J. Appl. Math. & Informatics Vol. **42**(2024), No. 3, pp. 607 - 623
https://doi.org/10.14317/jami.2024.607

EFFECTS OF RADIATION AND HEAT GENERATION ON MHD AND PARABOLIC MOTION ON CASSON FLUIDS FLOW THROUGH A ROTATING POROUS MEDIUM IN A VERTICAL PLATE

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Abstract. This article studies the effects of heat generation/absorption and thermal radiation on the unsteady magnetohydrodynamic (MHD) Casson fluid flow past a vertical plate through rotating porous medium with constant temperature and mass diffusion. It is assumed that the plate temperature and concentration level are raised uniformly. For finding the exact solution, a set of non-dimensional partial differential equations is solved analytically using the Laplace transform technique. The influence of various non-dimensional parameters on the velocity are discussed, including the effects of the magnetic parameter M, heat generation/absorption Q, thermal radiation parameter R, Prandtl number Pr, Schmidt number Sc, permeability of porous medium parameter, Casson fluid parameter γ, on velocity, temperature, and concentration profiles, which are discussed through several figures. It is found that velocity, temperature, and concentration profiles in the case of heat generation parameter Q, Casson fluid parameter γ, thermal Grashof number Gr, mass Grashof number Gc, Permeability Porous medium parameter K, and time t have retarding effects. It is also seen that the magnetic field M, Thermal Radiation parameter R, Prandtl field Pr, Schmidt number Sc have reverse effects on it.

AMS Mathematics Subject Classification : 65H05, 65F10.
Key words and phrases : Nonlinear equation, three-step iterative method, multi-step iterative method.

1. Introduction

The study of non-Newtonian fluid through porous medium has number of applications in science and Engineering. The number of investigators has investigated in non-Newtonian fluid like Casson fluid which exhibits the yield stress.

Received October 6, 2023. Revised December 9, 2023. Accepted February 20, 2024.
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In the human body the blood also can be treated as Casson fluid. Casson fluid model is widely used in food stuffs and biological materials, especially blood. It describes the steady shear stress and shear rate behaviour of blood. Amar et al.[1] discussed about heat transfer flow of casson fluid a moving wedge with convective boundary in presence of heat generation. The number of investigators has investigated their pioneer work done by Casson [6] analysed a flow equation for pigment oil suspensions of the printing ink type. The application of the minimal energy hypothesis to a Casson fluid was studied by McGregor et al. [13]. A mathematical study of peristaltic transport of a Casson fluid was found by Mermone et al. [14]. The process of mass transfer that occurs by the combine effects of concentration as well as temperature gradients is known as thermal diffusion or Soret effect. The experimental investigation of the thermal diffusion effect on mass transfer related problems was first performed by Charles Soret in 1879, Unsteady MHD free convective mass transfer flow past an infinite vertical porous plate with variable suction and Soret effect has been studied by Reddy et al. [18]. Maran et al. [10] researched heat and mass transfer on unsteady MHD free convection flow past a vertical plate with thermal diffusion and chemical reaction. Devi and Raj [8] investigated thermo diffusion effects on unsteady hydromagnetic free convection flow with heat and mass transfer past a moving vertical plate with time dependent suction and heat source in a slip flow regime. Mythreye et al. [16] considered chemical reaction and Soret effect on MHD free convective flow past an infinite vertical porous plate with variable suction. The Soret effect on MHD free convective flow over a vertical plate with heat source was investigated by Bhavana et al. [5]. Very recently studied Aruna et al. [2] studied magnetic field and hall effects onflow past a parabolic accelerated vertical plate in the existence of thermal radiation. Selvaraj and Jothi [3] researched on heat source effect on MHD and radiation absorption fluid past exponentially vertical plate through porous medium.

MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al. [28]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate were also studied by Soundalgekar et al. [29] the dimensionless governing equations were solved using Laplace transform technique. The radiative free convection flow of an optically thin gray-gas past semi-infinite vertical plate studied by Soundalgekar and Takhar[30]. Dilip Jose and Selvaraj [9] researched on convective heat and mass transfer on rotational effects of parabolic flow past in a vertical plate with chemical reaction. Lakshmikaanth et al. [13] studied hall current, heat source with radiational and chemical reaction effect of viscous flow. Rotational impact on MHD stream past a quickened perpendicular plate was concentrated by Muthucumaraswamy.et.al [19] researched rotational effect on MHD flow past an accelerated vertical plate with variable temperature and uniform mass diffusion. MHD Parabolic flow across an accelerating isothermal vertical plate with mass as well as heat diffusion was studied by Selvaraj et al. [20] in the presence of rotation. Selvaraj and Gowri [25] analyse the Rotational effect of unsteady MHD-Parabolic Flow Past a Vertical Plate through porous medium with uniform temperature mass diffusion. S. Constance Angela and A. Selvaraj [16] analysed Dufour and Hall Effects on MHD Flow past an Exponentially Accelerated Vertical Plate. U. S. Rajput and N. K. Gupta [28] discussed about Dufour effect on unsteady free convection MHD flow past an exponentially accelerated plate through porous medium. Kataria et al. [11-12] researched Soret and heat generation effects on MHD Casson fluid flow past an oscillating vertical plate embedded through porous medium .The present work is concerned with the Soret effect on MHD convective heat and mass transfer flow of an unsteady viscous incompressible electrically conducting fluid past a vertical plate in presence of rotation with thermal radiation and chemical reaction

2. Mathematical Formulation of the problem

Let us consider the Casson fluid stream through an infinite vertical plate in a porous medium. Here we consider x'-axis is taken along the plate upward direction to the fluid flow and y'-axis taken normal direction towards the plate. A Uniform magnetic field (B) of strength B_0 is applied on an electrically conducting fluid perpendicular to the plate. Initially at time $t' \leq 0$, both the plate and fluid are at rest and maintained at uniform temperature T'_∞ and uniform surface concentration C'_∞. At $t' \geq 0$, the plate is given a parabolic motion $u_0 t'^2$ with heat transfer starts of plate is lowered or raised to $T'_\infty + (T'_w - T'_\infty)t'/t_0$ at $t' \geq 0$ and concentration of the plate is lowered or raised to $C'_\infty + (C'_w - C'_\infty)t'/t_0$ at $t' \geq 0$ which is thereafter maintained constant T'_w & C'_w respectively. We assume that, rigid plate, incompressible flow, one-dimensional flow, free convection, and viscous dissipation term in the energy equation is neglected.

Under the above assumptions and taking into account the Boussinesq's approximation, governing partial differential equation with initial and boundary condition are

$$\rho\left(\frac{\partial u'}{\partial t'}\right) - 2\Omega' v' = \mu\left(1+\frac{1}{\gamma}\right)\left(\frac{\partial^2 u'}{\partial y'^2}\right) + g\rho\beta_{T'}(T'-T'_\infty) + g\rho\beta_{C'}(C'-C'_\infty) - \sigma B_0^2 u' - \frac{\mu\Phi}{k'} \tag{1}$$

$$\rho\left(\frac{\partial v'}{\partial t'}\right) + 2\Omega' u' = \frac{\partial^2 v'}{\partial y'^2} - \sigma B_0^2 v' \tag{2}$$

$$\rho c_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q'_r}{\partial y'^2} + Q(T'-T'_\infty) \tag{3}$$

$$\frac{\partial C'}{\partial t'} = Dm\frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

With the following initial and boundary conditions:

$$u' = 0, \quad T' = T'_\infty, \quad C' = C'_\infty, \quad \text{for all } y' \geq 0, \quad t' \leq 0$$

$$u' = u_0 t'^2, \quad T' = \begin{cases} T'_\infty + \left(\frac{T'_w - T'_\infty}{t_0}\right) t' & \text{if } 0 < t' < t_0 \\ T'_w & \text{if } t' \geq 0 \end{cases}$$

$$C' = \begin{cases} C'_\infty + \left(\frac{C'_w - C'_\infty}{t_0}\right) t' & \text{if } 0 < t' < t_0 \\ C'_w & \text{if } t' \geq 0 \end{cases} \tag{5}$$

As $y' \to \infty$ and $t' \geq 0$, $u' \to 0$, $T' \to T'_\infty$, and $C' \to C'_\infty$.

The local radiant for the case of an optically thin gray gas expressed by Rosseland approximation:

$$\frac{\partial q'_r}{\partial y'} = -4a^* \sigma^* ({T'_\infty}^4 - T'^4) \tag{6}$$

Where σ^* and a^* are Stefan Boltzmann constant and absorption coefficient respectively. Assuming that the temperature difference between the fluid within the boundary layer and free stream is small, so T'^4 can be expressed as a linear combination of the temperature, we expand T'^4 in Taylor's series about T'_∞, and neglecting higher-order terms, we get

$$\left(\frac{\partial T'}{\partial t'}\right)^4 \approx 4\left(\frac{T'_\infty}{T'_\infty}\right)^3 T' - 3\left(\frac{T'_\infty}{T'_\infty}\right)^4 \tag{7}$$

Substituting equations (6) and (7) into equation (3) reduces to:

$$\rho C_p \frac{\partial T'}{\partial t'} = k \frac{\partial^2 T'}{\partial y^2} + 16a^* \sigma \left(\frac{T'_\infty}{T'_\infty}\right)^3 \left(\frac{T'_\infty}{T'_\infty} - T'\right) \tag{8}$$

On suggesting the subsequent dimensionless quantities:

$$U = \frac{u'}{u_0}, \quad V = \frac{v'}{u_0}, \quad t = \frac{t'}{t_0}, \quad y = \frac{y'}{u_0}\frac{1}{t_0},$$
$$\theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, \quad C = \frac{C' - C'_\infty}{C'_w - C'_\infty}$$

$$\mathrm{Gr} = \frac{g\beta_{T'}(T'_w - T'_\infty)}{u_0^3}, \quad Gm = \frac{g\beta_{C'}(C'_w - C'_\infty)}{u_0^3}, \quad M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, \quad \mathrm{Pr} = \frac{\mu C_p}{k} \tag{9}$$

$$\mathrm{Sc} = \frac{v}{D_m}, \quad R = \frac{16\sigma^*(T'_\infty)^3}{k u_0^2}, \quad \gamma = \frac{\mu_{(\beta\sqrt{(2\pi c)})}}{p_y}, \quad Q = \frac{Q' v}{\rho c_p u_0^2}$$

Using (6) in equations (1) to (4), we have derived:

$$\frac{\partial U}{\partial t} - 2\Omega V = \mathrm{Gr}T + \mathrm{Gc}C + \left(1+\frac{1}{\gamma}\right)\frac{\partial^2 U}{\partial y^2} - MU - \frac{1}{K}U \tag{10}$$

$$\frac{\partial V}{\partial t} + 2\Omega U = \left(1+\frac{1}{\gamma}\right)\frac{\partial^2 V}{\partial y^2} - MV \tag{11}$$

$$\frac{\partial T}{\partial t} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 T}{\partial y^2} - R\theta + QT \tag{12}$$

$$\frac{\partial C}{\partial t} = \frac{1}{\mathrm{Sc}}\frac{\partial^2 C}{\partial y^2} \tag{13}$$

Now the set of equations (10) and (11) with the boundary condition (11) we present a complex velocity $q' = U + iV$ then into single equation.

$$\frac{\partial q'}{\partial t} = \mathrm{Gr}\theta + \mathrm{Gc}C + a\frac{\partial^2 q'}{\partial y^2} - mq' \tag{14}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial y^2} + Q\theta \tag{15}$$

$$\frac{\partial C}{\partial t} = \frac{1}{\mathrm{Sc}}\frac{\partial^2 C}{\partial y^2} \tag{16}$$

The starting and limit conditions using non-dimensional quantities are as follows:

$$q' = 0, \quad \theta = 0, \quad C = 0$$

for all $y \geq 0$ and $t \leq 0$.

$$q' = t^2, \quad \theta = 1, \quad C = 1, \quad y = 0, \quad \text{and} \quad t > 0 \tag{17}$$

$q' \to 0$, $\theta \to 0$, $C \to 0$ as $y \to \infty$ and $t > 0$ where $m = M + 2i\Omega + \frac{1}{K}$

3. Solution of the Problem

Laplace transforms are used to solve equations (14), (15), and (16), which have a dimensionless administering condition and an associated beginning and limit condition. A final inverse transform is done, and the solutions are determined in the following manner:

$$\begin{aligned} q' = \frac{\sqrt{\left(\frac{a\eta^2 t}{m} + t^2\right)}}{\sqrt{\frac{m}{a}}} \Bigg[& e^{-2\eta\sqrt{\frac{m}{a}}t}\,\mathrm{erfc}\left(\eta - \sqrt{\frac{m}{a}t}\right) \\ & + e^{2\eta\sqrt{\frac{m}{a}}t}\,\mathrm{erfc}\left(\eta + \sqrt{\frac{m}{a}t}\right)\Bigg] \\ + \frac{a}{4m} - t\sqrt{t}\frac{1}{\sqrt{\frac{m}{a}}} \Bigg[& e^{-2\eta\sqrt{\frac{m}{a}}t}\,\mathrm{erfc}\left(\eta - \sqrt{\frac{m}{a}t}\right) \end{aligned}$$

$$
\begin{aligned}
&- e^{2\eta\sqrt{\frac{m}{a}}t}\operatorname{erfc}\left(\eta+\sqrt{\frac{m}{a}t}\right)\Bigg]\\
&- \frac{2a}{m}\sqrt{\frac{t}{\pi}}e^{-(\eta^2-m/a)t} + G_r/b(1-aP_r)\Bigg[-e^{bt/2}\Bigg[e^{-2\eta\sqrt{\frac{m+b}{a}}t}\operatorname{erfc}\left(\eta-\sqrt{\frac{m+b}{a}t}\right)\\
&+ e^{2\eta\sqrt{\frac{m+b}{a}}t}\operatorname{erfc}\left(\eta+\sqrt{\frac{m+b}{a}t}\right)\Bigg]\\
&+ \frac{1}{2}\Bigg[e^{-2\eta\sqrt{\frac{m}{a}}t}\operatorname{erfc}\left(\eta-\sqrt{\frac{m}{a}t}\right)\\
&+ e^{2\eta\sqrt{\frac{m}{a}}t}\operatorname{erfc}\left(\eta+\sqrt{\frac{m}{a}t}\right)\Bigg]\Bigg]\\
&+ G_m/c(1-aS_c)\Bigg[\frac{1}{2}\Bigg[e^{-2\eta\sqrt{\frac{m}{a}}t}\operatorname{erfc}\left(\eta-\sqrt{\frac{m}{a}t}\right)\\
&+ e^{2\eta\sqrt{\frac{m}{a}}t}\operatorname{erfc}\left(\eta+\sqrt{\frac{m}{a}t}\right)\Bigg]\\
&- e^{ct/2}\Bigg[e^{-2\eta\sqrt{\frac{m+c}{a}}t}\operatorname{erfc}\left(\eta-\sqrt{\frac{m+c}{a}t}\right)\\
&+ e^{2\eta\sqrt{\frac{m+c}{a}}t}\operatorname{erfc}\left(\eta+\sqrt{\frac{m+c}{a}t}\right)\Bigg]\Bigg]\\
&- G_r/b(1-aP_r)\Bigg[\frac{1}{2}\Bigg[e^{-2\eta\sqrt{P_r}\sqrt{(R-Q)t}}\operatorname{erfc}\left(\eta\sqrt{P_r}-\sqrt{(R-Q)t}\right)\\
&+ e^{2\eta\sqrt{P_r}\sqrt{(R-Q)t}}\operatorname{erfc}\left(\eta\sqrt{P_r}+\sqrt{(R-Q)t}\right)\Bigg]\\
&+ e^{bt/2}\Bigg[e^{-2\eta\sqrt{P_r}\sqrt{(R+b-Q)t}}\operatorname{erfc}\left(\eta\sqrt{P_r}-\sqrt{(R+b-Q)t}\right)\\
&+ e^{2\eta\sqrt{P_r}\sqrt{(R+b-Q)t}}\operatorname{erfc}\left(\eta\sqrt{P_r}+\sqrt{(R+b-Q)t}\right)\Bigg]\Bigg]\\
&- G_m/c(1-aS_c)\Bigg[\operatorname{erfc}\eta\sqrt{S_c}\\
&- e^{ct/2}\Bigg[e^{-2\eta\sqrt{S_c ct}}\operatorname{erfc}\left(\eta\sqrt{S_c}-\sqrt{ct}\right)
\end{aligned}
$$

$$+ e^{2\eta\sqrt{S_c ct}} \operatorname{erfc}\left(\eta\sqrt{S_c} + \sqrt{ct}\right)\Bigg]\Bigg] \tag{18}$$

$$\theta = \frac{1}{2}\Big[e^{-2\eta\sqrt{P_r}\sqrt{(R-Q)t}} \operatorname{erfc}\left(\eta\sqrt{P_r} - \sqrt{(R-Q)t}\right) + e^{2\eta\sqrt{P_r}\sqrt{(R-Q)t}} \operatorname{erfc}\left(\eta\sqrt{P_r} + \sqrt{(R-Q)t}\right)\Big] \tag{19}$$

$$C = \operatorname{erfc}(\eta\sqrt{S_c}) \tag{20}$$

$$\operatorname{erfc}(a+ib) = \operatorname{erf}(a) + \frac{\exp(-a^2)}{2a\pi}\left[1 - \cos(2ab) + i\sin(2ab)\right] + \frac{2\exp(-a^2)}{\pi}\sum_{n=1}^{\infty}\frac{\exp(-\eta^2/4)}{\eta^2 + 4a^2}\left[f_n(a,b) + ig_n(a,b)\right] + \varepsilon(a,b)$$

where $a = 1 + \frac{1}{\gamma}$, $b = \frac{aPr(R-Q)-m}{1-aPr}$, $c = \frac{m}{aSc-1}$, and $\eta = \frac{y}{2\sqrt{t}}$,

$$f_n = 2a - 2a\cosh(nb)\cos(2ab) + n\sinh(nb)\sin(2ab)$$

and

$$g_n = 2a\cosh(nb)\sin(2ab) + n\sinh(nb)\cos(2ab)$$

$$|\varepsilon(a,b)| \approx 10^{-16}|\operatorname{erf}(a+ib)|$$

4. Results and discussions

Numerical calculations are made for several physical parameters, depending on the kind of flow and transport, Sr, M, t, Sc, and Gr, Gc, in order to interpret the findings and better comprehend the issue. The Prandtl number Pr is selected to have a value of 0.71, which is representative of air. For the above-mentioned parameters, the numerical values of the velocity, temperature, and concentration are calculated.

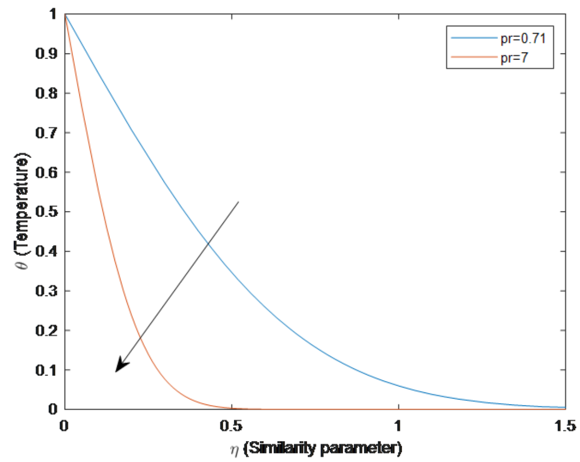

FIGURE 1. Temperature profile for different values of Pr

The effects of the Prandtl number Pr on the temperature profiles are illustrated in Fig. 1. It is seen that an increase in the Prandtl number leads to decreases in the temperature profiles.

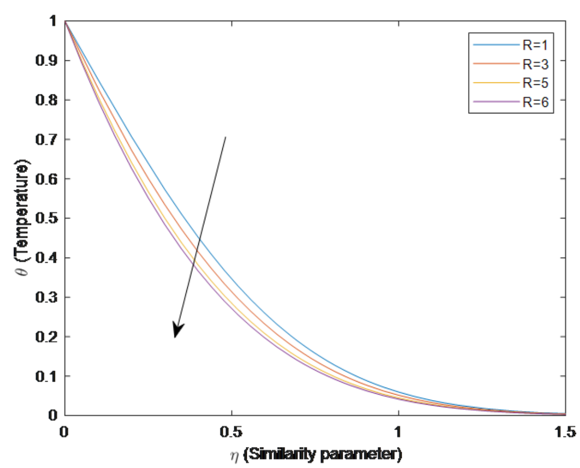

FIGURE 2. Temperature profile for different values of R

The effects of radiation parameter R on the temperature profiles are presented in Fig. 2. The effect of thermal radiation parameter is important in temperature profiles. It is observed that the temperature increases with decreasing radiation parameter. This shows there is a drop in temperature due to higher thermal radiation.

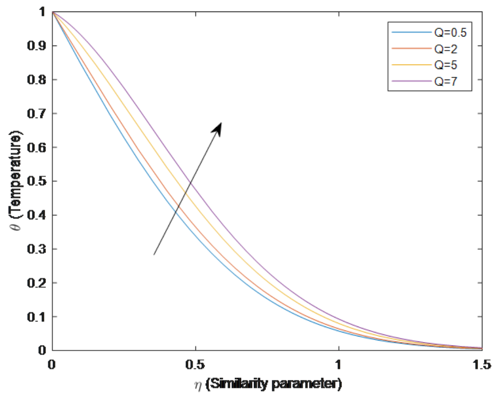

FIGURE 3. Temperature profile for different values of Q

The effects of heat generation parameter R on the temperature profiles are presented in Fig. 3. It is observed that the temperature increases with increasing heat generation parameter. This shows there is no increment in temperature due to higher generation parameter.

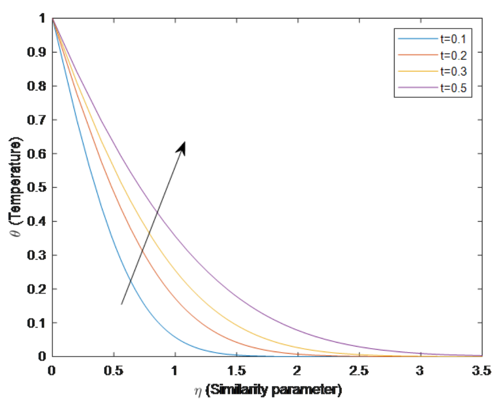

FIGURE 4. Temperature profile for different values of t

Figure 4 demonstrates the effect of Temperature profiles for different values of time (0.1, 0.2, 0.3, 0.5). It is observed that the wall temperature increases with increasing values of t.

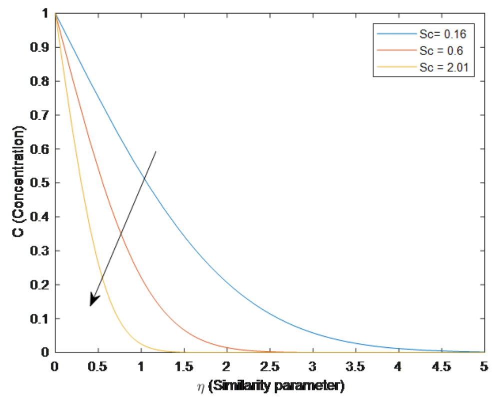

FIGURE 5. Concentration profile for different values of Sc

The effect of the Schmidt number Sc on the concentration profiles are presented in Fig. 5. It can be seen that with increasing value of the Schmidt number concentration decreases. Physically, increase in the Schmidt number leads to a decrease of molecular diffusivity which results in a decrease of concentration boundary layer. Hence, the concentrations of the species are higher for small values of Sc and lower for large values of Sc.

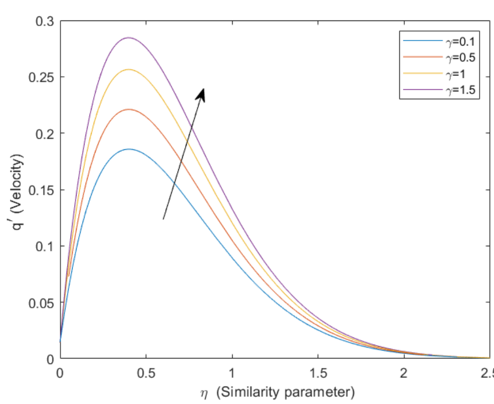

FIGURE 6. Velocity profile for different values of γ

The variation of the velocity profiles with Casson fluids parameter is presented in Fig. 6. It is noticed that there is a marked effect of increasing values of γ on the velocity distribution in the boundary layer. It is seen that the velocity profiles increase with increasing values of γ.

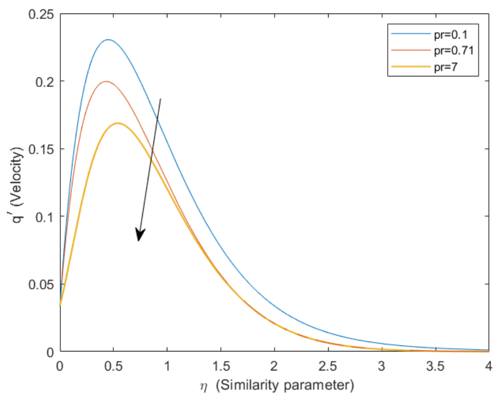

FIGURE 7. Velocity profile for different values of Pr

The effects of the Prandtl number Pr on velocity profiles are illustrated in Fig. 7. It is seen that an increase in the Prandtl number leads to decreases in the velocity profiles.

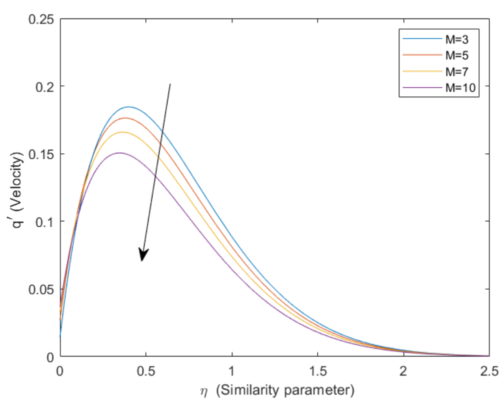

FIGURE 8. Velocity profile for different values of M

The effect of the magnetic parameter M on the velocity profiles can be seen from Fig. 8. The velocity curves show that the rate of transport is remarkably reduced with increasing values of the magnetic parameter indicating that the magnetic field tends to retard the motion of the fluid. Magnetic field may control the flow characteristics.

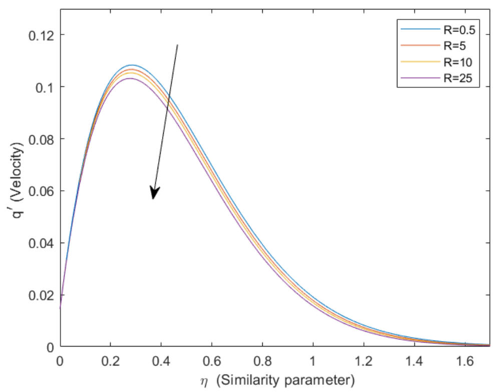

FIGURE 9. Velocity profile for different values of R

The effects of thermal radiation number R on the velocity profiles are shown in Fig. 9. It can be seen that the fluid velocity decreases with decrement of increasing values of thermal radiation parameter.

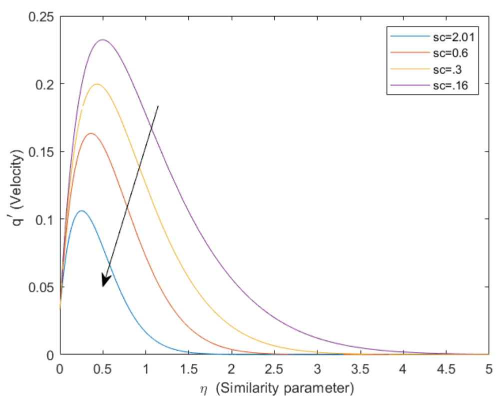

FIGURE 10. Velocity profile for different values of Sc

The influence of the Schmidt number Sc on the velocity profiles are shown in Fig. 10. It can be seen that the velocity of the fluid decreases with increasing values of Sc. This is due to the fact that increase of Sc leads to decrease of molecular diffusivity, which results in a decrease in the concentration and velocity boundary layer thickness.

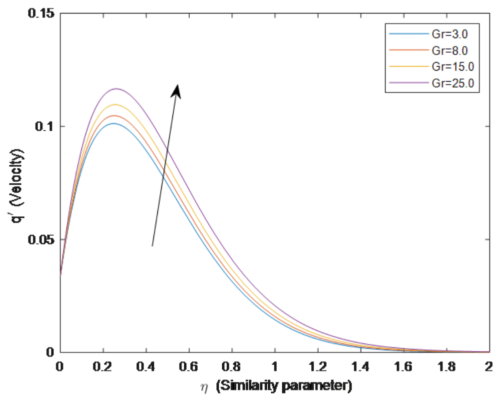

FIGURE 11. Velocity profile for different values of Gr

The variation of the velocity profiles with Grashof number Gr is presented in Fig. 11. It is seen that the fluid velocity increases with increasing Grashof number. This is due to the fact that buoyancy force enhances the fluid velocity and increases the boundary layer thickness with increase in the value of Grashof number.

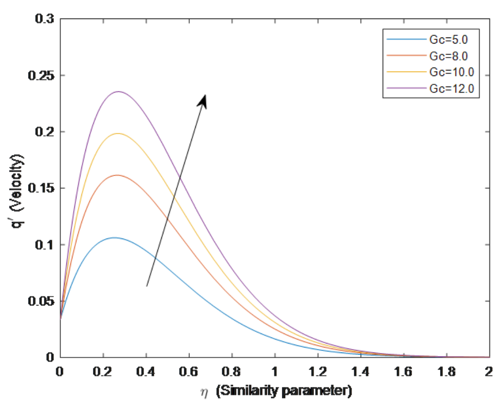

FIGURE 12. Velocity profile for different values of Gc

The variation of the velocity profiles with mass Grashof number Gc is presented in Fig. 12. It is seen that the fluid velocity increases with increasing mass Grashof number. This is due to the fact that buoyancy force enhances the fluid velocity and increases the boundary layer thickness with increase in the value of mass Grashof number.

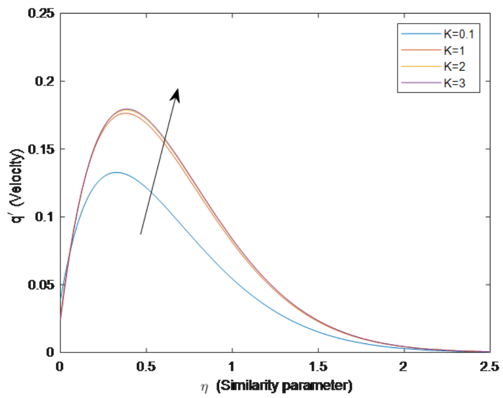

FIGURE 13. Velocity profile for different values of K

The variation of the velocity profiles with porous medium parameter K is presented in Fig. 13. It is seen that the fluid velocity increases with increasing the value of pirogue medium parameter. This is due to the fact that buoyancy force enhances the fluid velocity and increases the boundary layer thickness with increase in the value of K.

5. Conclusion

The purpose of this study was to obtain exact solutions for the effect of parabolic motion on unsteady natural convection of Casson fluid, thermal radiation, and heat generation effects past over an infinite vertical plate through porous medium in the presence of a transverse uniform magnetic field. The effects of the pertinent parameters on velocity, concentration, and temperature profiles are presented graphically. The most important concluding remarks can be summarized as follows:

- Temperature profile increases tendency with heat generation parameter Q and time t, whereas Prandtl Number Pr, thermal radiation parameter R reverse on it.
- Concentration boundary layer decreased with increasing the value of Schmidt number.
- Velocity decreases with an increase in Prandtl number Pr, magnetic parameter M, radiation parameter R, and Schmidt number Sc.
- Velocity increases with increasing values of permeability of porous medium K, thermal Grashof number Gr, mass Grashof number Gc, and Casson fluid parameter γ.

Conflicts of interest : The authors declare no conflict of interest.

Data availability : Not applicable

Acknowledgments : We would like to express our sincere gratitude to Vels Institute of Science, Technology and Advanced Studies, Chennai, for their invaluable support and resources provided for this research.

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