

Suction effect on the dynamics of EMHD casson nanofluid over an induced stagnation point flow of stretchable electromagnetic plate with radiation and chemical reaction

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ABSTRACT

This research examines the radiative characteristics of electromagnetohydrodynamic (EMHD) boundary layer flow with combined thermal transport properties on a reactive stretching surface using Casson nanofluid. The momentum, temperature, and diffusion equations governing flow equations are reduced to dimensionless forms through variable transformations. The remedies to the resulting equations are numerically generated using the MATLAB bvp4c. Validation against prior research is carried out. The impact of emerging factors on velocity, temperature, concentration patterns, drag force coefficient, Sherwood number, and Nusselt number are graphically represented and in tables. It indicates that when Prandtl number, lower variables of Suction, and Casson parameters increases with a decline in velocity distribution, the contrasting trend enhancement is perceived for modified Hartmann number. In addition, an increment in the modified Hartmann number increases the rate of energy, mass flux, and friction. Conclusively, As Lewis number, Brownian motion, and chemical reaction rise, the thickness of the concentration boundary layer decreases on the stretching Riga surface.

1. Introduction

Due to their extremely good rheological properties, non-Newtonian fluids have garnered tremendous interest among engineers and scientists. Their applicability in many technological, pharmaceutical, biomedical, and other science disciplines is rising daily. In this case, the Casson fluids (non-Newtonian) should be called shear-thinning liquids because they have zero viscosity at limitless shear rates. Jelly, honey tomato sauce, ketchup, smoothie.

The most popular examples are liquids, soups, chocolates, and human blood. El-zahar et al. [1] simulated the Magnetohydrodynamic convective flow of a Casson nanofluid through a spherical and rotating stagnation point of the free stream. They noted that the surface frictions and heat transmission rates are enhanced due to the Casson parameter and nanoparticles augmentation. The non-newtonian MHD flow past a stretching sheet cylinder of Casson nanofluid with Newtonian conditions was analysed by Naqvi et al. [2]. Using the Laplace transform method,

Reyaz et al. [3] employed Caputo-Fabrizio fractional derivative to scrutinize the influence of the radiative and chemical species of MHD Casson fluid. They reported that the difference in the fractional derivative parameter affects Casson fluid's behaviour between the time-dependent and independent time conditions. The magnetohydrodynamic Casson convective nanofluid flow via a spherical solid was reported by Firas et al. [4]. Subsequently, Shankaralingappa et al. [5] considered 3D Casson nanofluid flow with the impact of particle deposition across a stretching sheet. They noticed an enhancement in the thermal transportation and Casson parameter values with a decline in the axial velocities. Santoshi et al. [6] explored a numerical assessment of 3D combined flow of non-newtonian nanofluids of Carreau-Casson. By engaging Buongiorno's model, Zeeshan et al. [7] demonstrated the numerical evaluation of MHD Casson nanofluid via a cylinder. They revealed that friction displays approximately 20% increase, and conversely, the Nusselt number displays a 10% decline due to an upsurge of Casson fluid parameter. Amjad et al. [8] illustrated thermo investigation of Casson and micropolar nanofluid on a permeability

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Nomenclature

R	radiation parameter
C_∞	ambient fluid concentration
k^*	mean absorption
π_c	critical value of π
f_w	suction parameter
J_0	current density
T_w	surface temperature
Le	Lewis number
Nt	Thermophoresis parameter
y	coordinate axis normal to the plate
Bi	Biot number
Nb	Brownian motion
π	product of deformation rate
τ	shear stress
Y	dimensionless axis
T_∞	ambient energy
t'	time
m_0	magnetization of magnets (Tesla)

Pr	Prandtl number
l	magnets and electrodes width
σ^*	Stefan Boltzmann constant
E	modified Hartmann parameter
D	diffusivity term
S	associated with magnets and electrodes
ρ	density
k	thermal conductivity
μ_B	plastic dynamic viscosity
β	Casson fluid parameter
q_r	radiative heat flux
u	velocity
p_y	yield stress of the fluid
ν	kinematics viscosity
g	gravitational constant
C_p	specific heat capacity
K	reactive term
C_w	surface concentration
e_{ij}	$(i,j)^{th}$ component of the deformation

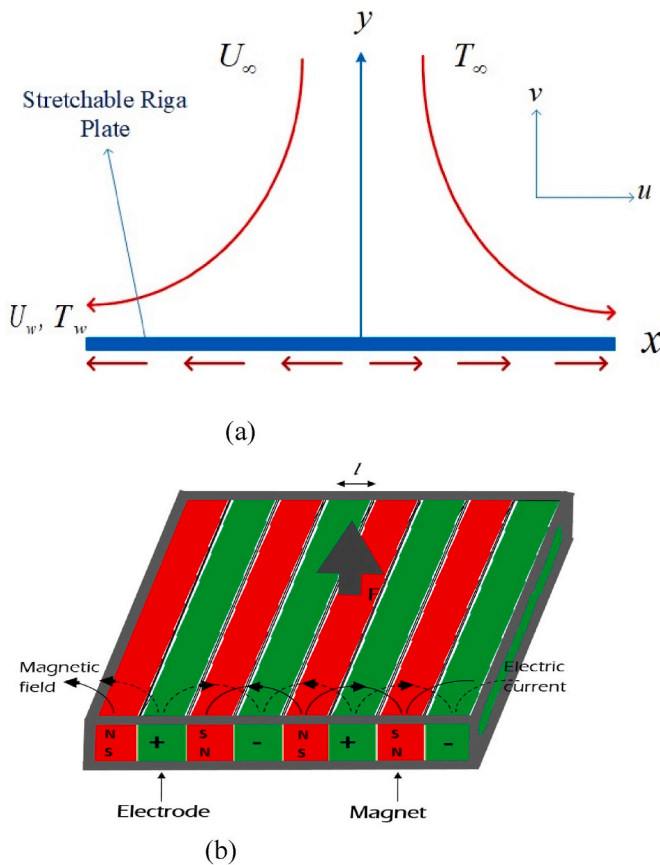


Fig. 1. (a) The plate configuration, (b) Riga plate, Asogwa et al. [26].

bent stretching surface beneath the stagnation area. Ghadikolaei et al. [9] explored MHD Casson nanofluid flow over a stretching sheet employing Buongiorno's model. They found that velocity distribution declines as a result of Casson fluid parameter augmentation. Biswas et al. [10] proffered stability convergence analysis by computational exploration of MHD Casson nanofluid flow in the presence of thermophoresis and Brownian motion.

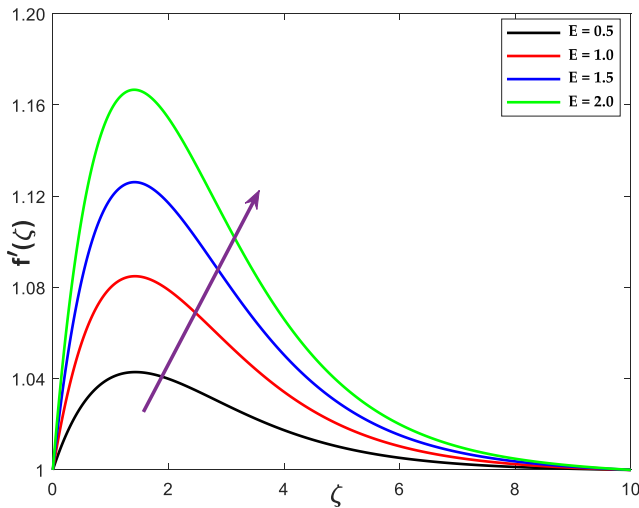
Table 1

Contrast of the values of $f''(0)$ in the absence of $E = 0$, with changing the values of $f'(0) = \alpha$ gives.

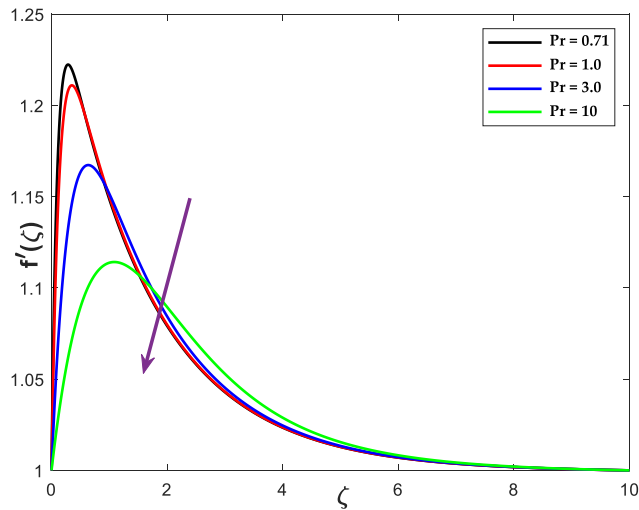
α	Wang [48]	Lok et al. [49]	Nandy & Pop [50]	Present Study
0	1.232588	1.232588	1.232588	1.232588
0.1	1.14656	1.146561	1.146560	1.146561
0.2	1.05113	1.051130	1.051131	1.05113
0.5	0.71330	0.713295	0.713296	0.713295
1	0.000000	0.000000	0.000000	0.000000
2	-1.88731	-1.887307	-1.887308	-1.887307
5	-10.26475	-10.264749	-10.264751	-10.264749

Radiant energy seems to significantly impact the rate of heat transfer and flow of many different types of nanofluid in bioengineering. The researchers became captivated by the effects of thermal radiation transition mechanisms as a result of the assessment of fabrication techniques. Thermal properties, thermal performance, and other physical aspects are fundamental in modern manufacturing and thermal processing. Hayat et al. [11] examined the radiation impact of rotating nanofluid with slip conditions. Applying the Koo–Kleinstreuer–Li model, Mohammadein et al. [12] investigated the radiative convection flow of Copper oxide nanofluid via a stretching sheet. They reported that the temperature of the fluid ratio & radiative parameter enhancement influenced the nanofluid temperature by escalation. Mohd-Sohut et al. [13] considered the 3D rotating nanofluid flow of a radiative stretching sheet. They noticed an upsurge in temperature distribution as a result of radiation & time-dependent parameters. The numerical exploration of thermal radiation on MHD nanofluid over a shrinking sheet was analysed by Bhatt et al. [14]. Using an analytical method, Asogwa et al. [15] examined the relationship between cupric and alumina nanoparticles on rapidly accelerated electromagnetic plate with thermal radiation. They concluded that thermal radiation augmentation improves cupric nanoparticles over alumina nanoparticles. Li et al. [16] evaluated 2nd-grade nanofluid with radiation and swimming microorganisms. Mahabaleswar et al. [17] deliberated MHD motion of CNTs with mono and multiple walls

With selected based fluids over a stretchable sheet. They reported that heat transmission is experienced due to an increase in radiative parameter. Considering radiative porous medium, Ali et al. [18] discussed nanoparticles' boundary layer fluid flow. Employing



a

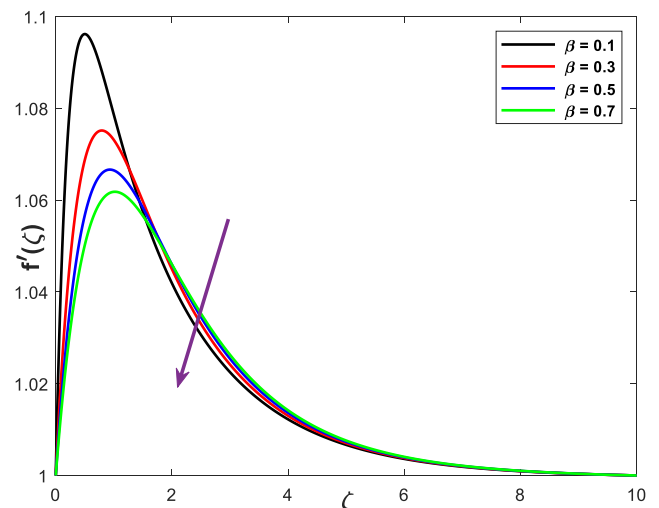


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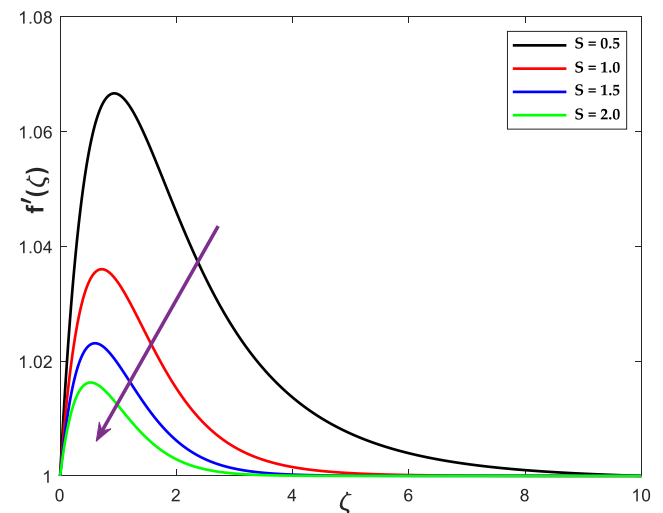
Fig. 2. (a) Velocity distribution $f'(\zeta)$ for various (Modified) Hartmann number E values. (b): Velocity distribution $f'(\zeta)$ for various Prandtl number (Pr) values.

Buongiorno's model, Wakif et al. [19] evaluated the effect of surface roughness and radiation on alumina nanoparticles and cupric nanoparticles of MHD fluid. They reported that the wall's roughness, Lorentz forces, and thermal radiation delays the appearance of convection cells medium. Zhang et al. [20] investigated MHD nanofluid with radiative transfer in porous materials.

Riga-plate is composed of electromagnetic actuator, which comprises a spanwise associated array of discontinuous electrodes and an everlasting magnet mounted on a plane surface. The unusual configuration of the Riga-plate leads to the formation of edge Lorentz forces, which lead to distortion of the pressure-gradient driven stretching sheet, stabilising its mobility by diminishing its propagation. The computational treatment of nanofluid flow through a Riga plate was investigated by Rafique et al. [21]. Alotaibi and Rafique [22] investigated the influence of microrotation on the flow of nanofluid in a vertical Riga plate. Khan et al. [23] demonstrated the effect of quartic reactions on the flow of a micropolar fluid across the Riga plate. Asogwa et al. [24]



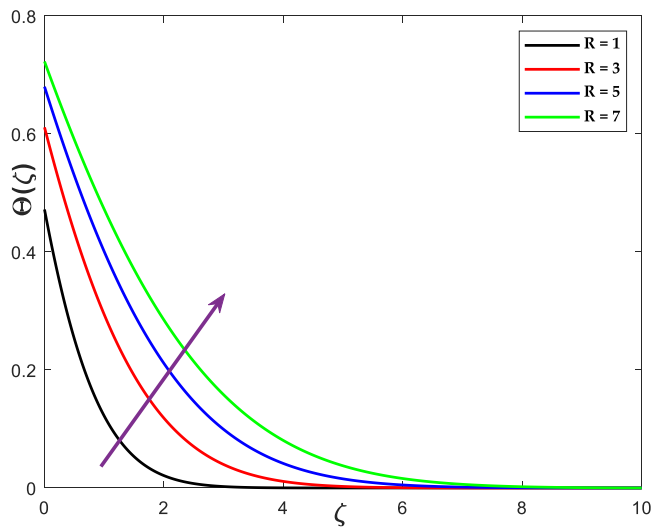
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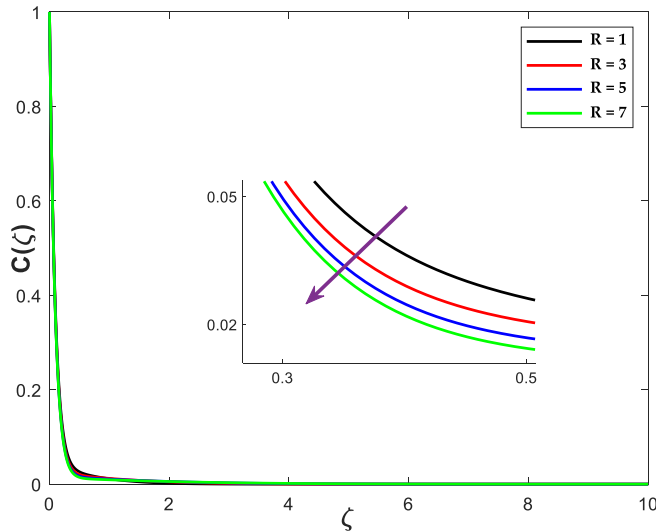
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Fig. 3. (a) Velocity distribution $f'(\zeta)$ for various Casson Parameter (β) values. (b): Velocity distribution $f'(\zeta)$ for various dimensionless factor (S) values.

investigated the role of ramping energy in non-newtonian fluid flow on a slanted electromagnetic plate with thermal absorption and reactive condition. Uwanta et al. [25] examined the cross diffusion impact of Magnetohydrodynamic fluid on a vertical channel. Asogwa et al. [26, 27] demonstrated the cross diffusion impact in porous media using an electromagnetic plate. Bilal et al. [28] examined the radiative properties of non-Newtonian fluid on a Riga surface. Fatunmbi et al. [29] computed the flow of Eyring-Powell nanofluid via a magnetization of the Riga plate. Reddy et al. [30] studied radiation and heat absorption effects on MHD boundary layer flow along an accelerated infinite vertical plate. Kumar et al. [31] evaluated heat radiation's effect on MHD nanofluid heat transfer. Kumar et al. [32] studied Soret impact on MHD Jeffrey fluid flow via a sliding permeable plate. Goud and Reddy [33] studied MHD heat and mass transmission through an accelerated plate. Reza-E-Rabbi et al. [34] used a nonlinear nanofluidic model to simulate MHD chemically reactive flow via an angled stretching surface. Swimming microorganisms in nano-bioconvective Williamson fluid was studied by Rana et al. [35]. In addition, Rana et al. [36] explored Williamson micropolar nanofluid by stretching sheet. Arifuzzaman et al.



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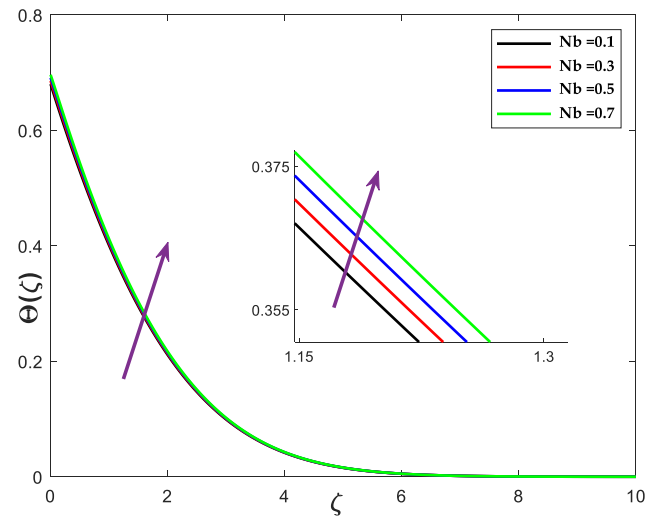
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Fig. 4. (a) Temperature distribution $\Theta(\zeta)$ for various Radiation parameter (R) values. (b): Concentration distribution $C(\zeta)$ for various Radiation parameter (R) values.

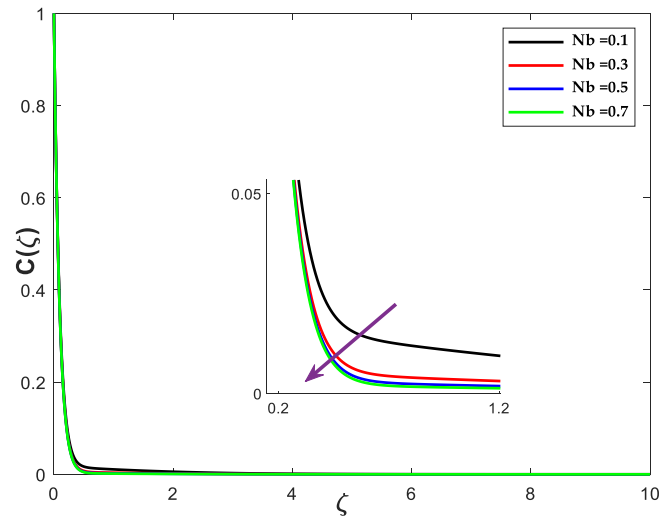
[37] studied chemically reactive, spontaneously convective MHD fluid flow via an oscillating porous plate. Asogwa et al. [38] studied non-Newtonian electromagnetic fluid flow through a ramped Riga surface. Jayaprakash et al. [39] evaluated passive control of nanoparticles in Oldroyd-B Nanofluid stagnation point flow. Chu et al. [40] described the radiative bioconvection flow of Maxwell nanofluid with heat generation. Chu et al. [41] explored Carreau nanomaterial hydromagnetic stagnation flow. Chu et al. Heat source/sink, radiative heat flow, and temperature-dependent thermal conductivity on Rabinowitsch fluid.

This work's other useful research materials can be found in Refs. [42–46].

Considering the existing literature described above, numerous studies on nanofluids flow have been conducted in a variety of circumstances. However, limited investigations into the influence of EMHD on nanofluid are being considered. Non-Newtonian fluids have a wide range of uses, including fusion reactor conditioning, hydrothermal storage, biomedical engineering, and heat oil recovery. Consequently, no study has been shown in which the effects of thermal radiation,



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b

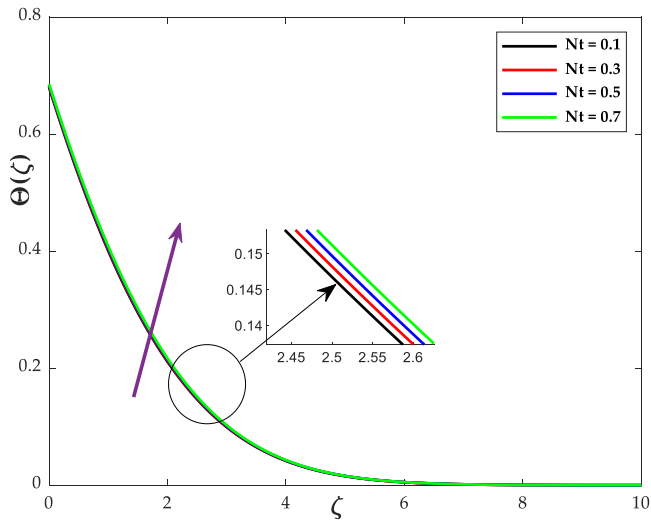
Fig. 5. (a) Temperature distribution $\Theta(\zeta)$ for various Brownian motion parameter (Nb) values. (b): Concentration distribution $C(\zeta)$ for various Brownian motion parameter (Nb) values.

Brownian motion, thermophoresis effect, Suction, and reactive species on the EMHD Casson nanofluid via Riga stretching surface are combined, as shown in Fig. 1. The intent of this examination is to respond to the following lingering questions:

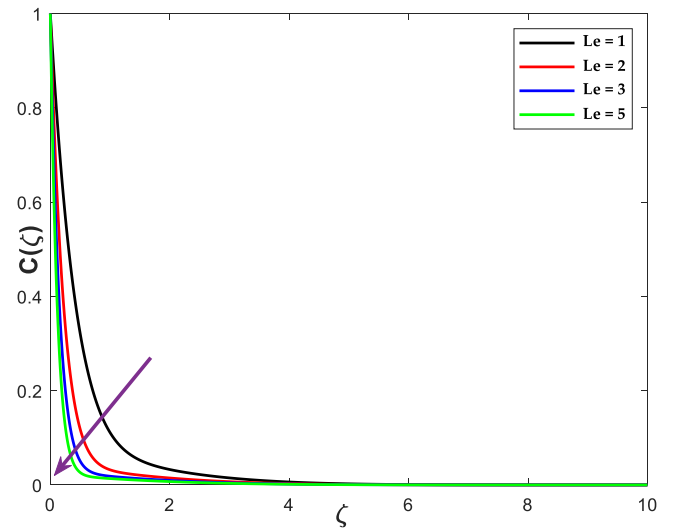
- Given the stagnation point, how do friction factor, heat, and mass distribution affect the overall stretchable Riga surface?
- Does the reactive species have a substantial effect on the Riga surface?
- What role does the Modified Hartmann number play in conveying the Casson nanofluid created by the stretching surface?

2. Formulation of the problem

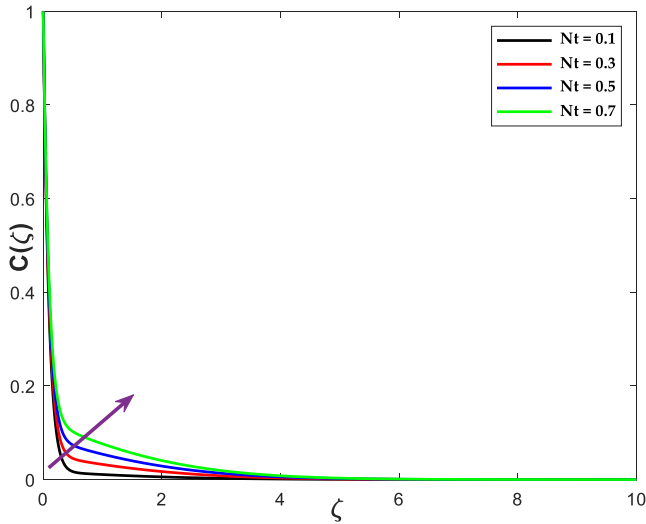
The Riga stretching and free stream velocities at the surface are $U_w = ax$ and $U_\infty = bx$ along x-direction from the stagnation point, following the exploration used by Mohammadein et al. [12], where a & b are constants. The equation depicts the fluid flow's rheological condition (Khan et al. [47]):



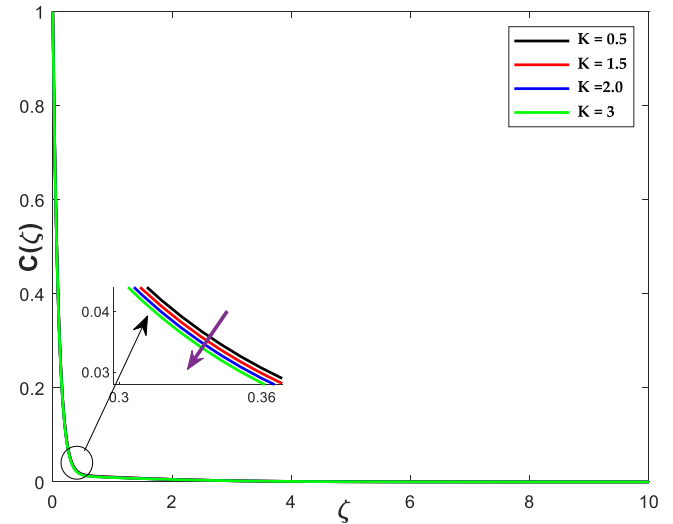
a



a



b



b

Fig. 6. (a) Temperature distribution $\Theta(\zeta)$ for various thermophoresis parameter (Nt) values. (b): Concentration distribution $C(\zeta)$ for various thermophoresis parameter (Nt) values.

$$T_{ij} = \begin{cases} \left(\mu_B + \frac{p_y}{\sqrt{2\pi}} \right) 2e_{ij} & \pi < \pi_c \left(\mu_B + \frac{p_y}{\sqrt{2\pi}} \right) 2e_{ij} \\ \pi > \pi_c \end{cases} \quad (1)$$

The two dimensional fluid flow equations are formulated as follows (Wang [48], Lok et al. [49], and Nandy & Pop [50]);

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (2)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + \frac{\partial u}{\partial t} = U_\infty \frac{dU_\infty}{dx} + \nu \left(1 + \frac{1}{\beta} \right) \frac{\partial^2 u}{\partial y^2} + \frac{\pi J_0 m_0}{8\rho} \exp\left(-\frac{\pi}{l}\right) y \quad (3)$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + \frac{\partial T}{\partial t} = \alpha_f \frac{\partial^2 T}{\partial y^2} + \psi \left[D_B \frac{\partial C}{\partial y} \frac{\partial T}{\partial y} + \frac{D_T}{T_\infty} \left(\frac{\partial T}{\partial y} \right)^2 \right] - \frac{1}{\rho} \frac{\partial q_r}{\partial y} \quad (4)$$

$$u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + \frac{\partial C}{\partial t} = D_B \frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty} \frac{\partial^2 T}{\partial y^2} - K^* (C - C_\infty) \quad (5)$$

The following constraints are coupled with them:

Fig. 7. (a) Concentration distribution $C(\zeta)$ for various Lewis number (Le) values. (b): Concentration distribution $C(\zeta)$ for various Chemical reaction Parameter (K) values.

$$\left. \begin{aligned} u = 0, \quad v = 0 \quad T = T_\infty, \quad C = C_\infty, \quad \forall y \geq 0, t \leq 0 \\ u = ax \quad v = v_w, \quad -k \frac{\partial T}{\partial y} = h_f (T_\omega - T), \quad C = C_w \text{ as } y = 0, t > 0 \\ u \rightarrow U_\infty, \quad T \rightarrow T_\infty, \quad C \rightarrow C_\infty \quad \text{as } y \rightarrow \infty \end{aligned} \right\} \quad (6)$$

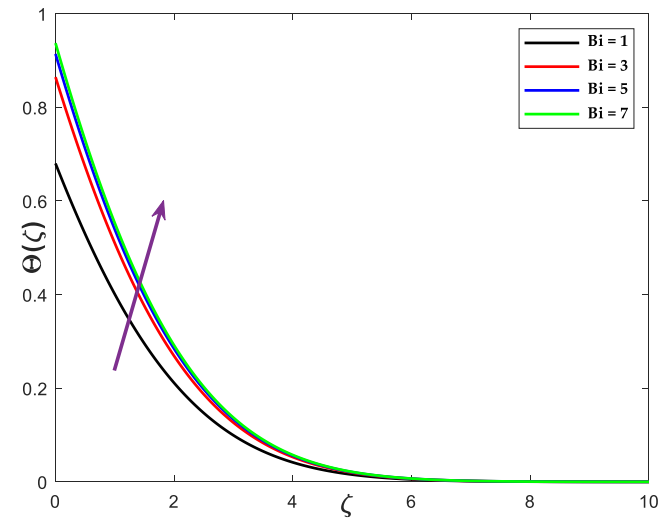
The Rosseland approximation is incorporated as

$$q_r = -\frac{4\sigma^*}{3k^*} \frac{\partial T^4}{\partial y} \quad (7)$$

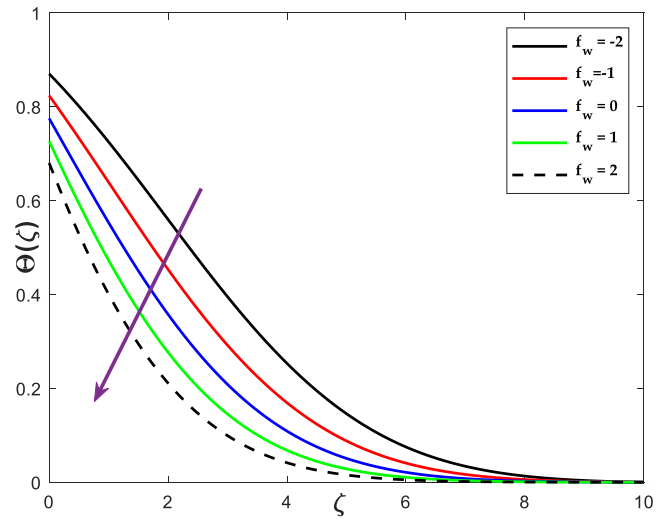
Suppose that the temperature variations are relatively minimal given that T^4 could be broadened via Taylor expansion about T_∞ and the elevated terms are omitted, the result is

$$T^4 = 4TT_\infty^3 - 3T_\infty^4 \quad (8)$$

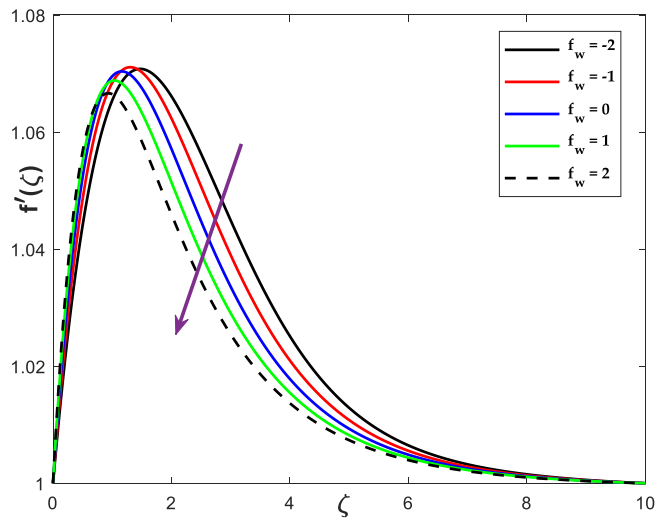
Equation (8) develops into



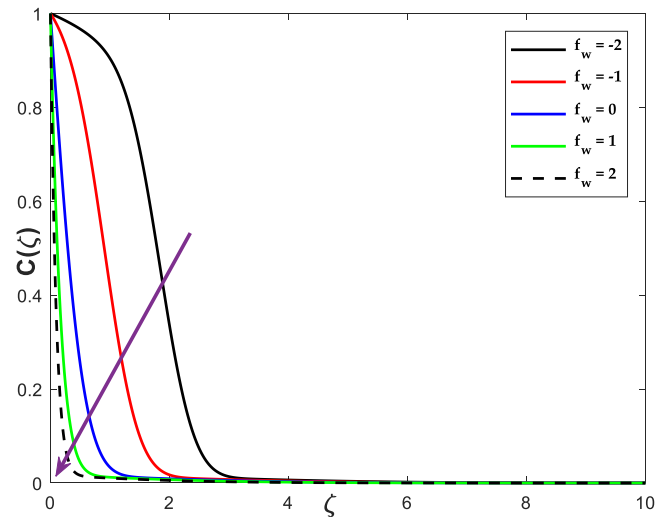
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a



b



b

Fig. 8. (a) Temperature distribution $C(\zeta)$ for various Biot number (Bi) values. (b): Velocity distribution $C(\zeta)$ for various Suction (f_w) values.

Fig. 9. (a) Temperature distribution $\Theta(\zeta)$ for various Suction (f_w) values. (b): Concentration distribution $C(\zeta)$ for various Suction (f_w) values.

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3k^*} \frac{\partial^2 T}{\partial y^2} \quad (9)$$

while equation (9) is entered for equation (3), we have:

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + \frac{\partial T}{\partial t} = \alpha_f \frac{\partial^2 T}{\partial y^2} + \psi \left[D_B \frac{\partial C}{\partial y} \frac{\partial T}{\partial y} + \frac{D_T}{T_\infty} \left(\frac{\partial T}{\partial y} \right)^2 \right] + \frac{16\sigma^* T_\infty^3}{3k^*} \frac{\partial^2 T}{\partial y^2} \quad (10)$$

The non-dimensional quantities are implemented:

$$\left. \begin{aligned} u &= \alpha f'(\zeta), \quad v = -\sqrt{a\alpha_f} f(\zeta), \quad \zeta = \sqrt{\frac{a}{\alpha_f}} y, \quad E = \frac{\pi J_0 m_0 v}{8\rho u_\infty^2}, \quad S = \sqrt{\frac{\pi^2 v}{l^2 a}}, \quad f_w = \frac{-v_w}{\sqrt{a\alpha_f}} \\ \Theta(\zeta) &= \frac{T - T_\infty}{T_w - T_\infty}, \quad C(\zeta) = \frac{C - C_\infty}{C_w - C_\infty}, \quad \text{Pr} = \frac{v\rho C_p}{k}, \quad R = \frac{4\sigma^* T_\infty^3}{kk^*}, \quad Bi = \frac{h_f}{k} \sqrt{\frac{\alpha_f}{a}}, \quad \lambda = \frac{b}{a}, \\ \psi &= \frac{(\rho C_p)_p}{(\rho C_p)_f} \end{aligned} \right\} \quad (11)$$

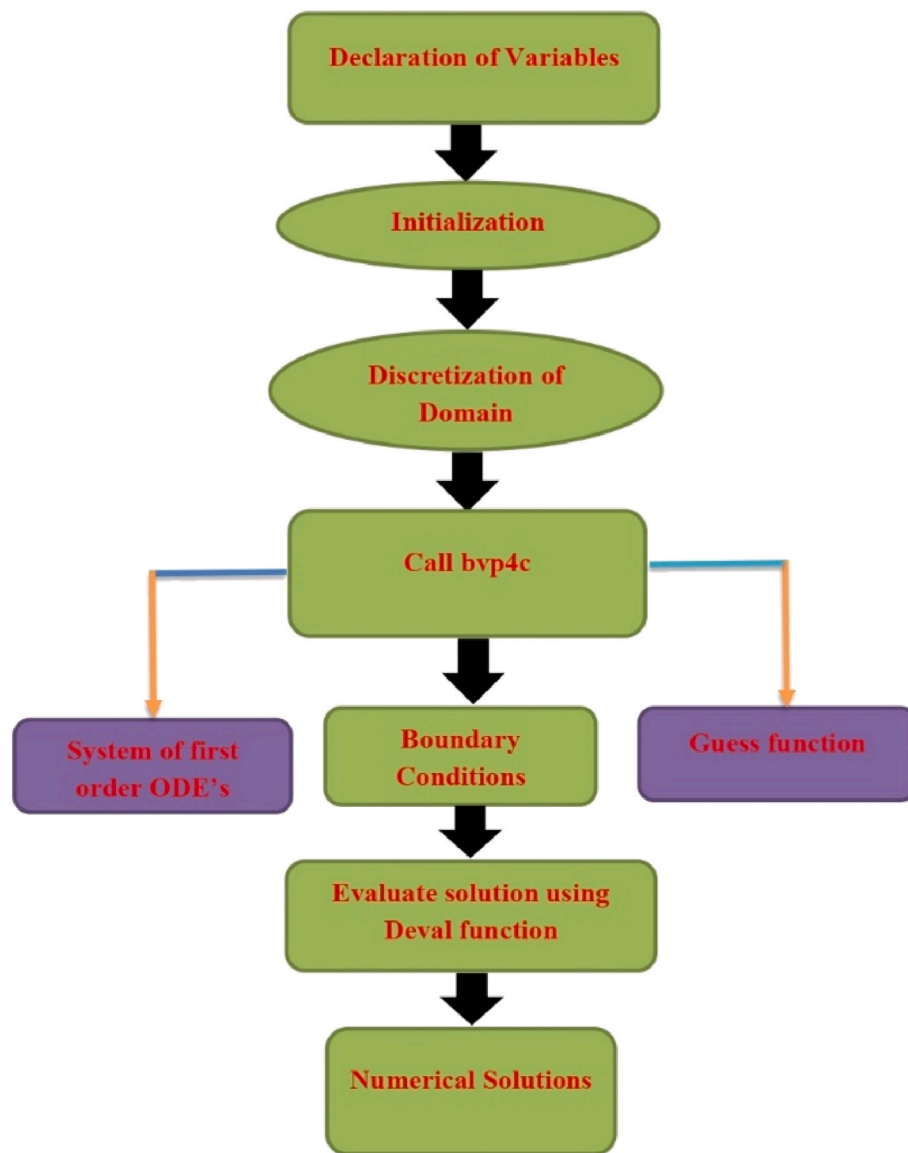


Fig. 10. Flow chart for the numerical scheme.

Table 2

The values of $f''(0)$, $(-\theta'(0))$ and $(-\varphi'(0))$ with the various values of Pr , β and E other values of fixed viz... $Le = 5$; $Nt = 0.1$; $Nb = 0.1$; $R = 5$; $\beta = 0.5$; $\lambda = 1.5$; $Pr = 6.8$; $fw = 2$; $Bi = 1$; $S = 0.5$;

Pr	β	E	$f''(0)$	$-\theta'(0)$	$-\varphi'(0)$
0.71	0.1	0.1	0.306263	0.227351	2.218245
1			0.247934	0.227308	2.216558
6.8			0.074584	0.226954	2.207359
	0.3		0.040172	0.226716	2.204053
	0.5		0.031159	0.226616	2.203041
		0.3	0.222192	0.229186	2.223842
		0.5	0.367851	0.231332	2.239693

Table 3

The values of $(-\theta'(0))$ and $(-\varphi'(0))$ with the various values of Nt , Nb and Le other values of fixed viz...; $R = 5$; $\beta = 0.5$; $\lambda = 1.5$; $Pr = 6.8$; $fw = 2$; $Bi = 1$; $E = 0.5$; $S = 0.5$;

Nb	Nt	Le	$-\theta'(0)$	$-\varphi'(0)$
0.1	0.1	5	0.226954	2.207359
0.3			0.222817	2.229297
0.5			0.218728	2.233674
0.1	0.3		0.225225	2.145849
	0.5		0.223504	2.083734
	0.1	7	0.226916	2.654453
		10	0.226881	3.257879

The non-dimensional components of equation (11) are swapped into equations (3), (5) and (10), producing:

$$Pr \left(1 + \frac{1}{\beta} \right) f'''(\zeta) + f(\zeta) f''(\zeta) - (f'(\zeta))^2 + E \exp(-S\zeta) + 1 = 0 \quad (12)$$

$$\left(1 + \frac{4}{3} R \right) \theta''(\zeta) + N_b \theta'(\zeta) C'(\zeta) + N_T (\theta'(\zeta))^2 + f(\zeta) \theta'(\zeta) = 0 \quad (13)$$

$$C''(\zeta) + Le f(\zeta) C'(\zeta) + \frac{N_b}{N_T} \theta''(\zeta) - KC(\zeta) = 0 \quad (14)$$

where

$$N_T = \frac{\psi D_T(T_w - T_\infty)}{T_\infty \alpha_f}, N_B = \frac{\psi D_B(C_\infty)}{\alpha_f}, Le = \frac{\alpha_f}{D_B} K = \frac{\alpha_f}{D_B}, K = \frac{\alpha_f K^*}{a} \quad (15)$$

The resulting conditions are as follows:

$$\left. \begin{aligned} f'(\zeta) = 1, \quad f(\zeta) = f_w, \quad \theta'(\zeta) = -Bi[1 - \theta(\zeta)], \quad C(\zeta) = 1 \quad \text{for } \zeta = 0 \\ f'(\zeta) \rightarrow \lambda, \quad \theta(\zeta) \rightarrow 0, \quad C(\zeta) \rightarrow 0, \quad \text{as } \zeta \rightarrow \infty \end{aligned} \right\} \quad (16)$$

3. Numerical procedure

One method for solving equations (12)–(14) is to utilise the software function `bvp4c`. This technique is used throughout the article to solve all ordinary differential equations. This technique is used to solve equations using a variety of physical parameters as inputs (15).

The three-stage Lobatto IIIa model may be numerically solved using Matlab's `bvp4c` solver, which employs a finite difference approach. The equations 12–14 must be turned into a system of first-order equations before MATLAB `bvp4c` may be utilised. let's just let which gives. $\zeta = [f \ f' \ f'' \ \theta \ \theta' \ C \ C']^T$

Step 1. We now have a system of equations of the first order.:

$$\frac{d}{d\zeta} \begin{pmatrix} \xi(1) \\ \xi(2) \\ \xi(3) \\ \xi(4) \\ \xi(5) \\ \xi(6) \\ \xi(7) \end{pmatrix} = \begin{pmatrix} \xi(2) \\ \xi(3) \\ -(ff'' - (f')^2 + Ee^{-S\zeta})/Pr \left(1 + \frac{1}{\beta}\right) \\ \xi(5) \\ -(N_B C' + N_T (\theta')^2 + f)/\left(1 + \frac{4R}{3}\right) \\ \xi(7) \\ -\left(Le f C' - K C C - \frac{N_B(N_B C' + N_T (\theta')^2 + f)}{N_T} \left(1 + \frac{4R}{3}\right)\right) \end{pmatrix} \quad (17)$$

Step 2. The numerical solution is performed using the MATLAB built-in `bvp4c` solver and the boundary conditions stated above, as well as an appropriate finite value for the far range boundary condition. This is defined as a significant of boundary values. (bvp). i.e. $\zeta \rightarrow \infty$ say $\zeta \rightarrow 10$.

Step 3. criteria that apply are as follows:

$$\begin{pmatrix} \xi a(1) \\ \xi a(2) \\ \xi a(5) \\ \xi a(6) \\ \xi b(2) \\ \xi b(4) \\ \xi b(6) \end{pmatrix} = \begin{pmatrix} f_w \\ 1 \\ -Bi(1 - \xi a(4)) \\ 1 \\ \lambda \\ 0 \\ 0 \end{pmatrix} \quad (18)$$

The scaling factor is denoted by the $\zeta = 0.01$, and the convergence criteria are defined to the fifth decimal place precision.

When `bvp4c` is used with matlab, it only needs three things to solve the BVP.

- An `odes` function for evaluating ODEs.
- A function `bcs` (boundary conditions) for calculating the residual of the boundary condition.
- A `solinit` structure that includes both a mesh estimate and the mesh solution. ODEs are processed similarly to IVP solvers in Matlab.

Flow chart the numerical scheme is clearly presented in Fig. 10.

4. The reliability and validation of results

The obtained findings are compared to those of Wang [48], Lok et al. [49], and Nandy & Pop [50] for stretching scenarios only where $Pr = 1$, $f_w = 0$ and $E = 0$. Table 1 compares the current result to the previous findings provided for various values of $f'(0) = \alpha$, revealing a good agreement.

5. Results and discussion

The derived flow of the nonlinear differential equations 12–14 with boundary conditions (15) was numerically solved using the MATLAB tool `bvp4c`. In this research, there is a huge emphasis on the relevance of the behaviour of physical parameters related to fluid profiles, which are provided in the form of figures and have been magnificently depicted. Impacts on some significant profiles are shown in Figs. 2a to 9b with $Le = 5$; $Nt = 0.1$; $Nb = 0.1$; $R = 5$; $\beta = 0.5$, $\lambda = 1.5$, $Pr = 6.8$; $= 2$; $Bi = 1$; $E = 0.5$; $S = 0.5$; set to the same value as in Figs. 2a to 9b.

Fig. 2a illustrates the velocity as a function of the Hartmann number (E). It displays a velocity increase at high E values. E's impact results in the amplification of external/internal forces, such as electric and adhesion. As a consequence of these forces, flow velocity increases, which increases the flow's momentum. Fig. 2b illustrates how the Prandtl number varies with velocity. It demonstrates that the velocity rapidly falls over the border area for Pr values that are considerable. The Prandtl digit Pr measures the rate of heat transfer and diffusion in a fluid flow. It is defined as a ratio of viscous to thermal diffusivity. As a consequence, it adds to a decrease in velocity.

Fig. 3a shows that when the Casson parameter increases, the fluid velocity declines. This is because of the inverse connection of yield stress, which leads to increasing values of lower yield stress, i.e. an increase in the Casson factor reduces fluid flexibility. Fig. 3b depicts the variation of the dimensionless parameter (S) in terms of velocity. As can be seen from this figure, the velocity profile decreases as the value of parameter S increases. Fig. 4a illustrates the behaviour of the radiation parameter (R) in a temperature field. As R increases, It notices that the temperature field becomes more dominating. A lower mean absorption coefficient leads to a larger radiation factor, which increases the temperature profile.

The values of the radiation parameter R are shown in Fig. 4b. This image shows that the radiation parameter R boosts the temperature profile and quickly enhances the boundary layer width. As seen in Fig. 5a, increasing the Brownian motion augment the energy distribution and the boundary layer thickness. Increases in the Brownian motion parameter Nb result in a drop in the nanoparticle concentration profile, as seen in Fig. 5b. Physically, the presence of nanoparticles causes an increase in the Brownian motion factor, which tends to reduce the nanoparticle concentration distribution and boundary layer thickness in Brownian motion-influenced outcomes.

As seen in Fig. 6a, increasing the thermophoresis parameter Nt increases the temperature distribution and boundary layer thickness. The thermophoresis factor is used to investigate the temperature profile inside a nanofluid flow. When the thermophoresis factor is increased, the thermophoresis force rises, assisting in the movement of nanoparticles from hot to cold regions, resulting in a rise in the temperature profile. When seen in Fig. 6b, as the thermophoresis factor Nt rises, the nanoparticle concentration curve and boundary layer thickness increase. Fig. 7a illustrates the influence of the Lewis number (Le) on the concentration profile. When Le grows, the temperature profile increases, and the concentration profile drops. This is because an increase in Le indicates a reduction in solute diffusivity, which results in a fall in concentration and an acceleration in mass transfer rate at the stretched surface.

The concentration curve for varying parameters of the chemical reaction parameter (K) is shown graphically in Fig. 7b. It is obvious from

this graph that the width and concentration region of the solutal border layer decrease with increasing values of K . Fig. 8a illustrates the effect of the slip parameter (Bi) on the temperature distribution. This figure indicates that when the Bi is increased, the temperature field and its related boundary layer thickness drop. This augmentation is rather considerable in the area immediately next to the wall but has a minimal impact farther away from the wall. As a result of the Suction f_w , the fluid is brought near the surface, which results in a reduction in momentum, thermal, and concentration thickness of the boundary layer. Figs. 8b–9b demonstrate this. Physically, positive suction parameter values create high pressure forces in the flow, while negative suction parameter values function in the opposite manner.

The fluctuation of the Skinfriction ($f''(0)$), reduced Nusselt number ($-\theta'(0)$) and reduced Sherwood number ($-\phi'(0)$) is illustrated in Table 2. It is clear that an increasing the values of Pr , β there is a decrement in $f''(0)$, ($-\theta'(0)$) and $\phi'(0)$ but the reverse impact is found in and ($-\phi'(0)$) with enhancing the values of and. E .

With the thermophoresis parameter (Nt), and Brownian motion parameter (Nb), and Lewis number (Le), the fluctuation of the reduced Nusselt number ($-\theta'(0)$) and reduced Sherwood number ($-\phi'(0)$) is illustrated in Table 3. It is found that the ($-\theta'(0)$) declines and $-\phi'(0)$ enhances for both increasing the values of Nb , Le and also ($-\theta'(0)$) enhances and $-\phi'(0)$ drops with rises of. Nt .

6. Conclusion

In this paper, the numerical modelling of EMHD transmission of non-Newtonian Casson nanofluid over a stretched sheet surface with Suction, radiation, and reactive influence is investigated. Using the MATLAB programme bvp4c, the following is a summary of the results:

- Greater suction input variables generate significant pressure forces in the flow on the Stretching surface, while lesser suction input factors have the opposite impact on the velocity distribution.
- Increasing the values of the magnetism and electrodes constituents (S) & Casson input variable (β) has a comparable impact on the velocity curves and drag coefficient as diminishing both.
- Convective property and Lewis number Bi has a significant impact on the Sherwood number. Furthermore, when the lewis number on the stretched surface grows, diffusion transfer increases.
- The thickness of the energy boundary layer grows as the Biot number, radiation, thermophoresis, and Brownian motion parameters rise.
- The concentration boundary layer's thickness decreases as the Lewis number, chemical reaction, and Brownian motion grow.
- As the Prandtl number improves, the drag force of the thermal boundary layer declines.
- Increasing the modified Hartmann number increases the rate of energy, mass flow, and surface friction.

Credit to author statement

Kanayo Kenneth Asogwa, B. Shankar Goud, and Yanala Dhar-mendar Reddy: Conceptualization, Methodology, Software, Writing – original draft, review & editing. **Kanayo Kenneth Asogwa, Y. Dhar-mendar Reddy, B. Shankar Goud, and A.A. Ibe:** Conceptualization, Software, Writing – original draft, Validation, Writing – review & editing, Investigation, review & editing. **Kanayo Kenneth Asogwa:** Formal analysis, Validation, Writing – original draft, review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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