A Mathematical Solution for Mixed Convection MHD Casson fluid Passing Through an Infinite Inclined Plate

Nur Fatihah Mod Omar
Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah

Zulkhibri Ismail
Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah

Rahimah Jusoh
Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah

Husna Izzati Osman
Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah

他

https://doi.org/10.5109/7395668

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1232-1238, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

A Mathematical Solution for Mixed Convection MHD Casson fluid Passing Through an Infinite Inclined Plate

Nur Fatihah Mod Omar[1], Zulkhibri Ismail[2], Rahimah Jusoh[3], Husna Izzati Osman[4], Ahmad Qushairi Mohamad[5],
[1,2,3,4]Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Persiaran Tun Khalil Yaakob, 26300 Gambang, Pahang, Malaysia,
[5]Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
zulkhibri@umpsa.edu.my

Abstract: *The mixed convection through an infinitely inclined plate of magnetohydrodynamic (MHD) Casson fluid flow has been conducted in this research. To investigate the influence of temperature, concentration, and velocity, the Laplace transform method has been employed in this research. This approach enables the analytical solution of the governing equations. The effect of key dimensionless parameters, namely Casson fluid parameter, inclination angle, magnetic parameter and time towards velocity, concentration, and temperature profiles, is presented through graphical representations supported by numerical data.*

Keywords: Casson fluid; Magnetohydrodynamics; Mixed convection; Inclined plate; Analytical solution / Laplace transform

1. INTRODUCTION

Magnetohydrodynamics (MHD) reflects the study of high-conductivity fluids in magnetisation [1]. The MHD field was first initiated by Hannes Alfven, a recipient of the Nobel Prize in Physics in 1970 [2]. Besides, these MHD flows are of great importance in diverse applications, including cancer treatment, MHD energy generators, biomedical flow control, magnetofluid rotary blood pumping, drug targeting through MHD, materials processing, separation devices, and bio-micro-fluidic devices utilising MHD [3]. The core principle of MHD is that a magnetic field can generate flows in a conductive fluid in motion, resulting in fluid polarisation and altering the magnetic field. The equations governing MHD integrate the Navier–Stokes equations from fluid dynamics with Maxwell's equations from electromagnetism. These magneto-fluids include liquid metals, plasmas, electrolytes, and saltwater [4]. Given its diverse technological and engineering applications, a comprehensive understanding and exploration of Magnetohydrodynamics (MHD) flow is crucial. The major goal of MHD fundamentals is to steer the flow field in a predetermined, specific direction by changing the boundary layer development. Consequently, implementing MHD appears to be a more adaptable and dependable approach for modifying flow kinematics. [5] Ismail et al. [6] conducted a study investigating the impact of magnetohydrodynamics (MHD) and radiation on natural convection through a porous medium past an infinitely inclined plate under ramped wall temperature conditions. They utilised the Laplace transform method in their analysis. Furthermore, Prasad et al. [7] discussed the thermal and species concentration characteristics of MHD Casson fluid along a vertical sheet. Additionally, Jagadesh et al. [8] analysed dissipative MHD Casson fluid flow, heat transfer and peristaltic pumping within an inclined channel. The results illustrated that an increase in both magnetisation and the Casson parameter led to an elevation in the heat transfer rate. Besides, Abrar and Kosar [9] explored heat transfer and characteristics and entropy formation in Casson fluid flow influenced by MHD over a wedge with viscous dissipation and thermal radiation. The main conclusions of the study are elevating both the magnetic and Eckert numbers, which leads to a swift increase in the fluid's energy, and enhancing the wedge angle and magnetic parameter, which leads to higher fluid velocity.

The advancement in fluid flow research is experiencing rapid growth, primarily driven by robust developments in industrial applications. This trend responds to the increasing demand for optimal outcomes in specific processes where fluid motions are crucial in material transport and mixing. Such scenarios are commonly encountered in various industries, including food production, beverage manufacturing, the oil sector, pharmaceuticals, gasoline engineering, plastics manufacturing, chemicals production and aerodynamic science [10]. In discovering the most effective methods to achieve superior end products, the use of classical fluids like water, which falls under the Newtonian type, is no longer adequate. This is attributed to the limitations in accurately describing the material properties of fluids, posing challenges in meeting the diverse demands of industrial applications [10]. Classified as a non-Newtonian fluid, the Casson fluid has a unique shear stress-strain relationship. At low shear strain, it behaves similar to an elastic solid, while at higher stress levels, it resembles a Newtonian fluid. This fluid is best elucidated as shear-thinning, with an infinite viscosity when the shear rate is zero. Examples of Casson fluids in real life include human blood, tomato and orange juice, and soup [11]. Dey et al. [12] conducted research to compare the behaviour of Casson viscosity and non-Newtonian Carreau models in simulating blood flow through an idealised artery with 75% eccentric stenosis. This study aims to improve the understanding and characterisation of non-axisymmetric arterial narrowing using non-Newtonian blood flow models. In 2023, Omar et al. [13] examined unsteady

MHD Casson fluid in porous medium and made conclusion that higher magnetic and Casson parameter values result in a decreased velocity field. On top of that, Abbas et al. [14] explored the application of double diffusion to Casson fluid convection, incorporating the Caputo-Fabrizio derivative in a microchannel. The increasing value of the Casson flow parameter shows a decreasing trend in the velocity profile. Additionally, Mahmood et al. [15] explained how mixed convective effects on concentration and temperature impact mass, heat, and non-Newtonian Casson fluid flow. This study shows that increasing the Casson parameter lowers the velocity profile.

Various physical configurations have been considered by researchers, including the inclined plate, owing to its wide range of practical applications in engineering and natural systems. The inclined plate serves as a significant model in studying heat and fluid flow in devices such as geothermal systems, heat exchangers, inclined solar panels and industrial cooling processes. In contrast to horizontal or vertical surfaces, inclined geometries add an extra gravitational component that influences buoyancy-driven flow, thereby increasing the complexity and realism of the analysis in many practical scenarios. Numerous researchers have investigated fluid flow over inclined plates, considering a variety of physical effects. For instance, Vijayaragavan et al. [16] have investigated transient convection in the flow of an MHD Casson fluid over an inclined surface. It is observed that an increase in the Dufour number leads to a reduction in axial velocity, as well as a decrease in species concentration. Besides, the velocity is found to decrease with increasing suction parameter under both heating and cooling conditions of the porous inclined plate. Later, Kumar et al. [17] formulated Casson MHD flow over an inclined moving plate considering the effects of aligned angle, Hall current, chemical reaction, and Soret parameters. The findings illustrate that a rise in the Schmidt number leads to a reduction in the concentration field, and a similar decreasing trend in concentration is observed with an increase in the chemical reaction parameter. As the Prandtl number increases, the temperature diminishes. The thermal boundary layer thickness grows with an increase in the perturbation parameter. Temperature is found to decrease with higher thermal radiation, while it increases with a rise in the heat source/sink parameter. The velocity increases as the solutal Grashof number and the thermal Grashof number (Gr) rise. Conversely, the fluid velocity decreases as the inclination angle α increases. A study of the flow features of MHD Casson fluid past a vertically inclined porous plate has been done, and it is observed that the velocity profile increases as the buoyancy parameters rise; the temperature declines with higher Prandtl numbers, while the concentration diminishes with increasing Schmidt number and chemical reaction rate [18]. Besides, a paper presents a numerical investigation into the effects of chemical reactions, thermal radiation, heat sources and thermal radiation on the flow of MHD Casson fluid over a nonlinearly inclined stretching surface, incorporating velocity slip within a Forchheimer porous medium. Graphical results show that the plate temperature declines with increasing radiation and Forchheimer porous medium parameters. Additionally, the concentration decreases due to the influence of the chemical reaction and a higher Schmidt number [19].

Motivated by the above literature and applications, the present research explores mixed convection MHD Casson fluid passing through an infinite inclined plate. The problem is in the occurrence of the magnetic parameter and inclination angle. The governing equations are solved analytically using the Laplace transform method. The results are presented graphically, and different physical aspects of the research have been discussed.

2. MATHEMATICAL FORMULATION

The time-dependent MHD mixed convection flow of an electrically conductive, non-compressible and viscous fluid in the vicinity of an infinitely inclined plate is considered. Concerning the coordinate system, the y -axis is aligned with the surface of the plate, which is inclined at an angle ϕ relative to the vertical $x*$ -plane. The following constitutive equation governs the motion of the fluid:

$$\rho\frac{\partial u'}{\partial t'}=\mu(1+\frac{1}{\gamma})\frac{\partial^2 u'}{\partial x'^2}+\rho g\beta_T\cos\phi(T'-T'_\infty)$$
$$+\rho g\beta_C\cos\phi(C'-C'_\infty)-\sigma B_\circ u'-\frac{\mu\varphi}{K}u' \quad (1)$$

$$\rho c_p\frac{\partial T}{\partial t}=k\frac{\partial^2 T'}{\partial x'^2}-\frac{\partial q'_r}{\partial x'} \quad (2)$$

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C'}{\partial x'^2} \quad (3)$$

of which C', T', u', delineate concentration, temperature and velocity respectively, γ stands for the non-Newtonian Casson fluid parameter, μ signifies dynamic viscosity, ρ stands for fluid density, g depicts gravity acceleration, σ exhibits the electrical conductivity, K illustrates the permeability of the porous medium, $B_\circ$ is known as an external magnetic field, β_C and β_T are the concentration and thermal expansion, c_p indicates the specific heat, k signifies the thermal conductivity, q_r reflects the radiative heat flux and D denotes the mass diffusion.

At the initial time $t'\le 0$, both the fluid and the plate are stationary and share the same concentration C'_∞ and temperature T'_∞. At time $t'>0$, both concentration and temperature are raised to a constant temperature and concentration, T'_w and C'_w while when $t'\ge 0$, concentration and temperature tend toward zero. The following condition explains the suitable boundary equations:

$$u'(x',0) = 0; \qquad u'(0,t') = At'; \qquad u'(\infty,t') = 0;$$

$$T'(x',0) = T'_\infty; \qquad T'(0,t') = T'_w; \qquad T'(\infty,t') = T'_\infty, \qquad (4)$$

$$C'(x',0) = C'_\infty; \qquad C'(0,t') = C'_w; \qquad C'(\infty,t') = C'_\infty,$$

Based on the governing equations, the temperature of the plates, T'_∞ and T'_w, are presumed to generate a radiative heat flux term. This term is simplified by applying the Rosseland approximation and is expressed as follows:

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

(5)

where $k*$ is the mean absorption coefficient and $\sigma*$ Stefan-Boltzmann constant. It is presumed that the temperature changes in the flow are minimal to approximate T^{*4} as a linear function of temperature. By expanding T^{*4} in a Taylor series around T_∞^* and higher-order terms is neglected, the Rosseland approximation becomes,

$$T'^4 \cong 4T'_\infty T - 3T_\infty^4$$

(6)

Rosseland approximation becomes,

$$q_r = -\frac{16\sigma^* T_\infty^{3*}}{3k^*}\frac{\partial^2 T^{*4}}{\partial y^{*2}}$$

(7)

The dimensionless variables are introduced as follows:

$$u = \frac{u'}{(vA)^{\frac{1}{3}}}; \qquad t = \frac{t' A^{\frac{2}{3}}}{v^{\frac{1}{3}}}; \qquad x = \frac{x' A^{\frac{1}{3}}}{v^{\frac{2}{3}}};$$

$$T = \frac{T' - T'_\infty}{T'_w - T'_\infty}; \quad C = \frac{C' - C'_\infty}{C'_w - C'_\infty}$$

(8)

Utilising Eqs. (1), (2), and (3), and applying the transformation given in Eq. (8), the governing equations for momentum, energy, and concentration are simplified into the following non-dimensional forms:

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u'}{\partial x'^2} + Gr\cos\theta + Gc\cos\theta - Bu \qquad (9)$$

$$\lambda\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} \qquad (10)$$

$$\frac{\partial C}{\partial t} = \frac{\partial^2 T}{\partial x^2} \qquad (11)$$

where,

where M reflects the magnetic parameter, K signifies the porosity parameter, Gr denotes the thermal Grashof number, Gc depicts the mass Grashof number, R stands for the radiation parameter, $\Pr$ represents the Prandtl number, and Sc indicates the Schmidt number.

The dimensionless initial and boundary conditions become:

$$u(x,0) = 0; \qquad u(0,t) = t; \qquad u(\infty,t) = 0;$$

$$T(x,0) = 0; \qquad T(0,t) = 1; \qquad T(\infty,t) = 0, \qquad (12)$$

$$C(x,0) = 0; \qquad C(0,t) = 1; \qquad C(\infty,t) = 0,$$

3. MATHEMATICAL SOLUTION

The method of the Laplace transform has been employed to analyse the equations. As a result, a solution for $u(x,t)$ can be obtained by solving the concentration $C(x,t)$ and the temperature $T(x,t)$ variables. The Eq. (2) and Eq. (3) which represent energy and concentration equations are decoupled from the momentum Eq. (1). Equations (9), (10), and (11) are resolved by employing the Laplace transform in the presence of Eq. (12), and by systematically solving the resulting expressions, we arrive at the following solutions:

Energy Equation:

$$\overline{T} = Ae^{-x\sqrt{\lambda s}} + Be^{x\sqrt{\lambda s}}$$

(13)

Concentration Equation:

$$\overline{C} = \frac{1}{s}e^{-x\sqrt{Scs}}$$

(14)

Momentum Equation:

$$\bar{u} = [\frac{1}{s^2} - a1(\frac{1}{a2(s-a2)} - \frac{1}{a2s}) - a3(\frac{1}{a4(s-a4)} - \frac{1}{a4s})e^{-x\sqrt{\frac{1}{z}}\sqrt{s+B}} + a1(\frac{1}{a2(s-a2)} - \frac{1}{a2s})e^{-x\sqrt{\lambda s}} + a3(\frac{1}{a4(s-a4)} - \frac{1}{a4s})e^{-x\sqrt{Scs}}$$

(15)

Thus, the analytical solutions of the temperature, subsequently concentration and followed by velocity are achieved from Eq. (13), Eq. (14), Eq. (15) through the application of the inversion of the Laplace transform. The resulting solutions are:

$$T = erfc(\frac{x}{2}\frac{\sqrt{\lambda}}{t})$$

(16)

$$C = erfc(\frac{x}{2}\sqrt{\frac{Sc}{t}}$$

(17)

$$U_0(x,t) = \begin{pmatrix} (\frac{t}{2} + \frac{x}{4}\sqrt{\frac{1}{BZ}})e^{x\sqrt{\frac{B}{Z}}} erfc((\frac{x}{2\sqrt{Zt}}) + \sqrt{Bt}) \\ +(\frac{t}{2} - \frac{x}{4}\sqrt{\frac{1}{BZ}})e^{-x\sqrt{\frac{B}{Z}}} erfc((\frac{x}{2\sqrt{Zt}}) - \sqrt{Bt}) \end{pmatrix}$$

$$U_1(x,t) = \begin{pmatrix} (\frac{a1}{2a2}e^{a2t}[e^{x\sqrt{\frac{B+a2}{Z}}} erfc(\frac{x\sqrt{1}}{2\sqrt{Zt}} + \sqrt{(B+a2)t} \\ +(e^{-x\sqrt{\frac{B+a2}{Z}}} eerfc(\frac{x\sqrt{1}}{2\sqrt{Zt}} - \sqrt{(B+a2)t}) \end{pmatrix}$$

$$U_2(x,t) = \begin{pmatrix} \frac{a1}{2a2}(e^{x\sqrt{\frac{B}{Z}}} erfc(\frac{x\sqrt{Sc}}{2\sqrt{t}}) + \sqrt{Bt} \\ +\frac{a1}{2a2}(e^{x\sqrt{\frac{B}{Z}}} erfc(\frac{x\sqrt{Sc}}{2\sqrt{t}}) + \sqrt{Bt} \end{pmatrix}$$

$$U_3(x,t) = \begin{pmatrix} \frac{a3}{2a4}e^{a4t}[e^{x\sqrt{\frac{B+a2}{Z}}} erfc(\frac{x}{2})\sqrt{\frac{1}{Z}} + \sqrt{(B+a4)t} \\ +e^{-x\sqrt{\frac{B+a2}{Z}}} erfc(\frac{x}{2})\sqrt{\frac{1}{Z}} - \sqrt{(B+a4)t}] \end{pmatrix}$$

$$U_4(x,t) = \begin{pmatrix} \frac{a3}{2a4}[e^{x\sqrt{\frac{B}{Z}}} erfc(\frac{x}{2})\sqrt{\frac{1}{Zt}} + \sqrt{Bt} \\ +e^{-x\sqrt{\frac{B}{Z}}} erfc(\frac{x}{2})\sqrt{\frac{1}{Zt}} - \sqrt{Bt}] \end{pmatrix}$$

cc

$$U_5(x,t) = \begin{pmatrix} \frac{a1}{2a2}e^{a2t}[e^{x\sqrt{a2\lambda}} erfc(\frac{x}{2})\sqrt{\frac{\lambda}{t}} + \sqrt{a2t} \\ +e^{-x\sqrt{a2\lambda}} erfc(\frac{x}{2})\sqrt{\frac{\lambda}{t}} - \sqrt{a2t}] \end{pmatrix}$$

$$U_6(x,t) = \begin{pmatrix} \frac{1}{a2}erfc(\frac{x}{2})\sqrt{\frac{\lambda}{t}} \end{pmatrix}$$

$$U_7(x,t) = \begin{pmatrix} \frac{a3}{2a4}e^{a4t}[e^{x\sqrt{a4Sc}} erfc(\frac{x}{2})\sqrt{\frac{Sc}{t}} + \sqrt{a4t} \\ +e^{-x\sqrt{a4Sc}} erfc(\frac{x}{2})\sqrt{\frac{Sc}{t}} - \sqrt{a4t}] \end{pmatrix}$$

$$U_8(x,t) = \begin{pmatrix} \frac{1}{2a4}erfc(\frac{x}{2})\sqrt{\frac{Sc}{t}} \end{pmatrix}$$

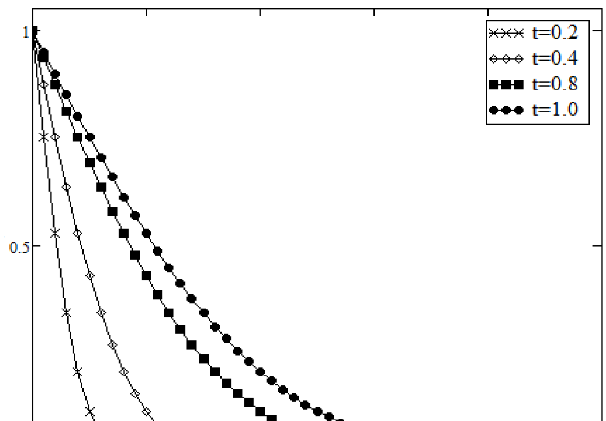
$$U(x,t) = U_0(x,t) - U_1(x,t) + U_2(x,t) - U_3(x,t) + U_4(x,t) + U_5(x,t) +- U_6(x,t) + U_7(x,t) - U_8(x,t)$$

(18)

4. RESULTS AND DISCUSSION

This section presents the results analysed earlier using graphical illustrations. The effects of several physical parameters, namely time, magnetic field, inclined plate angle, and Casson parameter, on the convective flow are analysed through temperature, concentration and velocity graphs. A comprehensive discussion of these graphs is provided.

Figure 1 illustrates how the concentration distribution changes over time for the unsteady flow. Initially, when the time t is small, the concentration rapidly declines from the surface into the fluid, indicating that mass diffusion is limited to a narrow region near the plate. However, as time progresses, the concentration values extend further into the fluid domain. This widening of the concentration profile suggests that the solute continues to diffuse away from the boundary as more time becomes available, resulting in a thicker concentration boundary layer. Although the peak concentration close to the wall may decrease



slightly due to dispersion, the overall mass spreads more broadly throughout the fluid. This behaviour highlights the temporal influence on solute transport in transient conditions.

Fig. 1. The significance of time, t in relation to the concentration profile.

Figure 2 depicts the temperature variation over the fluid domain for different moments in time. At early times, the thermal boundary layer is thin, and the fluid quickly loses temperature as the distance from the plate increases. As time advances, the thermal energy gradually diffuses deeper into the fluid, leading to a more uniform temperature distribution. The curves shift upward and broaden, indicating that heat transfer from the surface becomes more effective over time. This expansion of the thermal boundary layer confirms that the temperature at locations farther from the plate rises with time, a typical characteristic of unsteady heat conduction. Overall, the figure demonstrates that the heating effect becomes more pronounced as the system evolves temporally.

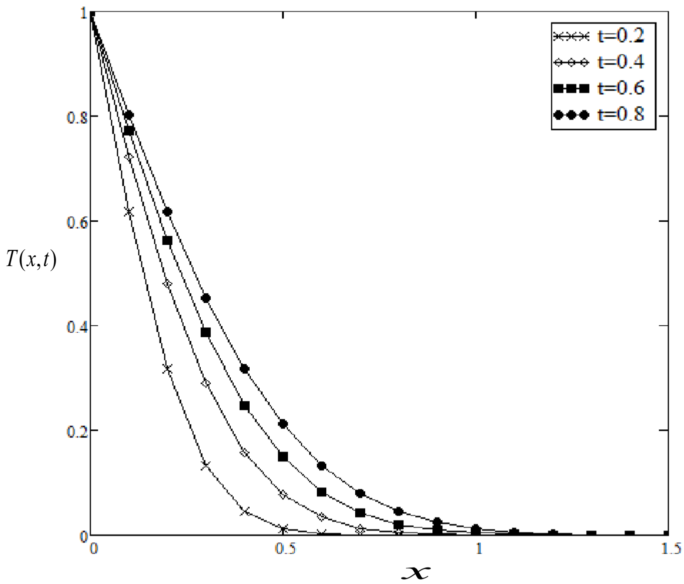
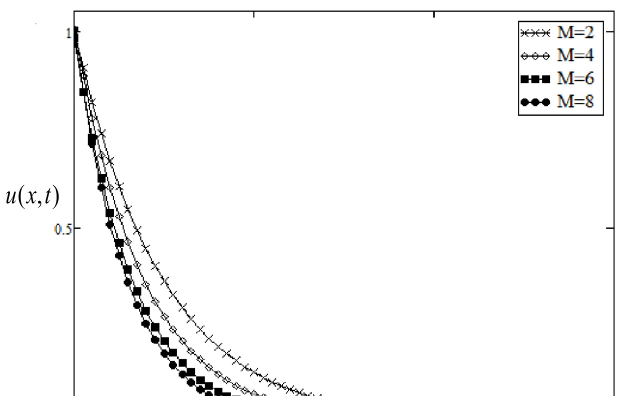


Fig. 2. The significance of time, t in relation to the temperature profile.

It is observed that the velocity diminishes as the magnetic field strength increases, as shown in Figure 3. Applying the transverse magnetic field gives a resistive force known as the Lorentz force, which consequently enhances the thickness of both the thermal boundary layers and momentum, as shown in Figure 3.



x

x

Fig. 3. The significance of the magnetic parameter, M in relation to the velocity profile.

Figure 4 illustrates that velocity increases as the inclination angle increases. This indicates that a greater inclination angle elevates fluid motion along the plate. In addition, the buoyancy force is influenced by the reductions in mass and thermal diffusion, as the value of $\cos\phi$ declines with the plate's deviation from the vertical position.

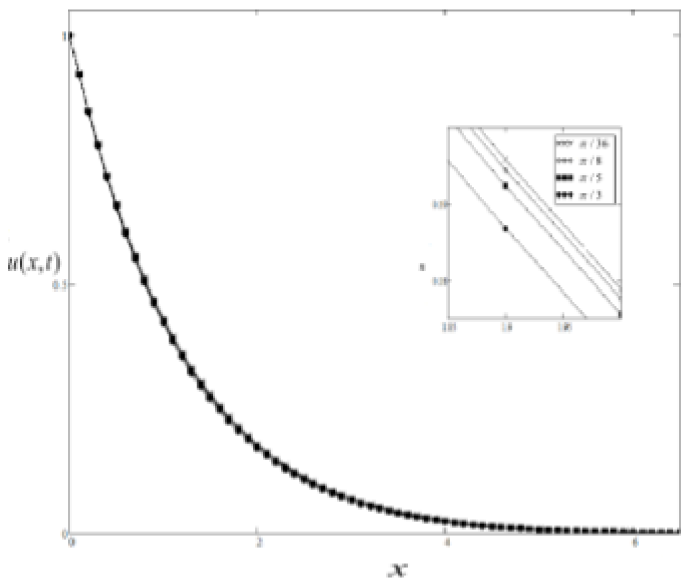
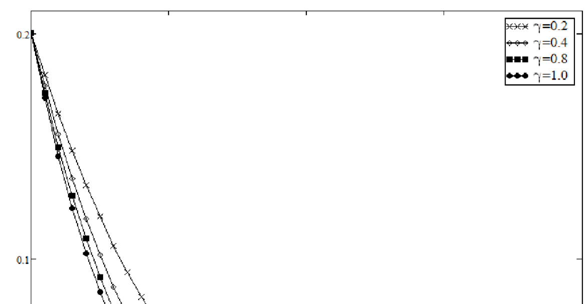


Fig. 4. The significance of inclination angle, ϕ in relation to the velocity profile.

Figure 5 depicts the profile of the Casson fluid velocity. The plot indicates that an increase in the Casson parameter leads to declining velocity. This trend suggests that higher values of the Casson parameter led to decreasing fluid motion, mainly due to increased viscosity. A higher Casson parameter corresponds to reduced yield stress, thus, it is easier for the fluid to begin flowing.



$u(x,t)$

x

Fig. 5. The significance of the Casson parameter, γ in relation to the velocity profile.

5. CONCLUSION

This research investigates the mixed convection magnetohydrodynamic (MHD) flow of a Casson fluid over an infinitely inclined plate. By applying the method of Laplace transform, the influence of temperature, concentration, and velocity is analysed. In summary, it is observed that:

- As time progresses, the concentration values extend further into the fluid domain
- As time advances, the thermal energy gradually diffuses deeper into the fluid, leading to a rising temperature.
- Velocity declines as the magnetic field strength increases.
- Elevation of the inclination angle velocity increases the velocity.
- As the Casson parameter increases, the velocity decreases.

6. ACKNOWLEDGEMENT

The authors thank and appreciate the Ministry of Higher Education Malaysia under the Fundamental Research Grant Scheme with reference number FRGS/1/2024/STG06/UMP/02/9 (Universiti Malaysia Pahang Al-Sultan Abdullah reference: RDU240132).

7. REFERENCES

[1] N.F.M. Omar, Z. Ismail, R. Jusoh, M. A. Ahmad, A. Q. Mohamad, An exact analysis of chemical reaction and porosity effects for mixed convective magnetohydrodynamics Casson fluid, Sigma J Eng Nat Sci. (2025).

[2] H. I. Osman, N.F.M. Omar, D. Vieru, and Z. Ismail, A study of MHD free convection flow past an infinite inclined plate, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. 92 (2022) 18-27.

[3] N. M. Hafez, A. M. Abd-Alla, and T. M. N. Metwaly, Influences of rotation and mass and heat transfer on MHD peristaltic transport of Casson fluid through inclined plane, Alexandria Engineering Journal. 68 (2023) 665-692.

[4] M. Gholinia, H. Javadi, A. Gatabi, Amirhossein Khodabakhshi and Davood Domiri Ganji, Analytical study of a two-phase revolving system of nanofluid flow in the presence of a magnetic field toimprove heat transfer, Sigma Journal of Engineering and Natural Sciences. 37(2019) 341-360.

[5] R. Kodi and O. Mopuri, Unsteady MHD oscillatory Casson fluid flow past an inclined vertical Porous plate in the presence of chemical reaction with heat absorption and Soret effects, Heat Transfer. 51 (2022) 733-752.

[6] Z. Ismail, A. Hussanan, I. Khan, and S. Shafie, MHD and radiation effects on natural convection flow in a porous medium past an infinite inclined plate with ramped wall temperature: An exact analysis, International Journal of Applied Mathematics and Statistics. 45 (2013) 77–86.

[7] K.V. Prasad, K. Vajravelu, H. Vaidya, N.Z. Basha, and V. Umesh, Thermal and species concentration of MHD Casson fluid at a vertical sheet in the presence variable fluid properties, Ain Shams Engineering Journal. 9 (2018) 1763-1779.

[8] V. Jagadesh, S. Sreenadh, M. Ajithkumar, P. Lakshminarayana, P. Lakshminarayana and G. Sucharitha, Investigation of dissipative heat transfer and peristaltic pumping on MHD Casson fluid flow in an inclined channel filled with porous medium, Numerical Heat Transfer, Part B: Fundamentals. (2023) 1-19.

[9] M. N.Abrar, & S. Kosar, Entropy generation and heat transfer characteristics in MHD Casson fluid flow over a wedge with viscous dissipation and thermal radiation.,ZAMM‐Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik, 104 (2024).

[10] T. Rahman, & A. Islam. Determination of Flow Characteristics and Performance Analysis of the Non-Rotating & Rotating Cylinder, Proceedings of international exchange and innovation conference on engineering & sciences (IEICES) (2020), 271-276.

[11] N. S. Khashi'ie, I. Waini, A.R. Kasim, Zainal, N.A. Zainal, A. Ishak, Pop, I. Pop, Magnetohydrodynamic and viscous dissipation effects on radiative heat transfer of non-Newtonian fluid flow past a nonlinearly shrinking sheet: Reiner–Philippoff model. Alexandria Engineering Journal. (2022) 61(10), 7605-7617.

[12] U.S. Mahabaleshwar, T. Maranna, and F. Sofos, Analytical investigation of an incompressible viscous laminar Casson fluid flow past a stretching/shrinking sheet. Scientific Reports. 12 (2022) 18404.

[13] S. Dey, T. Ibtida, CK. Roy, N. Sakib, Difference between non-Newtonian Carreau and Casson blood viscosity models to predict hemodynamics in idealized eccentric arterial stenosis: large eddy simulation modeling, Proceedings of international exchange and innovation conference on engineering & sciences (IEICES) (2020) 249-257.

[14] N.F.M. Omar, H. I. Osman, A. Q. Mohamad, R.

Jusoh, and Z. Ismail, Analytical solution of unsteady MHD casson fluid with thermal radiation and chemical reaction in porous medium, J. Adv. Res. Appl. Sci. Eng. Technol., 29 (2023), 185-194.
[15] S. Abbas, Z. U. Nisa, M. Nazar, M. Amjad, H. Ali, & Jan, A. Z. Jan, Application of heat and mass transfer to convective flow of Casson fluids in a microchannel with Caputo–Fabrizio derivative approach, Arabian Journal for Science and Engineering. 49 (2024) 1275-1286.
[16] Z. Mahmood, M. Ur Rehman, U. Khan, B. Ali, & M. I. Haque Siddiqui, Enhanced transport phenomena in Casson fluid flow over radiative moving surface: Influence of velocity and thermal slip conditions with mixed convection and chemical reaction, Modern Physics Letters B. 39 (2025) 2450383.
[17] R. Vijayaragavan, V. Bharathi, & J. Prakash, Heat and mass transfer effect of a Magnetohydrodynamic Casson fluid flow in the presence of inclined plate, Indian Journal of Pure & Applied Physics. 59 (2021) 28-39.
[18] K. Kranthi Kumar, CH. Baby Rani, and V. Papa Rao, Mhd Casson Fluid Flow with an Inclined Plate In the Presence of Hall and Aligned Magnetic Effects, Frontiers in Heat and Mass Transfer. 17 (2021) xx-xx.
[19] R. R. Vaddemani, R. Kodi, O. Mopuri, Characteristics of MHD Casson fluid past an inclined vertical porous plate, Materials Today: Proceedings. 49 (2022) 2136-2142.
[20] S. G. Bejawada, Y. D. Reddy, W. Jamshed, K. S. Nisar, A. N. Alharbi, R. Chouikh,Radiation effect on MHD Casson fluid flow over an inclined non-linear surface with chemical reaction in a Forchheimer porous medium, Alexandria Engineering Journal. 61 (2022) 8207-8220.