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Eyring-Powell MHD nanoliquid and entropy generation in a porous device with thermal radiation and convective cooling

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Abstract

This study investigates the flow of magnetohydromagnetic (MHD) Eyring-Powell chemical reaction nanoliquid in a permeable boundless device with wall cooling and thermal radiation. The fully developed Cauchy non-Newtonian fluid model is stimulated by species reaction and the stretching sheet under gravity influence. Using the Rosseland radiation approximation model with an appropriate similarity variable, the dimensionless coupled derivatives are obtained. A shooting numerical technique is utilized to determine the thermophysical effects on the flow characteristics. The solution results are computed and given in graphs and tables for clear demonstration and clarification. The results show that entropy is minimized by augmenting the magnetic field, porosity, and thermodynamic equilibrium. Also, parameters that enhance internal heat must be monitored to prevent chemical reaction nanoliquid blowup.

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1. Introduction

The dynamical flow of conducting fluid (hydromagnetic) has presently dominated the scientific research and discussion because of its many applications in power generation, agricultural technology, medicine and others, Hassan *et al.* [1]. The flow mechanics also assist in managing flow fluid velocity and improving lubricants [2,3]. However, magnetohydrodynamic liquid flow in a stretching plate will continue to be relevant in technology and industry due to its various usages in polymer extrusions, liquid condensation, photographic coasting, etc [4,5]. Therefore, to improve the significance and worth of electrically conducting liquid flow in a stretching surface, it becomes necessary to consider its effect on non-Newtonian fluids. Among these liquids is Powell-Eyring material that was formulated from the theory of liquids kinetic, and at small or huge shearing rate, it behaves like a Newtonian fluid. The fluid defines shear thinning properties; of such is toothpaste, ketchup, human blood and so on. Thus, accompany with heat transport, Salawu *et al.* [6,7] discussed the heat stability of Eyring-Powell with the impact Lorentz force, variable conductivity and electromagnetic heat. Parameters dependent flow characteristics and irreversibility were reported in the study. Nadeem and Saleem [8] examined in a rotating cone, the flow of en-

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ergy and mass transport of Eyring-Powell mixed convection. It was offered that the buoyancy ratio encouraged skin friction, but species and heat gradient are opposite to it. Akbar *et al.* [9] studied in a stretching plate, the Powell-Eyring MHD incompressible fluid with a report on the effects of some terms on the shear stress and flow velocity. It was noticed that magnetic field and material terms resists flow velocity. Zaidi *et al.* [10] investigated the stream of thermal dissipation of Poewll-Eyring in a wall jet. The study analysis was done using shooting procedures and found that the heat dissipation term boosted the overall flow dimensions. Some other analysis on Eyring-Powell can be obtained in [11-13].

Recently, due to technological advancement and its applications, nanoliquid has become the central of attraction to the engineers and scientists. The fluid with base liquid made-up of infinitesimal nanoparticles dimension, an example of such is metal, nanotubes carbon, and oxide, Idowu and Falodun [14]. When the base liquid is used, nanofluid is useful in improving the coefficient of heat conduction and heat convection transfer. Coupled with magnetic fields, magneto-nanomaterial is remarkably applicable in design of filters wavelength, filters optical fiber, optical switches and modulators, etc, Ishaq *et al.* [11]. As such, Hayat *et al.* [15] presented computed outcomes for a flow of squeezing magneto-nanofluid past a far stream domain. The Lorentz force is seen to have obviously impacted the flow velocity and thermal dispersion in the flow device. Alao *et al.* [16] carried out simulation on the radiative heat and species transport of chemically reacting flow with soret and dufour. The thermophoretic and Brownian terms are seen to respectively increase the temperature and species distribution in the chemical reaction region. Combining nanoliquid and Eyring-Powell fluid is of great importance in enhancing the effectiveness of technological devices for the best possible performance. As a result, Agbaje *et al.* [17] demonstrated the impact of radiative and thermal generation on the nanomaterial Eyring-Powell non-Newtonian fluid in a dwindling plate. The radiation and heat generation was observed to have significantly impacted the heat conduction and convective heat transport in a moving sheet. Malik *et al.* [18] used numerical scheme to compute the Eyring-Powell mixed convection nanomaterial MHD flow past a widening surface. It was observed that the chemical reaction and the Lewis number term reduces the fluid chemical distribution. In a vertical stretching plate, the hydromagnetic Powell-Eyring nanoliquid with radiation was investigated by [12,19]. Homotopy analytic technique was used and the results show that the radiation, Lewis and heat dissipation terms remarkably influenced the flow characteristics.

However, despite the numerous utilization of nanofluid and Eyring-Powell liquid, entropy generation in the system can significantly affect and diminish the efficiency of the thermal technological tools if no properly managed, Salawu et al. [20]. In thermodynamic structure, energy is lost due to the force of friction, the chemical reaction, the viscosity of the fluid and diffusion which resulted in entropy generation. The entropy generation measures the degree of irreversibility in a structure; this is determined using thermodynamic second law, Salawu and Oke [21]. Therefore, to optimize technology tools, entropy generation due to irreversible process should be minimized. As such, Rashidi et al. [22] discussed entropy generation of hydromagnetic swarm particle in a moving gyratory disk. The authors used optimization procedure and the neural artificial system to solve the problem and found that increasing magnetic field minimized irreversible process. Hayat et al. [23] presented silver and copper nanomaterials with minimization of entropy generation. The solution to the model was analytically obtained. Khan et al. [24] offered a declination of entropy generation for radiative nanoparticles in a stretching thin needle. It was seen that Nusselt number and wall drag force stimulated higher volume of fraction nanoliquid. Bhatti et al. [19] studied Powell-Eyring nanoparticles entropy generation in a porous moving plate. In the considered thermophysical terms, an enhancing function of irreversible process is observed. Some other studies on thermodynamic second law can be found in [25-28].

The present analysis examines the thermodynamic second law of chemical reactive Eyring-Powell nanoliquid with Joule heat and radiation in stretching convective cooling plate. This study is being motivated by the positive achieved results and the applications of non-Newtonian nanoliquid. Despite many related studies, no mathematical post or study on Eyring-Powell nanomaterial has been examined with Ohmic heating, heat generation, natural convection, heat radiation and chemical species. In the study, the entropy generation, irreversibility ratio, and heat and species distributions is examined in a cooling porous device to prevent the materials from distortion. The dimensionless quasilinear coupled derivatives are solved by shooting techniques to investigate the thermodynamic flow characteristics of the parameters dependent. The study is significant in reducing irreversibility process in order to enhance the utilization and efficiency of nano Eyring-Powell liquid. Also, the reaction flow behaviour to variation in parameters for proper monitored of technological devices.

2. Mathematical Formulation

Examine a hydromagnetic chemical reactive Eyring-Powell nanoliquid flow in permeable media. The flow is gravity-driven past a vertical stretching convective cooling plate at $y = 0$ and at $y > 0$, the MHD dominance takes place. The flow is inspired by induced Lorentz force and non-Newtonian material terms. As demonstrated in Figure 1, the flow is offered in x-axis and y-axis is normal to it. The homogenous chemical species occurs in a boundless domain and the stretching wall is exposed to thermal convective cooling satisfying the Newton's of law of cooling. Due to small effect of Reynolds number, the magnetic induction impact is ignored. The liquid viscoelastic behaviour is encouraged by the Eyring-powell non-Newtonian Cauchy formulation as presented below.

The non-Newtonian Eyring-Powell viscoelastic Cauchy formulation is described as [10,29]

$$C_{ij} = \frac{1}{\delta} sinh^{-1}\left(\frac{1}{\alpha_r}\frac{\partial w_i}{\partial x_j}\right) + \mu\frac{\partial w_i}{\partial x_j}. \quad (1)$$

The term C_{ij} denotes Cauchy tensor, α_r and δ represents the working fluid material term of Powell-Eyring while μ depicts the fluid coefficient viscosity. Thus,

$$sinh^{-1}\left(\frac{1}{\alpha_r}\frac{\partial w_i}{\partial x_j}\right) \cong \frac{1}{\alpha_r}\frac{\partial w_i}{\partial x_j} - \frac{1}{6}\left(\frac{1}{\alpha_r}\frac{\partial w_i}{\partial x_j}\right)^3, \left|\frac{1}{\alpha_r}\frac{\partial w_i}{\partial x_i}\right| < 1.(2)$$

The velocity of the flow is not created by species reaction but influenced by gravity and moving plate. Taking from all the assumptions, the approximated equations for the boundary layer mass conservation, momentum, temperature and chemical reaction balance of Eyring-Powell nanoliquid flow in permeable media are given as [6,9,11,13]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{3}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \left(\nu_{nf} + \frac{1}{\rho_{nf}\alpha_r\delta}\right)\frac{\partial^2 u}{\partial y^2} - \frac{1}{2\rho_{nf}\alpha_r\delta^3}\left(\frac{\partial u}{\partial y}\right)^2\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho_{nf}}u - \frac{\nu_{nf}}{K}u + g\beta_t(T - T_\infty) + g\beta_c(C - C_\infty), \tag{4}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{Q_a}{(\rho c_p)_{nf}}(T - T_\infty) + \alpha\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma_s T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2} + \tau\left\{D_B\left(\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right) + \left(\frac{D_T}{T_\infty}\right)\left(\frac{\partial T}{\partial y}\right)^2\right\} + \frac{\sigma B_0^2}{\rho_{nf}}u^2 + \frac{\nu}{K}u^2, \tag{5}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\left(\frac{\partial^2 C}{\partial y^2}\right) + \frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial y^2}\right) - R_0(C - C_\infty)^n. \tag{6}$$

The sustaining employed boundary conditions are according to [10,29]:

$$\begin{aligned} &u = u_w(x) = ax, \;\; v = 0, \;\; -k\frac{\partial T}{\partial y} = h_f(T_f - T), \\ &C = C_w \text{ at } y = 0, \\ &u \longrightarrow 0, \;\; T \longrightarrow T_\infty, \;\; C \longrightarrow C_\infty \text{ at } y \longrightarrow \infty. \end{aligned} \tag{7}$$

Here, the terms u, u denote the velocity modules in x and y, C, C_∞ and T, T_∞ are the fluid concentration, far stream concentration and fluid temperature, far stream temperature respectively. The terms ν_{nf}, μ_{nf} and ρ_{nf} are the nanofluid kinematic viscosity, fluid viscosity and density separately. Also, D_T, σ, D_B, $\beta_{t,c}$, K, g, Q_a, c_p, B_0, α, R_0 and n are correspondingly the thermophoretic diffusion, electric conductivity, Brownian diffusion, thermal expansion, porosity, gravity, heat generation, heat capacity, magnetic strength, thermal conduction, chemical reaction and reaction index. Meanwhile, α and δ are the Powell-Eyring terms.

The second term on the right hand side of equation (5) represent the approximated thermal Rosseland radiation, where σ_s and k^* are the Stefan-Boltzman and mean absorption terms. Using the succeeding associated variables for the transformation of equations (3)-(7)

$$\begin{aligned} &\theta(\eta) = \frac{T - T_\infty}{T_f - T\infty}, \; \phi(\eta) = \frac{C - C_\infty}{C_w - C\infty}, \; \eta = \left(\frac{a}{\nu}\right)^{\frac{1}{2}} y, \\ &u = axf'(\eta), \; v = -\sqrt{a\nu}f(\eta), \psi(x, y) = (x\nu)^{1/2}f(\eta). \end{aligned} \tag{8}$$

Here, ψ is the stream function and its satisfied $(u, v) = \left(\frac{\partial\psi}{\partial y}, -\frac{\partial\psi}{\partial x}\right)$. By applying the similarity variables of equation (8) on equations (3) to (7), equation (3) is spontaneously gratified while equations (4) to (7) gives

$$\begin{aligned} &(1 + \epsilon)f''' + ff'' - (f')^2 - \epsilon\lambda(f'')^2 f''' \\ &-(M + P)f' + Gr\theta + Gc\phi = 0, \end{aligned} \tag{9}$$

$$\left(1 + \frac{4}{3}Ra\right)\theta'' + Prf\theta' + PrNb\theta'\phi' + BrPr(M + P)(f')^2 + PrNr(\theta')^2 + PrQ\theta = 0, \tag{10}$$

$$\phi'' + Lef\phi' + \frac{Nb}{Nr}\theta'' - Le\Lambda\phi^n = 0. \tag{11}$$

With boundary conditions gives

$$\begin{aligned} &f(0) = 0, \;\; f'(0) = 1, \;\; \theta'(0) = -Bi(1 - \theta(0)), \\ &\phi(0) = 1, \;\; f'(\infty) = 0, \;\; \theta(\infty) = 0, \;\; \phi(\infty) = 0. \end{aligned} \tag{12}$$

where the terms $\epsilon = \frac{1}{\mu\alpha_r\delta}$ and $\lambda = \frac{a^3x^2}{2\alpha_r^2\nu}$ are the working fluid materials, $M = \frac{\sigma B_0^2}{\rho_{nf}a}$ is magnetic field, $P = \frac{\nu}{aK}$ is the porosity, $Gr = \frac{g\beta_t(T_f - T_\infty)}{a^2x}$ and $Gc = \frac{g\beta_c(C_f - C_\infty)}{a^2x}$ are the heat and species buoyancy number, $Nr = \frac{\tau D_T(T_f - T_\infty)}{T_\infty\nu}$ denotes thermophoretic, $Pr = \frac{\nu}{\alpha}$ is Prandtl number, $Ra = \frac{4\sigma_s T_\infty^3}{3\nu k_{nf}}$ is the radiation, $Nb = \frac{\tau D_B(C_f - C_\infty)}{\nu}$ defines Brownian motion, $Le = \frac{\nu}{D_b}$ connotes Lewis number, $Q = \frac{Q_0}{a(\rho c)_{nf}}$ the heat source, $\Lambda = \frac{R_n(C_f - C_\infty)^{n-1}}{a}$ is chemical reaction and $Br = \frac{u_w^2}{Cp(T_f - T_\infty)}$ denotes the heat term.

The wall drag (Cf), heat gradient (Nu) and mass gradient (Sh) are the engineering thermophysical quantities of inquisitiveness which are given as:

$$Cf = \frac{G_w}{\rho u_w^2}; \text{ where } G_w = \left(\mu + \frac{1}{\alpha_r\delta}\right)\frac{\partial u}{\partial y} - \frac{1}{2\alpha_r^3\delta}\left(\frac{\partial u}{\partial y}\right)^3, \tag{13}$$

$$Nu = \frac{aQ_w}{(T - T_\infty)k_{nf}}; \text{ where } Q_w = -k_{nf}\left(\frac{\partial T}{\partial y}\right), \tag{14}$$

$$Sh = \frac{aS_w}{(C - C_\infty)D_B}; \text{ where } S_w = D_B\left(\frac{\partial C}{\partial y}\right). \tag{15}$$

Using the variables in equation (8) on equations (13)-(15), the equations reduces to dimensionless for as:

$$\begin{aligned} &Cf = (1 + \epsilon)f''(0) + \frac{\epsilon\lambda}{3}\left(f''(0)\right)^3, \\ &Nu = -\left(1 + \frac{4}{3}Ra\right)\theta'(0), Sh = -\phi'(0). \end{aligned} \tag{16}$$

3. Entropy generation

A continuous irreversibility process is created in the flow of Eyring-Powell nanoliquid simulated by heat conduction, fluid friction and diffusive irreversibility, this process defined entropy generation. Entropy is generated when there is an exchange of heat between device wall and the Eyring-Powell hydromagnetic nanoliquid. The entropy volumetric rate for the considered non-Newtonian fluid with the impact of electric field, porosity, and magnetic field is defined according to [25-27]:

$$E_G = \frac{k_{nf}}{T_\infty^2}\left[\left(\frac{\partial T}{\partial y}\right)^2 + \frac{16\sigma_s T_\infty^3}{3k_{nf}}\left(\frac{\partial T}{\partial y}\right)^2\right] + \frac{\mu_{nf}}{T_\infty}\left[\left(1+\frac{1}{\rho_{nf}\alpha_r\delta}\right)\left(\frac{\partial u}{\partial y}\right)^2 - \frac{1}{6\rho_{nf}\alpha_r\delta}\left(\frac{\partial u}{\partial y}\right)^4\right] + \frac{\sigma B_0^2}{T_\infty}u^2 + \frac{\nu}{KT_\infty}u^2 + \frac{RD}{C_0}\left(\frac{\partial C}{\partial y}\right)^2 + \frac{RD}{T_\infty}\left(\frac{\partial C}{\partial x}\frac{\partial T}{\partial x} + \frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right), \quad (17)$$

the characteristics of entropy production is denoted as

$$E_H = \frac{(k_{nf}\nabla T)^2}{T_\infty^2 a^2}. \quad (18)$$

Applying equation (8) on equation (17), the non-dimensional entropy generation takes the form

$$N_c = \frac{E_G}{E_H} = \left(1+\frac{4}{3}Ra\right)(\theta')^2 + \frac{Re\varphi\gamma}{\Omega}\left(\frac{\varphi}{\Omega}(\phi')^2 + \phi'\theta'\right) + \frac{BrRe}{\Omega}\left[(1+\lambda)(f'')^2 - \frac{\lambda\epsilon}{3}(f'')^4 + (M+P)(f')^2\right], \quad (19)$$

where $\Omega = \frac{\Delta T}{T_\infty}$, $\gamma = \frac{C_\infty RD}{k_{nf}}$, $\varphi = \frac{\Delta C}{C_\infty}$, $Re = \frac{U_w a^2}{\nu}$.

Taken $N_p = \left(1+\frac{4}{3}Ra\right)\left(\theta'\right)^2$ and
$N_q = \frac{BrRe}{\Omega}\left[(1+\lambda)(f'')^2 - \frac{\lambda\epsilon}{3}(f'')^4 + (M+P)(f')^2\right] + \frac{Re\varphi\gamma}{\Omega}\left(\frac{\varphi}{\Omega}(\phi')^2 + \phi'\theta'\right)$,
The Bejan number (Be) is expressed as

$$Be = \frac{\left(1+\frac{4}{3}Ra\right)\left(\theta'\right)^2}{\frac{BrRe}{\Omega}\left[(1+\lambda)(f'')^2 - \frac{\lambda\epsilon}{3}(f'')^4 + (M+P)(f')^2\right] + \left(1+\frac{4}{3}Ra\right)(\theta')^2 + \frac{Re\varphi\gamma}{\Omega}\left(\frac{\varphi}{\Omega}(\phi')^2 + \phi'\theta'\right)}. \quad (20)$$

Here, $N_p + N_q = N_c$, and N_p represents the energy irreversibility, N_q connotes irreversibility due to diffusion, conduction and Joule heating. Be defines the ratio of irreversibility. The irreversibility of nanoliquid Powell-Eyring is dominated with chemical diffusion, Joule heat and heat transfer when $Be = 0$ but when $Be = 1$, the irreversibility of non-Newtonian nanoliquid is controlled by thermal conducting of the fluid with changes in the temperature.

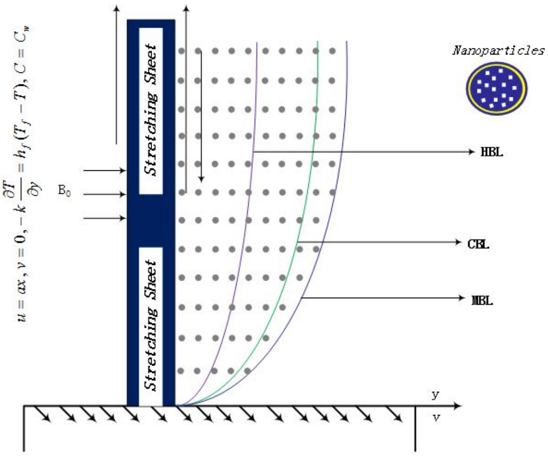

Figure 1. Flow schematic diagram

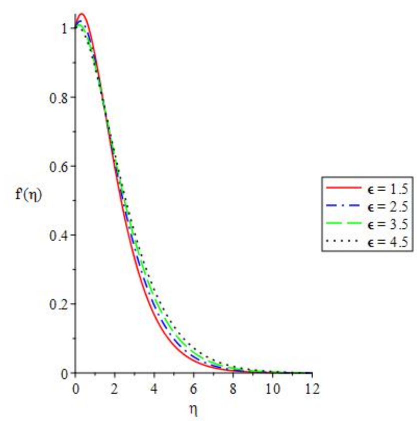

Figure 2. Flow rate field for various ϵ

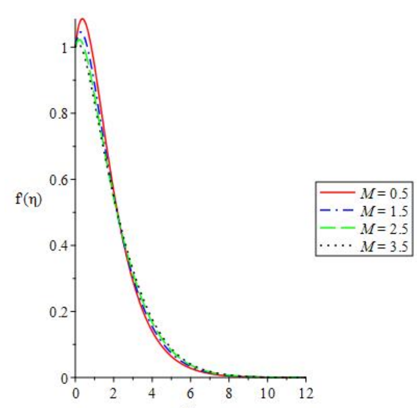

Figure 3. Velocity field for different M

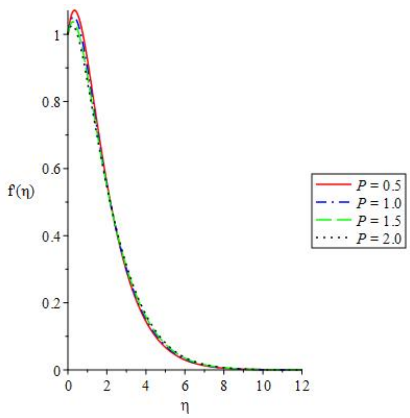

Figure 4. $f(\eta)$ against η for various P

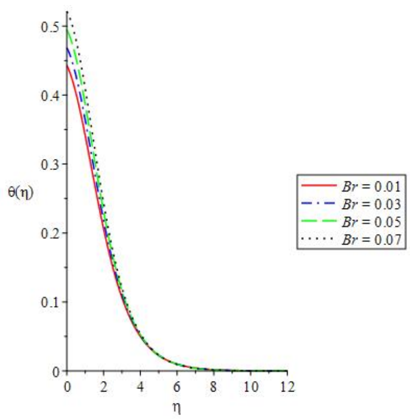

Figure 5. Heat profile for variation of *Br*

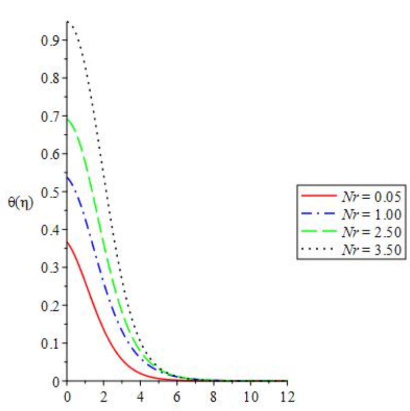

Figure 6. Plot of $\theta(\eta)$ versus η for Nr

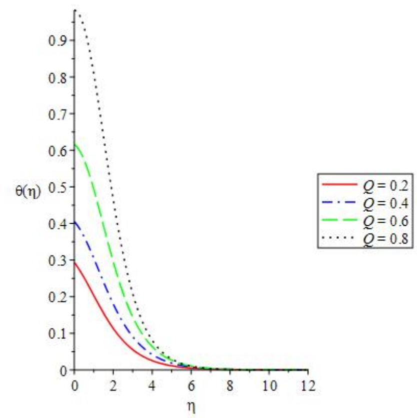

Figure 7. Temperature field for various Q

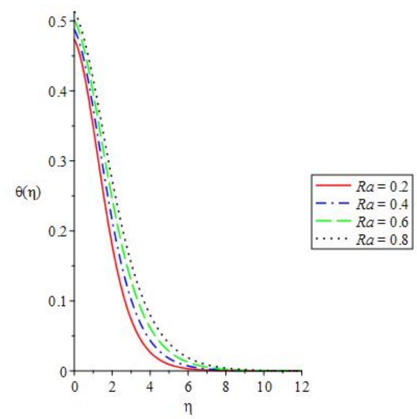

Figure 8. Rising *Ra* effect on temperature

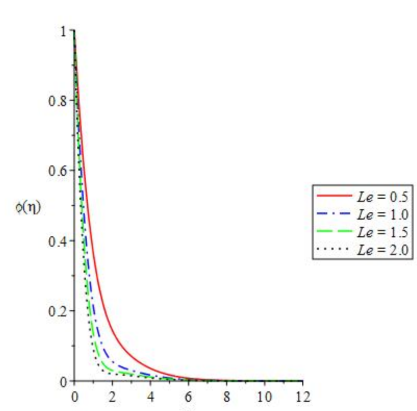

Figure 9. Reaction field for rising *Le*

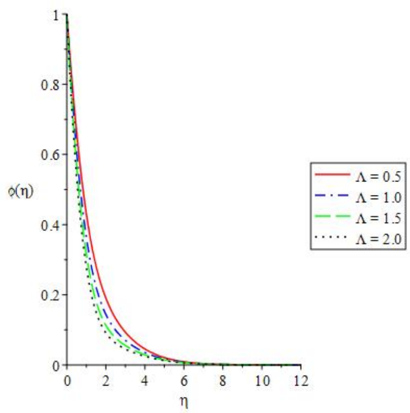

Figure 10. Effect of Λ on concentration

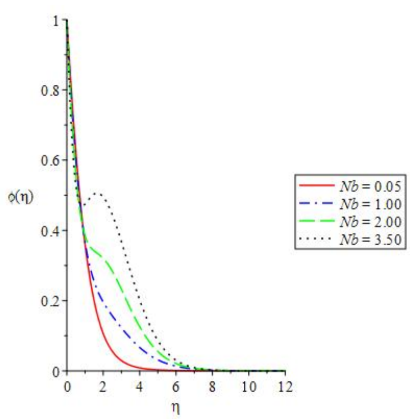

Figure 11. $\phi(\eta)$ versus η for various Nb

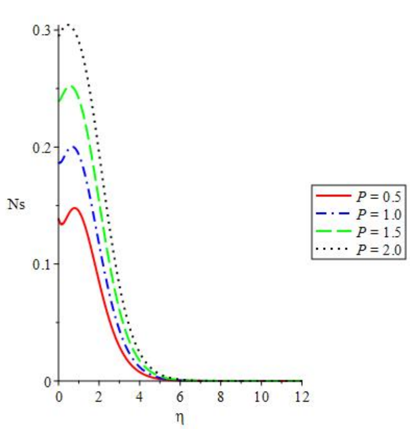

Figure 12. Entropy profile for different

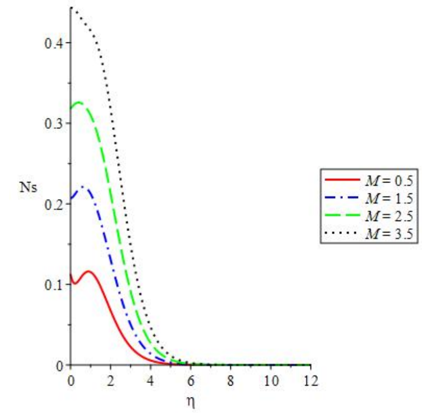

Figure 13. M impacts on entropy field

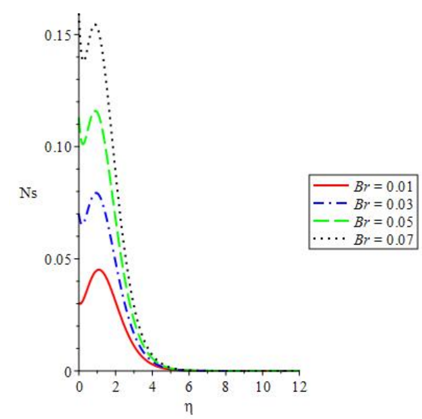

Figure 14. Irreversibility for increasing Br

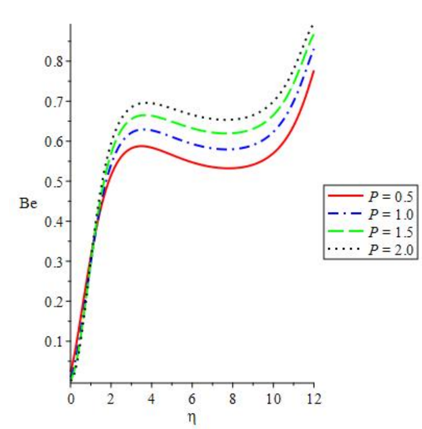

Figure 15. Impact of P on Bejan number

4. Method of Solution

Based on previous analysis, the following values $\epsilon = 0.5$, $\lambda = 0.1$, $n = 1.0$, $\Lambda = 1.0$, $P = 0.2$, $M = 0.5$, $Pr = 0.72$, $Ra = 0.5$, $Nb = 0.5$, $Nr = 0.5$, $Le = 0.5$, $Q = 0.5$, $Gr = 3.0$, $Gc = 3.0$, $Br = 0.05$, $Re = 1.0$, $\Omega = 0.5$, $\varphi = 0.2$, $\gamma = 0.3$ are set as default. A numerical shooting techniques is carried out on the MHD Eyring-Powell nanoliquid boundary value equations. The numerical method allows the transformation of boundary value equation to an initial value equation. At far field ($\eta \longrightarrow \infty$), a finite appropriate boundary value is assumed. Then the derivative of higher order is presented in first order derivative by assuming and substituting the following quantities in equations (9) to (12):

$$a_1 = f,\ a_2 = f',\ a_3 = f'',\ a_4 = \theta,\quad a_5 = \theta',\ a_6 = \phi,\ a_7 = \phi', \tag{21}$$

$$a_3' = \frac{-a_1a_3 + (a_2)^2 + (M+P)a_2 - Gra_4 - Gca_6}{(1+\epsilon) - \lambda\epsilon(a_3)^2}, \tag{22}$$

$$a_5' = \frac{-Pra_1a_5 - PrNba_5a_7 - BrPr(M+P)(a_2)^2}{1+\frac{4}{3}Ra} - \frac{PrNr(a_5)^2 + PrQa_4}{1+\frac{4}{3}Ra}, \tag{23}$$

$$a_7' = -Lea_1a_7 - \frac{Nb}{Nr}a_5' + Le\Lambda(a_6)^n, \tag{24}$$

The boundary conditions becomes

$$a_1(0) = 0,\ a_2 = 1,\ a_5(0) = -Bi(1 - a_4(0)),\ a_6 = 1,\quad a_2(\infty) = 0,\ a_4(\infty) = 0,\ a_6(\infty) = 0. \tag{25}$$

The reduced initial value equations (21) to (24) are to be solved. The unknown points $a_2(0) = r_1$, $a_5(0) = r_2$ and $a_7(0) = r_3$ are needed for computation. Therefore, the unknown values are initially guessed to allow computation which is carried out using integrating Runge-Kutta procedures with step size $\nabla\eta = 0.0001$. The same solution procedures is used for the physical quantities and the entropy generation.

5. Results and Discussion

The comparison of computed outcomes for the heat gradient and plate drag force is presented in tables 1 and 2. The comparison was done with relevant previous related studies in order to confirm the consistency and exactness of the present computed results. Table 1 denotes the compared results for heat gradient with the work of Tawade *et al.* [4], Ishaq *et al.* [11] and Salawu and Ogunseye [29]. Also, table 2 represents the skin friction numerical results as compared with the previous study of Hayat *et al.* [10] and Ogunseye *et al.* [30]. As seen from the tables, the computational values agreed well with about 10^{-6} relative error.

The computational values for the thermophyscial quantities of engineering interest are presented in table 3. Keeping other parameters fixed, the results demonstrated the effect of some parameters on the stretching wall. As obtained from the table, some terms have an increasing effect on the wall while some have a reducing impact on the stretching wall. The computed values depends on the momentum, thermal and reaction species boundary layers.

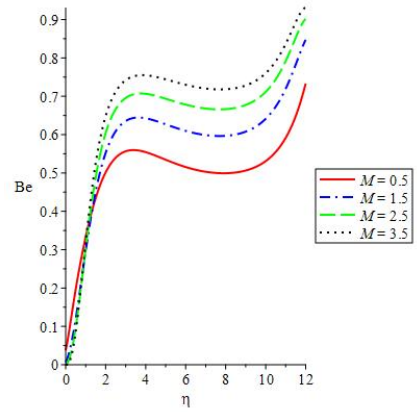

Figure 16. *M* effects on Bejan number

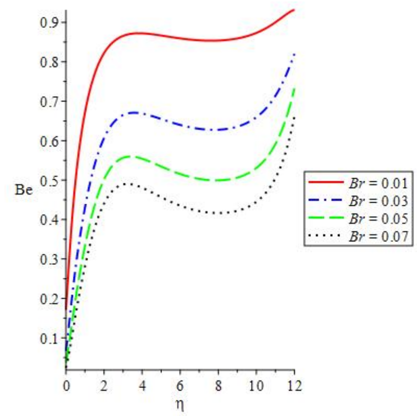

Figure 17. Irreversibility ratio field for *Br*

Th reaction of Eyring-Powell nanoliquid velocity in a vertical plate to the rising values of material term ϵ, magnetic term M, and porosity term P are respectively demonstrated in figures 2, 3 and 4. The dimensionless velocity $f'(\eta)$ is plotted against the dimensionless distance η as seen in the figures. With fixed values of other terms, the parameters ϵ, M and P show a decreasing effect on the viscoelastic nanoliquid flow rate near the stretching boundary wall. The reducing effect occurs close to the stretching vertical plate due to a rise in the molecular bonding force and lower internal heating. However, the parameters influence on the fluid velocity decreases steadily away from the plate. As the non-Newtonian fluid flows far from the plate, the heat produced in the chemical reaction system upsurges, due to an augmentation in the heat generation and Ohmic heating influencing the reaction rate that in turn reduced the viscoelastic fluid bonding force. Therefore, the flow rate is progressively expanded far the velocity field and converged far away the stream.

Table 1. Results comparison for the heat gradient.

λ	Pr	Nr	[4]	[11]	[30]	New results
0.2	1.0	0.1	0.3238	0.32102	0.32186	0.32186
0.3			0.3020	0.30042	0.30071	0.30071
0.4			0.2925	0.29142	0.29092	0.29092
	0.5		0.3717	0.37142	0.37129	0.37129
	1.5		0.1819	0.18229	0.18210	0.18210
		0.4	0.6117	0.61243	0.61238	0.61238
		0.6	0.6023	0.69143	0.70016	0.70016
		0.8	0.5013	0.50099	0.50083	0.50083

Table 2. Results comparison for the skin friction.

Nr	Nb	[10]	[31]	Present results
	0.5	1.21380	1.21380229	1.21380217
0.2		1.24143	1.24142703	1.24142698
0.5		1.37544	1.37544311	1.37544302
0.0		1.79329	1.79328569	1.79328551
0.2	1.0	1.25874	1.25873960	1.25873893
	1.5	1.26916	1.26016234	1.26016222

Table 3. Numerical values for the skin friction (Cf), Nusselt number (Nu) and Sherwood number (Sh)

M	λ	ϵ	Ra	Le	Nr	Nb	Cf	Nu	Sh
0.5	0.1	0.5	0.5	0.5	0.5	0.5	0.987613128	0.0567754810	0.937155927
0.7							0.937510305	0.0531214474	0.943378662
1.5							0.763440580	0.0377939599	0.970428985
	0.3						1.008526464	0.0567917496	0.937253896
	0.7						1.061377860	0.0568290633	0.937472853
		1.0					0.759445493	0.0564705972	0.934027849
		1.5					0.610097045	0.0562309677	0.931818099
			0.03				0.922979767	0.0603941793	0.941008972
			0.07				0.927870854	0.0601463768	0.940178666
				0.7			0.917559030	0.0532639565	1.108694229
				1.0			0.843402030	0.0497823360	1.320808092
					1.5		1.069353500	0.0495253726	0.919047457
					2.5		1.184217940	0.0407985312	0.920494831
						1.0	1.037237502	0.0542505586	0.998303261
						2.0	1.124838686	0.0498904892	1.170942782

Hence, the flow rate profiles for the considered fluid rises in the neighboring of the moving plate, but in opposite direction far-off the vertical surface.

The effect of some thermophysical terms on the energy distribution is confirmed in figures 5, 6, 7 and 8. The impact of heat dissipation *Br*, thermophoretic *Nb*, heat source *Q* and radiation *Ra* terms on the temperature distribution are separately presented in the plots. At different significance, the parameters vigorously influenced the thermal dispersion rate in the porous device. The strong heat encouragement is due to rises in the chemical reaction rate that leads to random motion and rapid collision of the fluid particles. Also, as heat source parameters is boosted, small or no thermal propagation of chemically non-Newtonian viscoplastic mixtures out of the system to the ambient. This is as a result of thermal boundary film is inspired, which in turn damped the heat transport in permeable media. In the temperature equation, the thermal source are propelled to enhance thermal transport in the Eyring-Powell chemical nanoliquid mixture, which leads to a complete increase in the temperature profiles. Thus, the parameters *Br*, *Nb*, *Q* and *Ra* inspires the temperature propagation in the moving vertical plate as depicted in figures 5, 6, 7 and 8.

Concentration profiles for various effects of some parameters are established in figures 9, 10 and 11. The figures depict the plot of $\phi(\eta)$ versus distance $\eta \longrightarrow \infty$ in a boundless domain. In figures 9 and 10, the response of the species concentration to variation in the Lewis number *Le* and chemical reaction Λ are illustrated. As obtained in the figures, both terms of equal variational values decrease the concentration field at different significant. The reducing impact is momentously noticeable in the Lewis number *Le* than chemical reaction Λ. The diminishing in the profiles is due to lower chemical reaction rate in the system that causes the species particles to react slowly and discouraged. Hence, increasing the values of both terms enhances nanoliquid chemical diffusion as the concentration boundary layer shrinks. Figure 11 depicts the impact of Brownian movement Nr on the reacting species profile. Rising values of the Brownian movement term increases the reaction rate and rapid random motion of the chemical particles, this then causes a rise in the reaction mass field as presented in the figure.

The respective influence of variation in the thermophysical terms porosity P, magnetic M and heat dissipation Br on the entropy generation is described in figures 12, 13 and 14. In a process where irreversibility is in existence, entropy generation is defined. This measure the amount of energy loss that causes degradation of technology system performance. As seen, the parameters encourages system irreversibility due to high energy dissipation near the stretching plate as the values of the parameters is raised. However, the irreversibility due chemical diffusive, friction and conducting heat decrease regularly few distance from the moving surface because the fluid thermodynamic equilibrium is rising gradually and continuously toward the free field. The decrease in the entropy generation continues until a balance thermodynamic equilibrium is attained and energy dissipation tends to zero. Hence, irreversibility reduces far the field as portrayed in figures 12, 13 and 14. The effect of porosity P, magnetic M and heat dissipation Br on the irreversibility ratio is respectively presented in figures 15, 16 and 17. Bejan number is the irreversibility heat transfer ratio to the sum of the irreversibility of fluid friction and heat transfer. The irreversibility ratio rises all over the considered system domain as demonstrated in figure 15 and 16. The overall rising in the magnitude of the Bejan number is because of the increasing rate in the heat transfer irreversibility in the non-Newtonian viscoelastic fluid regime. Meanwhile, heat dissipation term Br completely reduced the irreversibility ratio of the chemical diffusive system. The significant impact is very obvious within the chemical reaction due to strong fluid frictional effect that dominate the reactive system. Therefore, as depicted in figure 17, the Bejan number decreases momentously over the domain.

6. Conclusion

In the study, the entropy generation of Eyring-Powell chemical reaction nanoliquid was considered in a porous vertical boundless device with heat distribution. A shooting numerical technique is adopted for the solutions coupled with the Runge-Kutta scheme due to its convergence, consistency, and unconditional stability. Both quantitative and qualitative computed values were obtained in agreement with existing ones. Solution dependent parameters for the velocity, heat, volumetric irreversibility, and Bejan number are obtained. The investigation shows that the material properties, porosity, and magnetic field have little impact on the flow momentum. Also, the irreversibility process is minimized with an enhanced magnetic field, porosity, and thermodynamic equilibrium. Moreover, the terms that encourage temperature should be carefully managed to prevent the Eyring-Powell nanoliquid solution blowup. However, the results of this study are applicable to medical science, biotechnology, and chemical synthesis.

References

[1] A. R. Hassan, J. A. Gbadeyan & S. O. Salawu, "The effects of thermal radiation on a reactive hydromagnetic internal heat generating fluid flow through parallel porous plates", Springer Proceedings in Mathematics & Statistics **259** (2018) 183.

[2] E. O. Fatunmbi & S. O. Salawu, "Analysis of hydromagnetic micropolar nanofluid flow past a nonlinear stretchable sheet and entropy generation with Navier slips", Int. J. of modelling and Simulation **42** (2022) 359.

[3] S. O. Salawu & M. S. Dada, "Lie group analysis of soret and dufour effects on radiative inclined magnetic pressure-driven flow past a Darcy-forchheimer medium", J. of the Serbian Soc. for Comput. Mech. **12** (2018) 108.

[4] A. S. Idowu & B. O. Falodun, "Effects of thermophoresis, Soret-Dufour on heat and mass transfer flow of magnetohydrodynamics non-Newtonian nanofluid over an inclined plate", Arab J. of Basic and Applied Sci. **27** (2020) 149.

[5] A.S. Idowu, M.T. Akolade, J.U. Abubakar & B.O. Falodun, "MHD free convective heat and mass transfer flow of dissipative Casson fluid with variable viscosity and thermal conductivity effects", J. of Taibah Uni. for Sci. **14** (2020) 851.

[6] S. O. Salawu, R. A. Kareem & A. Abolarinwa & S. A. Shonola, "Radiative thermal criticality and entropy generation of hydromagnetic reactive Powell-Eyring fluid in saturated porous media with variable conductivity", Int. Communi. in Heat and Mass Transfer **124** (2021) 104613.

[7] S. O. Salawu, A. R. Hassan, A. Abolarinwa & N. K. Oladejo, "Thermal stability and entropy generation of unsteady reactive hydromagnetic Powell-Eyring fluid with variable electrical and thermal conductivities", Alexandria Engin. J. **58** (2019) 519.

[8] S. Nadeem & S. Saleem, "Mixed convection flow of Eyring-Powell fluid along a rotating cone", Results in Physics **4** (2014) 54.

[9] N. S. Akbar, M. Ebaid & Z. H. Khan, "Numerical analysis of magnetic field effects on Eyring-Powell fluid flow towards a stretching sheet", J. of Magnetism and Magnetic Materials **382** (2015) 355.

[10] T. Hayat, M. Awais & S. Asghar, "Radiative effects in a three dimensional flow of MHD Eyring-Powell fluid", J. Egypt Math. Soc. **21** (2013) 379.

[11] M. Ishaq, G. Ali, Z. Shah, S. Islam & 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 **20** (2018) 412.

[12] F. O. Akinpelu, R. A. Oderinu & A. D. Ohaegbue, "Analysis of hydromagnetic double exothermic chemical reactive flow with convective cooling through a porous medium under bimolecular kinetics", J. Nig. Soc. Phys. Sci. **4** (2022) 130.

[13] S. O. Adesanya, H. A. Ogunseye & S. Jangili, "Unsteady squeezing flow of a radiative Eyring-Powell fluid channel flow with chemical reactions", Int. J. of Thermal Sciences 125 (2018) 440-447.

[14] A.S. Idowu & B.O. Falodun, "Variable thermal conductivity and viscosity effects on non-Newtonian fluids flow through a vertical porous plate under Soret-Dufour influence", Mathematics and Computers in Simulation **177** (2020) 358.

[15] T. Hayat, T. Muhammad, A. Qayyum, A. Alsaedi & M. Mustafa, "On squeezing flow of nanofluid in the presence of magnetic field effects", J. of Molecular Liquids **213** (2016) 179.

[16] F. I. Alao, A.I. Fagbade & B. O. Falodun, "Effects of thermal radiation, Soret and Dufour on an unsteady heat and mass transfer flow of a chemically reacting fluid past a semi-infinite vertical plate with viscous dissipation", J. of the Nigerian Mathematical Soc. **35** (2016) 142.

[17] T. M. Agbaje, S. Mondal, S.S Motsa & P. Sibanda, "A numerical study of unsteady non-Newtonian Powell-Eyring nanofluid flow over a shrinking sheet with heat generation and thermal radiation", Alexandria Engin. J. **56** (2017) 81.

[18] M. Y. Malik, I. Khan, A. Hussain & T. Salahuddin, "Mixed convection flow of MHD Eyring-Powell nanofluid over a stretching sheet: a numerical study", AIP Advances **5** (2015) 117118.

[19] M. M. Bhatti, T. Abbas, M.M. Rashidi, M. S. Ali & Z. Yang, "Entropy generation on MHD Eyring-Powell nanofluid through a permeable stretching surface", Entropy **18** (2016) 224.

[20] S. O. Salawu, R.A. Oderinu & A. D. Ohaegbue, "Thermal runaway and thermodynamic second law of a reactive couple stress hydromagnetic fluid with variable properties and Navier slips", Scientific African **7** (2020) e00261.

[21] S. O. Salawu & S. I. Oke, "Inherent irreversibility of exothermic Chemical Reactive third-grade Poiseuille flow of a Variable Viscosity with Convective Cooling". J. Appl. Comput. Mech. **4** (2017) 167.

[22] M. M. Rashidi, M. Ali, N. Freidoonimehr & F. Nazari, "Parametric analysis and optimization of entropy generation in unsteady MHD flow over a stretching rotating disk using artificial neural network and particle swarm optimization algorithm", Energy **55** (2013) 497.

[23] T. Hayat, M.I. Khan, S. Qayyum, A. Alsaedi, "Entropy generation in flow with silver and copper nanoparticles", Colloids and Surfaces A **539** (2018) 335.

[24] M. W. A. Khan, M. I. Khan, T. Hayat & A. Alsaedi, "Entropy generation minimization (EGM) of nanofluid flow by a thin moving needle with nonlinear thermal radiation", Physica B: Condensed Matter **534** (2018) 113.

[25] A. M. Rashad, T. Armaghani, A.J. Chamkha & M.A. Mansour, "Entropy generation and MHD natural convection of a nanofluid in an inclined square porous cavity: Effects of a heat sink and source size and location", Chinese J. of Physics **17** (2017) 949.

[26] S. O. Salawu, M.S. Dada & O.J. Fenuga, "Thermal explosion and irreversibility of hydromagnetic reactive couple stress fluid with viscous dissipation and Navier slips", Theoretical & Applied Mechanics Letters **9** (2019) 246.

[27] J. Qing, M.M. Bhatti, M.A. Abbas, M.M. Rashidi & M. E. Ali, "Entropy generation on MHD casson nanofluid flow over a porous stretching/shrinking surface", Entropy **18** (2016) 123.

[28] M.H. Abolbashari, N. Freidoonimehr, F. Nazari & M. M. Rashidi, "Entropy analysis for an unsteady MHD flow past a stretching permeable surface in nano-fluid", Powder Technology **267** (2014) 256.

[29] E.O. Fatunmbi, A.T. Adeosun & S.O. Salawu, "Irreversibility analysis for Eyring–Powell nanoliquid flow past magnetized Riga device with nonlinear thermal radiation", Fluid **6** (2021) 416.

[30] S. O. Salawu & H.A. Ogunseye, "Entropy generation of a radiative hydromagnetic Powell-Eyring chemical reaction nanofluid with variable conductivity and electric field loading", Results in Engineering **5** (2020) 100072.

[31] H. A. Ogunseye, S.O. Salawu, Y.O. Tijani, M. Riliwan & P. Sibanda, "Dynamical analysis of hydromagnetic Brownian and thermophoresis effects of squeezing Eyring-Powell nanofluid flow with variable thermal conductivity and chemical reaction", Multidiscipline Modeling in Materials and Structures **15** (2019) 1100.