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Original Researcher Article

Numerical Investigation of Casson Nanofluid Flow over a stretching sheet with Thermophoresis, Brownian Motion, Magnetic Field and Chemical Reaction.

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ABSTRACT

This study presents a numerical analysis of steady boundary layer flow of a Casson nanofluid over a stretching sheet, incorporating the effects of magnetic field, porous medium, Brownian Motion, Thermophoresis and homogeneous chemical reaction. The governing nonlinear coupled ordinary differential equations for momentum, energy and nano particle concentration are derived using similarity transformations and solved via the shooting method integrated with a fourth order Runge-Kutta scheme. The impact of key physical parameters such as Casson parameter(β), Magnetic parameter(M), porous medium parameter(K_p),Brownian motion(N_b), thermophoresis(N_t), Prandtl number(P_r), Lewis number(L_e), suction/injection(f_"w") and chemical reaction rate(K_c) on the velocity, temperature and concentration profiles is examined in detail. Results indicate that increasing the Casson parameter reduces fluid velocity, while higher thermophoresis enhances thermal boundary layer thickness. The numerical outcomes are validated through convergence studies and compared with existing literature, demonstrating good agreement. This comprehensive parametric investigation provides insight in to the transport behavior of non-Newtonian nanofluids relevant to industrial and biomedical applications

Keywords: Casson fluid, Stretching sheet, Thermophoresis, Runge-Kutta method and Brownian Motion.

1. INTRODUCTION:

The investigation of boundary layer flow and heat transfer over a stretching sheet has gathered significant attention because of its broad in industrial and engineering process, primarily in material, manufacturing and biomedical fields such as polymer extrusion, plastic film stretchable electronics, wearable devices, Tissue, construction and Glass fiber production, metal forming and cooling of metallic sheets. In this context, A.C.V.ramuduet al. [1] investigated the heat and mass transfer in MHD Casson nanofluid flow past a stretching sheet with thermophoresis and Brownian motion. Extending these studies, V.V.L.Deepthi et al. [2] conducted a numerical study on Double diffusive effects on nanofluid flow towards a permeable stretching surface in presence of Thermophoresis and Brownian motion effects. T.L.Babu et al. [3] examined the joint effects of Brownian motion and thermophoresis on nanofluid flow past a stretching sheet: MHD and chemical reaction effects. Aiguo Zhu et al. [4] explored the numerical study of Heat and Mass transfer for Williamson Nanofluid over stretching sheet along with Brownian and Thermophoresis effects. Shalini and Rakesh [5] examined thermophoretic MHD flow with nonlinear radiative heat transfer and convective boundary over a nonlinearly stretching. M.Ali et al. [6] simulated heat transfer boundary layer flow past an inclined stretching sheet in presence of Magnetic field.

The investigation of nano fluid flow and heat transfer has gathered a lot of attention because of its enhanced thermal and transport properties such as energy system, biomedical engineering. The nano particles such as metals, carbon-based materials or oxides in to normal fluids like water or oil significantly enhances thermal conductivity, viscosity and convective heat transfer properties. Gangaiah T et al. [7] conducted a comprehensive study on Magneto hydro dynamic flow of nanofluid over an exponentially stretching sheet in presence of viscous dissipation and chemical reaction. Bachok et al. [8] examined unsteady boundary layer flow and heat transfer of a nanofluid over a permeable stretching sheet. Kalidas [9] Investigated nanofluid flow over nonlinear permeable stretching sheet with partial slip. Makinde and Aziz [10] extended the boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition. Kuznetsov and Nield [11] were systematically examined the natural convective boundary layer flow of a nanofluid past a vertical plate.

Magneto Hydro Dynamics (MHD) explores the action of electrically conducting fluids in the presence of magnetic fields. The applications in engineering and industrial process are electro magnetic pumps, MHD generators, nuclear reactor cooling systems, geothermal energy extraction and metallurgical process. Rashidi et al. [12] examined free convective heat and mass transfer for MHD fluid flow over a permeable vertical stretching sheet in the presence of the radiation and buoyancy effects. Turkyimazoglu [13] explored multiple solution of heat and mass transfer of MHD slip flow for the viscoelastic fluid over a stretching sheet. Muthucumaraswamy and Geetha [14] analyzed chemical reaction effects on MHD flow past a linearly accelerated vertical plate with variable temperature and mass diffusion in the presence of thermal radiation. Kesvaiah et al. [15] investigated MHD effect on convective flow of dusty viscous fluid with fraction in porous medium and heat generation. Rajaiah et al. [16] examined chemical and soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium. Alizadeh and Rahmdel [17] investigated MHD free convection flow of a dissipative fluid over a vertical porous plate in porous media. Jena et al. [18] studied chemical reaction effect on MHD Jeffery fluid flow over a stretching sheet through porous media with heat generation.

The investigation of nanofluid engineered colloidal solutions of nanoparticles in base fluids has gained important attention due to their enhanced thermal characteristics, making them suitable for applications in heat exchangers, solar energy systems and electronic cooling. Among the key mechanism affect nanofluid functioning are thermophoresis and Brownian motion. These facts significantly affect heat and mass transfer characteristics, especially in boundary layer flows under several thermal and magnetic conditions. Anbuchezhian et al. [19] exploredthe effects thermophoresis and Brownian motion on boundary layer flow of nanofluid in presence of thermal stratification due to solar energy. Mittal and Patel [20] analyzed the influence of thermophoresis and Brownian motion on mixed convection two dimensional MHD Casson fluid flow with nonlinear radiation and heat generation. Zhu et al. [21] conducted a numerical study of heat and mass transfer for Williamson nanofluid over stretching/shrinking sheet along with Brownian and Thermophoresis effects. Alreshidi et al. [22] investigated the effects of Brownian motion and thermophoresis on MHD three dimensional nanofluid flow with slip conditions and joule dissipation due to porous rotating disk. Jagadish et al. [23] studied the combined effects of thermophoresis and Brownian motion for thermal and chemically reacting Casson nanofluid flow over a linearly stretching sheet. Ramana Reddy et al. [24] examined the Thermophoresis and Brownian motion effects on unsteady MHD nanofluid flow over a slandering stretching surface with slip effects.

Chemical reaction plays a pivotal role in governing mass and heat transfer characteristics of nanofluids across diverse range of engineering and industrial applications such as chemical manufacturing, pharmaceutical processes, bioengineering, fuel combustion and material processing. In fluid flow with stretching sheet, the inclusion of chemical reactions allows for the modeling of mass transfer phenomena where reactive species interact and alter concentration distribution. Prasanna Kumara et al. [25] investigated effects of chemical reaction ana nonlinear thermal radiation on Williamson nanofluid slip flow over a stretching sheet embedded in a porous medium. Mishra et al. [26] studied simultaneous effects of chemical reaction and Ohmic heating with heat and mass transfer over a stretching surface: A numerical study. Anjali Devi et al. [27] analyzed effects of chemical reaction, heat and mass transfer on nonlinear MHD laminar boundary layer flow over a wedge with suction or injection. In another study, Tripathy et al. [28] explored chemical reaction effect on MHD free convective surface over a moving vertical plate through porous medium. Laltesh et al. [29] examined MHD micropolar fluid flow with hall current over a permeable stretching sheet under the impact of Dufour soret and chemical reaction. Sandhya et al. [30] extended heat and mass transfer effects on MHD flow past an inclined porous plate in the presence of Chemical reaction.

Mathematical Formulation

We consider a steady, incompressible, two-dimensional laminar boundary layer flow of a Casson nanofluid over a stretching sheet embedded in a porous medium. A uniform magnetic field of strength $\beta_0$is applied perpendicular to the surface. The model incorporates the effects of Brownian motion, thermophoresis and a first order chemical reaction.

Let x be the coordinate along the stretching surface and y be the coordinate normal to it. The velocity components in the x and y directions are u and v respectively. The surface is stretched with velocity $u_w(x) = ax$, where $a>0$ is a constant.

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}-\frac{\sigma\beta_0^2}{\rho}u-\frac{\nu}{k}u \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial y^2}\right)+\tau\left\{D_B\left(\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}\right)+\left(\frac{D_T}{T_\infty}\right)\left(\frac{\partial T}{\partial y}\right)^2\right\} \qquad (3)$$

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

Boundary conditions:

$$v=-v_w, u=u_w(x), T=T_w, C=C_w, at\, y=0. \qquad (5)$$

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

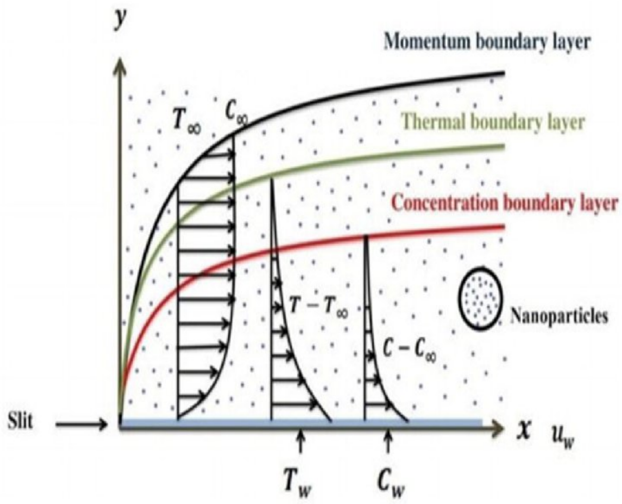

Fig 1 Schematic diagram of Physical problem

Here the velocity components along the x-axis and y-axis are denoted by u and v respectively. The kinematic velocity is expressed as $\nu = \frac{\mu}{\rho_f}$,Whereas the thermal diffusivity is defined by $\alpha = \frac{k}{(C\rho)_f}$The parameter D_B indicates the Brownian motion coefficient, D_T represent the diffusion coefficient for thermophoresis and $\tau = \frac{(\rho a)_p}{(\rho a)_T}$ denotes the relation in nano material's effective heat capacity and nano fluid heat capacity, β signifies Casson fluid parameter, T indicates the boundary layer temperature, T_∞ represent the ambient temperature. Here $u_w(x) = ax$ signifies the stretching sheet velocity, $T_w = T_\infty + b(x/1)^2$ denotes the stretching plate temperature, $C_w = C_\infty + c(x/1)^2$ represents nanoparticle volume fraction over the surface. We are engaged in the aforementioned BVP solution and thus suggest the following transformations of similarities.

$$\eta = \left(\frac{a}{\nu}\right)^{\frac{1}{2}} y, \qquad \psi = (a\nu)^{\frac{1}{2}} x\, f(\eta), \quad \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \quad \varnothing(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

$$u = axf'(\eta), \qquad \text{v} = -\left(\frac{a\mu}{\rho}\right)^{\frac{1}{2}} f(\eta) \tag{7}$$

In equation (7), f signifies the dimensionless stream function, the prime indicates differentiation w.r.t. η and the stream function ψ is used to describe the flow field and is defined such that the velocity components are given by: $u = \frac{\partial \psi}{\partial y}$, $\text{v} = -\frac{\partial \psi}{\partial x}$. Using transformation equation (7) in equation (1), The continuity equation is automatically satisfied, reducing equation (2) to (4) nonlinear ordinary differential equations.

$$\left(1 + \frac{1}{\beta}\right) f' - (M + K_P) f' - (f')^2 + f f'' = 0 \tag{8}$$

$$\theta'' + P_r f \theta' + P_r N_b \varnothing' \theta' + P_r N_t (\theta')^2 = 0 \tag{9}$$

$$\varnothing'' + \frac{N_t}{N_b}\theta'' + (P_r L_e)(f\varnothing') - K_c (P_r L_e)\varnothing = 0 \tag{10}$$

The corresponding boundary conditions are

$$At\ \eta = 0,\ f(0) = f_w, f'(0) = 1,\ \theta(0) = 1,\ \varnothing(0) = 1,$$
$$As\ \eta = \infty,\ f'(\infty) = 0,\ \theta(\infty) = 0,\ \varnothing(\infty) = 0. \tag{11}$$

In this context, $\varnothing$, θ and f represent the concentration of nanoparticles, temperature distribution and dimensionless velocity. The variable η denotes the similarity variable, while a prime symbol indicates differentiation w.r.t. η. The influencing parameters appearing in equations (8) to (11) are given as follows:

$$P_r = \frac{\nu}{\alpha},\ N_b = \left(\frac{\tau D_B}{\nu}\right)[C_w - C_\infty],\ N_t = \left(\frac{\tau D_T}{\nu T_\infty}\right)[T_w - T_\infty],$$

$$M = \frac{\sigma \beta_0^2}{a\rho}\ \&\ K_P = \frac{\nu}{ak},\ f_w = -\frac{\text{v}_w}{\sqrt{a\nu}} \tag{12}$$

The physical parameters of interest in this study are the local Sherwood number, The local Nusselt number and the local skin friction coefficient, which are defined as follows:

$$c_f = \frac{\tau_w}{\rho u_w^2}, Nu_x = \frac{x q_w}{k(T_w - T_\infty)}, Sh_x = \frac{x q_m}{D_B(C_w - C_\infty)} \tag{13}$$

Where wall Shear stress τ_w, all heat flux q_w , mass flux q_m are given by:

$$\tau_w = \rho\nu\left(\frac{\partial u}{\partial y}\right)_{y=0}, q_w = -k\left(\frac{\partial T}{\partial y}\right)_{y=0}, q_m = -D_B\left(\frac{\partial \varnothing}{\partial y}\right)_{y=0} \tag{14}$$

The values of governing parameters P_r, N_b, N_t, L_e, K_r, β the equations (8) to (10) are solved numerically with boundary conditions (11).

Numerical Solution:

The system of nonlinear, coupled boundary layer equations governing the momentum, energy and nanoparticle concentration for steady Casson nanofluid flow over stretching sheet was solved numerically using the classical fourth-order Runge-Kutta method in conjunction with a shooting technique. The boundary value problem was transformed into an equivalent initial value problem by converting each second order differential equation into a first order system. Unknown initial slopes were iteratively estimated using the secant method to satisfy the asymptotic boundary conditions at large η. The system of coupled nonlinear ordinary differential equations, derived via similarity transformations.

We define the following substitutions to the above equations in to a system of first-order ODEs:

$$y_1 = f, y_2 = f', y_3 = f'', \quad y_4 = \theta, y_5 = \theta', \ y_6 = \varnothing, y_7 = \varnothing'$$

Then, the system becomes

$$\left.\begin{aligned} y_1' &= y_2 \\ y_2' &= y_3 \\ y_3' &= \frac{y_2^2 + \left(M + K_p\right) y_2 - y_1 y_3}{\left(1 + \frac{1}{\beta}\right)} \\ y_4' &= y_5 \\ y_5' &= -P_r\left(y_1 y_5 + N_b y_7 y_5 + N_t y_5^2\right) \\ y_6' &= y_7 \\ y_7' &= -P_r L_e y_1 y_7 + \frac{N_t}{N_b} y_5' - K_c P_r L_e y_6 \end{aligned}\right\} \quad (15)$$

The boundary conditions are:

$$\left.\begin{aligned} y_1(0) &= fw \quad y_2(0) = 1 \quad y_6(0) = 1 \\ y_2(\infty) &= 0 \quad y_4(\infty) = 0 \quad y_6(\infty) = 0 \end{aligned}\right\} \quad (16)$$

Results and Discussion:

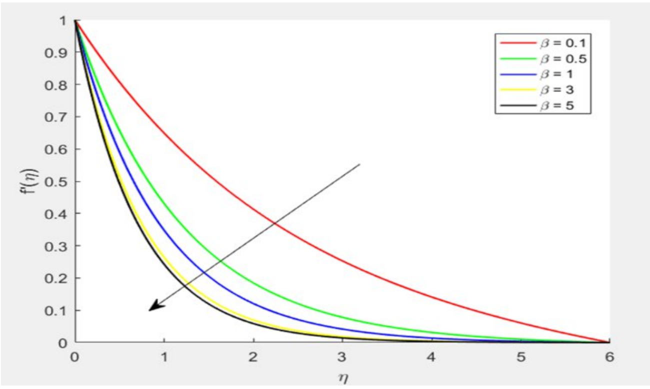

Fig.2: Velocity profiles for different values of β

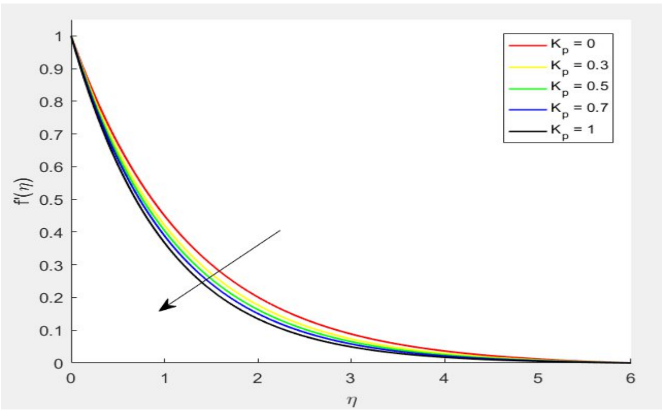

Fig.3: Velocity profiles for different values of K_P

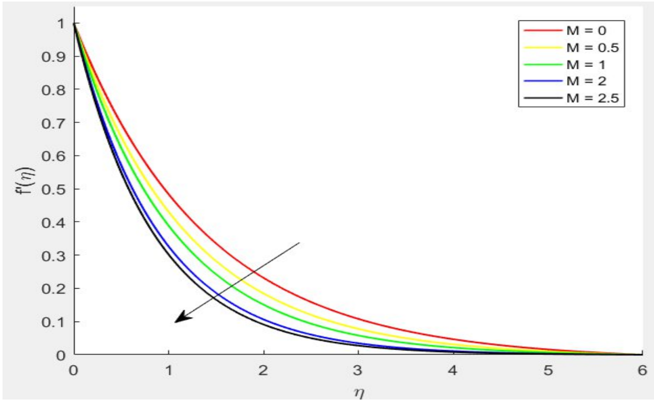

Fig.4: Velocity profiles for different values of M

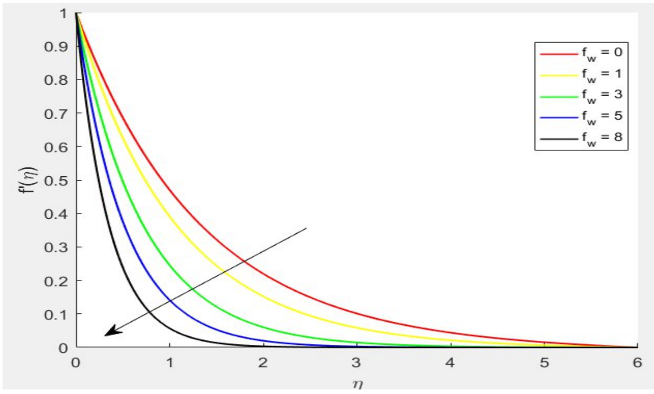

Fig.5: Velocity profiles for different values of f_w

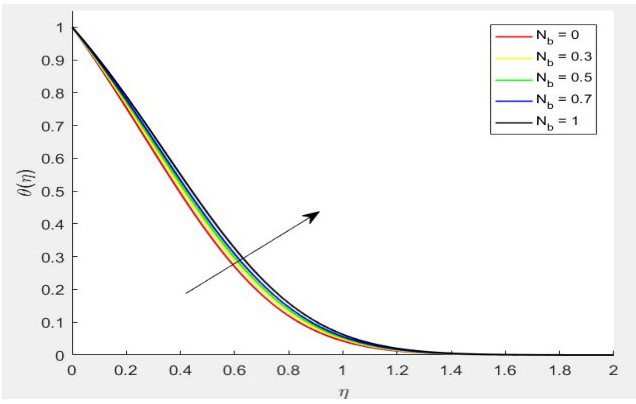

Fig.6: Temperature profiles for different values of N_b

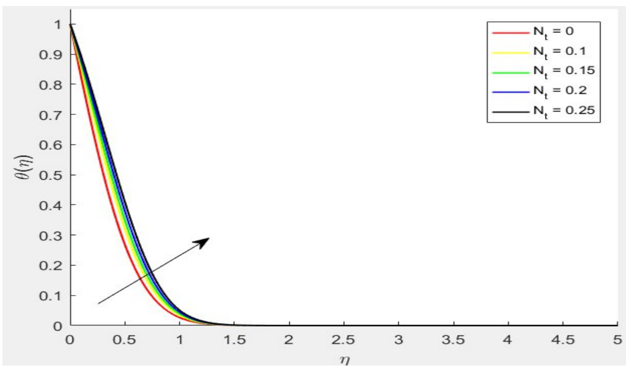

Fig.7: Temperature profiles for different values of N_t

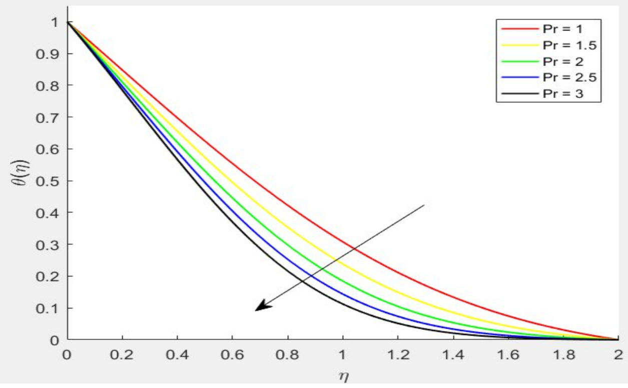

Fig.8: Temperature profiles for different values of P_r

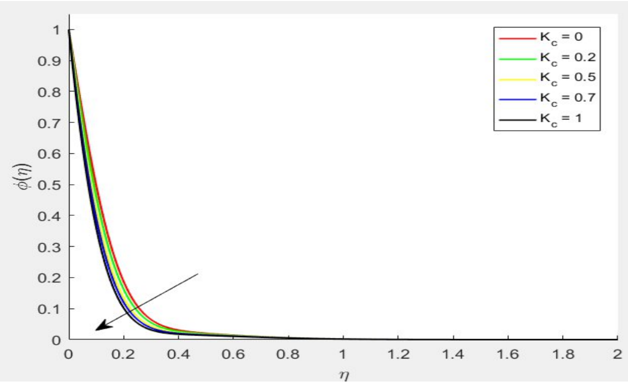

Fig.9: Concentration profiles for different values of K_c

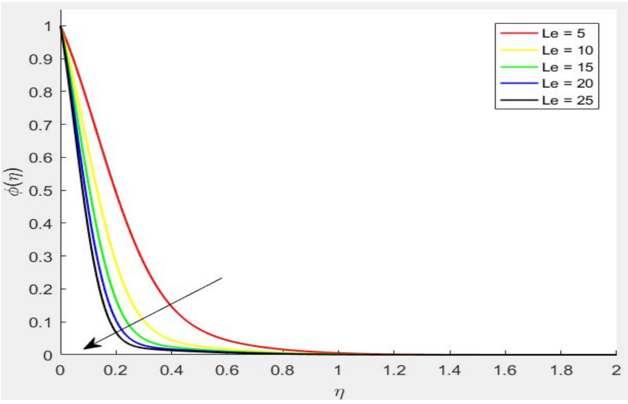

Fig.10: Concentration profiles for different values of L_e

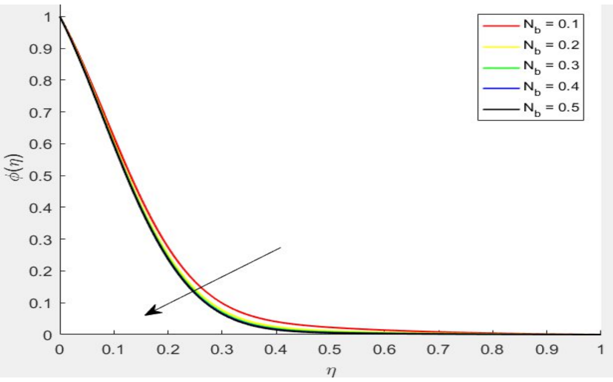

Fig.11: Concentration profiles for different values of N_b

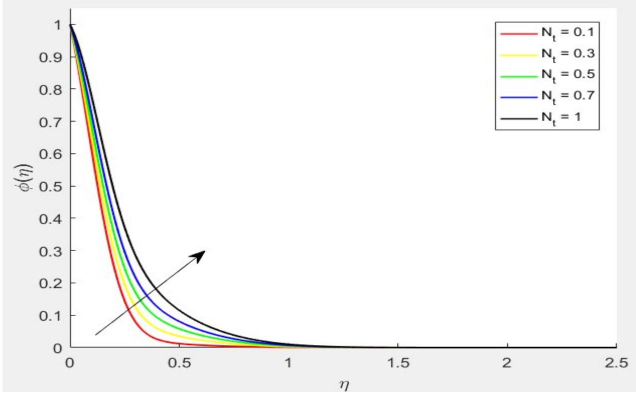

Fig.12: Concentration profiles for different values of N_t

From Fig.2 As the Casson fluid parameter β increases, the velocity profile $f'(\eta)$ decreases more quickly, indicating a thinner momentum boundary layer. This happen because a higher β corresponds to greater yield stress, increasing fluid resistance and decreasing the flow velocity.

From Fig.3 As K_P increases (e.g., from 0 to 1), the velocity $f'(\eta)$ decreases more rapidly. An increase in permeability K_P , increases the resistance of porous medium which will tend to decelerate the flow and reduce the velocity.

From Fig.4 As the magnetic parameter M increases (from 0 to 2.5) it introduces a Lorentz force that opposes the fluid motion which will decrease the velocity profile $f'(\eta)$. the curve for $M=0$ (no magnetic field) shows the highest velocity, while the curve for $M=2.5$ indicate the lowest velocity.

From Fig.5 AS the suction/injection parameter f_w from 0 to 8 increases, the velocity $f'(\eta)$ decreases more gradually, suction at the surface with draws fluid from the boundary layer, thereby reducing the fluid momentum near the wall and suppressing the velocity within the boundary layer. Consequently, the boundary layer becomes thinner and the velocity decreases with higher suction.

Form Fig.6 As the Brownian motion parameters N_b increase from 0 to 1, the temperature profile $\theta(\eta)$ increases due to more random motion of particles facilitating energy exchange. This means that for a given η (distance from the surface), the temperature of the fluid is higher with increasing N_b.

From Fig.7 As the thermophoresis parameter N_t increases (from 0 to 0.25), the temperature profile $\theta(\eta)$ increases. Thermophoresis causes nanoparticles to migrate from high- temperature to low-temperature regions this means that for a given η (distance from the surface), the temperature of the fluid is higher with increasing N_t

From Fig.8 The Prandtl number P_r which is the ratio of momentum diffusivity to thermal diffusivity, influences the rate of decreases of $\theta(\eta)$. As P_r increases thermal diffusivity decreases, so heat diffuses slowly through the fluid. This causes the thermal boundary layer becomes thinner than the velocity boundary layer. Because of slower heat transfer the fluid retains less heat, resulting in a lower temperature profile in the fluid region.

From Fig.9 When K_c increases the profile of $\varnothing(\eta)$ decreases. When $K_c = 0$ (i.e., no chemical reaction), the concentration degrades very slowly. $K_c = 1$ the decay is faster and the concentration closer to zero. A stronger chemical reaction (K_c), which consumes more solute. It improves the rate of mass transfer, reducing the concentration gradient.

If the chemical reaction rate increases the reactant is consumed faster. As a result, the concentration of the reactant (nanoparticle) decreases more rapidly.

From Fig.10 As the Lewis number (L_e) increases, the concentration profile $\varnothing(\eta)$ (dimensionless concentration gradient or mass flux) decreases. L_e is the dimensionless number, which is ratio of thermal diffusivity and mass diffusivity (concentration diffusivity). As L_e increases the mass diffusivity decreases. The concentration boundary layer becomes thinner as L_e increases. This specified by the curves dropping closer to zero for higher values of L_e.

From Fig.11 When the Brownian motion parameter increases, the concentration profile $\varnothing(\eta)$ decreases. Higher values of N_b create a faster decay in the concentration profile. Due to particles diffuse more uniformly (less concentration buildup near wall)

From Fig.12 The graph shows that as the thermophoresis parameter (N_t) increases, the concentration profile $\varnothing(\eta)$ increases. This means a stronger thermophoretic effect leads to higher concentrations within the boundary layer and the concentration boundary layer becomes thicker.

5. Conclusion:

The examination of Casson nanofluid flow over a stretching sheet is studied with the effect of magnetic parameter, Porosity parameter, Thermophoresis parameter, Brownian motion parameter, Chemical reaction parameter. The following conclusions are drawn.

An influence of Casson fluid parameter velocity fall down.

An impact of Magnetic parameter velocity decreased.

An impact of suction parameter velocity of fluid raised.

As influence of Brownian motion parameter, temperature of fluid increased and concentration fall down.

An enhancement of thermophoresis parameter, temperature and concentration of fluid raised.

Enhancement of Lewis number, concentration of fluid decreased.

An impact of chemical reaction parameter fluid concentration decreased.

An enhancement of Prandtl number, temperature of fluid decreases.

Nomenclature:

u,v	Velocity component w. r.t x & y-axis
ν	Kinematic fluid viscosity
β	Casson fluid parameter
σ	Electrical conductivity
β_0	Magnetic field
ρ	Fluid density
k	Nanofluid thermal conductivity
k_r	rate of chemical reaction
T	Fluid temperature within the boundary layer
T_w	Fluid temperature near the wall
T_∞	Fluid temperature far away from the wall
τ	Non dimensional skin friction
D_B	Brownian diffusion coefficient
C	Non dimensional fluid concentration
Cw	Fluid concentration near the wall
$C\infty$	Fluid concentration far away from the wall
D_T	Thermophoresis diffusion coefficient
η	Dimensionless similarity variable
ψ	Stream function
a	Constant
μ	Dynamic fluid viscosity
θ	Dimensionless temperature
$\varnothing$	Dimensionless concentration function
M	Magnetic parameter
K_p	Porosity parameter
P_r	Prandtl number
N_t	thermophoresis parameter
N_b	Brownian motion parameter
K_c	Chemical reaction parameter
S_c	Schmidt number
f_w	Suction/injection parameter
L_e	Lewis number

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REFERENCES

1. ACV Ramudu, K Anantha Kumar, V Sugunamma, N.Sandeep, Heat and Mass transfer in MHD Casson nanofluid flow past a stretching sheet with thermophoresis and Brownian motion. Wiley, 2020; 49(8):5020-5037
2. VVL Deepthi, VK Narla, R Srinivasa Raju, Double diffusive effects on nanofluid flow toward a permeable stretching surface in presence of Thermophoresis and Brownian motion effects: A numerical study. Numerical Methods for PDEs, Wiley, 2024. DOI: [10.1002/num.23086]

3. TL Babu, Krishna Kumari G, M Narsimha Rajashekar, Joint effects of Brownian motion and Thermophoresis on nanofluid flow past a stretching sheet: MHD and Chemical reaction effects. Journal of Advanced Research in Fluid Mechanics & Thermal Sciences,2024; 120(1), 68–84.
4. Aiguo Zhu, Haider Ali, Muhammad Ishaq, Muhammad Sheraz Junaid, Jawad Raza, Muhammad Amjad, Numerical study of Heat and Mass transfer for Williamson Nanofluid over Stretching/Shrinking sheet along with Brownian and Thermophoresis effects. 2022: 15(16), 5926
5. Shalini Jain, Rakesh Choudhary, Thermophoretic MHD flow and nonlinear radiative heat transfer with convective boundary conditions over a nonlinearly stretching sheet. 2017; arXiv:1702.02039.
6. M.Ali, M Alim and M Alam, Heat transfer boundary layer flow past an inclined stretching sheet in presence of magnetic field.. International Journal of Advancements in Research & Technology 3 (2014), pp. 34–40.
7. Gangaiah T, Saaidulu N, Venkata Lakshmi A. Magnetohydrodynamic flow of nanofluid over an exponentially stretching sheet in presence of viscous dissipation and chemical reaction. Jornal of Nanofluids. (2018) 2018, pp. 439-448(10)
8. Bachok N., Ishak A. and Pop I. Unsteady boundary layer flow and heat transfer of a nanofluid over a permeable stretching/shrinking sheet. Int. J. Heat Mass Transfer 55, 2102–2109 (2012).
9. Kalidas, Nanofluid flow over a nonlinear permeable stretching sheet with partial slip. Journal of the Egyptian Mathematical Society,2015, Pages 451-456.
10. Makinde OD, Aziz A: Boundary layer flow of a nanofluid past a stretching sheet with a convective boundary condition. Int.J.Therm. Sci. 50, 1326-1332 (2011).
11. Kuznetsov AV, Nield DA: Natural convective boundary layer flow of a nanofluid past a vertical plate. Int. J. Therm. Sci. 49, 243-247 (2010).
12. Md Mehdi Rashidi, Behnam Rostami, Navid Freidoonimehr and Saeid Abbas: free convective heat and mass transfer for MHD fluid flow over a permeable vertical stretching sheet in the presence of the radiation and buoyancy effects. 2014, Pages 901-912.
13. M.Turkyilmazoglu: Multiple solutions of heat and mass transfer of MHD slip flow for the viscoelastic fluid over a stretching sheet. International Journal of Thermal Sciences, 50 (2011), pp. 2264-2276.
14. R.Muthucumaraswamy, E.Geetha: Chemical reaction effects on MHD flow past a linearly accelerated vertical plate with variable temperature and mass diffusion in the presence of thermal radiation. Int. J. Appl. Mech. Eng., 18 (3) (2013), pp. 727-737.
15. D Chenna Kesavaiah, T. Ramakrishna Goud Nookala Venu, YV Seshagiri Rao (2021): MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, Journal of Mathematical Control Science & Applications, Vol. 7 (2), pp. 393-404.
16. M Rajaiah, A Sudhakaraiah, SVK Varma and P Venkata Lakshmi (2015): Chemical reaction and soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium. i-manager's Journal on Mathematics, Vol. 4(1), pp. 32-39.
17. Alizadeh.R and Rahmdel.K (2014): "MHD free convection flow of a dissipative fluid over a vertical porous plate in porous media", Advances in applied Science Research, Vol.5(4), pp. 31-42.
18. S Jena, S Mishra, G Dash: Chemical reaction effect on MHD Jeffery fluid flow over a stretching sheet through porous media with heat generation/absorption. International Journal of Applied Computational Mathematics, 3 (2) (2017), pp. 1225-1238
19. N Anbuchezhian, K Srinivasan, K Chandrasekaran, R Kandasamy, Thermophoresis and Brownian motion effects on boundary layer flow of nanofluid in presence of thermal stratification due to solar energy. ppl. Math. Mech. 33 (2012) 765–780.
20. Mittal AS, Patel HR. Influence of thermophoresis and Brownian motion on mixed convection two dimensional MHD Casson fluid flow with nonlinear radiation and heat generation. Phys A. 2016; 537:122710.
21. Zhu A, Ali H, Ishaq M, Junaid MS, Raza J, Amjad M. Numerical study of Heat and mass transfer for Williamson nanofluid over stretching/shrinking sheet along with Brownian and Thermophoresis effects. Energies. 2022; 15(16):5926.
22. NA Alreshidi, Zshah, A Dawar, P Kumam, M Shutaywi and W Watthayu, Brownian motion and thermophoresis effects on MHD three dimensional nanofluid flows with slip condition and joule dissipation due to porous rotating disk, Molecules 25 (2020), no. 729, 1–20.
23. Jagadish VT, Noeiaghdam S, Fernandez-Gamiz U, Govindan V and Balamuralitharan S., effects of thermophoresis and Brownian motion for thermal and chemically reacting Casson nanofluid flow over a linearly stretching sheet, Results in Engineering. (2022) 15, 100448.
24. Ramana Reddy JV, Sugunamma V, Sandeep N: Thermophoresis and Brownian motion effects on unsteady MHD nanofluid flow over a slandering stretching surface with slip effects. Alex Eng J. 2018; 57(4): 2465-2473.
25. Prasanna Kumara BC, BJ Gireesha, RSR Gorla and MR Krishnamurthy.2016. "Effects of chemical reaction and nonlinear thermal radiation on Williamson nanofluid slip flow over a stretching sheet embedded in a porous medium". Journal of Aerospace Engineering 29 (5). 1–10.
26. Mishra, S.R., and MM Bhatti.2017. "Simultaneous effects of chemical reaction and Ohmic heating with heat and mass transfer over a stretching surface: A numerical study". Chinese Journal of Chemical Engineering 25: 1137–1142.
27. SP Anjali Devi, R Kandasamy: Effects of chemical reaction, heat and mass transfer on nonlinear

MHD laminar boundary layer flow over a wedge with suction or injection. International communications in heat and mass transfer,29(5),2022, pages 707-716.

28. RS Tripathy, GC Dash, SR Mishra, S Bagg: Chemical reaction effect on MHD free convective surface over a moving vertical plate through porous medium. Alexandria Engineering Journal.54(3),2015, Pages 673-679.
29. Laltesh Kumar, Atar Singh, Vimal KJoshi, Kushal Sharma: MHD micropolar fluid flow with hall current over a permeable stretching sheet under the impact of Dufour-Soret and Chemical reaction. International Journal of Thermofluids, 2025,Volume 26, 101042.
30. A Sandhya, Venkata Ramana Reddy G, Deekshitulu Gvsr: Heat and mass transfer effects on MHD flow past an inclined porous plate in the presence of chemical reaction. International Journal of Applied Mechanics and Engineering 2020,25(3):86-102

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