Research Article

Assisting and Opposing Stagnation Point Pseudoplastic Nano Liquid Flow towards a Flexible Riga Sheet: A Computational Approach

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Nanofluids are used as coolants in heat transport devices like heat exchangers, radiators, and electronic cooling systems (like a flat plate) because of their improved thermal properties. The preeminent perspective of this study is to highlight the influence of combined convection on heat transfer and pseudoplastic non-Newtonian nanofluid flow towards an extendable Riga surface. Buongiorno model is incorporated in the present study to tackle a diverse range of Reynolds numbers and to analyze the behavior of the pseudoplastic nanofluid flow. Nanofluid features are scrutinized through Brownian motion and thermophoresis diffusion. By the use of the boundary layer principle, the compact form of flow equations is transformed into component forms. The modeled system is numerically simulated. The effects of various physical parameters on skin friction, mass transfer, and thermal energy are numerically computed. Fluctuations of velocity increased when modified Hartmann number and mixed convection parameter are boosted, where it collapses for Weissenberg number and width parameter. It can be revealed that the temperature curve gets down if modified Hartmann number, mixed convection, and buoyancy ratio parameters upgrade. Concentration patterns diminish when there is an incline in width parameter and Lewis number; on the other hand, it went upward for Brownian motion parameter, modified Hartmann, and Prandtl number.

1. Introduction

Mixed convection flow or a combination of free and forced convections exists in numerous electrify operations; both certainly occur in many engineering applications. Such applications mostly appear in heat exchangers, nuclear reactors, nanotechnology, atmospheric boundary layer flow, electronic equipment, and so on. These operations arise at some stage in the outcomes of buoyancy forces in combined convections or the effects of forced flow in free convection become significant [1]. The unsteady mixed convection flow closer to a stretching sheet throughout the years is an important kind of flow of functional substantial in engineering and industries [2]. Patel and Singh [3] investigated mixed convection micropolar fluid flow in a permeable medium

with a magnetic field towards a nonlinearly extendable surface. Arifin et al. [4] discussed the dusty Williamson mixed convection fluid flow towards a stretchable surface with the impact of an aligned magnetic field. Ishak et al. [5] investigated the stagnation-point mixed convection viscous fluid flow towards a stretchable surface in its plane. The non-Newtonian fluid form is essential to conceive the fluid flow in the latest industrial materials, so that the work productiveness could be improved. Shafiq et al. [6] studied the bioconvective second-grade nano liquid flow in the presence of chemical reaction and buoyancy effect. Naganthran et al. [7] demonstrated a computational approach that inspects the behavior of mixed convection steady stagnation-point Powell-Eyring fluid flow on a vertical stretching/shrinking surface. Azeman and Ishak [8] discussed numerically the

problem of the combined convection stagnation-point flow on a vertical sheet. Many researchers had also studied the mixed convectional flow [9–13].

The research of heat transmission triggered employing boundary layer flow of an incompressible fluid towards a stretched surface had received extended interest from the scientists and researchers due to its advantages in industry and engineering. Presently, huge exertion has been made to concentrate on this subject to the frame of reference of its different industrial and engineering applications. The effects of combined convection MHD on the boundary layer flow in the aspect of heat transport of Hematite-water nanofluid on a stretchable surface are demonstrated in [14]. Ahmad et al. [15] demonstrated the boundary layer flow by a curved stretched surface enclosed in a porous material.

Nowadays, to improve the abilities of heat transport of habitual fluids like water, glycerin, and engine oil because of the decay of the thermal effects, nanofluid is the classic bestowal to enhance the thermal conductivity. Nano liquid is a liquid that was invented by nanometer-sized particles and microfibers having a diameter less than 100 nm. Nanofluids are used in many operations to fulfill industrial requirements, like propellant combustion, drug delivery, cooling of automotive engines, extraction of geothermal forces, and heat transfer. Al-Hossainy and Eid [16] demonstrated the heat transfer enhancement and DFT Structure and calculations in hybrid nanofluid flow as an application of potential solar cell coolant in a double tube. Zaib et al. [17] discussed the partial slip impacts on micropolar mixed convection fluid flow holding kerosene/water-based TiO_2 nanoparticle over a Riga sheet; results were obtained for aiding and opposing flows. Choi was the first who introduced the idea of nanofluid. He suggested that a new category of heat exchanger liquids could be engineered by suspending metallic nanoparticles in conventional heat exchanger liquids [18]. Ahmed et al. [19] discovered the impact of variable viscosity on the MHD unsteady flow of carbon nanotubes on a shrinking surface. Saleem et al. [20] explored the theoretical treatment for the unsteady Walter's B nanofluid flow over a rotating cone in the magnetic regime. Many researchers had discussed the flow of nanofluids [21–39].

Lorentz force theoretically [40] and experimentally [41] is an efficient agent to reduce skin friction. Nadeem et al. [42] demonstrated that flow is induced through exponentially stretching surface within the time-dependent thermal conductivity. Mahdy and Hoshoudy [43] explored the electromagnetohydrodynamic (EMHD) unsteady non-Newtonian

nanotangent hyperbolic fluid that is electrically conducting towards a Riga surface in the presence of slip conditions and variable thickness.

The current examination adds a novel era for scientists to find the characteristics of pseudoplastic nanofluid. Here, we inspect heat transfer analysis and mixed convection stagnation-point flow of a pseudoplastic non-Newtonian nanofluid over a convectively heated flexible Riga plate. Obtained equations are solved by bvp4c numerically. The consequences of the given problem are demonstrated by parameters such as modified Hartmann number, mixed convection parameter, Brownian motion parameter, buoyancy ratio parameter, thermophoresis parameter, width parameter, stretching parameter, Weissenberg, Biot, Prandtl, and Lewis numbers to the velocity, thermal energy, and mass transmission towards the vertical elastic Riga plate.

2. Mathematical Modeling

We inspected the incompressible, two-dimensional, steady pseudoplastic nanofluid flow and heat transfer improvement examination over the vertical extendable Riga surface as shown in Figure 1. $u_w(x) = ax$ is the sheet stretched velocity and $u_\infty(x) = bx$ is the ambient fluid velocity, while the origin is fixed. It is assumed that the plate is heated by convection from a hot fluid at the temperature T_f and the plate is heated by convection fluid at a temperature T_∞ which is by heat transport coefficient h_f . Considering the Cartesian coordinates system, fluid flow velocity will change through x -axis and y -axis in a manner where the x -axis is taken vertically and the y -axis is taken horizontally as shown below.

The elemental equation of pseudoplastic fluid is [44]

$$\tau = \left[\mu_\infty + (\mu_0 - \mu_\infty) \left((1 + \Gamma \dot{\gamma})^d \right)^{(n-1/d)} \right] A_1, \quad (1)$$

where zero shear rate viscosity is μ_0 , infinite shear rate viscosity is μ_∞ , Γ and d are Carreau-Yasuda fluid parameters, A_1 is the Rivlin-Ericksen tensor, τ is the extra stress tensor, and $\dot{\gamma}$ is expressed as $\dot{\gamma} = \sqrt{\text{tr}(A_1^2)(1/2)}$; here, $A_1 = [(\text{grad} \mathbf{v})^t + \text{grad} \mathbf{v}]$. Take into account the fact that infinite shear rate viscosity $\mu_\infty = 0$; then, equation (1) takes the form

$$\tau = \left[\mu_0 \left((1 + \Gamma \dot{\gamma})^d \right)^{(n-1/d)} \right] A_1, \quad (2)$$

and, under these considerations, governing equations can be written as follows:

FIGURE 1: Sketch of the flow problem. (a) Physical geometry of the problem. (b) Riga plate.

$$\begin{aligned}
 \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} &= 0, \\
 u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} &= u_\infty \frac{du_\infty}{dx} + \nu \frac{\partial^2 u}{\partial y^2} + \nu \left[\frac{(n-1)}{d} \cdot (d+1) \Gamma^d \left(\frac{\partial u}{\partial y} \right)^d \frac{\partial^2 u}{\partial y^2} \right] \\
 &\quad + g \left[\frac{(1-C)\beta \rho_{fm}}{\rho_f} (T - T_\infty) - \left(\frac{\rho_p - \rho_{fm}}{\rho_p} \right) (C - C_\infty) \right] + \frac{\pi j_0 M_0}{8 \rho_f} e^{-(\pi/a_1)y}, \\
 u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} &= \alpha \frac{\partial^2 T}{\partial y^2} + \frac{(\rho c_p)_p}{(\rho c_p)_f} \left[D_B \frac{\partial C}{\partial y} \frac{\partial T}{\partial y} + \left(\frac{D_T}{T_\infty} \right) \left(\frac{\partial T}{\partial y} \right)^2 \right], \\
 u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} &= D_B \frac{\partial^2 C}{\partial y^2} + \left(\frac{D_T}{T_\infty} \right) \frac{\partial^2 T}{\partial y^2}.
 \end{aligned} \tag{3}$$

In the above equations, u and v are the velocity components in the x -axis and y -axis, respectively, ν is the viscosity coefficient, $((\rho c_p)_p / (\rho c_p)_f)$ is the proportion of nanoparticles heat capacity to that of the based fluid heat capacity, α is the thermal diffusivity of the based fluid, ρ_f is the density of the base fluid, c_p is the constant

pressure specific heat, D_T is thermophoresis diffusion coefficient, D_B is Brownian diffusion coefficient, and the subscripts ∞ , f , and np denote the values very far away from the solid surface, base fluid, and the nanoparticles, respectively.

The subjected boundary conditions are

$$\begin{aligned}
u &= u_w(x) = ax, \\
v &= 0, \\
-k \frac{\partial T}{\partial y} &= h_f(T_f - T), \\
D_B \frac{\partial c}{\partial y} + \left(\frac{D_T}{T_\infty} \right) \frac{\partial T}{\partial y} &= 0 \text{ at } y \longrightarrow 0,
\end{aligned} \tag{4}$$

$$\begin{aligned}
u &= u_\infty(x) = bx, \\
T &\longrightarrow T_\infty, \\
C &\longrightarrow C_\infty, \text{ at } y \longrightarrow \infty.
\end{aligned}$$

Invoking similarity variables are defined as,

$$\begin{aligned}
\psi &= \sqrt{avx} f(\eta), \\
\eta &= \sqrt{\frac{a}{v}} y, \\
u &= \frac{\partial \psi}{\partial y} = ax f'(\eta), \\
v &= \frac{\partial \psi}{\partial x}, \\
\theta(\eta) &= \frac{T - T_\infty}{T_f - T_\infty}, \\
\varphi(\eta) &= \frac{C - C_\infty}{C_\infty}.
\end{aligned} \tag{5}$$

By using the upper relationships, the continuity equation (3) is satisfied automatically. Equation (3) becomes the form of ordinary differential equations:

$$\begin{aligned}
\left[1 + \frac{(n-1)}{d} (d+1) W_e^d (f'')^d \right] f''' + r^2 \\
+ f f'' - (f')^2 + \lambda \theta - N_r \varphi + Z e^{-\gamma \eta} &= 0, \\
\frac{1}{\text{Pr}} \theta'' + \theta' f + Nb \varphi' \theta' + Nt (\theta')^2 &= 0, \\
\varphi'' + Le \text{Pr} f \varphi' + \frac{Nt}{Nb} \theta'' &= 0,
\end{aligned} \tag{6}$$

with boundary conditions

$$\begin{aligned}
f &= 0, \\
f' &= 1, \\
\theta' &= -Bi(1 - \theta), \\
Nb \varphi' + Nt \theta' &= 0 \text{ at } \eta \longrightarrow 0, \\
f' &= r, \\
\theta &= 0, \\
\varphi &= 0 \text{ at } \eta \longrightarrow \infty.
\end{aligned} \tag{7}$$

Here, prime denotes derivative for η , and other dimensionless characteristics are demonstrated as

$$\begin{aligned}
\lambda &= \frac{(1-c)\beta \rho_{fm}(T_f - T_\infty)g}{a^2 x \rho_f}, \\
N_r &= \frac{(\rho_p - \rho_{fm})c_\infty g}{a^2 x \rho_f}, \\
r &= \frac{b}{a}, \\
W_e^d &= \left(\frac{a^{3/2} x \Gamma}{\sqrt{v}} \right)^d, \\
Nt &= \frac{(\rho c_p)_p D_T (T_f - T_\infty)}{(\rho c_p)_f \nu T_\infty}, \\
\text{Pr} &= \frac{\nu}{\alpha}, \\
Nb &= \frac{(\rho c_p)_p D_B C_\infty}{(\rho c_p)_f \nu}, \\
Le &= \frac{\alpha}{D_B}, \\
Bi &= \frac{h_f}{k} \sqrt{\frac{\gamma}{a}}, \\
\alpha &= \frac{K}{(\rho c_p)_f}, \\
Z &= \frac{\pi j_0 M_0 x}{8 \rho_p u_w^2}, \\
\gamma &= \frac{-\pi}{a_1 \sqrt{(a/\nu_f)}}.
\end{aligned} \tag{8}$$

Here, Le , N_r , λ , Bi , and We_e denote Lewis number, buoyancy ratio parameter, mixed convection parameter, Biot number, and Weissenberg number, respectively, the symbol Z represents modified Hartmann number, γ denotes width parameter, Pr denotes Prandtl number, r is the stretching parameter, Nb is the Brownian motion characteristic, and Nt denotes the thermophoresis characteristics.

The skin friction coefficient C_f and local Nusselt number Nu_x definitions are

$$C_f = \frac{\tau_w}{\rho u_w^2}, \quad (9)$$

$$Nu_x = \frac{x q_w}{k(T_f - T_\infty)},$$

where q_w represents surface heat flux, τ_w represents surface shear stress, and q_m represents surface mass flux, where pseudoplastic fluid is

$$\tau_w = \left[\mu \left(1 + \left(\frac{n-1}{d} \right) \Gamma^d \left(\frac{\partial u}{\partial y} \right)^d \right) \frac{\partial u}{\partial y} \right]_{y=0}, \quad (10)$$

$$q_w = -k \left[\frac{\partial T}{\partial y} \right]_{y=0},$$

and, by using appropriate similarity variable equation (5), the expressions for skin friction and local Nusselt number become,

$$C_f Re_x^{1/2} = \left[f''(0) + \left(\frac{n-1}{d} \right) W_e^d (f''(0))^{d+1} \right], \quad (11)$$

$$Nu_x Re_x^{-1/2} = -\theta'(0),$$

3. Results and Discussion

The obtained flow of nonlinear differential equation (6) with boundary conditions (7) was numerically worked out by MATLAB program bvp4c method. In the present study, there is a strong focus on the importance of the behavior of physical characteristics associated with the fluid temperature, velocity, and concentration, and those are presented in the form of graphs and have been demonstrated splendidly. Figure 2 describes the behavior of the modified Hartmann number in the form of adding flow and opposing flow. Field of velocity inclined by increased values of Z and declined whenever the value of ($Z < 0$). Figure 3 demonstrates the performance of λ on $f'(\eta)$. Here, λ behaves increments when the values of λ rise, and a contrary behavior was shown for reverse flow. In Figure 4, boundary layer thickness expands immediately, with the value of N_r growing. It is also noticeable that the conflicting flow N_r declined. Figure 5 defines the variations of Nb on the velocity field, and it is revealed that thickness goes down in assisting flow, while it moves upward in case of increased values of Nb . Figure 6 shows the flow of Bi on the velocity pattern. With the increment of Bi , distribution of $f'(\eta)$ ascends. Figure 7

FIGURE 2: Consequences of Z on $f'(\eta)$.

FIGURE 3: Result of λ on $f'(\eta)$.

discusses the affection of γ on velocity flow; in this case, the value of γ grows and the boundary layer thickness diminishes. Figure 8 shows the structure of Nt velocity model. It can be seen that field of velocity gets larger with the values of Nt addition. Figures 9–11 show the exhibited impression of Pr and We_e on $f'(\eta)$; the profile of $f'(\eta)$ gets larger with the increment in the values of Pr and We_e . Figure 10 shows that while r is increased, boundary layer width increases. Variation of temperature flow is demonstrated in Figures 12–19. Figure 12 discusses the influence of Bi on temperature field, whether the value of Biot number grow temperature sketched expand. It is noted that when the value of Le becomes larger, the profile of $\theta(\eta)$ goes down, in Figure 13. It is revealed that impact of γ on $\theta(\eta)$ is that when we increase the value of γ temperature curve enhance for aiding flow and for opposing flow curve moves down in Figure 14. Figure 15 examines the performance of r on $\theta(\eta)$.

FIGURE 4: Influence of N_r on $f'(\eta)$. FIGURE 6: Variation of Bi on $f'(\eta)$. FIGURE 5: Impact of Nb on $f'(\eta)$. FIGURE 7: Upshot of γ on $f'(\eta)$.

In opposing and assisting flow, r shrinks on $\theta(\eta)$. Figure 16 obtains the implication of Nb . It shows that $\theta(\eta)$ becomes larger for increased values of Nb . Figures 17 and 18 show the behaviors of Nt and Pr , respectively; both are sketched towards down when the values of Nt and Pr grow. It can be easily observed that assisted flow falls and conflicting flow moves up for bigger values of Z on $\theta(\eta)$ in Figure 19.

Deviation of concentration field can be revealed in Figures 20–27. Figure 20 describes the effect of Z on $\varphi(\eta)$; the value of Z grows and then the boundary layer increases for aiding flow and decreases in opponent flow. Figure 21 shows that when we increase the values of γ , the concentration curve falls in assisting flow and moves up in opposing flow. It is noticeable that Figures 22 and 23 indicate the

performance of nanofluid parameters Nt and Nb on $\varphi(\eta)$, respectively. Both are dissimilar graphs; the pattern of $\varphi(\eta)$ diminishes in aiding flow and increases in opposing flow if the values of Nt bigger than the contrary graph are shown for Nb . Figures 24 and 25 explore the efficiency of Bi and Le over $\varphi(\eta)$. The boundary layer width falls whenever the value of one and the other increases. Figures 26 and 27 depict the behavior of r and Pr one by one. The impact of these two parameters on $\varphi(\eta)$ is that the growth of these parameters caused boundary layer increment. Figures 28–33 are created to examine the influence of λ and Z on streamlines. Table 1 is investigated; extensions in Nb, Nt, Le, Bi, Pr , and Z caused heat transfer coefficient to upgrade and degrade by the increase of γ . The consequences of λ on Nusselt numbers

FIGURE 8: Effect of Nt on $f'(\eta)$.

FIGURE 11: Consequences of We on $f'(\eta)$.

FIGURE 9: Result of Pr on $f'(\eta)$.

FIGURE 12: Impact of Bi on $\theta(\eta)$.

FIGURE 10: Influence of r on $f'(\eta)$.

FIGURE 13: Upshot of Le on $\theta(\eta)$.

FIGURE 14: Effect of γ on $\theta(\eta)$. FIGURE 17: Influence of Nt on $\theta(\eta)$. FIGURE 15: Impact of r on $\theta(\eta)$. FIGURE 18: Impact of Pr on $\theta(\eta)$. FIGURE 16: Deviation of Nb on $\theta(\eta)$. FIGURE 19: Consequences of Z on $\theta(\eta)$.

FIGURE 20: Impact of Z on $\phi(\eta)$.

FIGURE 23: Consequence of Nb on $\phi(\eta)$.

FIGURE 21: Effect of γ on $\phi(\eta)$.

FIGURE 24: Influence of Bi on $\phi(\eta)$.

FIGURE 22: Influence of Nt on $\phi(\eta)$.

FIGURE 25: Result of Le on $\phi(\eta)$.

FIGURE 26: Upshot of r on $\phi(\eta)$. FIGURE 27: Consequences of Pr on $\phi(\eta)$. FIGURE 28: Streamlines for $\lambda = 0.1$. FIGURE 29: Streamlines for $\lambda = 1$. FIGURE 30: Streamlines for $\lambda = 2$. FIGURE 31: Streamlines for $Z = 0.1$.

FIGURE 32: Streamlines for $Z = 0.5$. FIGURE 33: Streamlines for $Z = 1$.TABLE 1: Deviation of $Nu_x(Re_x)^{-(1/2)}$ for different amounts of characteristics.

λ	N_r	Nb	Nt	Le	d	We	n	Bi	Z	γ	Pr	$Nu_x(Re_x)^{-(1/2)}$		
												$r = 0.5$	$r = 1$	$r = 2$
0.1	0.1	0.1	0.1	0.1	1	0.1	1	0.1	0.1	0.1	7	0.09524	0.09550	0.09598
0.5	—	—	—	—	—	—	—	—	—	—	—	0.09524	0.09550	0.09598
1	—	—	—	—	—	—	—	—	—	—	—	0.09524	0.09550	0.09598
0.1	0.1	0.1	0.1	0.1	1	0.1	1	0.1	0.1	0.1	7	0.09524	0.09550	0.09598
—	—	1	—	—	—	—	—	—	—	—	—	0.09526	0.09551	0.09600
—	—	2	—	—	—	—	—	—	—	—	—	0.09528	0.09553	0.09601
0.1	1	0.1	0.1	0.1	1	0.1	1	2	0.5	1	7	1.02513	1.04844	1.10026
—	—	—	1	—	—	—	—	—	—	—	—	1.04508	1.06400	1.10922
—	—	—	3	—	—	—	—	—	—	—	—	1.07624	1.09004	1.12598
0.1	1	0.1	0.1	0.1	1	0.1	1	0.1	0.5	1	7	0.09530	0.09554	0.09601
—	—	—	—	0.3	—	—	—	—	—	—	—	0.09533	0.09556	0.09602
—	—	—	—	0.5	—	—	—	—	—	—	—	0.09536	0.09558	0.09603
0.1	1	0.1	0.1	0.1	1	0.1	1	0.1	0.5	1	7	0.09530	0.09554	0.09601
—	—	—	—	—	—	—	—	0.5	—	—	—	0.40213	0.40619	0.41437
—	—	—	—	—	—	—	—	1	—	—	—	0.67496	0.68576	0.70853
0.1	1	0.1	0.1	0.1	1	0.1	1	0.1	0.5	1	7	0.09530	0.09554	0.09601
—	—	—	—	—	—	—	—	—	1	—	—	0.09537	0.09559	0.09604

TABLE 1: Continued.

λ	N_r	Nb	Nt	Le	d	W_e	n	Bi	Z	γ	Pr	$Nu_x(Re_x)^{-(1/2)}$		
												$r = 0.5$	$r = 1$	$r = 2$
—	—	—	—	—	—	—	—	—	1.5	—	—	0.09544	0.09564	0.09606
0.1	1	0.1	0.1	0.1	1	0.1	1	0.1	0.5	1	7	0.09530	0.09554	0.09601
—	—	—	—	—	—	—	—	—	—	1.5	—	0.09528	0.09553	0.09601
—	—	—	—	—	—	—	—	—	—	2	—	0.09527	0.09552	0.09600
0.1	1	0.1	0.1	0.1	1	0.1	1	0.1	0.5	1	6.5	0.09513	0.09539	0.09588
—	—	—	—	—	—	—	—	—	—	—	8.5	0.09573	0.09594	0.09634
—	—	—	—	—	—	—	—	—	—	—	10.5	0.09616	0.09633	0.09667

TABLE 2: Variation of $C_f(Re_x)^{(1/2)}$ for different amounts of characteristics.

λ	N_r	Nb	Nt	Le	d	W_e	n	Bi	Z	γ	Pr	$C_f(Re_x)^{(1/2)}$		
												$r = 0.5$	$r = 1$	$r = 2$
0.1	0.1	0.01	0.1	0	1	1	1	0.1	0.1	1.5	7	−0.61859	0.04466	2.05609
0.5	—	—	—	—	—	—	—	—	—	—	—	−0.61406	0.04859	2.05910
1	—	—	—	—	—	—	—	—	—	—	—	−0.60839	0.05350	2.06286
0.1	0.1	0.1	0.1	0.1	1	1	1	0.1	0.1	1.5	7	−0.62883	0.03580	2.04931
—	—	0.5	—	—	—	—	—	—	—	—	—	−0.62427	0.03975	2.05233
—	—	1	—	—	—	—	—	—	—	—	—	−0.61859	0.04466	2.05609
0.1	0.1	0.1	0.1	0.1	1	0.1	1	0.1	0.1	1.5	7	−0.62546	0.03869	2.05167
—	—	—	1	—	—	—	—	—	1	—	—	−0.30441	0.34063	2.32326
—	—	—	3	—	—	—	—	—	1.5	—	—	−0.12896	0.50656	2.47328
0.1	0.1	0.1	0.1	0.1	1	0.1	1	0.1	0.1	0.1	7	−0.57767	0.07476	2.07641
—	—	—	—	—	—	—	—	—	—	1	—	−0.61658	0.04606	2.05726
—	—	—	—	—	—	—	—	—	—	2	—	−0.63130	0.03363	2.04763

numerically become constant. Table 2 shows numerical values of the skin friction coefficient. By increased values of λ , N_r , and Z , friction coefficient gets larger and friction reduced by higher values of γ .

(v) The numerical values of the skin friction coefficient increase by increasing the values of λ , N_r , and Z . The friction coefficient gets reduced by higher values of γ .

4. Conclusion

The following main resulting ideas are taken into account:

- Fluctuations of velocity were examined for some physical parameters; profile increases when Z , λ , N_r , Bi , Nt , and r increase; on the other hand, it declines if W_e , Pr , γ , and Nb get larger.
- It can be revealed that thermal boundary layer width gets down when the values of Le , r , Nt , Pr , and Z incline, and it becomes larger for higher values of Bi , γ , and Nb .
- It can be easily observed that concentration patterns increase when the values of Z , Nb , Pr , and r move upward and concentration boundary layer width diminishes, whereas it inclines in γ , Nt , Bi , and Le .
- When the values of the parameters Nb , Nt , Le , Bi , Pr , and Z incline, that caused heat transfer coefficient upgrade and degrade by the increase of γ . The consequences of λ on Nusselt numbers numerically become constant.

Abbreviations

C_f :	Skin friction coefficient (—)
b :	Body forces (Nm^{-3})
C_∞ :	Ambient fluid concentration (kgm^{-3})
φ :	Dimensionless concentration function (—)
Bi :	Biot number
D_T :	Thermophoresis diffusion coefficient (m^2s^{-1})
C :	Nanoparticles concentration (kgm^{-3})
D_B :	Brownian diffusion coefficient (m^2s^{-1})
f :	Dimensionless velocity function (—)
g :	Gravity acceleration (ms^{-2})
h_f :	Convection coefficient
Sh_x :	Local Sherwood number (—)
Nu_x :	Local Nusselt number (—)
Re_x :	Local Reynolds number (—)
Nt :	Thermophoresis parameter (—)
T_∞ :	Ambient temperature (K)
Nb :	Brownian motion parameter (—)
η :	Similarity variable (—)
K :	Thermal conductivity
u_w :	Stretching sheet velocity (ms^{-1})
T_f :	Hot fluid temperature (K)

u_{∞} :	External flow velocity (ms^{-1})
(u, v) :	Velocity components (ms^{-1})
(x, y) :	Cartesian coordinate components (m)
W_e :	Weissenberg number
Γ :	Time fluid parameter
τ :	Extra stress tensor (–)
n :	Power index
d :	Fluid characteristics (–)
N_r :	Buoyancy ratio parameter (–)
a_1 :	Width of the magnet between electrodes
μ_0 :	Zero shear rate viscosity
λ :	Mixed convection parameter
τ_w :	Surface shear stress (–)
ρ_p :	The density of the nanoparticles (kgm^{-3})
q_m :	Surface mass flux (–)
ρ_f :	The density of the base fluid (kgm^{-3})
j_0 :	Applied current density
ρ :	Density (kgm^{-3})
Pr :	Prandtl number (–)
q_w :	Surface heat flux (–)
γ :	Width parameter
np :	Nanoparticle (–)
r :	Stretching parameter (–)
μ_{∞} :	Infinite shear rate viscosity
M_0 :	Magnetization of permanent magnets
A_1 :	Rivlin-Ericksen tensor (–)
T :	Temperature (–)
θ :	The dimensionless heat temperature function (–)
α :	Thermal diffusivity (m^2s^{-1})
Z :	Modified Hartmann number
Le :	Lewis number (–).

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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