Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

First Order Chemical Reaction Effects on Unsteady MHD Casson Fluid Flow Past on Parabolic Accelerated Vertical Plate with Uniform Mass Diffusion and Variable Temperature in the Presence of Thermal Radiation

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ARTICLE INFO

Article history:
Received 5 March 2025
Received in revised form 6 June 2025
Accepted 18 June 2025
Available online 10 July 2025

Keywords:
Parabolic; MHD; Casson fluid; chemical reaction; vertical plate; radiation

ABSTRACT

This paper presents an analytical investigation into the unsteady free convection flow of Casson fluid past a parabolically accelerated vertical plate under the influence of a uniform magnetic field, thermal radiation, and chemical reaction. The study considers variable temperature and mass diffusion conditions to analysed the behaviour of velocity, temperature, and concentration profiles. The governing flow equations are analytically solved using the Laplace transform technique, and the obtained results are graphically interpreted using MATLAB software. The obtained results reveal that the velocity of the fluid increases with the increase of time (t), Mass Grashof number (Gm), and Thermal Grashof number (Gr). However, it exhibits an inverse relationship with the increase of the Prandtl number (Pr), Magnetic field parameter (M), Schmidt number (Sc), Thermal radiation parameter (R), and Chemical reaction parameter (K). The outcomes of this study can significantly contribute to industrial processes, including polymer manufacturing, food processing, metallurgical applications, and biomedical fluid dynamics, where the behaviour of non-Newtonian fluids under various thermal and concentration conditions is of paramount interest.

1. Introduction

In recent years, the study of unsteady free convection flow in non-Newtonian fluids has gained substantial attention due to its vast applications in industrial, mechanical, and biomedical engineering. Among various non-Newtonian fluids, Casson fluid has gained remarkable importance due to its practical applications in blood flow modelling, chocolate processing, polymer melts, and ink flow in printing devices. This fluid exhibits shear-thinning behaviour and shows lower viscosity

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https://doi.org/10.37934/arfmts.133.1.2436

under higher shear stress conditions, making it ideal for practical implementations. Armstrong *et al.,* [1] examined the impact of vertical plate rotation of homogeneous mass diffusion and parabolic flow in a porous medium with varying temperature. Aboel-Magd *et al.,* [2] provide a distinctive contribution by meticulously analysing the heat as well as mass transfer characteristics in Casson nanofluid influenced by bioconvection over disk. This study examines the correlation between gyrotactic bacteria and activation energy inside the system. Reddy *et al.,* [3] statistically examined the unstable behaviour of Casson liquid across a half-infinite penetrable vertical plate, incorporating effects from magnetohydrodynamics, thermal radiation, Soret effect, and Dufour effect. “The Casson liquid infiltrates the layer via the permeable vertical plate in physical geometry. Khan *et al.,* [4] investigated the effects of chemical activity and heat generation on MHD natural convection flow across a moving plate in porous media.

Previous studies [5-7] state that the effects of the Hall effect and thermos diffusion on radiation with a heat-absorbing fluid beyond a vertical plate with exponential acceleration and a temperature ramp. Unsteady MHD radiating and responding mixed convection past an impulsively initiated oscillating plate: a finite element numerical study. Sivakumar *et al.,* [8] examined how radiation impacted parabolic flow having exponentially accelerated mass diffusion & chemical reaction across an endless isothermal vertical plate. The complexities of rotational dynamics or heat radiation in parabolic flow are clarified by Sebastian *et al.,* [9]. Thermal and radiative effects on unsteady MHD flow of Casson fluid past a rotating porous medium with variable mass diffusion were examined by Prakash *et al.,* [10]. Konduru *et al.,* [11] studied and researched about the MHD Carreau Fluid Flow and Thermal Transfer with Radiation and Heat Source Effect. Noranuar *et al.,* [12] offer a theoretical analysis of heat transfer and boundary layer flow for Casson nanofluid on a linearly extending sheet, taking into account the presence of porosity and magnetic field effects. Mato *et al.,* [13] The unsteady MHD mixed convection flow of radiating and chemically reacting fluid past an impulsively initiated oscillating vertical plate with constant mass diffusion and varying temperature is investigated numerically. The Hall current is a component of the transport model used. A consistent magnetic field is applied perpendicular to the fluid flow direction.

According to Hari Babu *et al.,* [14] investigated the influence of Newtonian heating numerically on unsteady magnetohydrodynamic free convective flow of chemically reactive and radiating Heat sink and viscous dissipation effects are taken into account when conducting Casson fluid across an infinite oscillating vertical porous plate embedded in a porous material. Sekhar *et al.,* [15] looked into the effects of Newtonian heating on temperature and mass transport in unsteady MHD flows of Casson fluids over a perpendicular plate with heat radiating and chemical reactions are investigated, and the Casson fluids modelling was used to distinguish the non-Newtonian liquid behaviour. Akaje and Olajuwon [16] explores how the species heat transfer of an MHD Casson nanofluid flow with a stagnation point connected to Thompson and Troian boundary conditions is affected by the nonlinear radiative heat. Namala *et al.,* [17] investigate the heat and mass transport properties of a non-Newtonian Casson-Williamson nanofluid flowing across a porous stretched sheet. The viscoelastic properties of a fluid are obtained by merging Casson and Williamson fluids. Muthucumaraswamy and Sivasangari [18] discovered that MHD flow was rotated by an accelerating vertical plate with uniform mass diffusion and fluctuating temperature.

Rajput *et al.,* [19] used an effect of rotation and radiation on MHD flow is being studied with a vertical plate that has an impulsive start and a fluctuating temperature. Shamshuddin *et al.,* [20] study addresses three-dimensional Williamson fluid flow via a bidirectional inclined stretched plate with new Hall current, nonuniform heat source/sink, and nth-order chemical reaction features. Humane *et al.,* [21] expresses the Casson-Williamson fluid on a stretching surface is taken into consideration. Examined are the effects of thermal radiation, an external magnetic field, and chemical repercussions on fluid flow. All of the physical elements that contribute to the physical mechanism are taken into account when creating the model. Swarnalathamma *et al.,* [22] They evaluated the unstable MHD free convective Casson fluid movement across an infinite straight up inclined absorbent plate with a heat source and/or heat absorption. The stated equations are then extensively solved by utilizing the perturbation method. Extended MHD flow when rotation was exhibited on an accelerating vertical plate with mass diffusion and thermal fluctuations [23-26]. Selvaraj *et al.,* [27] investigated magnetohydrodynamic parabolic flow across an accelerated isothermal vertical plate, utilizing mass and heat diffusion when rotation was present. A technique that produces several exponential-form inverse Laplace transforms was extended by Hetnarski *et al.,* [28]. Azzam [29] examined how radiation affected a “semi-infinite moving vertical plate's MHD mixed free-forced convective flow at large temperature differentials. Researchers have examined the diffusion of a chemically reactive species in a laminar boundary layer flow [30].

Manay *et al.,* [31] have investigated how the length of the bluff body affects the flow structure. Kavitha *et al.,* [32] looked into a parabolic flow that went through a rotating isothermal plate with uniform temperature & mass diffusion while a chemical reaction occurred. Selvaraj *et al.,* [33] have researched and discussed the fact that the magnetohydrodynamic parabolic flow that passed through a rotating isothermal plate was accelerating. Nandakumar *et al.,* [34] looked into the Soret and MHD effects of parabolic flow going via vertical plate that was moving quickly. The plate was also rotating while chemical reactions and thermal radiation were occurring. According to Selvaraj *et al.,* [35] a specific examination of the unstable parabolic flow's rotational influence past impermeable as well as electrically driven fluid through uniform accelerated isothermal perpendicular plate has been established, based on the activity of a vertically working magnetic field. Selvaraj and Jothi [36] looked into how the heat source affected MHD and the radiation-absorbing fluid moving across a plate that was getting higher and higher and had a porous medium around it.

Previous studies [37-39] concluded that mass transfer across accelerated isothermal vertical plate utilizing a heat source produces radiation and chemical processes in a first-order incompressible fluid producing heat. Additionally, investigate and focus on how the unstable magnetohydrodynamic flow upon vertical plate in porous material has been affected by radiation, heat sources, Hall currents, and Dufour. Another study by Aruna *et al.,* [40] looked at the Hall as well as magnetic effects over a stream moving past a vertical plate that was moving at a parabolically fast rate. Ameer *et al.,* [41] focus with the radiative MHD flow of non-Newtonian Casson fluid across rapidly accelerating vertical surfaces, considering slip velocity in the rotating plate. This study provides a comprehensive theoretical framework for understanding how multiple physical phenomena interact in MHD Casson fluid flows, making it valuable for applications in materials science, polymer processing, and engineering heat transfer problems.

The novel contribution of this research lies in investigating the combined impact of thermal radiation, chemical reaction, and magnetic field on Casson fluid flow, which is relatively unexplored in existing literature. Deriving closed-form analytical solutions for velocity, temperature, and concentration profiles using the Laplace Transform method, which offers high accuracy for unsteady flow problems. Analysing the parabolic accelerated vertical plate, which introduces new physical interpretations regarding the fluid behaviour in Casson models under combined external influences. Several researchers have addressed MHD and thermal radiation separately, the combined impact of thermal radiation and chemical reaction on Casson fluid flow in a parabolically accelerated vertical plate has not been extensively explored, revealing a significant research gap. In particularly the Hall current and Joule heating effect and developing numerical models for Casson fluid using finite element methods.

2. Mathematical Analysis

The coordinate framework was developed to take into account the fluctuating movement of the Casson fluid model, which involves an electrically charged fluid flowing through a vertical plate. The plate is perpendicular to the y-axis, the z-axis is parallel to the plane, along with the x-axis travels upward parallel to the plate (Figure 1). The same transverse magnetic field allows the fluid to flow when it is applied at an angle to the y-axis. At time t, assumed to be at rest, the fluid and plate are kept at a consistent temp. or surface concentration. (0). “At time $\bar{t} \geq 0$, The plate begins to move in. $\bar{x}$-direction in opposition to the gravitational field and time-dependent” velocity $\bar{u}.$ Plate temperature are increased nor decreased to $\bar{T}_\infty + (\bar{T}_w - \bar{T}_\infty)\frac{{u_0}^2\bar{t}}{v}$ at $\bar{t} \geq 0$, and plate concentration is raised or lowered to $\bar{C}_\infty + (\bar{C}_w - \bar{C}_\infty)\frac{{u_0}^2\bar{t}}{v}$ at $\bar{t} \geq 0$. The rheological state eq. for Cauchy stress tensor of Casson fluid is” presented below:

$$\tau_{ij=}\begin{Bmatrix} 2e_{ij}\left(\mu_B + \frac{py}{\sqrt{2\pi}}\right) & \pi > \pi_c \\ 2e_{ij}\left(\mu_B + \frac{py}{\sqrt{2\pi_c}}\right) & \pi < \pi_c \end{Bmatrix} \tag{1}$$

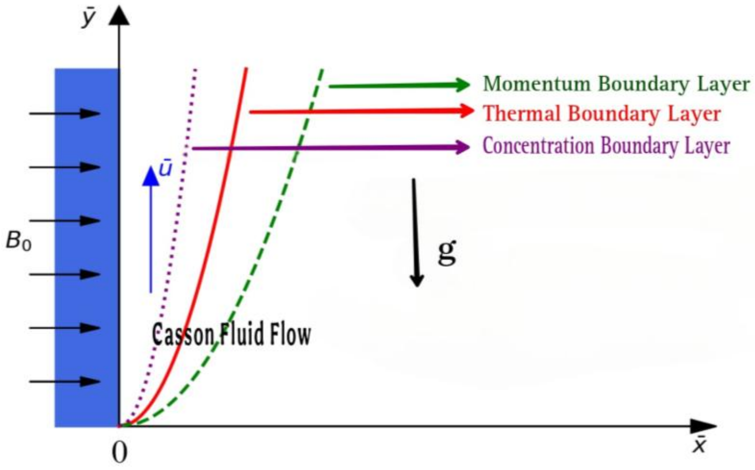

Fig. 1. Geometry of the problem

We obtain the following equation for concentration, temperature, and velocity. Initial boundary conditions are provided below.

$$\frac{\partial\bar{u}}{\partial\bar{t}} = \frac{\mu_{\boldsymbol{B}}}{\rho}\left(\frac{1}{1+\lambda}\right)\frac{\partial^2\bar{u}}{\partial\bar{y}^2} - \frac{\mu\bar{u}}{\rho\bar{k}_1} - \frac{\sigma{B_0}^2\bar{u}}{\rho} + g\beta(\bar{T} - \bar{T}_\infty) + g\beta_c(\bar{C} - \bar{C}_\infty) \tag{2}$$

$$\frac{\partial\bar{T}}{\partial t} = \frac{k}{\rho c_p}\frac{\partial^2\bar{T}}{\partial\bar{y}^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial\bar{y}} \tag{3}$$

$$\frac{\partial\bar{C}}{\partial\bar{t}} = \frac{1}{S_c}\frac{\partial^2\bar{C}}{\partial\bar{y}^2} - \bar{k}\ (\bar{C} - \bar{C}_\infty) \tag{4}$$

Boundary conditions for flows are expressed as:

$$\left.\begin{array}{l} \bar{u} = 0, \bar{T} = \bar{T}_\infty, \bar{C} = \bar{C}_\infty, \text{ for all } \bar{t} \leq 0;\ \bar{y} \geq 0 \\ \bar{u} = u_0\, \bar{t}^2\ , \bar{T} = \bar{T}_\infty + (\bar{T}_w - \bar{T}_\infty)\mathrm{A}\bar{t}\ , \bar{T} = \bar{C}_\infty + (\bar{C}_w - \bar{C}_\infty)\mathrm{A}\bar{t} \quad \text{at } \bar{y} = 0 \ \text{ for } \bar{t} > 0 \\ \bar{u} \to 0, \overline{T} \to \bar{T}_\infty, \overline{C} \to \bar{C}_\infty \ \text{ as } \bar{y} \to \infty \text{ for } \bar{t} > 0 \end{array}\right\} \tag{5}$$

The local gradient for optically slim gas can be written as:

$$\frac{\partial q_r}{\partial y} = -4\bar{a}\,\sigma\,({\bar{T}_\infty}^4 - \bar{T}^4) \tag{6}$$

Temperature modifications within flow are appropriately small and that $\bar{T}^4$maybe denoted as a temperature’s linear function. To attained $\bar{T}^4$ solving Taylor series about $\bar{T}_\infty$ and overlooking the terms that are higher in order, we attain:

$$\bar{T}^4 = 4{\bar{T}_\infty}^3\,\bar{T} - 3{\bar{T}_\infty}^4 \tag{7}$$

Substituting Eq. (6) and (7) in (3), we get:

$$\frac{\partial \bar{T}}{\partial \bar{t}} = \frac{k}{\rho c_p}\frac{\partial^2 \bar{T}}{\partial \bar{t}^2} - \frac{16\bar{a}\sigma}{\rho c_p}{\bar{T}_\infty}^3(\bar{T} - \bar{T}_\infty) \tag{8}$$

The following definitions apply to the dimensionless parameters and variables.

$$\left.\begin{array}{l} y = \frac{\bar{y}u_0}{v}\ , \mathrm{u} = \frac{\bar{u}}{u_0}\ , \mathrm{t} = \frac{{u_0}^2\bar{t}}{v}\ , T = \frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}\ \ C = \frac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty} \\ S_c = \frac{v}{D}, \mu = \rho v\ ,\ k_1 = \frac{{u_0}^2\bar{k}_1}{v^2}, P_{r=}\frac{\mu c_p}{k}, \ , G_r = \frac{g\beta_T v(\bar{T}_w-\bar{T}_\infty)}{{u_0}^3} \\ G_m = \frac{g\beta_C v(\bar{C}_w-\bar{C}_\infty)}{{u_0}^3}\ , M = \frac{\sigma\, {B_0}^2 v}{\rho\, {u_0}^2}\ , R = \frac{16\bar{a}\sigma v^2{\bar{T}_\infty}^3}{k\, {u_0}^2}, \mathrm{k} = \frac{v\bar{k}}{{u_0}^2} \end{array}\right\} \tag{9}$$

We have the dimensionless version of the following governing equation.

$$\frac{\partial U}{\partial t} = m\frac{\partial^2 U}{\partial y^2} - nU + G_r T + G_m C \tag{10}$$

$$\frac{\partial T}{\partial t} = \frac{1}{P_r}\frac{\partial^2 T}{\partial y^2} - \frac{R}{P_r}T \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - \mathrm{K}\mathrm{C} \tag{12}$$

and corresponding boundary conditions becomes:

$$\left.\begin{array}{l} U = 0, T = 0, C = 0\ \ for\ all\ y\ \ and \ \ \ t \leq 0 \\ U = t^2, T = t, C = 1\, for\ all\ y\ and\ t > 0 \\ U \to 0, \theta \to 0, C \to 0\ \ as\ y \to \infty \ \ \ and \ \ \ t > 0 \end{array}\right\} \tag{13}$$

3. Solutions

The dimensionless governing equations (10) to (12) can be solved with precision while adhering to the boundary constraints by applying the Laplace transform technique was regulate the fluid's concentration, velocity, temperature are given by:

$$C=\frac{1}{2}\left[exp\left(-y\sqrt{KSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}-\sqrt{Kt}\right)+exp\left(y\sqrt{KSc}\right)erfc\left(\frac{y\sqrt{Sc}}{2\sqrt{t}}+\sqrt{Kt}\right)\right] \tag{14}$$

$$T=\left[\begin{array}{l}\left(\frac{t}{2}-\frac{P_r y}{4\sqrt{R}}\right)\exp\left(-y\sqrt{R}\right)\,erfc\,\left(\frac{\sqrt{P_r}y}{2\sqrt{t}}-\sqrt{(R)t}\right)\\+\left(\frac{t}{2}+\frac{P_r y}{4\sqrt{R}}\right)\exp\left(y\sqrt{R}\right)\,erfc\,\left(\frac{\sqrt{P_r}y}{2\sqrt{t}}+\sqrt{(R)t}\right)\end{array}\right] \tag{15}$$

$$U=\left[\begin{array}{l}
\left(\frac{y^2}{8mn}+\frac{t^2}{2}\right)\left[\begin{array}{l}exp\left(\frac{-y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{nt}\right)\\+\,exp\left(\frac{y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{nt}\right)\end{array}\right]+\frac{y}{2\sqrt{mn}}\left(\frac{1}{4n}-t\right)\\
\left[\begin{array}{l}exp\left(\frac{-y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{nt}\right)\\-\,exp\left(\frac{y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{nt}\right)\end{array}\right]-\frac{y\sqrt{t}}{2n\sqrt{m\pi}}\exp\left(-\frac{y^2}{4mt}-nt\right)\\
+A_1\left[\begin{array}{l}exp\left(\frac{-y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{nt}\right)\\+\,exp\left(\frac{y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{nt}\right)\end{array}\right]\\
+A_2\left\{\begin{array}{l}\left(\frac{t}{2}-\frac{y}{4\sqrt{m\,n}}\right)\left[exp\left(\frac{-y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{nt}\right)\right]\\+\left(\frac{t}{2}+\frac{y}{4\sqrt{m\,n}}\right)\left[exp\left(\frac{y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{nt}\right)\right]\end{array}\right\}\\
+A_3\left[\begin{array}{l}exp\left(\frac{-y\sqrt{a+n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{(a+n)t}\right)\\+\,exp\left(\frac{y\sqrt{a+n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{(a+n)t}\right)\end{array}\right]\\
+A_4\left[\begin{array}{l}exp\left(\frac{-y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{nt}\right)\\+\,exp\left(\frac{y\sqrt{n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{nt}\right)\end{array}\right]\\
+A_5\left[\begin{array}{l}exp\left(\frac{-y\sqrt{b+n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}-\sqrt{(b+n)t}\right)\\+\,exp\left(\frac{y\sqrt{b+n}}{\sqrt{m}}\right)\;erfc\left(\frac{y}{2\sqrt{mt}}+\sqrt{(b+n)t}\right)\end{array}\right]\\
+A_6\left[\begin{array}{l}\exp\left(-y\sqrt{R}\right)\,erfc\,\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{\left(\frac{R}{P_r}\right)t}\right)\\+\exp\left(y\sqrt{R}\right)\,erfc\,\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{\left(\frac{R}{P_r}\right)t}\right)\end{array}\right]\\
+A_7\left[\begin{array}{l}\left(\frac{t}{2}-\frac{P_r y}{4\sqrt{R}}\right)\exp\left(-y\sqrt{R}\right)\,erfc\,\left(\frac{\sqrt{P_r}y}{2\sqrt{t}}-\sqrt{\left(\frac{R}{P_r}\right)t}\right)\\\left(\frac{t}{2}-\frac{P_r y}{4\sqrt{R}}\right)\exp\left(-y\sqrt{R}\right)\,erfc\,\left(\frac{\sqrt{P_r}y}{2\sqrt{t}}-\sqrt{\left(\frac{R}{P_r}\right)t}\right)\end{array}\right]
\end{array}\right]$$

$$\left[\begin{array}{l} +A_8\left[\begin{array}{l} xp\left(-y\sqrt{R+aP_r}\right)\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{\left(a+\frac{R}{P_r}\right)t}\right) \\ +\exp\left(y\sqrt{R+aP_r}\right)\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{\left(a+\frac{R}{P_r}\right)t}\right) \end{array}\right] \\ +A_9\left[\exp\left(-y\sqrt{S_c k}\right) erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{Rt}\right)+\exp\left(y\sqrt{S_c R}\right) erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{kt}\right)\right] \\ +A_{10}\left[\begin{array}{l} \exp\left(-y\sqrt{S_c(k+b)}\right) erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{(k+b)t}\right) \\ +\exp\left(y\sqrt{S_c(k+b)}\right) erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{(k+b)t}\right) \end{array}\right] \end{array}\right] \tag{16}$$

4. Results and Discussion

For physical understanding of the problem numerical computations are carried out for different physical parameters K, M, Pr, Gr, Gc, R, Sc, λ and t upon the nature of the flow and transport. Also, the values of Prandtl number Pr are chosen such that they represent (Pr = 7.0 for water and Pr= 0.71 for air). The numerical values of the velocity are computed for different physical parameters for velocity, temperature and concentration. Figure 2 explains how the Sc impacts the concentration falls with increasing SC. Physically, when the number of Sc rises, the concentration boundary layer decreases because it reduces molecular diffusion. Figure 3 illustrates how the time parameter (t) affects the concentration profile; the results show that concentration increases as time (t) increases. Figure 4 shows the effect of the chemical reaction parameter (k) on the concentration profile. The statistics reveal that as K increases, the concentration significantly decreases. Figure 5 highlights temperature variation as a function of time (t).

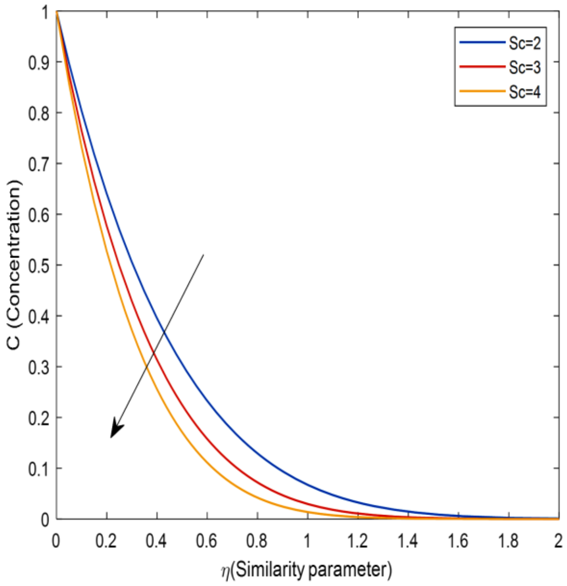

Fig. 2. Concentration profiles for distinct Sc values with t=0.2

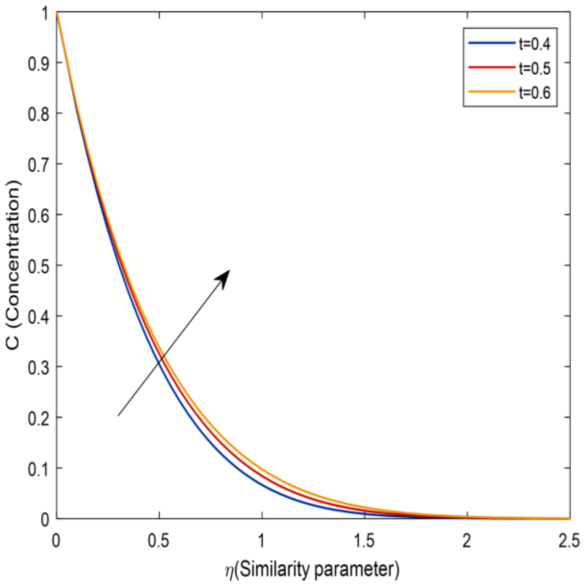

Fig. 3. Concentration profiles for various t values with Sc=2.01

The results show that as t increases, so do the temperature profiles. It indicates that heat diffusion becomes more dominant with time, resulting in an increase in temperature dispersion throughout the fluid. Figure 6 shows how the temperature profile is affected by Pr. These findings indicate that the temperature drops as Pr rises. These effects of higher radiation levels on radiative heat transport can be more profound. The temperature trend decreases as radiation quantities increase. However, depending on the system and the circumstances under study, the impact of radiation on temperature varies on Figure 7.

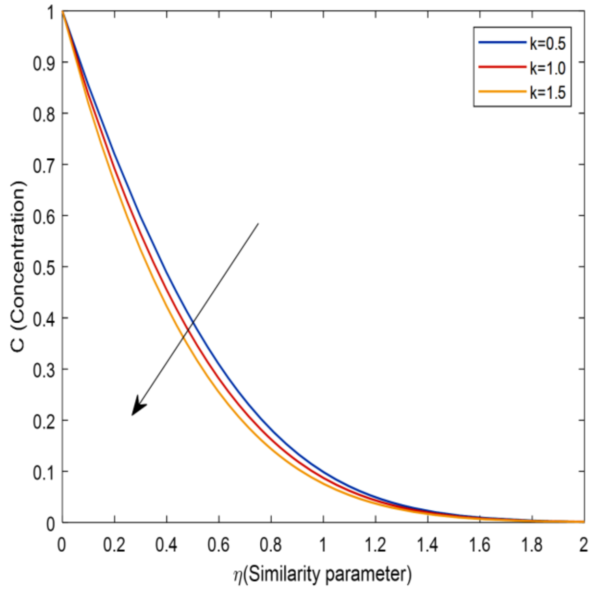

Fig. 4. Profiles of concentration for distinct K values with Sc=2.01,

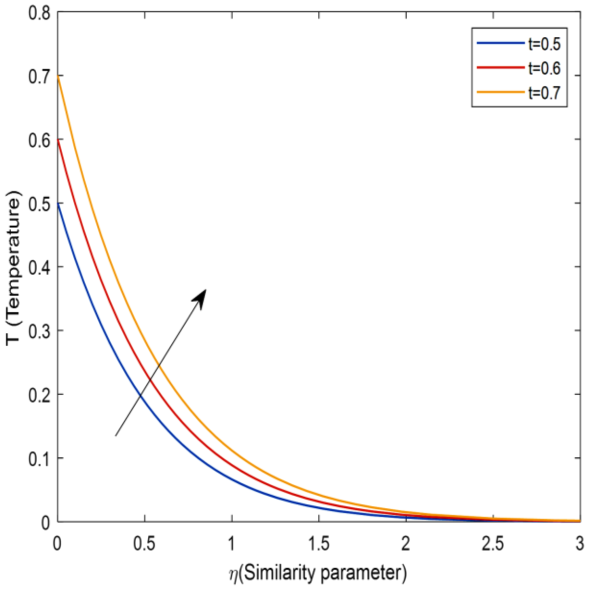

Fig. 5. Temperature profiles for distinct t values having Pr=0.71, R=2

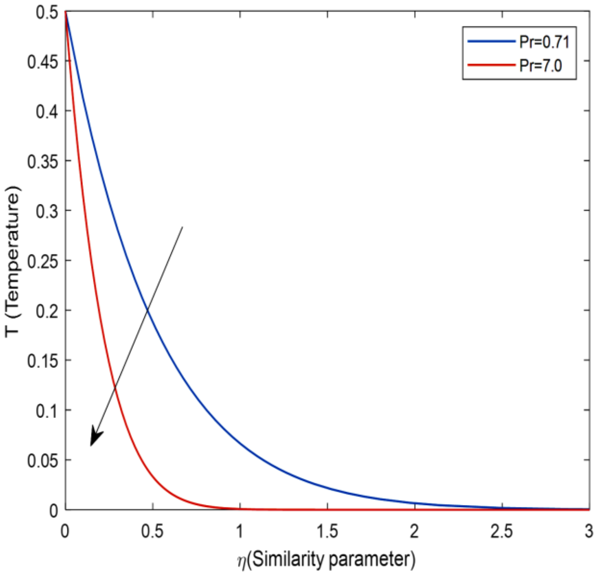

Fig. 6. Profiles of temperature for distinct (Pr) values with t=0.4, R=2

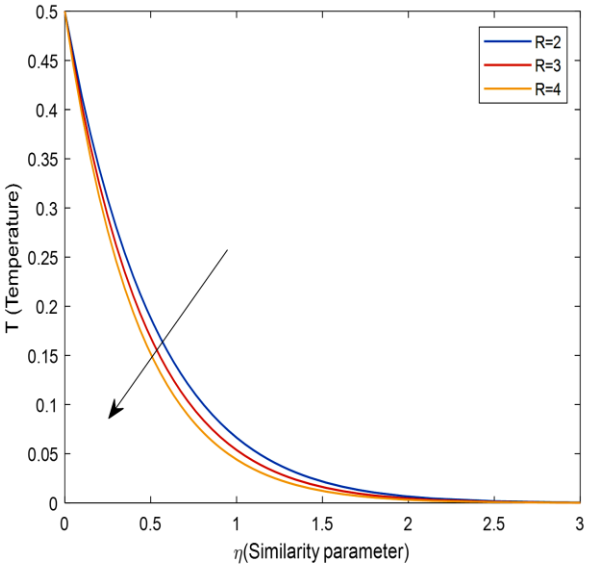

Fig. 7. Temperature profiles in Pr=0.71 and t=0.4 for different R

The time parameter (t) on the velocity (U) is seen in Figure 8. The findings show that the velocity profiles rise in combined with t. This implies that the fluid grows in momentum over time, increasing its overall velocity. Figure 9 illustrates how velocity profiles are affected by the Casson fluid parameter (λ). The results show that increasing (λ) leads to higher velocity. This is because a lower Casson fluid parameter equates to greater fluid viscosity. Casson fluids exhibit non-Newtonian behaviour, with fluidity increasing as λ increases. Figure 10 illustrates the impact of the Gm on velocity profiles. The data reveal that as Gm increases, so increasing velocity. Figure 11 illustrates the result of the Gr on velocity profiles. The measurements reveal that as Gr increases, so does velocity. As the Gm number increases, the fluid encounters stronger convective forces, which results in higher flow velocity.

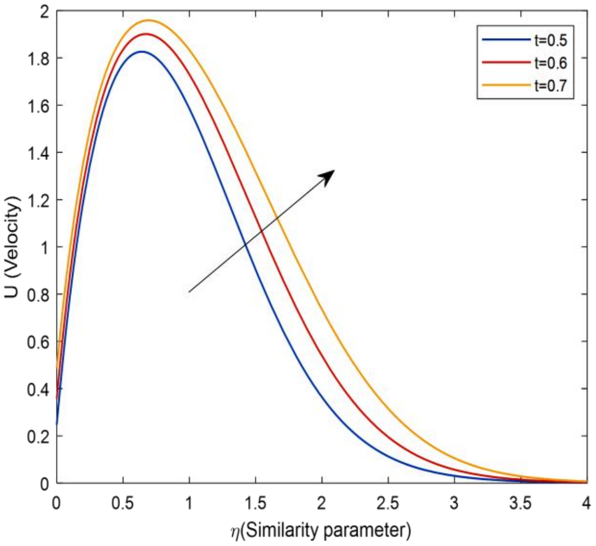

Fig. 8. Velocity profiles for distinct t values with Pr=0.71, Gm=Gr=5, Sc=2.01, R=4, M =0.7, λ = 0.35, t = 0.5

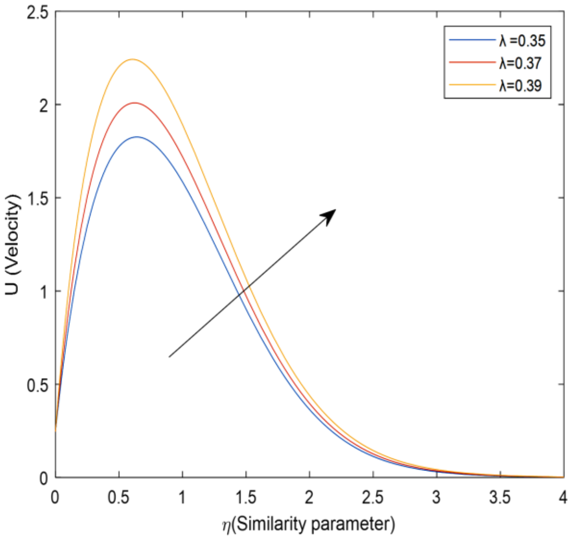

Fig. 9. Velocity profiles with M = 0.7, k (0.5, t = 0.5), Sc = 2.01, Gm = 5, R = 4, Gr = 5, Pr = 0.71 for different λ values

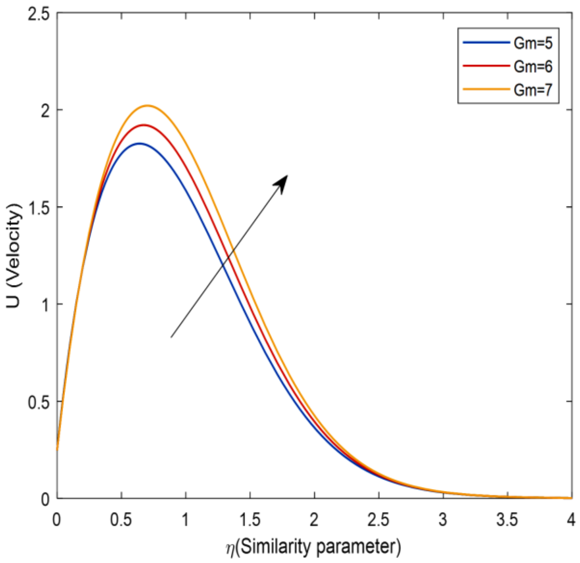

Fig. 10. Velocity profiles with Pr=0.71, M = 0.7, k(0.5, λ=0.35, t), Gr=5, Sc=2.01, R=4, t = 0.5) for different Gm values

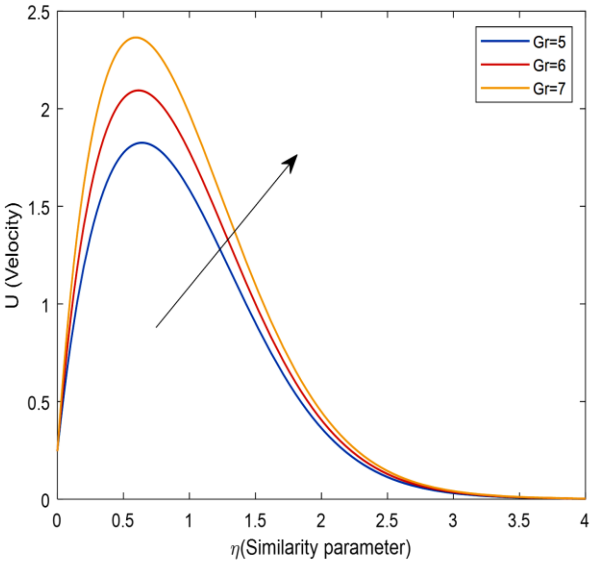

Fig. 11. Velocity profiles with Sc=2.01, Pr=0.71, R=4, M=0.7, k (0.5, λ=0."35, t = 0.5) for different Gr values

Figure 12 represents Sc's impact on velocity profiles. These results show that decreasing the Schmidt number can result in a higher velocity in some circumstances. In Figure 13 how heat is transmitted, and the particular movement conditions determine how the Prandtl number affects velocity rise in Pr can go in down. Figure 14 demonstrates that the M influences the velocity profile. The results suggest that when velocity falls as, its intensity of the magnetic field increases. Magnetic fields are the reason behind this. as a resistive force on the fluid, opposing its motion and reducing its velocity. Figure 15 indicates the effect of the thermal radiation parameter (R) on velocity profiles.

While radiative heat transfer does not directly affect fluid flow rates, the results show that as the radiation parameter (R) increases, the velocity decreases.

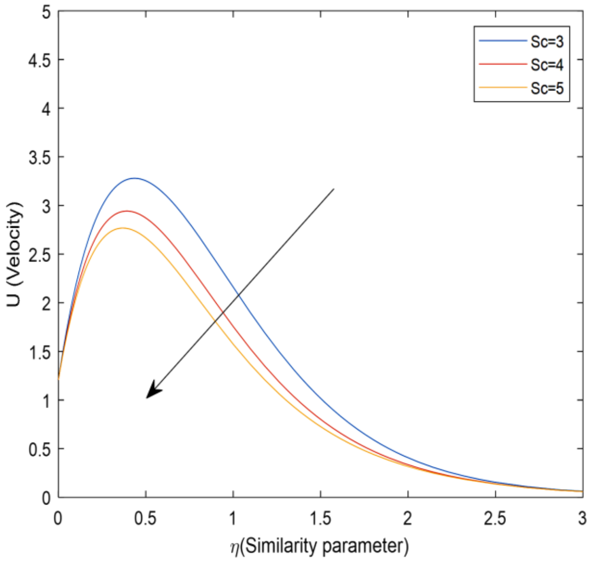

Fig. 12. Velocity profiles with Gm=5, M = 0.7, k (0.5, λ= 0.35, t=0.2), Gr=5, Pr=0.71, R=4. = 0.5) for different Sc values

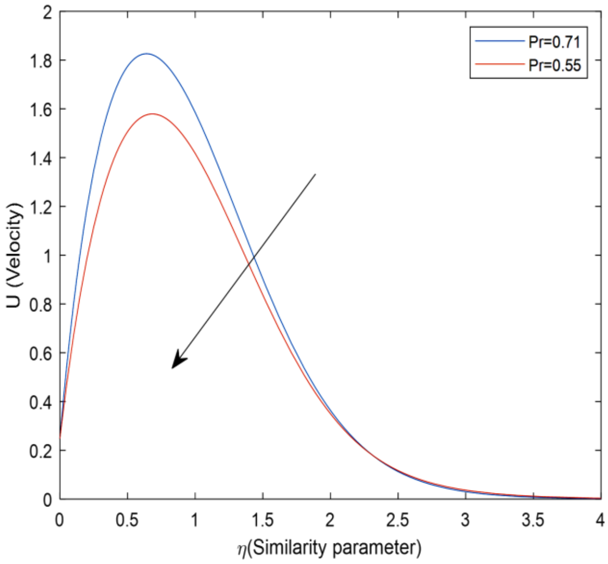

Fig. 13. Velocity profiles for specific Pr values with Gm=5, Gr=5, R=4, and Sc=2.01, M =0.7, k= 0.5,λ = 0.35,t=0.5

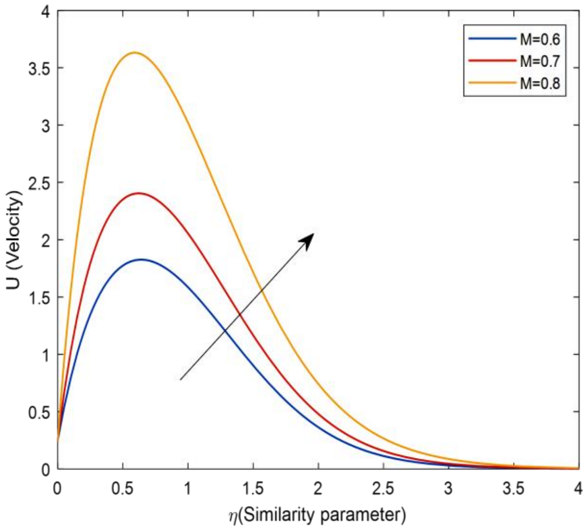

Fig. 14. Velocity profiles with k (0.5, λ = 0.35, t = 0.5), "Pr = 0.71, R = 4, Gm = 5, Sc = 2.01, Gr = 5, for various M" values

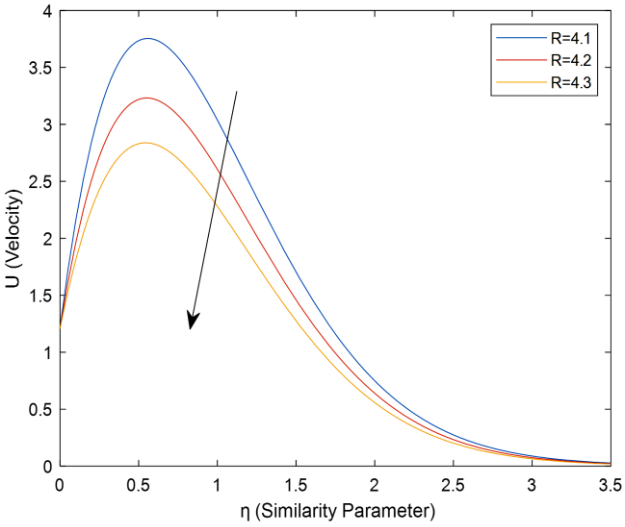

Fig. 15. Velocity profiles for distinct R values with Pr=0.71, Gm = Gr =5, S = 2.01, R=4, k = 0.5, M =0.7, λ = 0.35,t = 0.5

5. Conclusions

This research study concluded the transfer of mass and heat in the incidence of thermal radiation as well as the free convection MHD flow of a viscous, chemically reactive, electrically conducting, incompressible, and Casson fluid past a parabolically accelerated vertical plate. The numerical outcomes and graphical representations were utilized to interpret the behaviour of key physical parameters influencing the flow dynamics. The effects of time (t), Prandtl number (Pr), Grashof number (Gr), Mass Grashof number (Gm), Schmidt number (Sc), magnetic field parameter (M), thermal radiation parameter (R), chemical reaction parameter (K), Dufour number (Df), and heat generation parameter (Q) on the fluid flow characteristics were thoroughly investigated. Based on the results obtained, the following significant conclusions as follows:

i. It is observed that the velocity of the fluid increases with an increase in time (t), Thermal Grashof number (Gr), and Mass Grashof number (Gm), indicating that the presence of buoyancy forces significantly enhances the fluid motion. Conversely, an increase in the Schmidt number (Sc), Prandtl number (Pr), magnetic field parameter (M), thermal radiation parameter (R), and chemical reaction parameter (K) results in a decrease in velocity due to the dominance of resistive forces. This behaviour confirms that these parameters impose a retarding influence on the fluid flow.
ii. The temperature distribution increases with a rise in the Dufour number (Df) and heat generation parameter (Q), signifying that higher Dufour effects enhance heat transfer within the boundary layer. However, the temperature field decreases as the thermal radiation parameter (R) and Prandtl number (Pr) increases.
iii. The concentration field shows a declining trend with an increase in the Schmidt number (Sc) and chemical reaction parameter (K). This behaviour is attributed to the fact that higher Schmidt number intensifies molecular diffusivity.

Overall, the present study provides insightful conclusions regarding the behaviour of Casson fluid flow under combined effects of thermal radiation, chemical reaction, magnetic field, and free convection along a parabolically accelerated vertical plate. These findings are particularly significant in various industrial and engineering applications. Future research may extend this work by incorporating Hall current effects, Joule heating, and surface permeability to obtain a more realistic and generalized physical model.

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