Journal of Thermal and Fluid Science
Vol.5, Issue 2, December 2024, pp 35-46
https://doi.org/10.26706/jtfs.5.2.20240902

# Impacts of Mass Suction, Magnetic Field and Chemical Reaction On Powell - Eyring Nanofluid Flow

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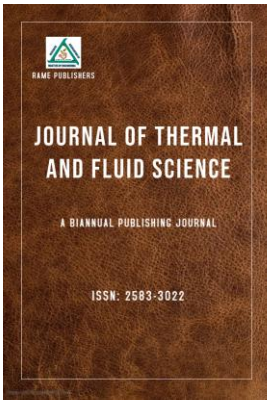


Article – Peer Reviewed
Received: 20 Sept 2024
Accepted: 25 Nov 2024
Published: 30 Dec 2024



**Cite this article:** Abubakar Assidiq Hussaini, Umar Aliyu Mujahid, Adamu Abdulkadir Tata, Jaafar Aliyu, "Impacts of Mass Suction, Magnetic Field and Chemical Reaction On Powell- Eyring Nanofluid Flow", Journal of Thermal and Fluid Science, RAME Publishers, vol. 5, issue 2, pp. 35-46, 2024.
https://doi.org/10.26706/jtfs.5.2.20240902

**Abstract:** Within the present research, the researchers investigated at the magnetohydrodynamic (MHD) flow through the boundary layer of Powell-Eyring nanofluid across an irregular stretching material with variable permeability. The researchers investigated a fluid with electrical conductivity alongside a magnetic parameter implemented transversely to its material. The computational equations were generated through a method called boundary layer approximation by employing non-dimensional values. The process of research is subjected to new conventional boundaries constraints that require nil nanoparticle mass flux. Appropriate conversions have been employed for turning all of the partial differential equations towards certain ordinary differential equations. Maple has been employed to deal with the non- linear flow of momentum, temperature, alongside nanoparticle concentration problems. Visual examination of relevant parameters is distributed among graphical depictions along with table values. subsequently, the we discovered that greater quantities of the amount of mass suction parameter enhance both fluid's temperature and concentration profiles while having no effect on the momentum profile. The impacts of the magnetic field parameter showed that the momentum profile dropped while the ambient temperature and nanoparticle concentration curves flipped. Higher values of the permeability parameter improve both the temperature and concentration profiles, nonetheless momentum profile does not improve at all. Chemical reactions have little influence on velocity or temperature, just on nanoparticle concentration profiles.

**Keywords:** Powell- Eyring; Variable thickness surface; mass Suction; permeability of the surface; Chemical reaction

## 1. Introduction

Nanofluids comprise substances made up of nanometer-sized particles, or nanoparticles. Nanoparticles are often composed of compounds that consist of alumina, titanium, along with copper oxide, together with carbide compounds along with alloys like golden and copper. The diamond & carbon nanomaterials were previously being employed in nanofluid applications. Those nanostructures have the ability to improve the thermal properties of the base substances. Base fluids encompass gasoline, water, ethylene glycol, bio fluids, polymerization solutions, and some surfactants. Furthermore, electromagnetic nanofluid represents an identical material with both magnetic and liquid properties. Magnetic field connection to nanofluids is essential to address with circumstances including soothing nuclear powered reactors by employing liquid sodium, respectively, hyperthermia, optical modulators, magnetic resonance imaging, tunable optical fiber filters, optical grating, , drug administration, artery blockage removal are among the applications. Choi [1] was the first to describe such aqueous dispersion. Buongiorno [2] studied turbulent movement processes within nanofluids.

Subsequently created a computational system for investigating nanofluid flow that includes Brownian motion along with thermophoretic distribution of nanoparticles. Khan and Pop [3] created a 2D elasticity flow of nanofluid. Makinde and Aziz [4] expanded their approach to include convective boundary conditions. They proved that convective heating has a major effect on the thermal boundary layer. With these factors in mind, many engineers and scientists are investigating nanofluid flows from a variety of perspectives. There are few exemplary studies in this approach among the attempts (see [5-13]. In the actual world, most fluids, including water, kerosene oil, ethylene, glycol, and others, are poor heat conductors due to their low thermal conductivity characteristics

To address this issue and improve the thermal conductivity or other thermal characteristics of these fluids, a recently developed process is applied, which involves adding nano-sized particles of excellent conductors such as copper, aluminum, titanium, iron, and other oxides to the fluids. (See [14, 15, and 16]. Here are some of the research employed in the creation of magneto-physiological flow devices and the manufacture via electricity conductive bio-polymeric fluids.

Tarakaramu et al. [17] and Sudarsana et al. [18] proposed the Buongiorno nanofluid flow with heat radiation impact. Hayat et al. [19], Sarojamma et al. [20], Uma Devi and Mabood [23], Shehzad et al. [24], Naz et al. [25], and Yadav [26] were the first to produce non-Newtonian fluid flow over a spinning disk, while Mabood et al. [21] and Hassan [22] were the pioneers in various physical aspects. The primary purpose of Hussaini et al. [27] was to investigate the impact of heat generation/absorption on an existing mathematical model. Asghar et al. [28] investigated the effects of heat production, absorption, and slip velocity on a vertically decreasing sheet. Convection is modelled numerically using a two-dimensional magnetic nanofluid. They investigated an Al2O3- Cu/water composite nanofluid with water as the base liquid and solid nanoparticles of copper (Cu) and alumina (Al2O3). Modern composite nanofluids improve heat transfer efficiency. They used the Tiwari-Das model to explore the effects of solid volume % of copper, heat generation/absorption, MHD, mixed convection, and velocity slip factors on velocity and temperature distributions. Soliman et al. [29] investigated the 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 influence of Joule heating, non-linear thermal radiation, viscous dissipation, and heat generation/absorption in the presence of heat and mass convection, taking Brownian motion and thermophoresis coefficients into account.

## 2. Related Work

El-Arabawy [30] investigated the influence of suction and injection on the flow and heat transfer properties of a continuous moving plate in a micro-polar fluid in the presence of radiation. The boundary layer equations are turned into nonlinear ordinary differential equations. The distribution of velocity, microrotation, and temperature profiles inside the boundary layer is investigated numerically. The impacts of changing the Prandtl number, radiation parameter, and porosity parameter are assessed. Kannan et al. [31] numerically investigate the heat and mass transfer characteristics of boundary layer flow about a stretching sheet in a porous medium filled with TiO2- water and Al2O3- water-based nanofluids, in the presence of internal heat generation or absorption and viscous dissipation with variable suction or injection effects. The relevant computational formulation is set up via the boundary layer approach following analyzing the features regarding nanoparticles in magnetohydrodynamic process of Powell-Eyring fluid through a sheet that stretched using various thicknesses and accounting for the effects of Brownian motion and thermophoresis, as well as more realistic boundary conditions imposed at the boundary. Hayat et al. [32] used the Homotopic approach to get convergent series solutions. Alkinidri et al. [33] investigated the effect of mass and heat transfer on the magnetohydrodynamic (MHD) bioconvective peristaltic transport of Powell-Eyring nanofluid along a curved channel with a radius-dependent magnetic field. Modified Darcy's, Ohmic heating, motile gyrotactic microorganisms, thermal radiation, and variable characteristics, Brownian, and thermophoresis motion are all examined. Hussaini [34] examined an impact of heat generation and heat absorption upon magnetohydrodynamic nanofluid flow across a stretched sheet. He also went into great detail on how other factors affect momentum, temperature, nanoparticle concentration, and Nusselt number profiles. He concentrated his research on the impacts of heat generation and absorption, magnetic fields, solar radiation, and other variables. The use of hybrid nanofluids containing three different oxide nanoparticles (Aluminum-Copper, Aluminum-Silver, and Silver-Copper) in combination with a base fluid of water was examined in detail by Anwar et al. [35], who also considered the influence of a magnetic field perpendicular to the flow direction and heated source/sink phenomena. They also carefully analyzed and visualized the hybrid nanofluids using a variety of plots to examine the detailed behavior of these hybrid nanofluids under various conditions. Khan et al. [36] numerically and significantly demonstrated the magnetohydrodynamic properties of Sisko nanomaterial across a linear stretching plane.

Brownian motion and thermophoresis are included into the Sisko nanofluid model. The effects of mixed convection, chemical reactions, and nonlinear thermal radiation are investigated. Furthermore, activation energy and double stratification circumstances are discussed in their research. The domineering coupled PDEs were attempted, in addition to constructing a local non-similarity technique using the bvp4c MATLAB built-in program. Other relevant researches in the field include the following [37- 41].

## 3. Description of the Problem

We study an incompressible Powell-Eyring nanofluid flowing continuously in two dimensions (2D) across a non-linear stretchable sheet. A non-linear stretchy sheet forms the flow's boundary. Brownian motion and thermophoresis effects are considered. Convective heat and mass conditions are imposed at the border. It is also assumed that the sheet's surface is heated by a hot fluid. $T_f, C_f$ as temperature and concentration respectively. Using Cartesian coordinates, with the x-axis aligned with the stretching sheet and the y-axis normal to it, we extend the sheet at y = 0 along the x−direction with velocity uw (x) = axn, where a and n are the positive constants. The fluid is electrically transmitted through a non-uniform magnetic field B (x) in the y-direction (see Fig. 1), ignoring the effects of the electric field and Hall current.

The following are the equations for the Powell-Eyring nanofluid's two-dimensional (2D) boundary layer flow in the current scenario [32]:

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

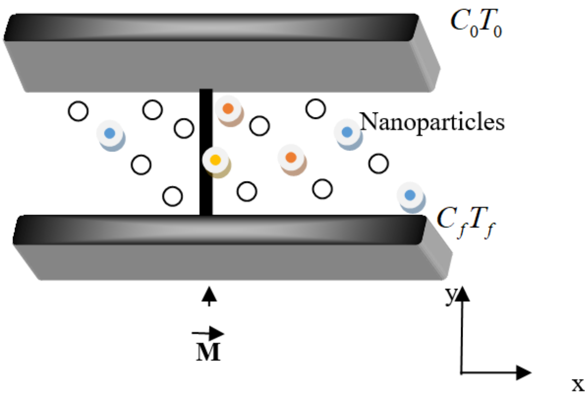


**Figure 1:** Geometry of the problem

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

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

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial y^2}\right)-k_c(C-C_\infty), \qquad \ldots (4)$$

Subject to the boundary conditions

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

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

Here u and v are the corresponding velocity components parallel, respectively, to the x and y directions, $\nu=\frac{\mu}{\rho}$ designates the kinematic viscosity, $\rho$ the fluid density, d and $\beta$ are the material liquid parameters of Powell-Eyring model, $\sigma$ is the electrical conductivity, B is the Magnetic field, k is the permeability parameter, $\rho_{nf}$ is density of the nanofluid, $\alpha_{nf}$ is the for thermal diffusivity, $D_T$ represents the thermophoresis diffusion, n the thermal diffusivity of liquid, Q denotes the Heat flow, $D_B$ indicates the Brownian diffusion coefficient, T the temperature of the fluid, C the nanoparticles concentration, $k_c$ is the coefficient of chemical reaction, $T_w$ and $T_\infty$ are the sheet and ambient fluid temperatures and $C_\infty$ the ambient fluid nanoparticles concentration. Transformations are expressed as follows [32]:

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

$$\eta = y\sqrt{\left(\frac{n+1}{2}\right)\frac{U_0(x+b)^{n-1}}{\nu}}, \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}, \varphi(\eta)=\frac{C-C_\infty}{C_\infty}, \quad ...(7)$$

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

$$(1+N)f''' + ff'' - \left(\frac{2n}{n+1}\right)f'^2 - N\left(\frac{n+1}{2}\right)\lambda f''^2 f''' + \left[k_1 - \left(\frac{2}{n+1}\right)M^2\right]f' = 0, \quad ...(8)$$

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

$$\varphi'' + \Pr Lef\varphi' + \left(\frac{Nt}{Nb}\right)\theta'' + k_2\varphi = 0, \quad ...(10)$$

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

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, $k_1$ *and* $k_2$ are the permeability parameter and chemical reaction parameter respectively, 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

$$N=\frac{1}{d\beta\mu}, \lambda=\frac{U_0^3}{4d^2\nu}(x+b)^{3n-1}, M^2=\frac{\sigma B_0^2}{\rho U_0}, k_1=\frac{2U_w\mu_e}{k}, \Pr=\frac{\nu}{\alpha_f},$$

$$Nb=\tau\frac{DbC_\infty}{\nu}, Nt=\tau\frac{D_T(T_w-T_\infty)}{\nu T_\infty}, Le=\frac{\alpha_f}{D_B}, A=\frac{Q}{\alpha_f T_w \rho_{nf}}, k_2=\frac{aU}{\nu}, \quad ...(12)$$

The following is an expression for the surface drag coefficient and surface heat transfer:

**Table 1**: The thermo-physical properties of water and nanofluid (base fluid) as in Kumar et al [40]

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

These are the dimensionless quantities:

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

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

**Table 1**: Thermo-physical properties

| | $\rho$ $(kgm^{-3})$ | $Cp$ $(kg^{-1}k^{-1})$ | $k$ $(Wm^{-1}k^{-1})$ | $\beta\times10^{-5}$ $(k^{-1})$ |
|---|---|---|---|---|
| Water | 997.1 | 4179 | 0.6130 | 21 |
| $Fe_3O_4$ | 5180 | 670 | 80.4 | 20.6 |

**Table 2**: Comparative values of $f''(0)$ and $-\theta'(0)$ with published results of [40].

| Varying parameter | Hayat et al. [32] | | Present result | |
|---|---|---|---|---|
| S | $f''(0)$ | $-\theta'(0)$ | $f''(0)$ | $-\theta'(0)$ |
| 0 | 1.28181 | 0.767768 | 1.28181 | 0.767766 |
| 0.3 | - | - | 1.38501 | 0.896891 |
| 0.6 | 1.5982 | 1.014571 | 1.59828 | 1.014580 |
| 0.8 | - | - | 1.70173 | 1.732067 |
| 1.0 | - | - | 1.98016 | 2.497629 |

## 4. Results And Discussions

To investigate the properties of temperature, non-dimensional momentum, and nanoparticle concentration for different values of developing components including mass suction, magnetic field, permeability, and chemical reaction parameters, Figures 2(a)–5(c) are grouped. Figure 2(a) depicts the impact of the mass suction parameter on the momentum profile. It is evident that raising the parameter values has no effect at all. Figure 2(b) depicts the fluctuation of the temperature profile for the mass suction parameter. Larger values of the mass suction parameter equate to a drop in temperature owing to wall stretching, resulting in a lower temperature profile. Figure 2(c) depicts the impact of the mass suction parameter on nanoparticle concentrations. It is evident that when the parameter increases, so does the nanoparticle concentration profile. Furthermore, Figure 3(a) depicted the influence of magnetic parameters on the momentum profile. It can be observed here that any increase in the parameter causes the fluid's momentum to decrease. The reverse is found for both temperature and concentration profiles. Figure 3(b) depicts the link between the temperature profile and the magnetic parameter, demonstrating that any increase in the parameter increases the temperature of the system. Similarly, fig. 3(c) depicts the link between nanoparticle concentration profiles and magnetic fields; as the parameter values grow, so does the profile.

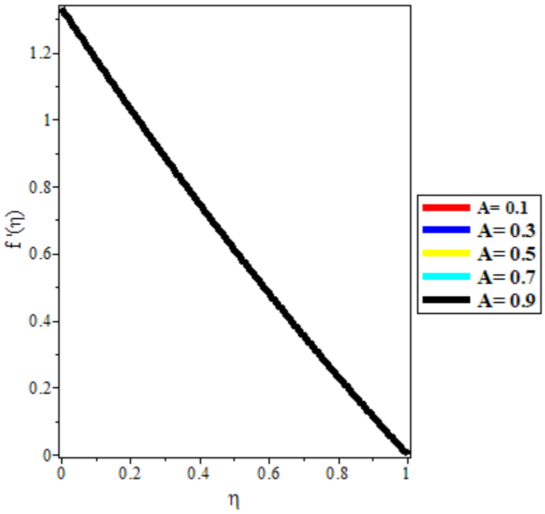


**Figure 2a:** Influence of mass suction on momentum profile

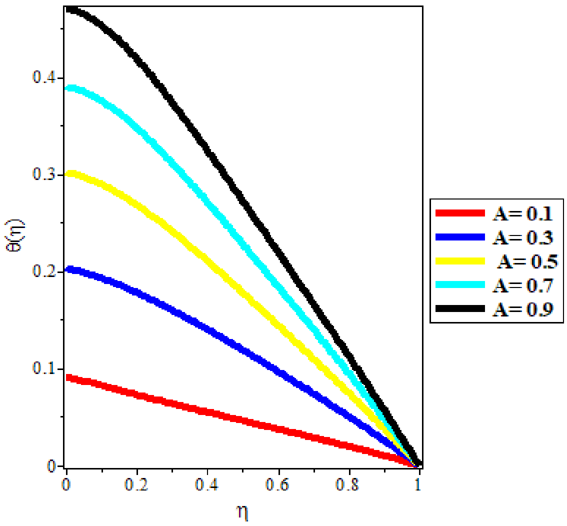


**Figure 2b:** Influence of mass suction on temperature profile

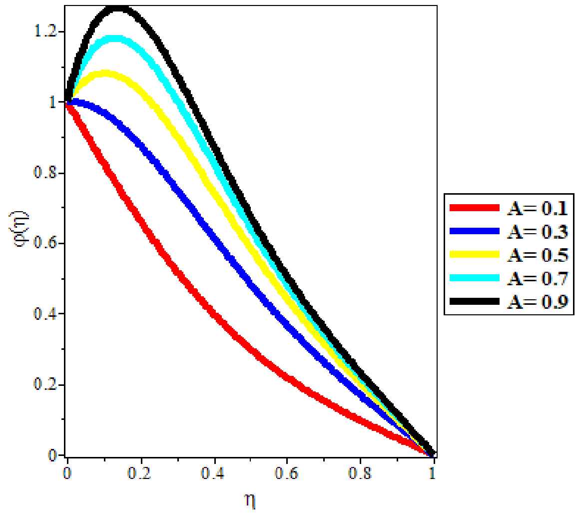


**Figure 2c:** Influence of mass suction on concentration profile

Figure 3(a) depicts how the momentum profile varies in response to a magnetic field. It is noted that when the parameter values grow, the fluid's momentum decreases. In contrast, as seen in fig. 3(b), the thickness of the thermal and solutal boundary layers rises as the magnetic field value increases. Physically, this may be described as follows: when the thermal conductivity parameter increases, there is more area for heat to enter the Casson flow. As the heat increases, the temperature profiles are influenced and tend to rise.

It is worthwhile to note that the concentration behaves in the same way as the temperature increases with the increase in values of magnetic parameter as shown on fig. 3(c). Figure 4(a) shows that when the permeability parameter increases, so does the momentum profile.

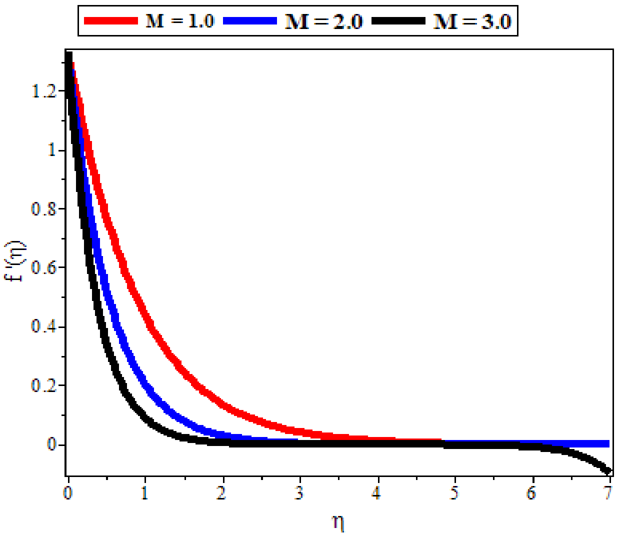


**Figure 3a:** Influence of magnetic parameter on momentum profile

Permeability is a measure of how easily a fluid flows through a porous substance. It's a crucial metric in fluid dynamics, particularly for studying flow through porous media like rocks, soil, and biological tissues. The permeability parameter improves the fluid's momentum for the following reasons: increased permeability equals less resistance when the fluid passes through the porous material.

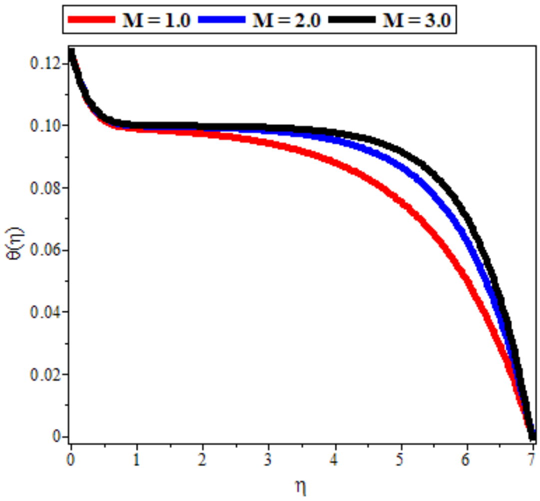


**Figure 3b:** Influence of magnetic parameter on temperature profile

As a result, the fluid retains its velocity and momentum more readily. Furthermore, permeability is proportional to the fluid's flow rate. When permeability rises, so does the flow rate, which indicates that more fluid moves at a given velocity, resulting in higher momentum. Furthermore, in porous media, viscous force can slow the fluid and diminish its motion. However, when permeability is great, the fluid may flow more readily, lowering viscous dissipation and maintaining momentum.

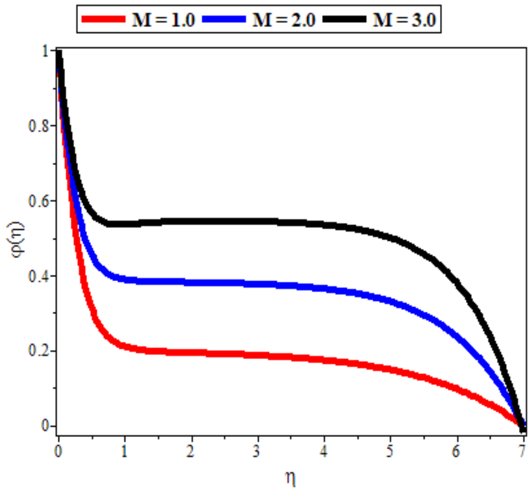


**Figure 3c:** Influence of magnetic parameter on concentration profile

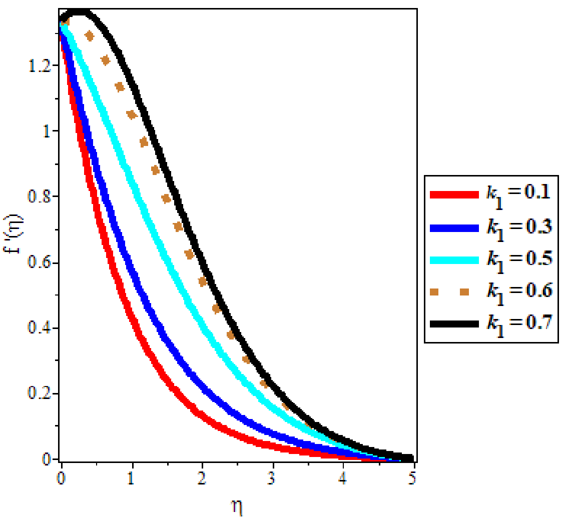


**Figure 4a:** Infuence of impermeability parameter on momentum profile

Additionally, when the fluid passes through the porous medium, its inertia (resistance to change in motion) increases. High permeability allows for inertial effects, which lead to greater momentum. In a nutshell, the permeability parameter improves a fluid's momentum via lowering resistance, increasing flow rate, reducing viscous dissipation, and strengthening inertial effects. In contrast, as seen in fig. 4(b), increasing the permeability parameter lowers the temperature profile. This is clear given the following implications. First of all, increasing the permeability parameter values will undoubtedly allow fluids to flow more freely, perhaps improving convective heat transfer. As the fluid flows, it removes heat from the source, lowering the system's temperature. Second, when a fluid passes through a porous material with high permeability, it dissipates heat more effectively. The increased surface area and flow rate allow the fluid to dissipate heat more effectively, resulting in a reduction in temperature. Higher permeability parameter values also diminish the thermal boundary layer, enhance turbulence, and, in some situations, the flow of fluid through a porous material can have a cooling effect, akin to blowing air over a heated surface. The moving fluid can transfer heat away from the surface, lowering the temperature. Finally, it is important to highlight that the link between permeability and temperature is complicated and influenced by a variety of factors, including the specific fluid, porous material, and flow conditions.

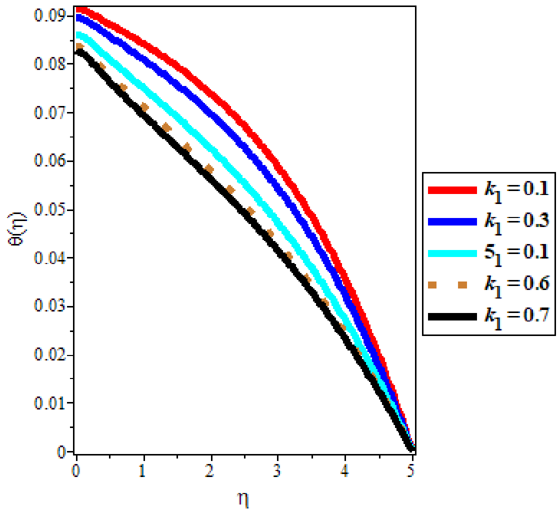


**Figure 4b:** Inclucence of imermeability parameter on temperature profile

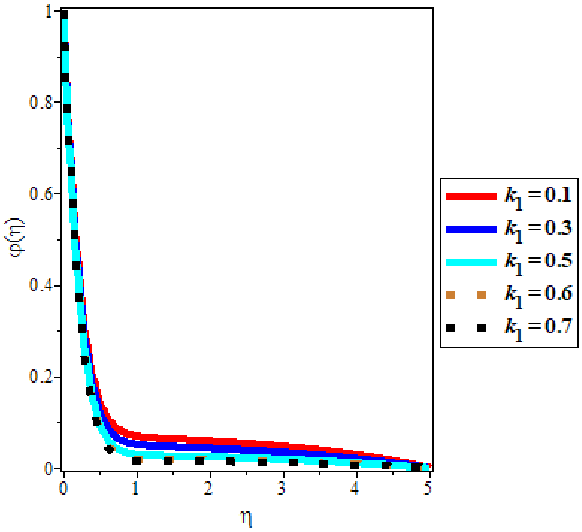


**Figure 4c:** Influence of impermeability parameter on concentration profile

In the same vein, Figure 4(c) depicts the concentration fluctuation in respect to the permeability parameter. Permeability may impact a fluid's concentration profile, and high permeability can often result in a reduction in the concentration gradient. The causes are as follows: higher dispersion, enhanced mixing, shorter diffusion length, increased convective transport; and, in some instances, high permeability might lead to homogeneity. Figure 5(a) depicts the fluctuation in momentum as the chemical reaction values vary. This chart clearly shows that there is no effect on raising or reducing the values of this parameter, which is due to the following reasons:

First, the law of conservation of momentum asserts that a closed system's overall momentum remains constant throughout time. Chemical reactions take place inside the fluid, and the momentum of the reactants is retained and transmitted to the products. Furthermore, chemical processes do not involve any external forces that may alter the fluid's motion. Furthermore, chemical reactions entail the transformation of internal energy into various types of energy. Finally, the momentum equation does not physically include the term for chemical reaction.

Figure 5(b) depicts the influence of various values of the chemical reaction parameter on the temperature profile; with higher numerical values of the chemical reaction parameter, it is clear that the rate of heat transfer for couple stress nanofluid motion is the same as the pure fluid; the mass transfer rate is also significant in the current study, while the boundary layer thickness increases. As a result, the temperature profile remains unchanged.

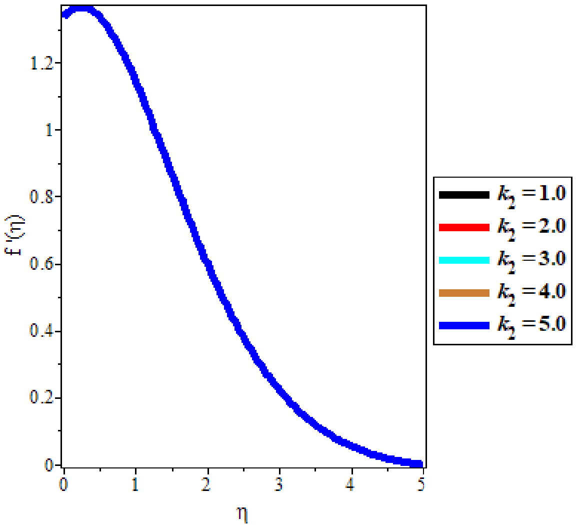


**Figure 5a:** Influence of chemical reaction parameter on momentum profile

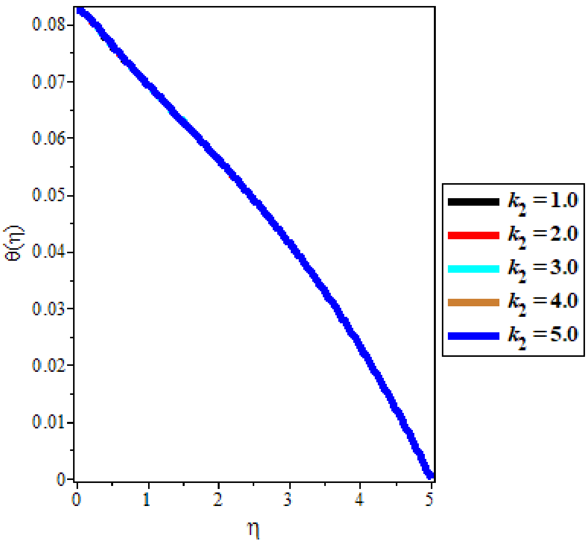


**Figure 5b:** Influence of chemical reaction parameter on temperature profile

Figure 5(c) shows how the chemical reaction parameter affects the concentration of nanoparticles. The concentration of the fluid is thought to grow with higher values of the chemical reaction parameter for the following reasons. To begin, chemical reactions can cause nanoparticles to nucleate and develop. As the reaction progresses, more nanoparticles are produced, increasing the concentration. Second, precipitation reactions can occur when the concentration of reactants exceeds their solubility limit, resulting in the creation of nanoparticles. Third, chemical processes can cause nanoparticles to aggregate and agglomerate, or dissolve and redeposit onto bigger nanoparticles in the fluid, boosting their concentration in certain places. Furthermore, chemical reactions can cause local supersaturation, resulting in the creation of nanoparticles and a rise in concentration.

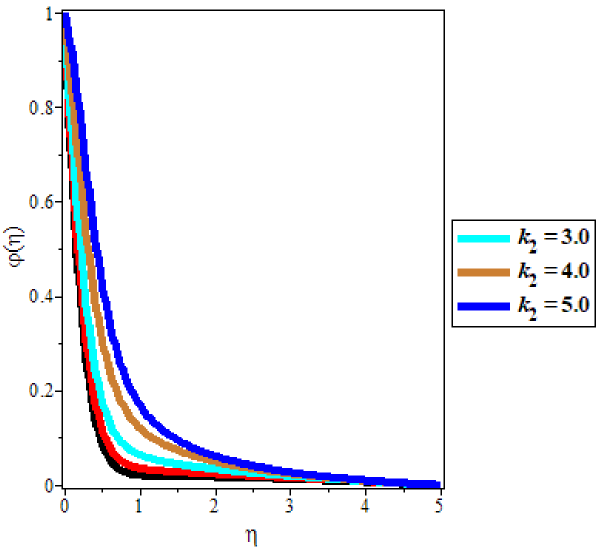


**Figure 5c:** Influence of chemical reaction parameter on concentration profile

## 5. Conclusions

Powell-Eyring nanofluid's MHD stretchable fluid flow across a sheet with different thicknesses was examined. The following are concise statement of the primary results:

1. Momentum profile does not show any effect with an increase in mass suction and chemical reaction parameters. However, momentum profile increases with an increase in permeability parameter. Reverse is the case with magnetic field.
2. The temperature profile shows no effect with the chemical reaction parameter. Furthermore, the temperature of the system is enhanced with the permeability parameter. Reverse is observed with mass suction and magnetic parameter.
3. An increase in mass suction, magnetic field, and chemical reaction parameters results in an increase in the nanoparticle concentration profile. When the permeability parameter rises, which decrease the nanoparticle concentration profile.

Conclusively, our study has not only filled a significant knowledge vacuum in the field of fluid dynamics, but it also has promise for future use in a range of scientific and technical fields.This research can be extended by considering effects of some parameters such as permeability of the fluid, thermal radiation or diffusion effects. Furthermore, this work can be extended by considering effects of motile microorganism.

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