

Research Article

Chemical Reaction and Generalized Heat Flux Model for Powell–Eyring Model with Radiation Effects

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In the current research, the numerical solutions for heat transfer in an Eyring–Powell fluid that conducts electricity past an exponentially growing sheet with chemical reactions are examined. As the sheet is stretched in the *x* direction, the flow occupies the region y > 0. MHD, radiation, joule heating effects, and thermal relaxation time are all used to represent the flow scenario. The emergent problem is represented using PDEs, which are then converted to ODEs using appropriate similarity transformations. The converted problem is solved numerically using the SLM method. The main goal of this paper is to compare the results of solving the velocity and temperature equations in the presence of *K* changes through SLM, introducing it as a precise and appropriate method for solving nonlinear differential equations. Tables with the numerical results are created for comparison. This contrast is important because it shows how precisely the successive linearization method can resolve a set of nonlinear differential equations. Following that, the generated solution is studied and explained in relation to a variety of engineering parameters. Additionally, the thermal relaxation period is inversely proportional to the thickness of the thermal boundary layer and the temperature, but the Eckert number *Ec* is the opposite. As *Ec* grows, the temperature within the channel increases.

1. Introduction

Non-Newtonian fluids are widely encountered and are used in a wide variety of engineering applications. Some of these applications are notable and are applied in the paper, food, personal care products, textile coating, and suspension solutions industries. These fluids have mostly been divided into three categories: differential, rate, and integrals. Recent technological and engineering advancements have resulted in the development of a diverse range of non-Newtonian fluids with a number of major differences from viscous fluids. Ziegenhagen [1] explored the slow flow of a Powell-Eyring type fluid and used variation techniques to obtain results. He studied the behavior of Oldroyd and Powell-Eyring fluids and discovered that both fluids behave identically in situations involving extremely slow fluid flow. Sirohi et al. [2] studied it by observing the flow of Powell-Eyring fluid around the accelerating plate. They compared three distinct techniques. Yoon and Ghajar [3] pioneered the concept of a stretched sheet by providing a

precise solution to the resulting differential system. Recent academics have investigated this topic from a variety of perspectives [4–12]. Mushtaq et al. [13] investigated the Powell–Eyring fluid flow and heat transport past a stretched sheet exponentially. They discovered that increasing the velocity ratio parameter results in a thinned boundary layer. Malik et al. [12] examined the Powell–Eyring fluid flow and heat transport with varying viscosity over a stretching cylinder by examining the steady condition. They concluded that as Prandtl and Reynolds numbers increase, the boundary layer shrinks. Sher Akbar et al. [14] studied the effect of magnetic factors on Eyring–Powell fluid flow past a stretched surface. They investigated flow resistance as the magnetic and hydrodynamic properties of the fluid under study increased.

Kumar and Srinivas [15] investigated the Powell–Eyring nanofluid passing via an inclined permeable sheet. They demonstrated that temperature increases as thermophoresis parameter values increase. While the contrary is true for nanoparticle concentration due to higher chemical reactions and Brownian parameters, increasing thermophoresis parameter values results in an increase in concentration. Pal and Mondal [16] demonstrated magneto-bioconvection of the Powell-Eyring nanofluid via a vertically stretched sheet that is convectively heated and also contains motile, gyrotactic microorganisms. They discovered that as the Schmidt number and chemical reaction parameters increase, the concentration of nanoparticles drops. Thermal relaxation time is the time required for fluid to return to its original temperature after being heated. It is a frequently used parameter for determining the time required for heat to leave a fluid. Hayat and Nadeem [17] investigated the effects of mass flux models on Eyring-Powell fluid flow in three dimensions. They discovered that temperature and thermal-relaxation time have an inverse relationship. Reddy et al. [18] studied the effect of chemical reactions on the activation energy of the Eyring-Powell nanofluid flow via a stretching cylinder. They concluded that as the relaxation parameter increases, the temperature curves decrease in shape. It takes a long time for an increase in the relaxation parameter assessment to transfer heat to neighboring material particles. Additionally, the Nusselt number improves behavior when nondimensional thermal relaxation calculations are performed.

Mustafa [19] researched the Maxwell fluid with a generalized heat flux model for rotating flow and heat transfer. They also discovered that the thermal relaxation period is inversely proportional to temperature and thermal boundary thickness. Ishaq et al. [20] demonstrated that the entropy production of the Eyring-Powell fluid flow with nanofluid thin film flow can be calculated by considering the heat radiation and MHD impact. They discovered that when the Brinkmann, Hartmann, and Reynolds numbers grow, so does the entropy profile. For increasing values of the Eyring-Powell and radiation parameters, the entropy profile reduces. The Eyring-Powell nanofluid flow with nonlinear mixed convection and entropy generation was explored by Alsaedi et al. [21]. They arrived at the conclusion that entropy generation showed a falling tendency for some fluid parameter values while increasing for others. Through a permeable stretching surface, Bhatti et al. [22] studied the irreversibility of the MHD Eyring-Powell nanofluid. More interesting articles can be seen in [23-30] and cross references.

According to the existing literature, no attempt has been made to investigate the electrically conducting Eyring–Powell fluid with radiation, thermal relaxation time, and joule heating effects beyond an exponentially stretched sheet with chemical reaction. This work visually depicts and tabulates the impacts of various flow parameters encountered in the governing equations. The SLM technique is used to solve the issue numerically, which is more computationally efficient. The relevant results are graphed and quantitatively analyzed. This research fills a void in the literature and lays the groundwork for future researchers to contribute their perspectives to the open literature. This is structured as follows: Section 1



FIGURE 1: Interpretation of momentum and thermal boundary layers.

contains the literature survey; Section 2 contains the mathematical formulation; Section 3 contains the methodology; Section 4 has the results; and Section 5 contains the conclusion.

2. The Problem's Formulation

Consider an incompressible Powell–Eyring fluid flowing across an exponentially stretched surface subjected to magnetic, joule heating, thermal radiation, and thermal relaxation periods, as illustrated in Figure 1. The sheet is put on the *x*-and *y*-axes, respectively, and the flow is restricted to $y \ge 0$. Let $U_w(x) = ae^{(x/l)}$, represent the sheet velocity, $U_{\infty} = be^{(x/l)}$ represent the external fluid velocity, and $T_w(x) = T_{\infty} + ce^{(x/2l)}$ represent the surface temperature, with T_{∞} being the ambient temperature.

The governing equations so obtained are given as (see for example, [13], [21], [22], [31]).

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U_{\infty}\frac{dU_{\infty}}{dx} + \left(v + \frac{1}{\rho\beta C_0}\right)\frac{\partial^2 u}{\partial y^2} - \frac{1}{2\rho\beta C_0^3}\left(\frac{\partial u}{\partial y}\right)^2$$
$$\cdot \frac{\partial^2 u}{\partial y^2} - \frac{\sigma}{\rho}B_0^2(u_{\infty} - u), \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p} \left(-\nabla \cdot \mathbf{q}\right) + \frac{\sigma B_0^2}{\rho C_p} u^2 - \frac{1}{\rho C_p} \frac{\partial q_{\text{rad}}}{\partial y},\tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - H(x)(C - C_{\infty}), \qquad (4)$$

where $\nu, \rho, u(x, y), \nu(x, y), \beta, C_0, T, k, q_{rad}, C_p, B_0, q, C, D, H(x)$ are kinematic viscosity, fluid density, velocities, fluid

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parameters, temperature, thermal conductivity, thermal radiation, specific heat at constant-pressure, strength of the magnetic field, heat flux, the consternation field, diffusion coefficient, and chemical reaction rate, respectively, which satisfy the relation

$$q + \delta_t \left(\frac{\partial q}{\partial t} + V \cdot \nabla q - q \cdot \nabla V + (\nabla \cdot V) q \right).$$
 (5)

The appropriate boundary conditions are

$$u = U_w(x) = ae^{x/l}, \quad v = 0,$$

$$T = T_w(x) = T_{\infty} + ae^{x/2l},$$

$$C = C_w(x) = C_{\infty} + ae^{x/2l} \text{ at } y = 0,$$

$$u \longrightarrow U_{\infty}(x) = be^{x/l}, T \longrightarrow T_{\infty}, \text{ as } y \longrightarrow \infty.$$

$$(6)$$

Using the similarity transformations as follows:

$$\eta = \sqrt{\frac{a}{2\nu L}} e^{x/2L} y,$$

$$u = a e^{x/L} f'(\eta),$$

$$v = -\sqrt{\frac{\nu a}{2L}} e^{x/2L} [f(\eta) + \eta f'(\eta)],$$

$$\theta(\eta) = \frac{T - T_{\infty}}{T_w - T_{\infty}},$$

$$\phi(\eta) = \frac{C - C_{\infty}}{C_w - C_{\infty}}.$$
(7)

The continuity equation is satisfied in the same way using (6), and (2)-(5). is transformed into the following form:

$$(1+K)f''' + ff'' - 2f'2 - K\Gamma f''2f''' + 2\lambda^2 - M(\lambda - f') = 0,$$
(8)

$$(1+Rd)\dot{\theta'} + \Pr\left(\left(f\theta' - \theta f'\right) - \gamma\left(3f^{2}\theta - \theta f f' + f^{2}\dot{\theta'} - 3f f'\theta'\right)\right) + MEcf'^{2} = 0,$$
(9)

$$\dot{\phi'} + S_C \left(f \phi' - f' \phi - C_R \phi \right) = 0, \tag{10}$$

$$f(0) = 0,$$

$$f'(0) = 1,$$

$$\theta(0) = 1,$$

$$\phi(0) = 1,$$

$$f'(\infty) \longrightarrow \lambda,$$

$$\phi(\infty) \longrightarrow 0,$$

$$\theta(\infty) \longrightarrow 0,$$

$$\theta(\infty) \longrightarrow 0,$$

where $\lambda = b/a, K = 1/\mu\beta C, \Gamma = U_w^3/4\nu LC^2, Pr = \mu C_p/k,$ $M = \delta/\rho (2LB_0^2/U_w), Rd = 16T_\infty^3 \sigma^*/3k^*C_p\mu,$

$$Ec = \frac{U_w^2}{C_p c e^{x/2l}},$$

$$\gamma = \delta_t \frac{a e^{x/L}}{2L},$$

$$S_c = \frac{\nu}{D},$$

$$C_R = \frac{2LH}{U_w}.$$
(12)

Here, λ and Pr denote velocity ratio and Prandtl number, respectively. Where, S_c Schmidt number, C_R chemical reaction parameter, and Γ are the dimensionless fiuid

parameters. Since Γ is a function of x, therefore, we use a local similarity solution of (8)–(10) that allows us to analyze parameter behavior. For K = 0, we have the case of a Newtonian fluid. The C_f and the local Nu are mathematically described as follows:

$$C_{f} = \frac{t_{w}}{\rho U_{w}^{2}},$$

$$Nu = \frac{xq_{w}(1+Rd)}{k(T_{w}-T_{\infty})}.$$
(13)

Here, τ_w and q_w are mathematically described as follows:

$$\tau_{w} = \left(\mu + \frac{1}{\beta C}\right)|_{y=0} - \frac{1}{6\beta C^{3}} \left(\frac{\partial u}{\partial y}\right)^{3}|_{y=0}, q_{w}$$

$$= -k \left(\frac{\partial T}{\partial y}\right)|_{y=0}.$$
(14)

The mathematical form of the local Nusselt number and skin friction coefficient are given as follows:

$$\sqrt{2Re.}C_{f} = \frac{(1+K)}{f''(0)} - \frac{K\Gamma}{3} \cdot (f''(0))^{3}, \ \frac{\sqrt{2L/xNu}}{Re_{x}^{1/2}}$$

$$= -\theta'(0)(1+Rd),$$
(15)

where the local Reynolds numbers are $Re = U_w L/\nu$, $Re_x = U_w x/\nu$.

3. Solution Methodology

Bhatti et al. [22] solved a non-Newtonian model known as the Powell-Eyring fluid model using the collocation approach. Rahimi et al. [23] addressed this model numerically by using a sequential linearization approach and the Chebyshev spectral collocation method. Agrawal and Kaswan [24] solved the Eyring-Powell fluid model using a fourthorder precision methodology (BVP4C) and the homotopy analysis method (H.A.M). Jafarimoghaddam [25] studied the Eyring-Powell model and described fluid flow and heat transfer over a stretching sheet. He then solved the governing PDEs by using homotopy perturbation and homotopy analysis methods to convert them to ODEs. The thirdorder nonlinear ordinary differential equations (7) and the second-order nonlinear ordinary differential equations (8) are expressed as differential equations and solved using the successive linearization technique (SLM) [26, 31] in this article.

3.1. Procedure of Computational. SLM is used to find the numerical solutions for the nonlinear systems (8)–(10) that conform to the boundary condition (11). We choose the initial guess functions for the SLM solution, i.e., $f(\eta)$, $\theta(\eta)$ and $\phi(\eta)$ are in the form

$$f(\eta) = f_i(\eta) + \sum_{m=0}^{i-1} F_m(\eta),$$

$$\theta(\eta) = \theta_i(\eta) + \sum_{m=0}^{i-1} \theta_m(\eta),$$

$$\phi(\eta) = \phi_i(\eta) + \sum_{m=0}^{i-1} \phi_m(\eta).$$

(16)

Here, the two functions $f_i(\eta)$ and $\theta_i(\eta)$ are representative unknown functions. $F_m(\eta), m \ge 1, \theta_m(\eta), m \ge 1$ are successive approximations, which are obtained by recursively solving the linear part of the equation that results from substituting (15) in the governing equations. The mean idea of the SLM is that the assumption of unknown function $f_i(\eta), \theta_i(\eta), \text{ and } \phi_i(\eta)$ are very small when *i* becomes larger; therefore, the nonlinear terms in $f_i(\eta), \theta_i(\eta), \text{ and } \phi_i(\eta)$, and their derivatives are considered to be smaller and thus neglected. The intimal guess functions $F_o(\eta), \theta_i(\eta)$, and $\phi_i(\eta)$, which are selected to satisfy the boundary conditions

$$F_{0}(\eta) = 0, F_{0}'(\eta) = 1 \quad at \quad \eta = 0,$$

$$F_{0}'(\eta) \longrightarrow 0, \quad F_{0}''(\eta) \longrightarrow 0 \quad at \quad \eta \longrightarrow \infty,$$

$$\theta_{o}(0) = 1, \quad \theta_{o}(\infty) \longrightarrow 0,$$

$$\phi_{o}(0) = 1, \quad \phi_{o}(\infty) \longrightarrow 0.$$
(17)

Which are taken to be in the form

$$F_{0}(\eta) = (1 - e^{-\eta})$$

 $\theta_{0}(\eta) = e^{-\eta},$ (18)
 $\phi_{0}(\eta) = e^{-\eta}.$

TABLE 1: The skin friction coefficient -f''(0), the local Nusselt number $-\theta'(0)$, and the local Sherwood number $-\phi'(0)$.

Order of approximation	-f''(0)	$- heta^{\prime}\left(0 ight)$	$-\phi^{\prime}\left(0 ight)$
1	0.994899093	0.999993051	0.971675797
10	1.165245830	0.998642538	0.633874092
15	1.165245830	0.998641243	0.633874092
20	1.165245830	0.998641243	0.633874092
30	1.165245830	0.998641243	0.633874092
50	1.165245830	0.998641243	0.633874092

TABLE 2: The local Nusselt number for different values of *K* and Γ , when $\lambda = 0.1$, $Rd = Ec = C_R = M = Sc = \gamma = 0$, and Pr = 1.

V	Г	λ	- heta(0)			
К			HAM [13]	Numerical [13]	Present	
0.0	0.1	0.1	0.977953	0.977955	0.9777595	
0.5			1.022158	1.022158	1.0214463	
1.0			1.050549	1.050549	1.0489857	
1.5			1.070644	1.070644	1.0683282	
0.5	0.0		1.023016	1.023016	1.0227978	
	0.5		1.018406	1.018406	1.0159453	
	1.0		1.012648	1.012648	1.0072281	

3.2. Convergence Analysis. Table 1 illustrates the convergence for the numerical values of the skin friction coefficient, the local Nusselt number, and the local Sherwood number for various values of the parameters involved in using SLM, when $E_c = M = \Gamma = K = \gamma = M = \lambda = 0.10, C_R = \Pr = 1, Rd = 0.2.$

3.3. Numerical Scheme Testing. Here, we test the validity of our numerical results and contrast them with those of published works as limiting examples. As a result, we compare the current results to those obtained in reference [13], and we discover that they are in reasonable agreement, as shown in Table 2.

4. Result and Discussion

The velocity ratio parameter, the fluid parameter k, the magnetic parameter M, the nondimensional fluid parameter, and the velocity profile are all monitored for variation. Additionally, this section discusses the influence of the Prandtl number Pr, the velocity ratio parameter, the fluid parameter k, the Eckert number Ec, the radiation parameter Rd, the thermal relaxation time T, and the magnetic parameter M on the dimensionless temperature $\theta(\eta)$. Lastly, this section shows the effect of the velocity ratio parameter, the fluid parameter k, the magnetic parameter M, the Schmidt number S_c , and the chemical reaction parameter C_R on the dimensionless concentration $\emptyset(\eta)$. Two types of boundary layers near the sheet have evolved in a flow with exponentially changing free stream velocity over an exponentially stretched sheet. This means that they are dependent on the velocity ratio parameter b/a, for values of b/a greater than or equal to one. Additionally, it's worth noting that when b/a = 1, no velocity boundary layer arises near the



FIGURE 2: Change in the value of $f'(\eta)$ for different values of λ .



FIGURE 3: Change in the value of $f'(\eta)$ for different values of k.

sheet. The velocity profiles for various values are depicted in Figure 2. The influence of the fluid parameter K on the velocity is seen in Figure 3. A rise in K can be interpreted as either a fall in viscosity or a decline in the Powell-Eyring fluid's rheological effects. Here, we see that velocity and the thickness of the boundary layer are rising functions of K when $\lambda < 1$. This observation leads to the conclusion that the increase in the elastic effects of the Powell-Eyring fluid leads to a thinner momentum boundary layer. However, an opposite trend is noticed when $\lambda > 1$. increasing *K* results in a drop in fluid viscosity, which results in an increase in velocity. Additionally, as K increases, the viscosity of the fluid becomes lower due to which the increase in the velocity of the fluid accrues. The velocity profile declines as Γ grows but changes toward the border, indicating that the boundary layer's thickness has decreased, which is depicted in Figure 4. As the magnetic field intensity increases, the velocity profile



FIGURE 4: Change in the value of $f'(\eta)$ for different values of Γ .



FIGURE 5: Change in the value of $f'(\eta)$ for different values of M.

in Figure 5 drops. This is because an increase in the Lorentz force creates resistance to fluid flow, resulting in a drop in the velocity profile.

The fluctuation of the velocity ratio parameter on the temperature profile is depicted in Figure 6. The temperature is discovered to be a decreasing function of λ . This data may imply that a greater sheet velocity results in a thicker thermal boundary layer. As *K* increases, there is a slight reduction in temperature, as illustrated in Figure 7. Due to the lack of viscous dissipation effects, the fluid parameter *K* is not explicitly included in the energy calculation, and hence has a reduced effect on the thermal boundary layer. Figure 8 illustrates the effect of *Pr* on temperature $\theta(\eta)$. The temperature profile falls as $Pr = \mu C_p/k$ increases. Additionally, rising values of *Pr* decreases the thickness of the thermal boundary layer. As a result, heat travels rapidly, leading to a decrease in fluid temperature.



FIGURE 6: Change in the value of $\theta(\eta)$ for different values of λ .



FIGURE 7: Change in the value of $\theta(\eta)$ for different values of.

The influence of radiation on temperature distributions can be seen in Figure 9. Increases in Rd result in an increase in heat fluxes from the sheet, which results in a rise in temperature. *Ects* effect on the temperature profile $\theta(\eta)$ is depicted in Figure 10. As the Ec value grows, the sheet's wall temperature increases. Due to the fact that when Ec is high, the rate of heat transfer at the surface is low, and the thickness of the thermal boundary layer increases. Frictional heating happens at the surface, raising the fluid's temperature. The effect of thermal relaxation time γ on the temperature profile is illustrated in Figure 11. Temperature and thermal relaxation time have been found to have an inverse connection. Physically, when we increase the pressure, the fluid elements have to work harder to transfer heat to their neighboring components, resulting in a temperature drop. When $\gamma = 0$, heat rapidly spreads throughout the fluid. Figure 12 illustrates the effects of the magnetic parameter M



FIGURE 8: Change in the value of $\theta(\eta)$ for different values of Pr.



FIGURE 9: Change in the value of $\theta(\eta)$ for different values of Rd.

on the temperature profile. When K increases, there is a slight reduction in concentration, as seen in Figure 13. The fluid parameter K is not explicitly included in the energy calculation since there are no effects of viscous dissipation, which reduces its impact on the concentration boundary layer. Figure 14 depicts the effect of the magnetic field M on dimensionless concentration. The increase in M is thought to raise the concentration profile. Figure 15 shows how the velocity ratio parameter varies in relation to the concentration profile. It is shown that the concentration decreases as it increases. According to these findings, a thicker concentration boundary layer is produced by a higher sheet velocity. The effect of the Schmidt number S_c on dimensionless concentration is shown in Figure 16. It is seen that as the Schmidt number S_c increases, the concentration falls. Figure 17 shows how the chemical reaction C_R affected the



FIGURE 10: Change in the value of $\theta(\eta)$ for different values of Ec.



FIGURE 11: Change in the value of $\theta(\eta)$ for different values of γ .



FIGURE 12: Change in the value of $\theta(\eta)$ for different values of *M*.



FIGURE 13: Change in the value of $\emptyset(\eta)$ for different values of k.



FIGURE 14: Change in the value of $\emptyset(\eta)$ for different values of *M*.



FIGURE 15: Change in the value of $\mathscr{O}(\eta)$ for different values of λ .



FIGURE 16: Change in the value of $\emptyset(\eta)$ for different values of Sc.



FIGURE 17: Change in the value of $\emptyset(\eta)$ for different values of CR.

TABLE 3: The local skin friction coefficient, the Nusselt number, and the local Sherwood number coefficient for different values of K, Γ , C_R and Pr, when $\lambda = 0.1$, Rd = 0.2, Ec = 1, M = 0.1, Sc = 0.22, $\gamma = 0.1$.

Κ	Г	λ	C_R	Pr	-f''(0)	- heta(0)	$-\phi^{\prime}\left(0 ight)$
0.0	0.1	0.1	1	1	1.221318822	1.012648801	0.630823360
0.1					1.165245830	0.969874308	0.633874092
0.2					1.116369456	0.980347509	0.636646743
0.3					1.073275828	0.989750630	0.639183845
0.4					1.034911535	0.998251857	0.641518987
0.5	0.0				0.997518705	1.007551228	0.644179699
	0.3				1.006411953	1.002811373	0.642676417
	0.4				1.009395133	1.001205355	0.642174480
			1.5		1.009395133	1.001205355	0.729626197
			2		1.009395133	1.001205355	0.806157921
			2.5		1.009395133	1.001205355	0.875167884
			3		1.009395133	1.001205355	0.938573309
				1.5	1.009395133	1.296772664	0.938573309
				2	1.009395133	1.547608045	0.938573309
				2.5	1.009395133	1.769224802	0.938573309

concentration profile. The concentration decreases as the C_R of the chemical reaction rises.

The local Nusselt number is listed in Table 2, and was estimated using the SLM. In Table 3, the skin friction coefficient increases as k increases. As a result, as Γ increases, the coefficient of friction on the skin lowers. According to Mushtaq et al. [13], on an exponentially stretched surface, the magnitude of the skin friction coefficient decreases significantly as the velocity ratio grows. It has already been noted that when k grows, the thermal boundary layer's thickness decreases. As a result, the heat transfer rate at the stretching sheet is increased. Additionally, as Γ grows, the size of the local Nusselt population decreases dramatically. Additionally, it increases as the values of k and λ increase.

5. Concluding Remarks

In this article, the numerical solution for thermal transport in the Powell–Eyring model via generalized heat flux over an exponentially stretching sheet with a chemical reaction is obtained. By resolving expressions for velocity, temperature, and concentration distributions, the SLM approach is utilized to numerically solve the flow equations. The impact of the Powell–Eyring fluid parameter K, magnetic parameter M, Eckert number *Ec* radiation parameter *Rd*, thermal relaxation time γ , and chemical reaction was investigated and presented in tables. The validity of the current results was tested, and they were contrasted with those that had previously been published [13]. Table 2 shows a limited example where there is strong agreement. The study's most important features are listed as follows

- (i) The velocity increases as the fluid parameter *K* is increased, while reverse behaviour is noticed for the temperature profile.
- (ii) For increasing values of the magnetic parameter *M*, the velocity profile falls while the temperature rises. In addition, as the resistance to flow increases, the magnetic field intensity and *K* increase.
- (iii) The temperature and thickness of the thermal boundary layer are inversely related to the thermal relaxation time γ , whereas the Eckert number *Ec* has the opposite trend. With an increase in *Ec*, the temperature within the channel rises.
- (iv) Increasing values of the *Rd* (radiation parameter) increase the heat fluxes from the surface, which will cause an increase in the fluid's temperature and velocity.
- (v) Simulations of local Nusselt number are verified with published work.

Abbreviations

- *u*, *v*, *w*: Velocity components, *m/s*
- λ : Ratio of expansion rates
- U_w : Stretching velocity, m/s
- *K*, Γ: Dimensionless Powell Eyring fluid parameters
- U_{∞} : Velocity of external flow, *m/s*

Pr:	Prandtl number
L:	Characteristic length, m
C_f :	Skin friction coefficient
T_w :	Surface temperature, K
Nu:	Local Nusselt number
T_{∞} :	Ambient temperature, K
$ au_w$:	Wall sheer stress
<i>τ</i> :	Stress tensor, N/m^2
q_w :	Surface heat flux
ν :	Kinematic viscosity, m^2/s
Re, Re_x :	Local Reynolds numbers
μ:	Dynamic viscosity, <i>Kg/m.s</i>
<i>B</i> :	Magnitude of magnetic field vector, Kg/s^2 .A
ρ :	Density of the fluid, Kg/m^3
q_{rad} :	Radiative heat flux
β:	Powell-Eyring material parameter, Pa ⁻¹
K^* :	Mean absorption coefficient, m^{-1}
C:	Powell–Eyring material parameter, s^{-1}
σ^* :	Stefan Boltzmann constant, $W/m^2.K^4$
C_p :	Specific heat, J/Kg.K
γ [‡] :	Dimensionless thermal relaxation time
T:	Temperature of the/fluid, K
δ_t :	Thermal relaxation time
<i>k</i> :	Thermal conductivity of the fluid, <i>W/m.K</i>
Ec:	Eckert number
Rd:	Radiation parameter
M:	Magnetic parameter
S_C :	Schmidt number
C_R :	Chemical reaction parameter.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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References

- A. Ziegenhagen, "The very slow flow of a Powell-Eyring fluid around a sphere," *Applied Scientific Research*, vol. 14, no. 1, pp. 43–56, 1964.
- [2] V. Sirohi, M. G. Timol, and N. L. Kalthia, "Powell-Eyring model flow near an accelerated plate," *Fluid Dynamics Research*, vol. 2, no. 3, pp. 193–204, 1987.
- [3] H. K. Yoon and A. J. Ghajar, "A note on the Powell-Eyring fluid model," *International Communications in Heat and Mass Transfer*, vol. 14, no. 4, pp. 381–390, 1987.
- [4] L. J. Crane, "Flow past a stretching plate," Zeitschrift für angewandte Mathematik und Physik ZAMP, vol. 21, no. 4, pp. 645–647, 1970.

- [5] K. R. Rajagopal, T. Y. Na, and A. S. Gupta, "Flow of a viscoelastic fluid over a stretching sheet," *Rheologica Acta*, vol. 23, no. 2, pp. 213–215, 1984.
- [6] T. R. Mahapatra and A. S. Gupta, "Stagnation-point flow of a viscoelastic fluid towards a stretching surface," *International Journal of Non-linear Mechanics*, vol. 39, no. 5, pp. 811–820, 2004.
- [7] R. Cortell, "MHD flow and mass transfer of an electrically conducting fluid of second grade in a porous medium over a stretching sheet with chemically reactive species," *Chemical Engineering and Processing: Process Intensification*, vol. 46, no. 8, pp. 721–728, 2007.
- [8] N. Bachok, A. Ishak, and I. Pop, "Melting heat transfer in boundary layer stagnation-point flow towards a stretching/ shrinking sheet," *Physics Letters A*, vol. 374, no. 40, pp. 4075–4079, 2010.
- [9] S. Abbasbandy and H. Roohani Ghehsareh, "Solutions of the magnetohydrodynamic flow over a nonlinear stretching sheet and nano boundary layers over stretching surfaces," *International Journal for Numerical Methods in Fluids*, vol. 70, no. 10, pp. 1324–1340, 2012.
- [10] T. Naseem, U. Nazir, E. R. El-Zahar, A. M. Algelany, and M. Sohail, "Numerical computation of dufour and soret effects on radiated material on a porous stretching surface with temperature-dependent thermal conductivity," *Fluid*, vol. 6, no. 6, p. 196, 2021.
- [11] T. Naseem, U. Nazir, and M. Sohail, "Contribution of Dufour and Soret effects on hydromagnetized material comprising temperature-dependent thermal conductivity," *Heat Transfer*, vol. 50, no. 7, pp. 7157–7175, 2021.
- [12] M. Y. Malik, A. Hussain, and S. Nadeem, "Boundary layer flow of an Eyring–Powell model fluid due to a stretching cylinder with variable viscosity," *Scientia Iranica*, vol. 20, no. 2, pp. 313–321, 2013.
- [13] A. Mushtaq, M. Mustafa, T. Hayat, M. Rahi, and A. Alsaedi, "Exponentially stretching sheet in a Powell–Eyring fluid: numerical and series solutions," *Zeitschrift für Naturforschung A*, vol. 68, no. 12, pp. 791–798, 2013.
- [14] N. Sher Akbar, A. Ebaid, and Z. H. Khan, "Numerical analysis of magnetic field effects on Eyring-Powell fluid flow towards a stretching sheet," *Journal of Magnetism and Magnetic Materials*, vol. 382, pp. 355–358, 2015.
- [15] B. Kumar and S. Srinivas, "Unsteady hydromagnetic flow of Eyring-Powell nanofluid over an inclined permeable stretching sheet with joule heating and thermal radiation," *Journal of Applied and Computational Mechanics*, vol. 6, no. 2, pp. 259–270, 2020.
- [16] D. Pal and S. K. Mondal, "Magneto-bioconvection of Powell Eyring nanofluid over a permeable vertical stretching sheet due to gyrotactic microorganisms in the presence of nonlinear thermal radiation and Joule heating," *International Journal of Ambient Energy*, vol. 43, pp. 924–935, 2019.
- [17] T. Hayat and S. Nadeem, "Aspects of developed heat and mass flux models on 3D flow of Eyring-Powell fluid," *Results in Physics*, vol. 7, pp. 3910–3917, 2017.
- [18] S. R. R. Reddy, P. Bala Anki Reddy, and A. M. Rashad, "Activation energy impact on chemically reacting Eyring-Powell nanofluid flow over a stretching cylinder," *Arabian Journal for Science and Engineering*, vol. 45, no. 7, pp. 5227–5242, 2020.
- [19] M. Mustafa, "Cattaneo-Christov heat flux model for rotating flow and heat transfer of upper-convected Maxwell fluid," *AIP Advances*, vol. 5, no. 4, Article ID 047109, 2015.

- [20] M. Ishaq, G. Ali, Z. Shah, S. Islam, and S. Muhammad, "Entropy generation on nanofluid thin film flow of Eyring–Powell fluid with thermal radiation and MHD effect on an unsteady porous stretching sheet," *Entropy*, vol. 20, no. 6, p. 412, 2018.
- [21] A. Alsaedi, T. Hayat, S. Qayyum, and R. Yaqoob, "Eyring-Powell nanofluid flow with nonlinear mixed convection: entropy generation minimization," *Computer Methods and Programs in Biomedicine*, vol. 186, Article ID 105183, 2020.
- [22] M. M. Bhatti, T. Abbas, M. M. Rashidi, M. E. S. Ali, and Z. Yang, "Entropy generation on MHD Eyring–Powell nanofluid through a permeable stretching surface," *Entropy*, vol. 18, no. 6, p. 224, 2016.
- [23] J. Rahimi, D. D. Ganji, M. Khaki, and K. Hosseinzadeh, "Solution of the boundary layer flow of an Eyring-Powell non-Newtonian fluid over a linear stretching sheet by collocation method," *Alexandria Engineering Journal*, vol. 56, no. 4, pp. 621–627, 2017.
- [24] R. Agrawal and P. Kaswan, "MHD Eyring-Powell nanofluid past over an unsteady exponentially stretching surface with entropy generation and thermal radiation," *Heat Transfer*, vol. 50, no. 5, pp. 4669–4693, 2021.
- [25] A. Jafarimoghaddam, "On the homotopy analysis method (HAM) and homotopy perturbation method (HPM) for a nonlinearly stretching sheet flow of Eyring-Powell fluids," *Engineering Science and Technology, an International Journal*, vol. 22, no. 2, pp. 439–451, 2019.
- [26] S. et al, A. K. Alzahrani, A. O. M. Sidahmed, and K. K. Viswanathan, "A note on thin-film flow of Eyring-Powell fluid on the vertically moving belt using successive linearization method," *International Journal of Advanced and Applied Sciences*, vol. 6, no. 2, pp. 17–22, 2019.
- [27] S. Batool, G. Rasool, N. Alshammari, I. Khan, H. Kaneez, and N. Hamadneh, "Numerical analysis of heat and mass transfer in micropolar nanofluids flow through lid driven cavity: finite volume approach," *Case Studies in Thermal Engineering*, vol. 37, Article ID 102233, 2022.
- [28] G. Rasool, A. Shafiq, Y. M. Chu, M. S. Bhutta, and A. Ali, "Optimal homotopic exploration of features of cattaneochristov model in second grade nanofluid flow via Darcyforchheimer medium subject to viscous dissipation and thermal radiation," *Combinatorial Chemistry & High Throughput Screening*, 2021.
- [29] G. Rasool, A. Shafiq, and D. Baleanu, "Consequences of Soret–Dufour effects, thermal radiation, and binary chemical reaction on Darcy Forchheimer flow of nanofluids," *Symmetry*, vol. 12, no. 9, p. 1421, 2020.
- [30] G. Rasool, N. A. Shah, E. R. El-Zahar, and A. Wakif, "Numerical investigation of EMHD nanofluid flows over a convectively heated riga pattern positioned horizontally in a Darcy-Forchheimer porous medium: application of passive control strategy and generalized transfer laws," *Waves in Random and Complex Media*, pp. 1–20, 2022.
- [31] M. A Mohammed Ahmed, M. E. Mohammed, and A. A. Khidir, "On linearization method to MHD boundary layer convective heat transfer with low pressure gradient," *Propulsion and Power Research*, vol. 4, no. 2, pp. 105–113, 2015.