# MHD Casson Fluid with Radiative Heat and Mass Transfer past an Impulsively Moving Inclined Plate

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*Abstract:* - This paper explores the flow of Casson fluid that passes a moving inclined plate with the influence of double diffusions and radiation, where the fluid is imposed electrically conductive and moves through a porous medium. Several suitable non-dimensional variables are suggested in the model using partial differential equations with initial and boundary conditions. The corresponding non-dimensional governing equations are solved with the help of Laplace transform method. Analytical solutions to momentum, energy, and concentration are obtained, and the expression is in exponential and complementary error functions of Gauss. Finding solutions is limited to similar solutions for previous studies on Casson and viscous fluids as a special case. Computations are performed, where the outcomes are examined for embedded flow parameters.

*Key-Words:* - Casson fluid, radiation, heat and mass transfer, Laplace transform, MHD, inclined plate, porous medium.

Received: May 25, 2023. Revised: October 21, 2023. Accepted: December 13, 2023. Published: December 31, 2023.

## 1 Introduction

In recent years, non-Newtonian fluids have been viewed as a more appropriate technique for scientific and technological applications than Newtonian fluids. In contrast to Newtonian fluids, non-Newtonian fluids are not only seen in natural phenomena such as avalanches and mudslides, but also in real-life technologies. Its applications are implemented across a diverse range of industrial sectors due to their vital applications areas, such as biological substances, chemicals food products, personal care items, and more. The automotive industry is one of the applications that widely use the benefit of non-Newtonian fluid studies. For example, the shock absorbers and dampers viscosity are controlled by the magnetic field, and the high shear rates generated by turbulent flow cause the fluid to thicken and provide significant damping forces when needed. Consequently, scientists are intrigued by a complicated area of non-Newtonian fluids, particularly Casson fluid. [1], numerically analyzed the behavior of free convection Casson fluid in a square porous cavity. [2], examined how chemical reactions, heat sources, and temperature gradients influence MHD Casson fluid flow on a flat surface in the Forschimmer medium. The heat transport via non-Newtonian fluids in different geometrics employing efficient methods has attracted the attention of the scientific community, [3], [4], [5], [6].

Magnetohydrodynamics (MHD) finds application in various fluid flow scenarios and boasts a diverse range of uses, encompassing fields such as medicine, oil industry operations, aviation, MHD power generation, nuclear reactors, and even astronomy. [7], studied the effect of MHD natural convection flow of nanofluids with ramped wall velocity and temperature on the dependent time *t*, near an infinitely vertical plate embedded in a porous medium. [8], explored the incompressible viscous fluid of unsteady free convection flows in water with heat/sink in a vertical cylinder containing a mixture of 47nm alumina nanoparticles. [9], examined the magnetite nanoparticles in a free convection flow nanofluid with MHD. [10], investigates the impact of Hall current, ion slip events, and heat radiation on an unsteady free convection MHD Jeffery fluid next to an endlessly vertically rotating porous plate. [11], effectively investigated the effect of Joule heating in the MHD hybrid nanofluid flow with heat transmission on a moving plate.

Thermal radiation, on the other hand, is the transportation of energy via the motion of particles within a liquid. Radiation's effect on MHD flow is significant in engineering, technology, and many industrial applications that operate at high temperatures. These processes include paper plate production, metal component cooling, electronic chip manufacturing, and petroleum pump operation. [12], electronically conducting Cason fluid flow and heat transfer characteristics of an exponentially expanding curved surface with convection boundary conditions. [13], explored a two-dimensional unsteady Caisson fluid with stagnation point radiative flux through a permeable stretched surface under an unsteady heat source. [14], numerically examined the natural convective MHD Casson fluid flow with radiation past an upright cylinder with entropy heat production. Several interesting articles as [15], [16], [17], [18], [19], [20] are devoted to the study of thermal radiation considering non-Newtonian fluids.

Transportation phenomena play a significant role in the realm of fluid dynamics. When a fluid moves across a surface, the exchange of heat and mass takes place. This heat exchange is not only attributable to the external of heat source, but it can also result from frictional forces at play. The applications of the transportation process are diverse and encompass various technologies and fields including refrigeration compressors, air conditioning systems, automobile engines, and numerous thermodynamic systems. Researchers have been closely investigating the phenomenon of heat transfer occurring when fluids flow over paraboloid surfaces. The effect of transport processes on Walter's B liquid flow over the topmost catalyst surface of a paraboloid was performed by [21]. [22], evaluated the effect of double diffusions on the peristaltic flow of Williamson fluid within a gap of concentric tubes. [23], investigated steady Marangoni-driven boundary layer flow, heat, and mass transfer characteristics of nanofluids using a second-grade fluid to assess the influence of activation energy on chemically reactive. [24], investigated a three-dimensional nonlinear Carreau fluid revolution on a paraboloid surface, accounting for the effects of radiation and concentration during liquid motion. [25], explored the novelty of the Johnson-Segalman peristaltic fluid flow in the asymmetric curved channel in the existence of the transportation process.

Recent research aims to explore the properties of porosity flow in unsteady Casson fluid on a moving inclined plate with radiant mass and heat transfer. This research is focusing on the Casson fluid which it has a special behavior which is it has variable viscosity depending on the stress state. We also consider the fluid static phase where the fluid is at rest and the fluid under forces and motion where Casson fluid is under radiative mass and heat transfer. This study is inspired by the industrial applications of Casson fluids such as biomedical engineering, making it a subject of interest for researchers. Based on [26], finding, they studied the MHD fluid flow of an unsteady Casson with free convection via an oscillating vertical plate at a uniform temperature. However, our present work considers the plate to be a moving inclined plate that different from their paper. The analytical solutions for the momentum, energy, and mass equations are derived using the Laplace transform method under the Boussinesq approximation. Changes in fluid velocity, heat, and mass were visually shown, and the results were mathematically presented to support the study.

## 2 Mathematical Formulation

Consider an unsteady Casson MHD fluid flow through a moving inclined plate with isothermal wall temperatures. Figure 1 depicts the physical model's coordinate system in a porous medium with three boundary layers; momentum, energy, and mass. On the plate, A magnetic field $\beta_o$ is transmitted, and the influence of chemical reactions is expected to play a role in this study.

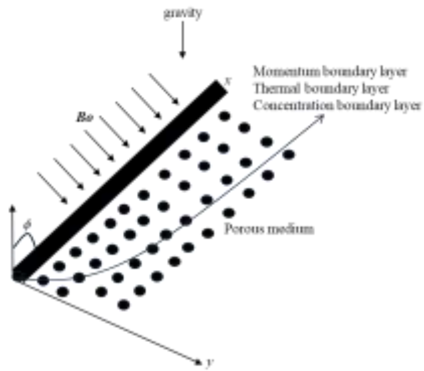


Fig. 1: Physical model and coordinate system

The dimensional governing equations as shown below:

$$\frac{\partial u^*}{\partial t^*}=v\left(1+\frac{1}{\gamma}\right)\frac{\partial^2 u^*}{\partial y^{*2}}-\frac{\sigma B_0^2}{\rho}u^*-\frac{v}{K^*}u^* +g\beta_T\cos\varphi\left(T^*-T_\infty^*\right)+g\beta_C\cos\varphi\left(C^*-C_\infty^*\right), \quad (1)$$

$$\frac{\partial T^*}{\partial t^*}=\frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}, \quad (2)$$

$$\frac{\partial C^*}{\partial t^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-K_r\left(C^*-C_\infty^*\right), \quad (3)$$

where $u^*$, $T^*$, $C^*$, $v$, $\gamma$, $\sigma$, $\rho$, $K^*$, $g$, $\beta_T$, $\beta_C, k$, $c_p$, $q_r$, $D$, and $K_r$ represents velocity, temperature, concentration, kinematic viscosity, Casson fluid parameter, electrical expansion, fluid density, the permeability of the porous medium, gravitational force, thermal expansion, concentration expansion, its thermal conductivity, specific heat, radiative heat flux, mass diffusion and chemical reaction parameter, respectively.

The approximate initial and boundary conditions are defined as:

$$\begin{aligned}
&u^*=0, T^*=T_\infty^*, C^*=C_\infty^*,\\
&\text{for } y^*\ge 0 \text{ and } t^*\le 0,\\
&u^*=u_o, T^*=T_w^*, C^*=C_w^*,\\
&\text{for } y^*=0 \text{ and } t^*>0,\\
&u^*\to 0, T^*\to T_\infty^*, C^*\to C_\infty^*,\\
&\text{for } y^*\to\infty \text{ and } t^*\ge 0.
\end{aligned} \quad (4)$$

From the given conditions above, at time $t^*\le 0$, initially, the fluid and the plate are at rest with the identical temperature $T_\infty^*$ and concentration $C_\infty^*$. When $t^*>0$, temperature and concentration are elevated to $T_w^*$ and $C_w^*$. Both diffusions are getting closer to zero when $t^*\ge 0$.

The non-dimensional variables are presented as follows:

$$y=\frac{y^*}{L}, t=\frac{t^*(vg)^{1/3}}{L}, u=\frac{u^*}{(vg)^{1/3}}, \quad T=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*}, C=\frac{C^*-C_\infty^*}{C_w^*-C_\infty^*}. \quad (5)$$

The $T_\infty^*$ and $T_w^*$ are meant to create radiative heat flux, and under the Rosseland approximation, radiation is given as:

$$\frac{\partial q_r}{\partial y}=-\frac{4\sigma^*}{3K^*}\frac{\partial T^{*4}}{\partial y^*}, \quad (6)$$

where the mean absorption coefficient is represented by $\sigma^*$. The variations of temperature are assumed to be sufficiently insignificant, so that $T^{*4}$ can be linearized. Taylor series is utilized to expand $T^{*4}$ to $T_\infty^*$ and ignore higher-order terms, therefore

$$T^{*4}\cong 4T_\infty^* T-3T_\infty^4. \quad (7)$$

Approximation of Rosseland becomes,

$$\frac{\partial q_r}{\partial y}=-\frac{16\sigma^*}{3K^*}\frac{\partial^2 T^{*4}}{\partial y^{*2}}. \quad (8)$$

Using equation (5), the non-dimensional equations of (1), (2) and (3) becomes:

$$\frac{\partial u}{\partial t}=\left(1+\frac{1}{\gamma}\right)\frac{\partial^2 u}{\partial y^2}-Mu-\frac{u}{K}+G_rT+G_cC, \quad (9)$$

$$\frac{\partial T}{\partial t}=\frac{(1+R)}{Pe}\frac{\partial^2 t}{\partial y^2}, \quad (10)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Pe_c}\frac{\partial^2 C}{\partial y^2}-KrC, \quad (11)$$

where

$$G_r = \cos\varphi\beta_T\left(T_w^* - T_\infty^*\right),\ G_c = \cos\varphi\beta_c\left(C_w^* - C_\infty^*\right),$$

$$M = \frac{\sigma B_0^2}{\mu}\left(\frac{v}{\sqrt{g}}\right)^{4/3},\ Pe = \mathrm{Re}\,\mathrm{Pr},\ Pe_c = \mathrm{Re}\,Sc,$$

$$R = \frac{16\alpha\sigma^* T_\infty^* L^2}{k}.$$

From the above equation , Hartmann number of magnetic parameter $M$, porosity parameter $K$, thermal Grashof number $Gr$, concentration Grashof number $Gc$, radiation parameter $R$, Peclets's number of heat transfer $Pe$, $Pe_c$ for Peclet's number of mass transfer, Reynold number $\mathrm{Re}$, Prandtl number $\mathrm{Pr}$ and $Sc$ for Schmidt number. The length characteristic can be identified as :

$$L = \frac{v^{2/3}}{g^{1/3}}. \tag{12}$$

The dimensional initial and boundary conditions have been simplified to non-dimensional form, as provided by:

$$\begin{aligned} &u = 0,\ T = 0,\ C = 0 \text{ for } y \geq 0 \text{ and } t \leq 0, \\ &u = 1,\ T = 1,\ C = 1 \text{ for } y = 0 \text{ and } t > 0, \\ &u \to 0,\ T \to 0,\ C \to 0 \text{ for } y \to \infty \text{ and } t \geq 0. \end{aligned} \tag{13}$$

# 3 Result and Discussion

The outcomes of the earlier section are laid out to easily comprehend the physical meaning and graphical elucidation. Maintaining constancy in the variable denoted as $\gamma = 0.5$, $m = 1.0$, $Gr = 2.0$, $Gm = 2.0$, $R = 0.3$ and $\phi = \pi/4$ is a key aspect of this study, unless otherwise specifically referenced, [27].

Figure 2 and Figure 3 shows the comparison of velocity profiles from the present study with [26] and [28]. From the results, we consider that there is valid accuracy between the previous study and the present study based on the plotted graph between them. In addition, it is verified that all the plotted graph satisfies all the boundary conditions.

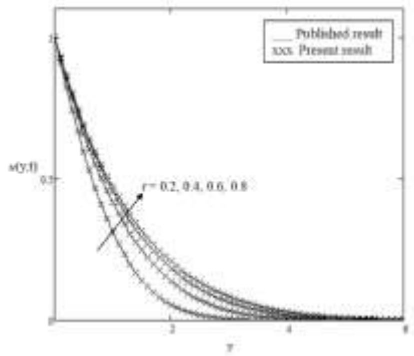


Fig. 2: Comparison of velocity profiles from the present study with [26]

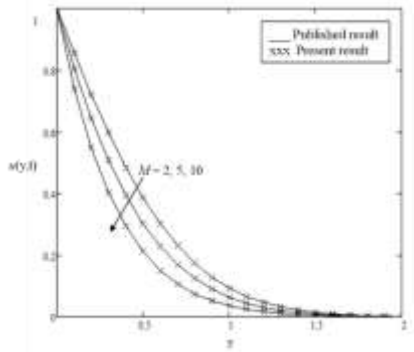


Fig. 3: Comparison of velocity profiles from the present study with [28]

Figure 4 illustrates the Casson parameter effect on the velocity profile. The graph demonstrates that the velocity drops as the Casson parameter rises. This phenomenon is caused by a reduction in resistance to yield stresses, leading to a decrease in the overall flow field. Consequently, the velocity profile experiences a decline.

Figure 5 illustrates how the velocity field behaves in response to varying values of the porous medium. Velocity increases as a part of the resistance to flow because of increases in the porous medium value. In simpler terms, the diminishing frictional force that blocks the flow causes the velocity to increase.

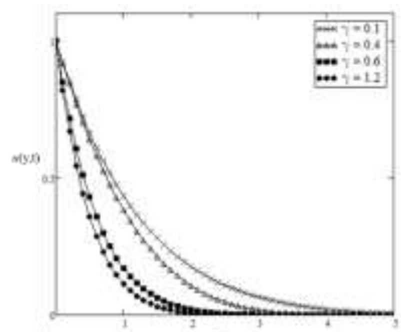


Fig. 4: Velocity profiles with different values of Casson parameters

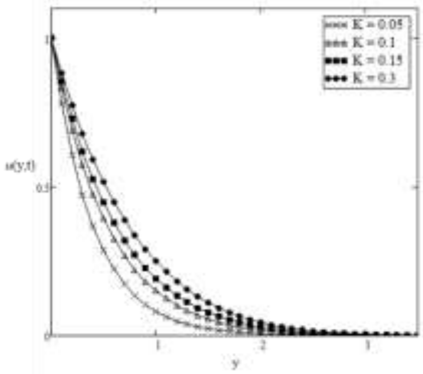


Fig. 5: Velocity profiles with different values of porosity parameters

Figure 6 depicts a graphical representation of fluid velocity as it varies with the chemical reaction parameters. The graph clearly shows that the chemical reaction rises as does its fluid velocity. This situation happens when the thinning of the boundary layer, occurs as a consequence effect of hydrodynamics and concentration along the flow path as chemical reactions intensify.

Figure 7 plots the velocity profile against the magnetic parameter. The graph displays that when magnetic parameters grow, a velocity profile emerges. However, it is crucial to note that increases in velocity are often quite minor, indicating a gradual growth. The Lorentz force, a resistive force that happen in this occurrence can be attributed to the application of a transverse magnetic field. Consequently, the magnetic field enhances the border layers' thickness in momentum and thermal regions. In return, this condition contributes to the cooling process, for example, the electronic systems and radiators while simultaneously restraining the rate of velocity growth.

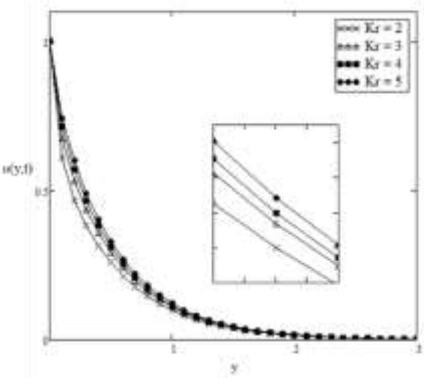


Fig. 6: Velocity profiles with different values of chemical reaction parameters

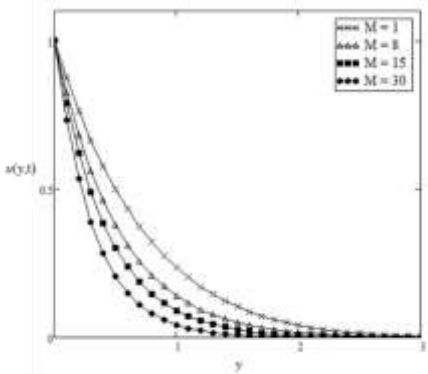


Fig. 7: Velocity profiles with different values of magnetic field parameters

Figure 8 indicates how the fluid responds to a surge in the radiation parameter. The spike value of thermal radiation value boosted the stored kinetic energy in the fluid, thereby improving the fluid's motion and speeding up the velocity.

Figure 9 depicts the rising velocity as the inclination angle increases. This phenomenon occurs because a higher inclination angle promotes the fluid's movement within the plate. When the plate is tilted away from the oriented vertically, it also impacts the buoyancy force, because both the thermal and mass diffusion decreases along with the inclination angle.

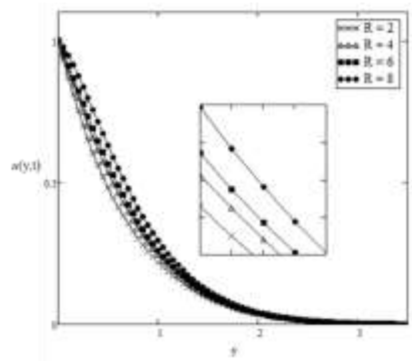


Fig. 8: Velocity profiles with different values of radiation parameters

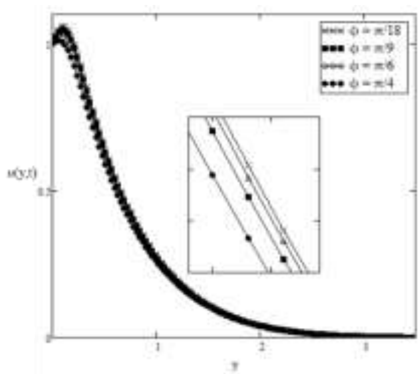


Fig. 9: Velocity profiles with different values of inclination angle

Figure 10 illustrates the elevation of thermal fields in the wake of a spike of radiation parameter. This phenomenon transpires because of the heightened conduction associated with the rising radiation parameter, causing the fluid temperature to incline away from the surface at every point. Figure 11 shows concentration profiles with various Peclet numbers. As we can see from the graph, it is shown that when the Peclet number increases, the concentration also increases.

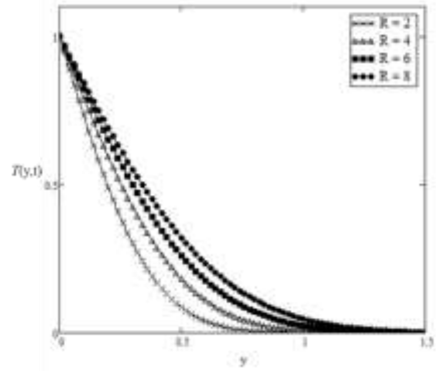


Fig. 10: Temperature profiles with different values of radiation parameters

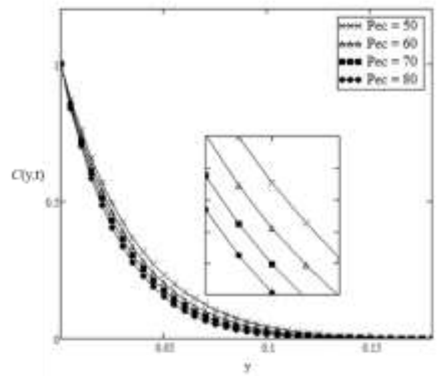


Fig. 11: Concentration profiles with different values of Peclet numbers

## 4 Conclusion

This study presents an exact solution to the dynamics of a convective MHD Casson fluid over a moving inclined plate with isothermal wall temperature. This study investigates the characteristics of porosity and chemical reactive interactions of Casson fluids. The formulas for momentum, energy, and concentration were calculated using the Laplace transformation method. The study's pivotal findings are graphically represented for the momentum, energy, and concentration fields and these significant results are summarized below.

- Casson parameter increases causing velocity to decrease.
- The rising value of the porosity employed an impedance to the flow, hence velocity increased.
- The chemical reaction rate increases will make velocity increases.
- Fluid velocity reacts actively with the magnetic parameter.
- The increment in thermal radiation value has escalated the stored kinematic energy in the fluid, thus enhancing the fluid's motion and increasing the velocity.
- Promoting the inclination angle accelerates fluid motion across the plate.
- Temperature fields expand with the rise values in the radiation parameter.

*Acknowledgement:*
The authors are pleased to acknowledge that the present research was funded by Universiti Malaysia Pahang Al-Sultan Abdullah via the grant UIC221516.

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**Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)**

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

**Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself**

This research is funded by grant UIC221516 from Universiti Malaysia Pahang Al-Sultan Abdullah.

**Conflict of Interest**

The authors have no conflicts of interest to declare.