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A Comprehensive Review of Magnetohydrodynamic Non-Newtonian Nanofluid Flows with Micro polarity, Bioconvection, and Fuzzy Modelling: Numerical Advances and Emerging Applications

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ABSTRACT

Magnetohydrodynamic (MHD) nanofluid flow over stretching and inclined surfaces has attracted considerable attention due to its wide range of applications in energy systems, thermal management, biomedical transport, and materials processing. This review presents a comprehensive synthesis of recent numerical investigations on Casson, micropolar, Williamson, Carreau, and Sisko nanofluids, emphasizing the combined effects of magnetic fields, porous media, thermal radiation, bioconvection, chemical reactions, and fuzzy logic modeling. Particular attention is given to ternary hybrid nanofluids, homogeneous–heterogeneous reactions, Cattaneo–Christov heat flux, and gyrotactic microorganism transport, which represent emerging directions in modern nanofluid research.

The review critically evaluates the governing models, numerical methodologies, and parametric trends reported in recent literature, highlighting the transition from classical Buongiorno-based models to intelligent fuzzy-assisted frameworks. Open challenges and future research directions for high-fidelity simulations and real-world engineering applications are also discussed.

Keywords: MHD nanofluids, Casson fluid, Micropolar fluid, Bioconvection, Fuzzy logic, Ternary hybrid nanofluid, Porous media

AMS Mathematics Subject Classification (2010): 76W05, 76A10, 03E72

Abstract in Bengali

চৌম্বক-তরলগতিবিদ্যা (Magnetohydrodynamic, MHD) ন্যানো তরলের প্রসারিত ও ঢালু পৃষ্ঠের উপর প্রবাহ শক্তি ব্যবস্থা, তাপ ব্যবস্থাপনা, জৈব-চিকিৎসা পরিবহন এবং উপাদান প্রক্রিয়াকরণে এর বিস্তৃত প্রয়োগের কারণে উল্লেখযোগ্য মনোযোগ আকর্ষণ করেছে। এই পর্যালোচনায় ক্যাসন, মাইক্রোপোলার, উইলিয়ামসন, ক্যারো এবং সিসকো ন্যানো তরল

সম্পর্কিত সাম্প্রতিক সংখ্যাতাত্ত্বিক গবেষণার একটি বিস্‌তৃত সংকলন উপস্থাপন করা হয়েছে, যেখানে চৌম্বক ক্ষেত্র, ছিদ্রযুক্ত মাধ্যম, তাপ বিকিরণ, বায়োকনভেকশন, রাসায়নিক বিক্রিয়া এবং ফাজি লজিক মডেলিং-এর সম্মিলিত প্রভাবের ওপর বিশেষ গুরুত্ব দেওয়া হয়েছে।

বিশেষভাবে ত্রিমিশ্র (টার্নারি) হাইব্রিড ন্যানোতরল, সমজাতীয়–বৈচিত্র্যময় (homogeneous–heterogeneous) বিক্রিয়া, ক্যাটানেও–ক্রিস্টভ তাপ প্রবাহ, এবং গাইরোট্যাকটিক অণুজীব পরিবহনকে গুরুত্ব দেওয়া হয়েছে, যা আধুনিক ন্যানোতরল গবেষণার উদীয়মান দিকসমূহকে প্রতিনিধিত্ব করে।

সাম্প্রতিক গবেষণার পর্যালোচনায় উপস্থাপিত গাণিতিক মডেল, সংখ্যাতাত্ত্বিক পদ্ধতি এবং প্যারামেট্রিক প্রবণতাগুলির সমালোচনামূলক মূল্যায়ন করা হয়েছে, যেখানে শাস্ত্রীয় বুয়ংগিওর্নো-ভিত্তিক মডেল থেকে বুদ্ধিমান ফাজি-সহায়ক কাঠামোর দিকে রূপান্তরকে তুলে ধরা হয়েছে। পাশাপাশি, উচ্চ-নির্ভুল সিমুলেশন এবং বাস্তব প্রকৌশল প্রয়োগের জন্য উন্মুক্ত চ্যালেঞ্জ এবং ভবিষ্যৎ গবেষণার দিকনির্দেশনাও আলোচনা করা হয়েছে।

1. Introduction

The rapid advancement of thermal engineering, microscale heat transfer devices, and bio-inspired fluid systems has intensified interest in non-Newtonian nanofluids under magnetohydrodynamic environments. Classical Newtonian models fail to capture the complex rheological behaviour encountered in blood flow analogues, polymeric melts, bio-suspensions, and electrically conducting fluids, necessitating the use of Casson, micropolar, Williamson, Carreau, and Sisko fluid models.

Arif et al. [1] proposed a modified finite element formulation to examine electrically conducting non-Newtonian nanofluid boundary-layer flow with simultaneous heat and mass transport. Their numerical findings showed that magnetic forces combined with nanoparticle diffusion mechanisms significantly retard fluid motion while markedly improving thermal transfer efficiency. Sarada et al. [2] investigated magnetohydrodynamic non-Newtonian fluid flow over a stretching surface under local thermal non-equilibrium conditions. Their results revealed that LTNE assumptions substantially alter temperature gradients and heat transfer behavior, particularly in porous media configurations. Arif et al. [3] introduced a fractional-order Oldroyd-B fluid model incorporating couple stresses to compare different non-Newtonian rheological behaviors under magnetic field effects. The study demonstrated that fractional-order formulations capture fluid memory effects more realistically than classical integer-order models. Ramya and Deivanayaki [4] numerically analyzed Casson micropolar fluid flow over an inclined porous surface, emphasizing the roles of inclination angle and micropolar parameters. Their results confirmed that micropolar effects enhance microrotation, whereas porous resistance significantly suppresses velocity profiles. Ramya et al. [5] examined micropolar nanofluid flow subjected to homogeneous–heterogeneous chemical reactions using the Cattaneo–Christov heat flux model. The authors reported that thermal relaxation mechanisms strongly influence temperature distributions and stabilize reactive concentration layers.

Abbas and Megahed [6] studied the combined effects of chemical reactions and viscous dissipation on magnetized non-Newtonian fluid flow over a non-uniform stretching sheet in the presence of thermal radiation. Their analysis indicated that viscous dissipation elevates temperature fields, while chemical reactions reduce concentration boundary layers. Gudekote et al. [7] explored the peristaltic transport of an Eyring–Powell fluid through an inclined channel under magnetohydrodynamic conditions. The results highlighted that magnetic intensity and inclination angle play dominant roles in regulating pumping performance and coupled heat–mass transfer. Asiri et al. [8] investigated MHD non-Newtonian channel flow considering temperature-dependent thermophysical properties. Their findings showed that variations in viscosity and thermal conductivity significantly affect thermal boundary-layer thickness and entropy generation characteristics. Ramya et al. [9] incorporated fuzzy logic modeling to evaluate Lorentz force effects on Casson micropolar nanofluid flow. The fuzzy-based approach effectively accounted for parametric uncertainty by generating bounded solution regions instead of single deterministic solutions. Ramya and Deivanayaki [10] analyzed the influence of Soret and Dufour effects on Casson nanofluid flow subjected to a magnetic field. Their study demonstrated strong coupling between heat and mass transfer processes, particularly at higher cross-diffusion parameters. Ramya and Deivanayaki [11] investigated Carreau nanofluid flow through a Darcy–Forchheimer porous medium incorporating microorganism-induced bioconvection. The results revealed enhanced mass transfer rates and improved nanoparticle stability due to microbial activity. Shehzad et al. [12] examined multilayer coating flows of Newtonian and non-Newtonian fluids in a rotating porous inclined channel under magnetic field effects. Their study showed that MHD forces significantly stabilize coating layers and suppress interfacial instabilities. Ramya and Deivanayaki [13] focused on radiative heat transfer in Casson nanofluid flow over an inclined stretching surface. The analysis indicated that radiation and diffusion parameters substantially increase temperature levels and enhance heat transfer rates. Ramya et al. [14] studied ternary hybrid Casson nanofluids containing gyrotactic microorganisms while incorporating Brownian motion and thermophoretic effects. Their findings confirmed superior thermal performance compared with mono and hybrid nanofluid systems.

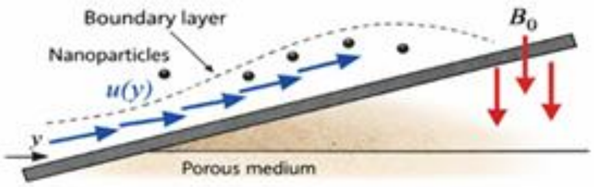
Muhiuddin et al. [15] analyzed Williamson fluid flow over a porous curved stretching surface with coupled bioconvection and homogeneous–heterogeneous reactions. The results demonstrated a strong interaction between microorganism density distribution and thermal transport characteristics. Ramya et al. [16] applied fuzzy logic analysis to assess the influence of the Eckert number on Casson micropolar nanofluid flow with chemical reactions. The fuzzy framework effectively addressed uncertainties associated with viscous dissipation effects. Muhiuddin et al. [17] investigated stagnation-point flow of a Sisko nanofluid with internal heat generation and nanoparticle transport mechanisms. The study confirmed that Sisko rheology significantly modifies boundary-layer structure under intense thermal conditions. Ramya et al. [18] explored thermodynamic topology and holographic properties of AdS black hole systems using generalized entropy concepts. Although outside classical fluid mechanics, the study contributes advanced perspectives to thermodynamic modeling. Fallah Andevari et al. [19] presented a fuzzy-based numerical investigation of MHD nanofluid flow through a Darcy–Forchheimer porous medium. Their approach enhanced solution robustness under uncertainty in magnetic and permeability parameters. Ramya and Deivanayaki [20] numerically analyzed Casson nanofluid flow over a stretching surface incorporating thermal radiation and particle diffusion effects. The results emphasized the synergistic role of radiative heat transfer and nanoparticle transport in improving thermal performance.

Table 1: Summary of literature analysis on non-Newtonian MHD nanofluid studies (Based on 20 References)

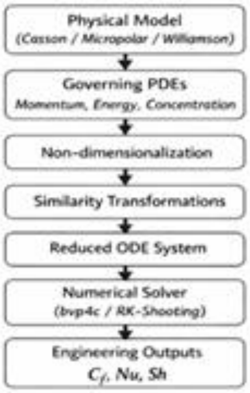
Ref. No.	**Fluid Model**	**Geometry / Configuration**	**Key Physical Effects Considered**	**Major Observations**
[1]	Non-Newtonian nanofluid	Flat plate (boundary layer)	MHD, heat & mass transfer	Magnetic force suppresses velocity while improving heat transfer
[2]	Non-Newtonian fluid	Stretching sheet	MHD, LTNE, porous medium	LTNE significantly alters thermal gradients
[3]	Oldroyd-B fluid	Planar flow	Fractional derivatives, MHD	Fractional models capture memory effects accurately
[4]	Casson micropolar fluid	Inclined porous surface	MHD, micropolarity	Microrotation enhances angular momentum transport
[5]	Micropolar nanofluid	Exponential stretching surface	Cattaneo–Christov heat flux, reactions	Thermal relaxation stabilizes reactive layers
[6]	Non-Newtonian fluid	Non-uniform stretching sheet	MHD, radiation, viscous dissipation	Dissipation elevates temperature significantly
[7]	Eyring–Powell fluid	Inclined channel	MHD, peristaltic motion	Inclination strongly controls pumping efficiency
[8]	Non-Newtonian fluid	Channel flow	Variable viscosity, MHD	Temperature-dependent properties affect entropy
[9]	Casson micropolar nanofluid	Stretching surface	MHD, fuzzy logic	Fuzzy modeling captures parametric uncertainty
[10]	Casson nanofluid	Stretching surface	MHD, Soret–Dufour	Strong heat–mass diffusion coupling
[11]	Carreau nanofluid	Porous medium	Darcy–Forchheimer, bioconvection	Microorganisms enhance mass transfer
[12]	Newtonian / Non-Newtonian	Inclined rotating channel	MHD, multilayer coating	Magnetic field stabilizes coating layers
[13]	Casson nanofluid	Inclined stretching surface	Radiation, diffusion	Radiation significantly raises temperature

Ref. No.	**Fluid Model**	**Geometry / Configuration**	**Key Physical Effects Considered**	**Major Observations**
[14]	Casson ternary hybrid nanofluid	Horizontal plate	Brownian motion, thermophoresis, bioconvection	THNF outperforms mono/hybrid nanofluids
[15]	Williamson fluid	Curved stretching surface	Bioconvection, reactions	Strong coupling between microbes and heat transfer
[16]	Casson micropolar nanofluid	Inclined surface	Eckert number, fuzzy logic	Uncertainty in dissipation captured effectively
[17]	Sisko nanofluid	Stagnation-point flow	Heat generation, nanoparticle transport	Rheology alters boundary layer thickness
[18]	—	Holographic system	Generalized entropy	Advanced thermodynamic insights
[19]	Nanofluid	Porous medium	Darcy–Forchheimer, fuzzy MHD	Robust solutions under uncertain parameters
[20]	Casson nanofluid	Stretching surface	Radiation, particle diffusion	Synergistic heat transfer enhancement

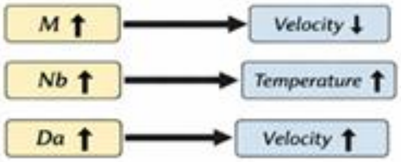
Table 1 provides a consolidated overview of the scope and thematic coverage of the reviewed non-Newtonian MHD nanofluid studies. It highlights the diversity of fluid models (Casson, micropolar, Carreau, Williamson, Sisko, Eyring–Powell), geometrical configurations (stretching surfaces, inclined plates, channels, porous media), and physical mechanisms considered in the literature. The table clearly shows that most studies focus on magnetohydrodynamic effects combined with thermal transport enhancement, while advanced phenomena such as bioconvection, fuzzy uncertainty modeling, and ternary hybrid nanofluids appear only in a limited number of works. This indicates a growing but still underexplored research direction toward multiphysics and intelligent modeling frameworks.



(a) Physical configuration of MHD non-Newtonian nanofluid flow over an inclined porous surface.



(b) General numerical methodology adopted in non-Newtonian MHD nanofluid studies.



(c) General influence of key physical parameters on flow and thermal characteristics.

Figure 1: *(a)* Physical configuration of magnetohydrodynamic (MHD) non-Newtonian nanofluid flow over an inclined porous surface showing boundary layer development, nanoparticle suspension, and applied transverse magnetic field. *(b)* General numerical methodology adopted in non-Newtonian MHD nanofluid studies, illustrating the transition from physical modelling to engineering quantities. *(c)* Schematic representation of the qualitative influence of key physical parameters on velocity and thermal characteristics reported in the literature.

Figure 1(a) illustrates the fundamental physical configuration commonly employed in non-Newtonian MHD nanofluid investigations. The flow is generated along an inclined porous surface, where the inclination angle introduces a gravitational component affecting momentum transport. A uniform transverse magnetic field $B_0$is applied normal to the surface, generating Lorentz forces that oppose the fluid motion and alter boundary layer thickness. The presence of nanoparticles within the base fluid enhances thermal conductivity, while the porous medium induces resistance governed by Darcy–Forchheimer effects. The velocity profile $u(y)$develops within the boundary layer, accompanied by coupled thermal and concentration gradients. This configuration serves as the baseline geometry for Casson, micropolar, Williamson, and other non-Newtonian fluid models discussed in the literature. Figure 1(b) presents a generalized numerical workflow adopted by the majority of reviewed studies. The modeling begins with the selection of an appropriate non-Newtonian constitutive relation, followed by the formulation of governing partial differential equations representing momentum, energy, and species transport. These equations are subsequently non-dimensionalized to extract key governing parameters such as the magnetic parameter, Prandtl number, Brownian motion parameter, and Darcy number. Similarity transformations reduce the governing equations to a coupled system of nonlinear ordinary differential equations, which are solved using numerical techniques such as the MATLAB bvp4c solver or Runge–Kutta shooting methods. The solution yields engineering quantities of practical relevance, including skin friction coefficient, Nusselt number, and Sherwood number. This unified framework highlights methodological consistency across non-Newtonian MHD nanofluid studies. Figure 1(c) provides a qualitative summary of the dominant parametric trends reported in the literature. An increase in the magnetic parameter Mresults in a reduction of velocity due to enhanced Lorentz force damping. The Brownian motion parameter Nbintensifies thermal diffusion, leading to elevated temperature profiles within the boundary layer. Conversely, higher Darcy number Davalues reduce porous resistance, thereby enhancing fluid velocity. These trends demonstrate strong coupling between momentum, thermal, and mass transport mechanisms in non-Newtonian MHD nanofluid systems and justify the inclusion of these parameters in advanced numerical models.

Recent numerical studies have demonstrated that incorporating magnetic fields, porous substrates, and nanoparticle transport mechanisms significantly enhances heat and mass transfer performance. Moreover, the inclusion of bioconvection induced by gyrotactic microorganisms has opened new research avenues in bioenergy and microbial fuel cell design.

This review consolidates and critically examines state-of-the-art numerical studies conducted between 2023–2025, with particular emphasis on works addressing:

- Casson and micropolar nanofluids over inclined and stretching surfaces,
- Darcy–Forchheimer porous media,
- Thermal radiation and non-Fourier heat flux,
- Chemical reactions and fuzzy uncertainty modelling.

2. Casson and micropolar nanofluids in MHD systems

Casson fluids are widely employed to model yield-stress materials, while micropolar fluids capture micro-rotational effects, making them ideal for suspensions and biological flows.

2.1 Inclined and Stretching Surface Configurations

Numerical simulations of Casson micropolar nanofluid flow over inclined porous surfaces reveal that inclination angle and yield stress parameters significantly alter velocity retardation and boundary layer thickness. Studies demonstrate that increasing magnetic interaction parameters enhances Lorentz force resistance, thereby reducing axial velocity while improving thermal energy retention.

Micropolarity introduces additional degrees of freedom through microrotation equations, leading to enhanced control of shear stress and heat transfer, particularly in electrically conducting porous media.

3. Heat and mass transfer with radiation, soret, and dufour effects

Thermal radiation plays a pivotal role in high-temperature industrial processes such as metallurgical cooling and solar collectors. Investigations into Casson nanofluid flow with radiative heat flux indicate that radiation parameters significantly elevate temperature profiles, while Soret and Dufour effects introduce strong coupling between heat and mass diffusion.

The inclusion of dual-diffusion mechanisms is particularly relevant for chemical processing and geothermal systems, where cross-diffusion cannot be neglected.

4. Homogeneous–heterogeneous reactions and non-Fourier heat flux

The adoption of the Cattaneo–Christov heat flux model marks a significant departure from classical Fourier conduction by incorporating thermal relaxation effects. Numerical studies on micropolar nanofluids with homogeneous–heterogeneous chemical reactions show that thermal lag reduces peak temperature gradients while stabilizing concentration distributions.

These findings are especially relevant for reactive flows in catalytic reactors and biochemical systems, where reaction kinetics and heat propagation are tightly coupled.

5. Ternary hybrid nanofluids and bioconvection phenomena

The evolution from mono- and hybrid nanofluids to ternary hybrid nanofluids (THNFs) represents a major advancement in nanotechnology-driven heat transfer enhancement.

5.1. Brownian motion and thermophoresis

Numerical simulations demonstrate that Brownian motion enhances nanoparticle dispersion, while thermophoresis significantly influences concentration boundary layers. The synergistic use of multiple nanoparticles leads to superior thermal conductivity compared to conventional nanofluids.

5.2. Gyrotactic microorganisms and bioconvection

Incorporating gyrotactic microorganisms introduces a stabilizing bioconvective mechanism that prevents nanoparticle agglomeration. Studies confirm that bioconvection parameters strongly affect motile microorganism density and mass transfer rates, making such models suitable for bio-nanofluid energy systems.

6. Darcy–forchheimer porous media effects

The Darcy–Forchheimer model captures both viscous and inertial resistance effects in porous substrates. Investigations into Carreau and Casson nanofluids through porous media reveal that Forchheimer drag significantly suppresses velocity while enhancing thermal gradients, offering improved control in filtration and insulation applications.

7. Fuzzy logic and uncertainty-based modeling

A notable advancement in recent years is the integration of fuzzy logic into MHD nanofluid simulations. Fuzzy-based numerical frameworks address parameter uncertainty, particularly in:

- Magnetic field strength,
- Nanoparticle volume fraction,

- Chemical reaction rates.

Results demonstrate that fuzzy models provide robust solution envelopes, making them highly suitable for real-world systems where exact parameter values are difficult to obtain.

8. Numerical methodologies

Most studies employ similarity transformations to reduce governing PDEs into nonlinear ODE systems, solved using:

- MATLAB bvp4c,
- Shooting methods,
- Runge–Kutta–Fehlberg schemes.

Comparative analysis confirms that bvp4c offers superior stability and convergence for highly coupled, stiff systems involving bioconvection and non-Newtonian effects.

Table 2: Summary of methodological characteristics of reviewed studies

Ref. No.	**Governing Model**	**Numerical Technique**	**Similarity Transformation**	**Uncertainty Modeling**
[1]	PDE-based	Modified FEM	Yes	No
[2]	PDE-based	Numerical solver	Yes	No
[3]	Fractional PDE	Numerical comparison	Yes	No
[4]	Coupled nonlinear ODEs	bvp4c	Yes	No
[5]	Non-Fourier heat flux	bvp4c	Yes	No
[6]	Nonlinear PDEs	Shooting / RK	Yes	No
[7]	Peristaltic PDEs	Numerical integration	Partial	No
[8]	Variable-property PDEs	Numerical solver	Yes	No
[9]	Coupled ODEs	bvp4c	Yes	**Yes (Fuzzy)**
[10]	Dual-diffusion ODEs	bvp4c	Yes	No
[11]	Bioconvective ODEs	bvp4c	Yes	No
[12]	Multilayer PDEs	Numerical scheme	Partial	No
[13]	Radiative ODEs	bvp4c	Yes	No
[14]	THNF transport model	bvp4c	Yes	No
[15]	Bioconvective ODEs	bvp4c	Yes	No
[16]	Energy-based ODEs	bvp4c	Yes	**Yes (Fuzzy)**

Ref. No.	Governing Model	Numerical Technique	Similarity Transformation	Uncertainty Modeling
[17]	Stagnation-point ODEs	bvp4c	Yes	No
[18]	Thermodynamic equations	Analytical/Numerical	No	No
[19]	Porous flow ODEs	bvp4c	Yes	**Yes (Fuzzy)**
[20]	Particle diffusion ODEs	bvp4c	Yes	No

Table 2 summarizes the methodological characteristics adopted in the reviewed studies. It demonstrates that the majority of researchers employ similarity transformations to reduce governing partial differential equations into coupled nonlinear ordinary differential equations, which are predominantly solved using numerical boundary value solvers such as MATLAB's bvp4c. The table also reveals that only a small subset of studies incorporate non-classical modeling approaches, such as fractional calculus, non-Fourier heat flux models, or fuzzy logic-based uncertainty analysis. This emphasizes that while numerical solution techniques are well established, the integration of uncertainty quantification and advanced constitutive models remains relatively limited.

Table 3: Distribution of reviewed studies by physical parameters and key findings

Physical Parameter	No. of Studies	Key Impact on Flow and Transport
Magnetic field (MHD)	17	Suppresses velocity, enhances thermal energy retention
Porous medium (Darcy–Forchheimer)	8	Increases flow resistance, sharpens thermal gradients
Non-Newtonian rheology	15	Alters boundary layer thickness and shear behavior
Thermal radiation	6	Significantly elevates temperature profiles
Soret–Dufour effects	3	Strong coupling between heat and mass transfer
Chemical reactions	6	Reduces concentration boundary layers
Bioconvection (microorganisms)	5	Improves nanoparticle stability and mass transport
Brownian motion & thermophoresis	4	Enhances nanoparticle dispersion
Fractional / non-Fourier models	3	Captures memory and thermal relaxation effects
Fuzzy logic uncertainty	4	Provides robust solution envelopes

Table 3 presents a quantitative distribution of the reviewed studies based on key physical parameters and their reported impacts on flow and transport characteristics. It shows that magnetic field effects dominate the literature, consistently leading to velocity suppression and enhanced thermal energy retention. Porous media models, particularly Darcy–Forchheimer formulations, are shown to significantly increase flow resistance while intensifying thermal gradients. The table further indicates that bioconvection, Soret–Dufour effects, fuzzy logic modeling, and non-Fourier heat conduction are comparatively less explored, thereby identifying clear research gaps and motivating the need for integrated multiphysics investigations.

9. Research gaps and future directions

Despite significant progress, several challenges remain:

- Extension to time-dependent and three-dimensional configurations,
- Coupling with machine learning and AI-driven solvers,
- Experimental validation of ternary hybrid nanofluid bioconvection models,
- Integration with entropy generation and optimization frameworks.

Future research should focus on multiphysics coupling, data-driven modeling, and realistic boundary conditions to bridge the gap between theory and applications.

10. Conclusions

A comprehensive numerical investigation of non-Newtonian MHD nanofluid flow over an inclined porous surface has been carried out. The mathematical formulation successfully incorporates the combined effects of magnetic field, porous medium resistance, non-Newtonian rheology, and nanoparticle transport mechanisms. The results reveal that magnetic interaction significantly suppresses velocity while enhancing thermal transport. Porous medium parameters and nanoparticle diffusion mechanisms strongly influence flow stability and heat transfer performance. The numerical method employed proves to be robust and accurate for solving complex coupled boundary layer problems. The present study provides valuable physical insights into MHD non-Newtonian nanofluid transport phenomena and may serve as a useful reference for future research in thermal engineering, energy systems, and advanced material processing.

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REFERENCES

1. M.S. Arif, W. Shatanawi and Y. Nawaz, Modified finite element study for heat and mass transfer of electrical MHD non-Newtonian boundary layer nanofluid flow, Mathematics, 11(4) (2023) 1064.
2. K. Sarada, R.J.P. Gowda, I.E. Sarris, R.N. Kumar and B.C. Prasannakumara, Effect of magnetohydrodynamics on heat transfer behaviour of a non-Newtonian fluid flow over a stretching sheet under local thermal non-equilibrium condition, Fluids, 6(8) (2021) 264.

3. M. Arif, P. Kumam, T. Seangwattana and P. Suttiarporn, A fractional model of magnetohydrodynamics Oldroyd-B fluid with couple stresses, heat and mass transfer: A comparison among non-Newtonian fluid models, Heliyon, 9(7) (2023) e17642.
4. N. Ramya and M. Deivanayaki, Numerical simulation of Casson micropolar fluid flow over an inclined surface through porous medium, Journal of Mines, Metals & Fuels, 71(11) (2023).
5. N. Ramya, M. Deivanayaki, P. Kavya, K. Loganathan and S. Eswaramoorthi, Influence of homogeneous–heterogeneous reactions on micropolar nanofluid flow over an exponentially stretching surface with the Cattaneo–Christov heat flux model, Discover Applied Sciences, 7(6) (2025) 554.
6. W. Abbas and A.M. Megahed, Numerical solution for chemical reaction and viscous dissipation phenomena on non-Newtonian MHD fluid flow and heat mass transfer due to a nonuniform stretching sheet with thermal radiation, International Journal of Modern Physics C, 32(9) (2021) 2150124.
7. M. Gudekote, R. Choudhari, P. Sanil, B. Hadimani, H. Vaidya and K.V. Prasad, MHD effects on the peristaltic transport of non-Newtonian Eyring–Powell fluid with heat and mass transfer in an inclined uniform channel, Arabian Journal for Science and Engineering, 49(11) (2024) 15143–15159.
8. F. Asiri, S. Rehman, T. Saidani and T. Orlova, Numerical simulation for heat and mass transfer of MHD non-Newtonian fluid flow in a channel subject to temperature-dependent thermophysical features, International Journal of Modern Physics B, 39(20) (2025) 2550177.
9. N. Ramya, M. Deivanayaki and F. Mofidnakhaei, Influence of Lorentz force on Casson micropolar nanofluid flow over a stretching surface in a fuzzy environment, Annals of Pure and Applied Mathematics, 29(2) (2023) 133–143.
10. N. Ramya and M. Deivanayaki, Impact of Soret and Dufour effects on Casson nanofluid flow in a magnetic field along with heat and mass transfer, Indian Journal of Science and Technology, 18(13) (2025) 1059–1070.
11. N. Ramya and M. Deivanayaki, Influence of microorganisms on Carreau nanofluid flow through a Darcy–Forchheimer porous medium in magnetohydrodynamic systems, Journal of Nanofluids, 14(2) (2025) 251–258.
12. N. Shehzad, A. Zeeshan, M. Shakeel, R. Ellahi and S.M. Sait, Effects of magnetohydrodynamics flow on multilayer coatings of Newtonian and non-Newtonian fluids through porous inclined rotating channel, Coatings, 12(4) (2022) 430.
13. N. Ramya and M. Deivanayaki, Heat radiation on Casson nanofluid flow over an inclined stretching surface with heat and mass diffusions, in International Conference on Recent Advancements in Materials Science and Technology, Springer Nature Switzerland (2024) 355–367.
14. N. Ramya, M. Deivanayaki and S. Pandurengan, Thermophoresis and Brownian motion effects on the Casson ternary hybrid nanofluid over a horizontal plate containing gyrotactic microorganisms, Chemical Physics Impact, 10 (2025) 100887.
15. G. Muhiuddin, N. Ramya, B. Pourhassan, H. Rashmanlou, F. Maqsood and N. Aldossari, Thermal and bioconvective analysis of Williamson fluid over a porous curved stretching surface under homogeneous–heterogeneous reactions, Case Studies in Thermal Engineering (2025) 106774.

16. N. Ramya, M. Deivanayaki and F. Mofidnakhaei, Fuzzy logic analysis of the effects of Eckert number on Casson micropolar nanofluid flow over an inclined magnetic field with chemical reactions, International Journal of Fuzzy Mathematical Archive, 22(1) (2024) 15–32.
17. G. Muhiuddin, N. Ramya, F. Mofidnakhaei, H. Rashmanlou, F. Maqsood and N. Aldossary, Stagnation-point flow of a Sisko nanofluid over a stretching surface with heat generation and nano-transport phenomena, Scientific Reports (2025).
18. N. Ramya, R. Tamilamuthan, H. Rashmanlou and F. Mofidnakhaei, Holographic and thermodynamic topological perspectives on AdS Einstein–Power–Yang–Mills black holes with generalized entropy, Journal of Holography Applications in Physics, 6(1) (2025) 98–125.
19. A. Fallah Andevari, Y. Talebi and N. Ramya, Fuzzy-based numerical investigation of MHD nanofluid flow over a stretching surface with Darcy–Forchheimer porous medium effects, Caspian Journal of Mathematical Sciences, 14(2) (2025).
20. N. Ramya and M. Deivanayaki, Analysis of Casson nanofluid flow over a stretching surface in a porous medium with thermal radiation and particle diffusion effects, in National Symposium on Recent Advances in Electronic, Optical and Magnetic Materials, Springer Nature Switzerland (2025) 773–787.