Journal of Advanced Zoology

ISSN: 0253-7214

Volume 44 Issue S-5 Year 2023 Page 1121:1129

Three Dimensional Casson nanofluid Flow with Convective Boundary Layer via Stretching Sheet

G. Radha[1], B. Reddappa[2], Nainaru Tarakaramu[3*,4*], V.K. Somasekhar Srinivas[5,6], Sivajothi Ramalingam[7], N. Mallikarjuna Reddy[8], Kotte Amaranadha Reddy[9], K. Bhagya Lakshmi[10]

[1] Associate Professor of Mathematics, Department of Humanities and Science, KSRM College of Engineering (Autonomous), Kadapa-516003, Andrapradesh, India

[2, 9] Department of Mathematics, Kalasalingam Academy of Research and Education (Deemed to be University), Krishnankoil, Srivilliputhur, Tamilnadu-626126, India

[3, 5] Department of Mathematics, School of Liberal Arts and Sciences, Mohan Babu University, Sree Sainath Nagar, Tirupati-517102, Andrapradesh, India*

[4, 6] Department of Mathematics, Basic Science and Humanities, Sree Vidyanikethan Engineering College, Sree Sainath Nagar, Tirupati-517102, Andrapradesh, India*

[7] Department of Management, R L Institute of Management Studies (A Unit of Subbalakshmi Lakshmipathy College of Science) Madurai-625022, Tamil Nadu, India

[8] RJS FIRST GRADE COLLEGE, Koramangala, Bangaluru-560034, Karnataka, India

[10] Department of Mathematics, Humanities and Basic Sciences, Annamacharya Institute of Technology & Sciences, Tirupati, Andhra Pradesh, India

**Corresponding author's Email: nainaru143@gmail.com*

Article History

Received: 06 June 2023
Revised: 05 Sept 2023
Accepted: 20 Oct 2023

Abstract

The present work examined Casson nanofluid in a three-dimensional boundary layer motion via stretching sheet. The study focuses on analyzing the behavior of a Casson nanofluid, which is one type of non-Newtonian fluid. The study appears to involve solving partial differential equations related to fluid flow, heat transfer, and mass transfer. These PDEs are transformed into ordinary differential equations using standard similarity variables. To solve the ODEs, the researchers employ the Runge-Kutta-Fehlberg (R-K-F) 4th order iterative scheme. It appears that higher values of the Biot number can significantly affect the temperature and concentration profiles in the Casson liquid flow.

Keywords: *Casson Fluid, Nanofluid, Stretching Sheet, Convective.*

1. Introduction

The study of nanofluids has drawn a lot of interest in the field of fluid mechanics and heat transfer, primarily owing to their unique thermal characteristics and potential usage in various engineering and industrial processes. Firas et al. [1] have investigated the steady laminar 2-D incompressible MHD natural convection flow that occurs around a solid sphere submerged in a Casson nanofluid. Shah et al. [2] investigated entropy optimization in electrically conducting Casson nanofluid flowing over a stretchable nonlinear surface. Jamshed et al. [3] examined role of solar thermal transport in Casson nanofluid with slip condition. Adebowale Martins et al. [4] evaluated the second-order velocity slip and heat transfer caused by nanofluid along with non-Darcian Casson flow over a permeable stretching surface. Abo-Dahab et al. [5] studied the viscoelastic fluid flow over a nonlinearly stretched surface. Sahoo and Nandkeolyar [6] examined entropy production in a three-dimensional Casson nanofluid flow that conducts electricity. Akaje and Olajuwon [7] examined the impact of nonlinear radiative heat on species heat transfer while taking Thompson and Troian boundary conditions. Satya Narayana et al. [8]

investigated the fluid flow over an internally heated and horizontally stretched surface. Akinshilo et al. [9] examined the non-Newtonian Casson nanofluid flow around a small needle. Mahanta et al. [10] focused on the real-world uses of nanoparticles in non-Newtonian base fluids, particularly in the fields of energy conversion and heat generation.

Suresh Kumar et al. [11] studied the behavior of Casson nanofluid flow via an exponentially stretching surface, with activation energy, thermal radiation, Brownian motion, and thermophoresis. Taj and Salahuddin [12] examined the effect of viscous dissipation and nonlinear radiation in three-dimensional Williamson fluid flow via exponentially stretching surface. Ibrahim and Fawzy [13] investigated the effects of Arrhenius activation energy in a rotating flow of Casson nanofluid. Wang et al. [14] studied the impact of activation energy on 3D nanofluid motion over a stretching surface with slip conditions. Showkat Ahmad et al. [15] encountered the non-Newtonian Casson fluid's magnetohydrodynamic flow over a stratified extending sheet Jana Reddy et al. [16] investigated the Casson nanofluid flow characteristics over a permeable, non-linearly stretched sheet. Wang et al. [17] examined the effects of activation energy and chemical reactions in non-Newtonian liquid flow over a stretching sheet. Suresh Kumar et al. [18] studied the Brownian and thermophoresis effects with activation energy and nonlinear thermal radiation on mixed convection Casson fluid flow over a vertical cone. Tarakaramu et al. [19] have studied the non-Newtonian nanofluid flow in three dimensions over a porous stretching sheet. Zeeshan et al. [20] have evaluated various flow scenarios in applied sciences, particularly in areas like nuclear reactor cooling. Khan et al. [21] have examined the generation of entropy during the radiative spinning motion of a Casson nanofluid. Alrehili et al. [22] contributed many engineering applications by investigating the behavior of dissipative Carreau nanofluids flowing. Abideen et al. [23] have investigated heat transfer in a radiative nanofluid flowing over a curved surface. Recently, some of authors [24-26] developed three dimensional Casson nanofluid motion via stretching sheet.

2. Materials And Methods

Mathematical Analysis

The mathematical model as consider by using following aspects such as:

- Consider the 3D convective incompressible couple stress non-Newtonian Casson liquid motion via with thermal radiation.
- We considered the liquid motion through x^*, y^* directions.
- The fluid motion considers at stretching sheet in z^* is vanishes.
- The velocity components of axial and transverse direction $u = U_w^*(x^*) = a_1 x^*$, $v = V_w^*(x^*) = b_1 y^*$ as shown in **Fig.1**.

The rheological equation of Casson liquid motion has to be consider as follows

$$\tau_{ij} = \begin{cases} \left(2\mu_0^* + \dfrac{2p_y^*}{\sqrt{2\pi^*}}\right)e_{ij}, & if\ \pi^* \ge \pi_1^* \\ \left(2\mu_0^* + \dfrac{2p_y^*}{\sqrt{2\pi_1^*}}\right)e_{ij}, & if\ \pi^* < \pi_1^* \end{cases} \tag{1}$$

Where, $p_y^* = e_{ij}e_{ij}$ and $\beta = \mu_B^* \sqrt{2\pi_1^*} / \mathrm{p}_y^*$.

The fundamental equations of continuity, heat and concentration Eqs can be formulated by using eq. (1)

$$\frac{\partial u}{\partial x^*}+\frac{\partial v}{\partial y^*}+\frac{\partial w}{\partial z^*}=0 \tag{2}$$

$$u\frac{\partial u}{\partial x^*}+v\frac{\partial u}{\partial y^*}+w\frac{\partial u}{\partial z^*}=\upsilon^*\left(1+\beta^{-1}\right)\frac{\partial^2 u}{\partial\left(z^*\right)^2} \tag{3}$$

$$u\frac{\partial v}{\partial x^*}+v\frac{\partial v}{\partial y^*}+w\frac{\partial v}{\partial z^*}=\upsilon^*\left(1+\beta^{-1}\right)\frac{\partial^2 v}{\partial\left(z^*\right)^2} \tag{4}$$

(4)

$$u\frac{\partial T^*}{\partial x^*}+v\frac{\partial T^*}{\partial y^*}+w\frac{\partial T^*}{\partial z^*}=\alpha\frac{\partial^2 T}{\partial z^{*2}}+\tau\left(D_B\frac{\partial T}{\partial z^*}\frac{\partial C}{\partial z^*}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial z^*}\right)^2\right) \tag{5}$$

$$u\frac{\partial C}{\partial x^*}+v\frac{\partial C}{\partial y^*}+w\frac{\partial C}{\partial z^*}=\left(D_B\frac{\partial^2 C}{\partial\left(z^*\right)^2}+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial\left(z^*\right)^2}\right)\right) \tag{6}$$

The present relevant model boundary conditions as

$$\begin{aligned}&z^*=0 \quad at \quad u_1=a_1x^* \quad \mathrm{v}=b_1y^* \quad \mathrm{w}_1=0,\ -k\frac{\partial T^*}{\partial z^*}=H_1(\mathrm{T}_f^*-\mathrm{T}^*) \quad -D^*\left(\frac{\partial C}{\partial z}\right)=H_2\left(C_f-C\right)\\ &z^*\to\infty \quad as \quad u_1\to 0 \quad \mathrm{v}_1\to 0,\ u_1'\to 0,\ \mathrm{v}_1'\to 0,\ T^*\to T_\infty^*,\ C\to C_\infty\end{aligned} \tag{7}$$

The similarity transformations as below

$$\left.\begin{aligned}&\eta_1=\sqrt{\frac{a_1}{\upsilon_f^*}}z^*, \qquad u=a_1x^*f'(\eta_1), \qquad v=a_1y^*g'(\eta_1), \qquad \mathrm{w}=-\sqrt{a_1\upsilon^*}(f(\eta_1)+g(\eta_1))\\ &\qquad\qquad \theta(\eta_1)=\frac{T-T_\infty}{T_w-T_\infty}, \qquad \phi(\eta_1)=\frac{C-C_\infty}{C_w-C_\infty}\end{aligned}\right\} \tag{8}$$

Using above **Eq. (8)**, we are converting **Eq. (3)-(6)** into below format

$$f'''=\left[\frac{1}{\left(1+\frac{\beta}{\beta}\right)}\right]\left[-f''(f+\mathrm{g})+2f'(f'+g')\right] \tag{9}$$

$$g'''=\left[\frac{1}{\left(1+\frac{\beta}{\beta}\right)}\right]\left[-g''(f+\mathrm{g})+2g'(f'+g')\right] \tag{10}$$

$$\theta''=-\mathrm{Pr}\left[-(f+\mathrm{g})\theta'-N_b\theta'\phi'-N_t(\theta')^2\right] \tag{11}$$

$$\phi''=-Le\left((f+\mathrm{g})\phi'-\left(\frac{N_t}{N_b}\right)\mathrm{Pr}\left[-(f+\mathrm{g})\theta'-N_b\theta'\phi'-N_t(\theta')^2\right]\right) \tag{12}$$

Corresponding B.Cs. as below

$$\left.\begin{aligned}&f=0, \quad g=0, \quad f'=1, \quad g'=1, \quad \theta'=-Bi_1(1-\theta), \quad \phi'=-Bi_2(1-\phi) \quad at \quad \eta_1=0\\ &f'\to 0, \quad g'\to 0, \quad \theta\to 0, \quad \phi\to 0, \qquad\qquad as \quad \eta_1\to\infty\end{aligned}\right\} \tag{13}$$

Moreover, the skin-friction coefficient and Nusselt number are below

$$\left.\mathrm{Re}_x^{0.5} C_{fx} = \left(1+\frac{1}{\beta}\right) f''(0), \quad \mathrm{Re}_x^{0.5} C_{fy} = \left(1+\frac{1}{\beta}\right) g''(0)\right\} \tag{14}$$

3. Results and Discussion
Analysis of Phytochemicals and Percentage yield

Fig. 2 predicts the β (Casson Fluid Parameter) on $f'(\eta)$. These observations suggest that the Casson fluid parameter plays a critical role in determining both the velocity profile within the boundary layer. Increasing β results in reduced velocity.

Fig. 3 presented Pr (Prandtl number) on $\theta(\eta)$. This behaviour is consistent with the physical interpretation of the Prandtl number. A higher Prandtl number implies that heat is conducted less efficiently within the fluid compared to the momentum transfer (velocity). This can have significant implications for heat transfer processes, such as conduction, convection, and boundary layer phenomena.

Fig. 4(a)-4(b) presented the N_b (Brownian Motion Parameter) on $\theta(\eta)$, $\phi(\eta)$. We have described characteristic of the influence of Brownian motion on nanoparticle dispersion and transport within a fluid. When N_b is higher, it implies that Brownian motion becomes more significant, causing nanoparticles to move more erratically within the fluid. This increased movement can lead to enhanced mixing and heat transfer, which, in turn, results in a thicker thermal boundary layer and higher temperatures within the nanofluid.

In summary of N_t (Thermophoresis Parameter) exhibited on $\theta(\eta)$, $\phi(\eta)$ as shown in **Figs. 4(a)-4(b)**, respectively. The rise in fluid temperature and concentration with an increase in the thermophoresis parameter N_t is linked to the behavior of nanoparticles within the fluid.

Fig. 5 shows characteristics of Lewis number on $\phi(\eta)$. These observations indicate that the Lewis number plays a significant role in determining the behavior of nanoparticle concentration profile in the presence of Brownian diffusion. A higher Lewis number implies that thermal diffusion is more dominant relative to molecular diffusion, leading to decreased Brownian diffusion and, consequently, a thinner concentration boundary layer and reduced nanoparticle concentration near the sheet.

Table. 1 presented the variation of Casson Fluid Parameter on Skin friction coefficients

Conclusions:

The main contribution results as presented as following:

- ❖ The velocity of Casson fluid is declined with large statistical values of Casson liquid parameter.
- ❖ The temperature and concentration are high for enlarge values of Biot number of temperature and concentration.

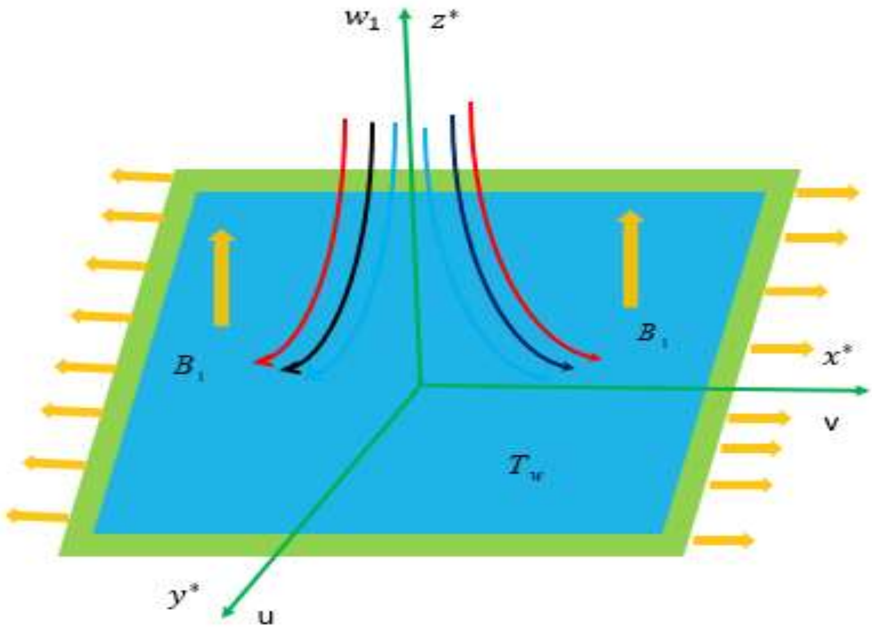

Fig. 1 Flow Geometry

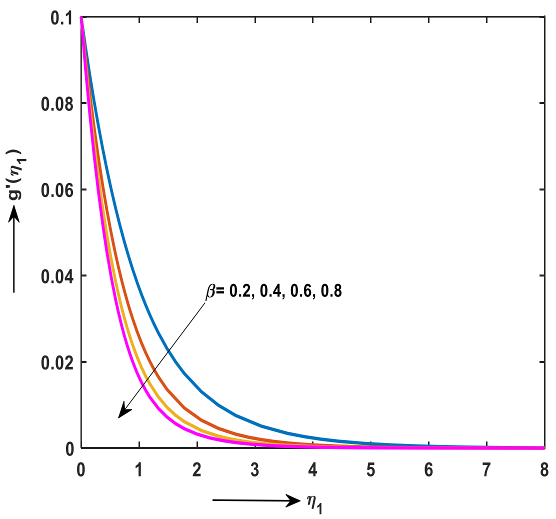

Fig. 2 Influence of β on $g'(\eta_1)$

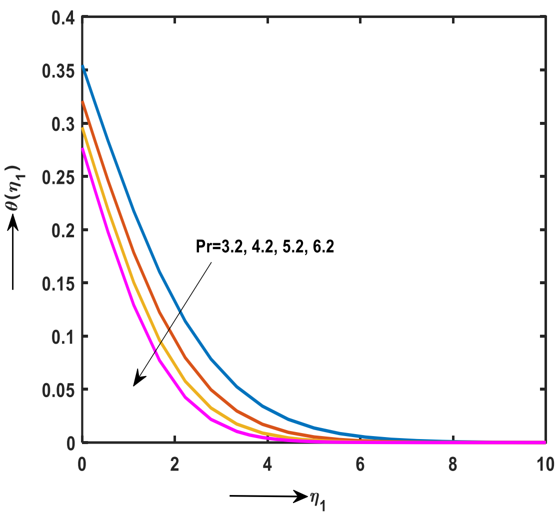

Fig. 3 Influence of Pr on $\theta(\eta)$

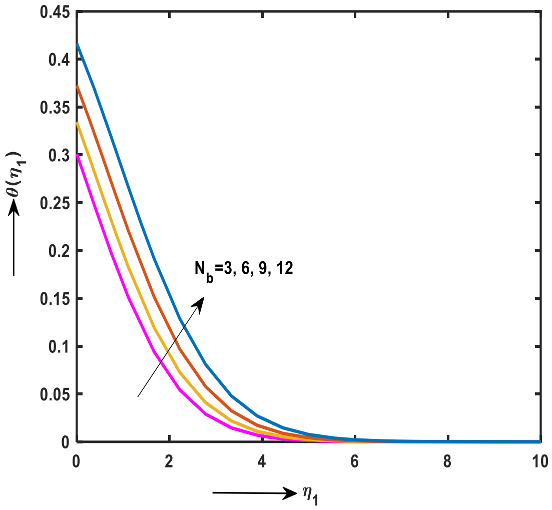

Fig. 3 Influence of N_b on $\theta(\eta)$

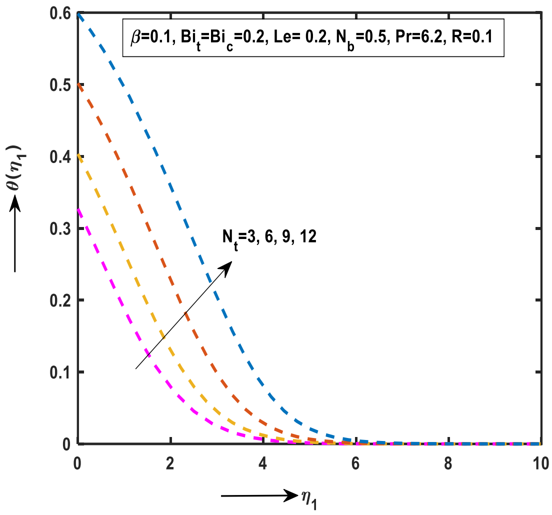

Fig. 4(a) Influence of N_b on $\theta(\eta)$

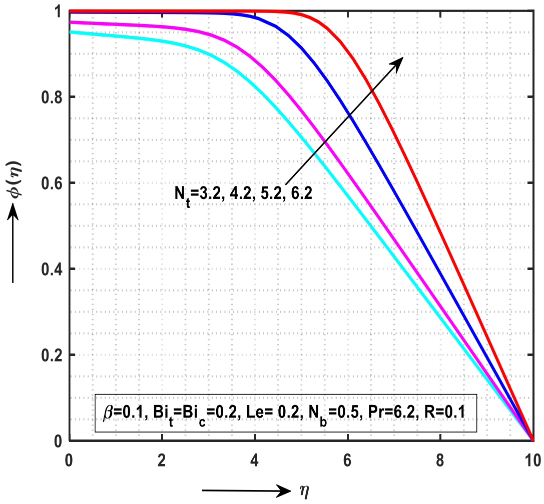

Fig. 4(b) Influence of N_b on $\phi(\eta)$

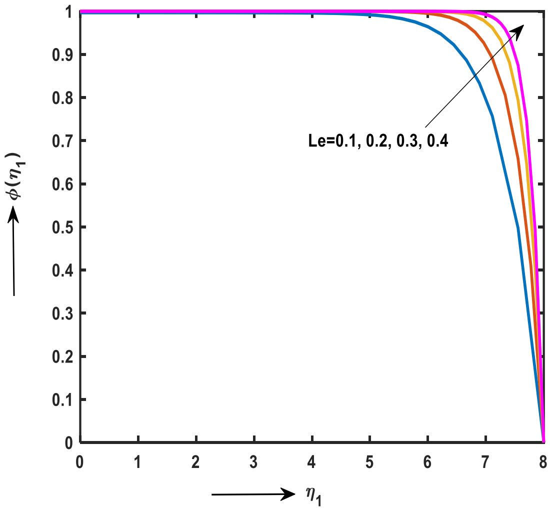

Fig. 5 Influence of Le on $\phi(\eta)$

Table 1. Variation of the Casson Fluid Parameter on Skin friction coefficients:

β	$-\left(1/_{1+\beta}\right) f''(\eta)$	$-\left(1/_{1+\beta}\right) g''(\eta)$
∞	1.2105	0.00945
0.5	1.2212	0.12891
1	2.1221	0.32548
1.5	2.2234	0.29358
2	3.0023	0.32546
2.5	3.1589	0.33564
3	3.2558	0.45689
3.5	3.2258	0.44512
4	3.3348	0.45891
4.5	3.4568	0.48901
5	3.5891	0.51254

Nomenclature	
$a_1,\ b_1$ Constants	T_∞ Ambient fluid temperature
Nu_x Nusselt number	U_∞ Free stream velocity
u, v, w Velocity components along x^*, y^*, z^*	U_w, V_w Stretching velocities
C Nanoparticle volume fraction	W_c Maximum cell swimming speed
C_p Specific heat constant $(kJ / kg\ K)$	λ_i Slip factors $= N_i\sqrt{a_1\mu^*}$
C_f Skin friction coefficient	*Greek symbols*
C_∞ Uniform ambient concentration $(\mathrm{Kg\,m^{-3}})$	ρ_f Fluid density
C_w Nanoparticle concentration $(\mathrm{Kg\,m^{-3}})$	$(\rho c)_p$ Heat capacity of the nanoparticle
D_n Diffusivity of microorganisms	$(\rho C)_{bf}$ Base fluid
D_B Brownian diffusion	ρ_f Fluid density
D_T Thermophoresis diffusion $(m^2.s^{-1})$	$(\rho c)_f$ Heat capacity of the field $(kJ\ kg^{-1})$
f' Dimensionless velocity	ϕ Dimensionless concentration
f Dimensionless stream function	η_1 Similarity variable
h_f Heat transfer coefficient	μ^* Dynamic viscosity $(Pa.s^{-1})$
k^* Mean absorption coefficient	θ Dimensionless temperature
Le Lewis number $\dfrac{\alpha_m}{D_B}$	ρ_f Fluid density $(\mathrm{Kg.m^{-3}})$
N_t Thermophoresis parameter $= \dfrac{\tau^* D_T (T_w - T_\infty)}{\alpha_m T_\infty}$	Bi_t Surface Convection Parameter $\dfrac{h_f}{k}\left(\sqrt{\upsilon / a}\right)$
N_b Brownian motion coefficient $= \dfrac{\tau^* D_B (C_w - C_\infty)}{\alpha_m}$	Bi_c Surface Convection Parameter $\dfrac{h_s}{D_B}\left(\sqrt{\upsilon / a}\right)$
$N_1,\ N_2$ Slip coefficients in x and y	τ^* Ratio of the nanoparticle to fluid $(\rho c)_p / (\rho c)_f$
Pr Prandtl number $= \dfrac{\upsilon^*}{\alpha_m}$	υ^* Kinematic viscosity $= \dfrac{\mu^*}{\rho_f}$ $(m^2 s^{-1})$
R Thermal Radiation $= \dfrac{16\sigma^* T_\infty^3}{3k^* K^*}$	*Subscripts*
T_f Temperature of hot fluid	∞ condition at free stream
T Fluid temperature	w wall mass transfer velocity $(\mathrm{m\,s^{-1}})$

Re_x Reynolds number	
Sc Schmidt number $= \dfrac{\upsilon^*}{D_n}$	
Abbreviations	
HT Heat Transfer	TC Thermal Conductivity
TR Thermal Radiation	NPs Nanoparticles
NFs Nanofluids	SS Stretching Sheet
CF Casson Fluid	

References:

1. Firas A.A., T. Hamzeh Alkasasbeh, A.M. Rashad, and R. Idrisa, MHD natural convection of Sodium Alginate Casson nanofluid over a solid sphere, Result in Physics, 16 (2020) 102818. Https://doi.org/10.1016/j.rinp.2019.102818.
2. Z. Shah, P. Kumam and W. Deebani, Radiative MHD Casson Nanofluid Flow with Activation energy and chemical reaction over past nonlinearly stretching surface through Entropy generation, Scientific Reports, 10 (2020) 4402. Https://doI.or g/10.038/s41598-020-61125-9.
3. W. Jamshed, S. Suriya Uma Devi, M. Goodarzi, M. Prakash, N. Kottakkaran Sooppy, M. Zakarya, A.A. Abdel-Haleem, Evaluating the unsteady Casson nanofluid over a stretching sheet with solar thermal radiation: An optimal case study, Case Studies in Thermal Engineering, 26 (2021) 101160. https://doi.org/10.10 16/j.csite.2021.1011 6.0.
4. O. Adebowale Martins, O. Adebayo Ajala, A. Abdulraheem and A. Oladimeji Akindele, The influence of variable electrical conductivity on non-Darcian Casson nanofluid flow with first and second-order slip conditions, Partial Differential Equations in Applied Mathematics, 4 (2021) 100084. Https://doi.org /10.1016/j.pad iff.2021.100084.
5. S.M. Abo-Dahab, M.A. Abdelhafez, F. Mebarek-Oudina and S.M. Bilal, MHD Casson nanofluid flow over nonlinearly heated porous medium in presence of extending surface effect with suction/injection, Indian Journal of Physics, 95(12) (2021) 2703-2717. https://doi.org/10.1007/s12648-020-01923-z.
6. A. Sahoo and R. Nandkeolyar, Entropy generation and dissipative heat transfer analysis of mixed convective hydromagnetic flow of a Casson nanofluid with thermal radiation and Hall current, Scientific Reports, 11 (2021) 3926. https://doi.org/10.1038/s 41598-021-83124-0.
7. T.W. Akaje and B.I. Olajuwon, Impacts of Nonlinear Thermal Radiation on a Stagnation Point of an Aligned MHD Casson Nanofluid Flow with Thompson and Troian Slip Boundary Condition, Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer, 6(1) (2021) 1-15.
8. P.V. Satya Narayana, N. Tarakaramu, G. Sarojamma, I.L. Animasaun, Numerical Simulation of Nonlinear Thermal Radiation on the 3D Flow of a Couple Stress Casson Nanofluid Due to a Stretching Sheet, Journal of Thermal Science and Engineering, (2021). https://doi.org/10.1115/1.4049425.
9. A.T. Akinshilo, F. Mabood and A.O. Ilegbusi, Heat generation and nonlinear radiation effects on MHD Casson nanofluids over a thin needle embedded in porous medium, International Communications in Heat and Mass Transfer, 13(2) (2021) 021028. https://doi.org/10.1016/j.icheatmasstransfer.2021.105547.
10. G. Mahanta, M. Das, M.K. Nayak and S. Shaw, Irreversibility Analysis of 3D Magnetohydrodynamic Casson Nanofluid Flow Past Through Two Bi-Directional Stretching Surfaces with Nonlinear Radiation, Journal of Nanofluids, 10(3) (2021) 316-326(1). Doi:10.1166/jon.2021.1793.
11. Y. Suresh Kumar, S. Hussain, K. Raghunath, A. Farhan, G. Kamel and M. Sayed Eldin and M. Ijaz Khan, Numerical analysis of magnetohydrodynamics Casson nanofluid flow with activation energy, Hall current and thermal radiation, Scientific Reports, 13 (2023) 4021. https://doi.org/10.1038/s41598-023-28379-5.
12. M. Taj and T. Salahuddin, Analysis of viscously dissipated three-dimensional flow of Williamson fluid with nonlinear radiation and activation energy, Alexandria Engineering Journal, 76(1) (2023) 595-607.
13. https://doi.org/10.1016/j.aej.2023.06.043.
14. G.M. Ibrahim and N.A. Fawzy, Arrhenius energy effect on the rotating flow of Casson nanofluid with convective conditions and velocity slip effects: Semi-numerical calculations, Heat Transfer, 52(1) (2023) 687-706. https://doi.org/10.1002/htj.22712.
15. F. Wang and N. Tarakaramu, N. Sivakumar, P.V. Satya Narayana, and D. Harish Babu, R. Sivajothi, Three dimensional nanofluid motion with convective boundary condition in presents of nonlinear thermal radiation via stretching sheet, Journal of the Indian Chemical Society, 100(2) (2023) 100887. http://dx.doi.org/10.1016/ j. jics.2023.100887.

16. L. Showkat Ahmad, A. Sadia, A. Saeed and B. Gabriella, A Stratifed flow of a non-Newtonian Casson fluid comprising microorganisms on a stretching sheet with activation energy, Scientific Reports, 13 (2023) 11240. https://doi.org/10.1038 /s41598-023-38260-0.
17. S. Jana Reddy, P. Valsamy and D. Srinivas Reddy, Numerical Solutions of Casson-Nano Fluid Flow Past an Isothermal Permeable Stretching Sheet: MHD, Thermal Radiation and Transpiration Effects, Journal of Nanofluids, 12(6) (2023) 1503-1511(9). http://dx.doi.org/1 0.1166/jon.2023.2034.
18. F. Wang, N. Tarakaramu, M.V. Govindaraju, N. Sivakumar, K. Bhagya Lakshmi, P.V. Satya Narayana and R. Sivajothi, Activation energy on three-dimensional Casson nanofluid motion via stretching sheet: Implementation of Buongiorno's model, Journal of the Indian Chemical Society, 100(2) (2023) 100886. http://dx.doi.org/1 0.1016/j.jics.2023.100886.
19. Y. Suresh Kumar, Y. Madhavi Reddy, M. Siva Mala and P. Srinivasa Rao, Effects of Activation Energy Diffusion Thermo and Nonlinear Thermal Radiation on Mixed Convection Casson Fluid Flow Through a Vertical Cone with Porous Media in the Presence of Brownian Motion and Thermophoresis, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 61(11) (2023). https://doi.org/10.37934/arfmts.108.1.7592.
20. N. Tarakaramu, P.V. Satya Narayana, N. Sivakumar, D. Harish Babu, K. Bhagya Lakshmi, Convective Conditions on 3D Magnetohydrodynamic (MHD) Non-Newtonian Nanofluid Flow with Nonlinear Thermal Radiation and Heat Absorption: A Numerical Analysis, Journal of Nanofluids, 12(2) (2023) 448-457(10). http://dx.doI.org/10 .1166/jon.2023.1939.
21. A. Zeeshan, O.U. Mehmood, F. Mabood and F. Alzahrani, Numerical analysis of hydromagnetic transport of Casson nanofluid over permeable linearly stretched cylinder with Arrhenius activation energy, International Communications in Heat and Mass Transfer, 130 (2022) 105736.
22. A. Khan, Z. Shah, E. Alzahrani and I. Saeed, Entropy generation and thermal analysis for rotary motion of hydromagnetic Casson nanofluid past a rotating cylinder with Joule heating effect, International Communications in Heat and Mass Transfer, 119 (2020) 104979. https://doi.org/10.1016/j.Icheatmass transfer.2020.104979.
23. M. Alrehili, Improvement for engineering applications through a dissipative Carreau nanofluid fluid flow due to a nonlinearly stretching sheet with thermal radiation, Case Studies in Thermal Engineering, 42 (2023) 102768. https://doi.org/10.1016 /j. csite.2023.102768.
24. Z.U. Abideen and S. Rai Sajjad Saif, Impact of thermal radiation and internal heat generation on Casson nano-fluid flowing by a curved stretchable surface with suspension of carbon nanotubes, Heliyon, 9(8) (2023) e18941. https://doi.org/10.1016/j.heliyon.2023.e 18941.
25. N. Tarakaramu, N. Sivakumar, P.V. Satya Narayana, R. Sivajothi, Viscous Dissipation and Joule Heating Effects on 3D Magnetohydrodynamics Flow of Williamson Nanofluid in a Porous Medium Over a Stretching Surface with Melting Condition, ASME Open Journal of Engineering, (2022). DOI: 10.1115/1.4055183.
26. N. Tarakaramu, N. Sivakumar, N. Tamam, P.V. Satya Narayana and R. Sivajothi Ramalingam, Theoretical analysis of Arrhenius activation energy on 3D MHD nanofluid flow with convective boundary condition, Modern Physics Letters B, (2023). DOI: 10.1142/S0217984923410099.
27. S. Jagadeesh, M. Chenna Krishna Reddy and N. Tarakaramu, H. Ahmad, S. Askar and S.S. Abdullaev, Convective heat and mass transfer rate on 3D Williamson nanofluid flow via linear stretching sheet with thermal radiation and heat absorption, Scientific Reports, (2023). https://doi.org/10 .1038 /s41 598-023-36836-4.