, Abdul Fattah Chandio, Zahir Shah, Narcisa Vrinceanu, Wejdan Deebani, Meshal Shutaywi, Liaquat Ali Lund, "Magnetized mixed convection hybrid nanofluid with effect of heat generation/absorption and velocity slip condition", *Heliyon* Vol. **9**, **13189**, **2023**. https://doi.org/10.1016/j.heliyon.2023.e13189.

[29] M. Sayed Abo-Dahab, A. Ramadan Mohamed, Abdelmoaty M. Abd-Alla, Mahmoud S. Soliman, "Double-diffusive peristaltic MHD Sisko nanofluid flow through a porous medium in presence of non-linear thermal radiation, heat generation/ absorption, and Joule heating', *Scientific Reports,* Vol. **13**, **1432**, **2023** https://doi.org/10.1038/s41598-023-27818-7.

[30] A.M. Hassan El-Arabawy, "Effect of suction/injection on the flow of a micropolar fluid past a continuously moving plate in the presence of radiation', *International Journal of Heat and Mass Transfer* Vol. **46**, pp. **1471**–**1477**, **2003**.

[31] K. Gangadhar Kannan, T. DasaradhaRamaiah, K. Sakthivel, G. Boundary layer flow of nanofluid to analyse the heat absorption/ generation over a stretching sheet with variable suction/injection in the presence of viscous dissipation, *international Journal of Ambient Energy, Vol.* ***41****, No 9, pp.* ***969-980***, **2020**. *doi: 10.1080/01430750.2018.1501738.*

[32] T. Hayat, Ikram Ullah, A. Alsaedi, M. Farooq,"MHD flow of Powell-Eyring nanofluid over a non-linear stretching sheet with variable thickness. Results in Physics", Vol. **7**,**189**–**196**, **2017**.

[33] J. Iqbal, F. M. Abbasi, M. Alkinidri, H. Alahmadi "Heat and mass transfer analysis for MHD bioconvection peristaltic motion of Powell- Eyring nanofluid with variable thermal characteristics", *Case Study in Thermal Engineering, Vol.* **43**, **102692**, **2022,** https://doi.org/10.1016/j.csite.2022.102692.

[34] Abubakar Assidiq Hussaini, "Magnetohydrodynamic (MHD) nanofluid flow over a non- linear stretchable surface in the presence of Heat generation/ absorption', *International Journal of Scientific Research in Mathematical and Statistical Sciences,* Vol. **10**, No **6**, **41- 50**, **2023**.

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