Digital Transformation

AI in Multidisciplinary Applications

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Preface

The rapid advancement of digital technologies has fundamentally reshaped the way knowledge is created, applied, and shared across disciplines. Digital Transformation: AI in Multidisciplinary Applications explores the transformative role of Artificial Intelligence as a catalyst for innovation in diverse domains such as engineering, healthcare, business, education, social sciences, and the creative industries. This book brings together interdisciplinary perspectives that demonstrate how AI-driven solutions enhance decision-making, optimize processes, and address complex real-world challenges. Emphasis is placed on emerging trends including machine learning, data analytics, intelligent automation, and ethical AI, highlighting their practical implications and societal impact. Designed for academicians, researchers, students, and industry professionals, the volume bridges theoretical foundations with applied case studies and contemporary research. By fostering cross-disciplinary dialogue and collaboration, this book aims to inspire innovative thinking and responsible adoption of AI technologies, contributing to sustainable digital transformation and future-ready solutions in an increasingly interconnected world.

Editors

CONTENTS

Chapter - 24

RADIATIVE HEAT TRANSFER IN ROTATING CASSON FLUID FLOWS THROUGH POROUS MEDIA

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Abstract

This chapter examines the unsteady flow of a Casson fluid past a vertical plate in a rotating porous medium, accounting for thermal radiation and heat generation. Using Laplace transforms, the study identifies that velocity is enhanced by heat generation and medium permeability but inhibited by higher radiation and Prandtl numbers. These findings provide critical insights for industrial applications like oil recovery and polymer manufacturing.

Keywords: Casson fluid, porous medium, vertical plate, Rotation, Radiation

1. Introduction

There are several uses for studying non-Newtonian fluids through porous media in research and engineering. Casson fluid has gotten a lot of attention because of its yield stress qualities. Blood is frequently represented as a Casson fluid in biomedical settings. This model is also used a lot in food and biological materials because it accurately explains how blood behaves under continuous shear stress and shear rate. Amar et al. [1] examined the heat transfer flow of Casson fluid over a moving wedge with a convective boundary amid heat creation. Numerous researchers have advanced this domain, building upon the foundational study by Casson [4], who examined a flow equation for pigment-oil suspensions akin to printing ink. McGregor et al. [7] examined the minimal energy theory in relation to Casson fluid, whereas Mermone et al. [8] performed a mathematical analysis of the peristaltic transport of Casson fluid.

Thermal diffusion, also known as the Soret effect, is the movement of mass caused by differences in concentration and temperature. Charles Soret conducted the inaugural experimental study on thermal diffusion in mass transfer issues in 1879. Maran et al. [6] investigated heat and mass transfer in unsteady MHD free convection flow across a vertical plate, taking into account thermal diffusion and chemical reaction. Devi and Raj [5] examined the effects of thermo-diffusion on unstable hydromagnetic free convection flow, incorporating heat and mass transfer past a moving vertical plate, along with time-dependent suction and a heat source in a slip flow regime. More recently, Aruna et al. [2] examined the effects of magnetic fields and the Hall effect on flow past a parabolically accelerated vertical plate subjected to heat radiation. Selvaraj and Jothi [3] examined the influence of a heat source on magnetohydrodynamic (MHD) and radiation-absorbing fluid flow via an exponentially accelerating vertical plate within a porous medium. This study examined the synergistic effects of radiation, heat generation, rotation, and the properties of porous media on the behaviour of Casson fluid flow. These findings are particularly beneficial in biomedical applications, including blood flow in rotating medical devices, and in geophysical and industrial processes involving non-Newtonian fluids affected by heat influences.

2. Mathematical Formulation

Let us consider a Casson fluid stream over 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 is taken normal direction towards the plate. The assumptions and taking into account Boussinesq's approximation, the governing partial differential equation with initial and boundary conditions are

$$\frac{\partial U}{\partial t} - 2\Omega V = GrT + GcC + (1 + \frac{1}{\gamma})\frac{\partial^2 U}{\partial y^2} - MU - \frac{1}{K}U \tag{1}$$

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

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - R\theta + Q\theta \tag{3}$$

$$\frac{\partial C}{\partial t} = \frac{1}{sc}\frac{\partial^2 C}{\partial y^2} \tag{4}$$

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

$$\frac{\partial q'}{\partial t} = \mathrm{Gr}\theta + \mathrm{Gc}C + a\frac{\partial^2 q'}{\partial y^2} - mq' \tag{5}$$

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

$$\begin{aligned} &q' = 0, \quad \theta = 0, \quad C = 0 \quad for\ all\ y \geq 0\ and\ t \leq 0 \\ &q' = t^2, \quad \theta = 1, \quad C = 1 \quad y = 0 \text{ and } t > 0 \\ &q' \to 0, \quad \theta \to 0, \quad C \to 0 \quad y \to 0 \text{ as } y \to \infty \text{ and } t > 0 \end{aligned} \tag{6}$$

where $m = 2i\Omega + \frac{1}{K}$

3. Solution

Laplace transforms are used to solve the equations (3), (4), and (5), which have a dimensionless administration condition and associated initial and boundary conditions. A final inverse transform is done, and the solutions are determined in the following manner. A final inverse transform is done, and the solutions are determined in the following manner.

$$\theta = \frac{1}{2}\left[\begin{array}{l} e^{-2\eta\sqrt{P_r}\sqrt{(R-Q)t}} erfc\left(\eta\sqrt{P_r} - \sqrt{(R-Q)t}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{(R-Q)t}} erfc\left(\eta\sqrt{P_r} + \sqrt{(R-Q)t}\right) \end{array}\right] \tag{7}$$

$$C = erfc(\eta\sqrt{Sc}) \tag{8}$$

$$q' = \left\{\begin{array}{l} \left[\frac{a\eta^2 t}{(m)} + t^2\right]\frac{1}{2}\left[e^{-2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta - \sqrt{\frac{m}{a}t}\right) + e^{2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta + \sqrt{\frac{m}{a}t}\right)\right] \\ + \left[\frac{a}{4(m)} - t\right]\sqrt{t}\frac{1}{\sqrt{\frac{m}{a}}}\left[e^{-2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta - \sqrt{\frac{m}{a}t}\right) - e^{2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta + \sqrt{\frac{m}{a}t}\right)\right] \\ -\frac{2a}{m}\sqrt{t/\pi}e^{-\left(\eta^2 - \frac{m}{a}\right)t} \end{array}\right\} \tag{9}$$

$$+\frac{G_r}{b(1-aP_r)}\left\{\begin{array}{l} -\frac{e^{bt}}{2}\left[e^{-2\eta\sqrt{\left(\frac{m+b}{a}\right)t}} erfc\left(\eta - \sqrt{\left(\frac{m+b}{a}\right)t}\right) + e^{2\eta\sqrt{\left(\frac{m+b}{a}\right)}} erfc\left(\eta + \sqrt{\left(\frac{m+b}{a}\right)t}\right)\right] \\ +\frac{1}{2}\left[e^{-2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta - \sqrt{\frac{m}{a}t}\right) + e^{2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta + \sqrt{\frac{m}{a}t}\right)\right] \end{array}\right\}$$

$$+\frac{G_m}{c(1-aS_c)}\left\{\begin{array}{l} \frac{1}{2}\left[e^{-2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta - \sqrt{\frac{m}{a}t}\right) + e^{2\eta\sqrt{\frac{m}{a}t}} erfc\left(\eta + \sqrt{\frac{m}{a}t}\right)\right] \\ -\frac{e^{ct}}{2}\left[e^{-2\eta\sqrt{\left(\frac{m+c}{a}\right)t}} erfc\left(\eta - \sqrt{\left(\frac{m+c}{a}\right)t}\right) + e^{2\eta\sqrt{\left(\frac{m+c}{a}\right)}} erfc\left(\eta + \sqrt{\left(\frac{m+c}{a}\right)t}\right)\right] \end{array}\right\}$$

$$-\frac{G_r}{b(1-aP_r)}\left[\begin{array}{l} \frac{1}{2}\left[e^{-2\eta\sqrt{P_r}\sqrt{(R-Q)t}} erfc\left(\eta\sqrt{P_r} - \sqrt{(R-Q)t}\right) + e^{2\eta\sqrt{P_r}\sqrt{(R-Q)t}} erfc\left(\eta\sqrt{P_r} + \sqrt{(R-Q)t}\right)\right] \\ +\frac{e^{bt}}{2}\left[\begin{array}{l} e^{-2\eta\sqrt{P_r}\sqrt{(R+b-Q)t}} erfc\left(\eta\sqrt{P_r} - \sqrt{(R+b-Q)t}\right) \\ +e^{2\eta\sqrt{P_r}\sqrt{(R+b-Q)t}} erfc\left(\eta\sqrt{P_r} + \sqrt{(R+b-Q)t}\right) \end{array}\right] \end{array}\right]$$

$$-\frac{G_m}{c(1-aS_c)}\left\{erfc\eta\sqrt{Sc} \_ \frac{e^{ct}}{2}\left[e^{-2\eta\sqrt{((Sc)c)t}} erfc(\eta\sqrt{Sc} - \sqrt{ct}) + e^{2\eta\sqrt{((S_c)c)t}} erfc(\eta\sqrt{Sc} + \sqrt{ct})\right]\right\}$$

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.

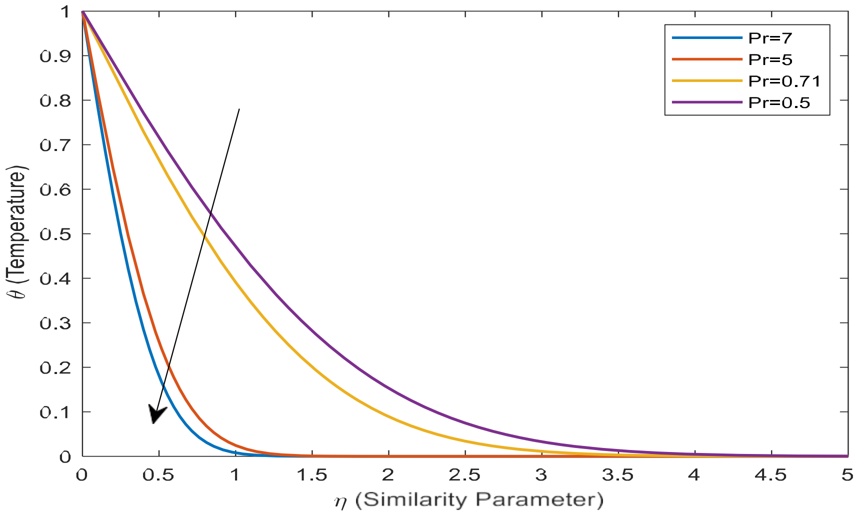

Fig. 1 Temperature profile for different values of pr

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

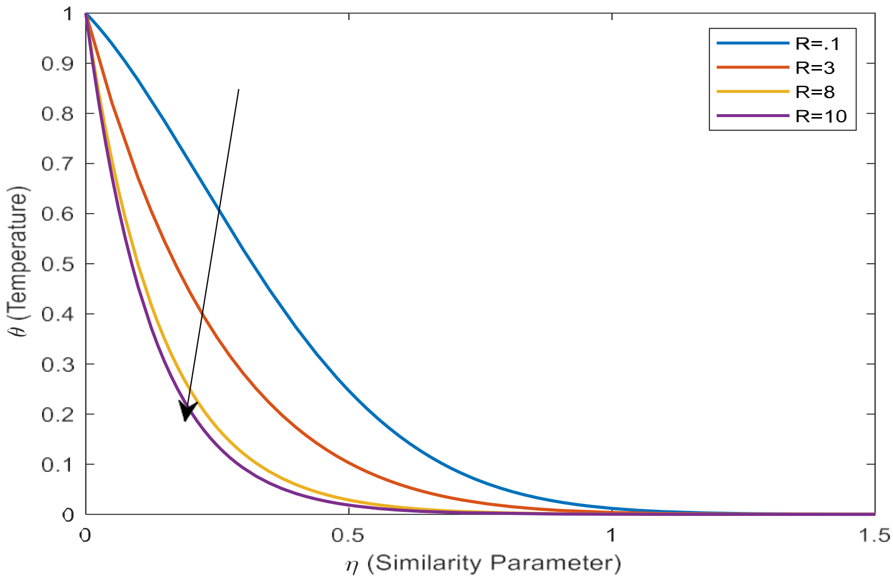

Fig.2 Temperature profile for different values of R

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

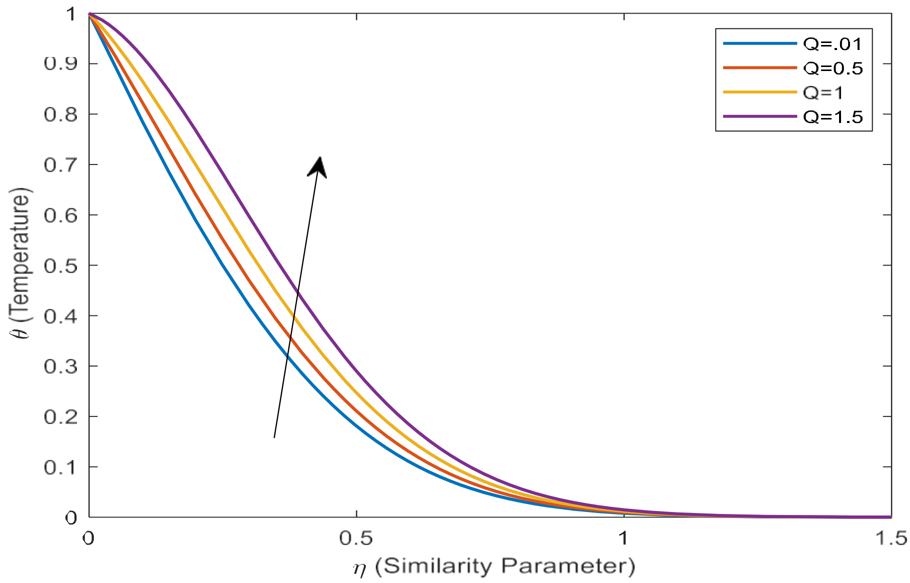

Fig.3 Temperature profile for different values of Q

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 the higher generation parameter

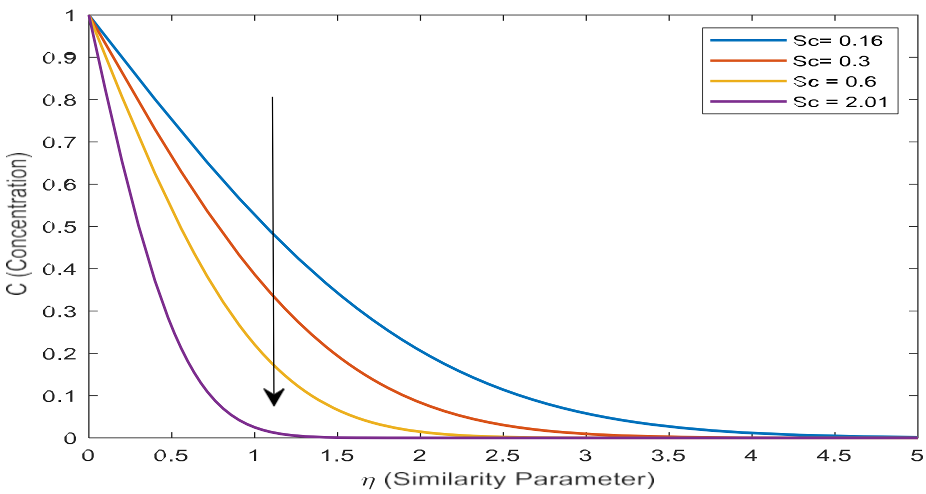

Fig.4 Concentration profile for different values of Sc

The effect of the Schmidt number Sc on the concentration profiles is presented in Fig.4. It can be seen that with increasing value of the Schmidt number, concentration decreases. Physically, an increase in the Schmidt number leads to a decrease in molecular diffusivity, which results in a decrease of concentration boundary layer. Hence, the concentrations of the species are higher for small values of c S and lower for large values of Sc.

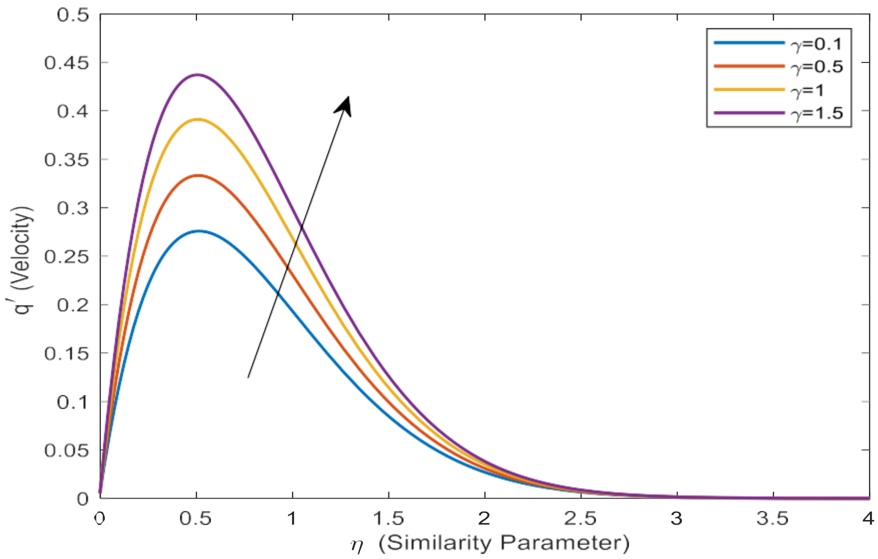

Fig.5 Velocity profile for different values of γ

The variation of the velocity profiles with the Casson fluid parameter is presented in Fig.5. 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.

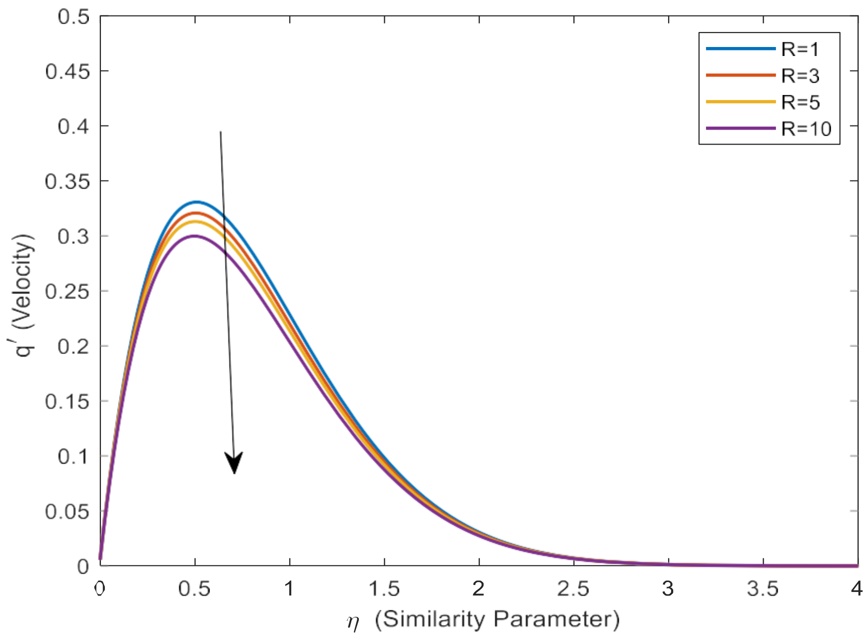

Fig.6 Velocity profile for different values of R

The effects of thermal radiation number R on the velocity profiles are shown in Fig.6. It can be seen that the fluid velocity decreases with decrement of increasing values of thermal radiation parameter.

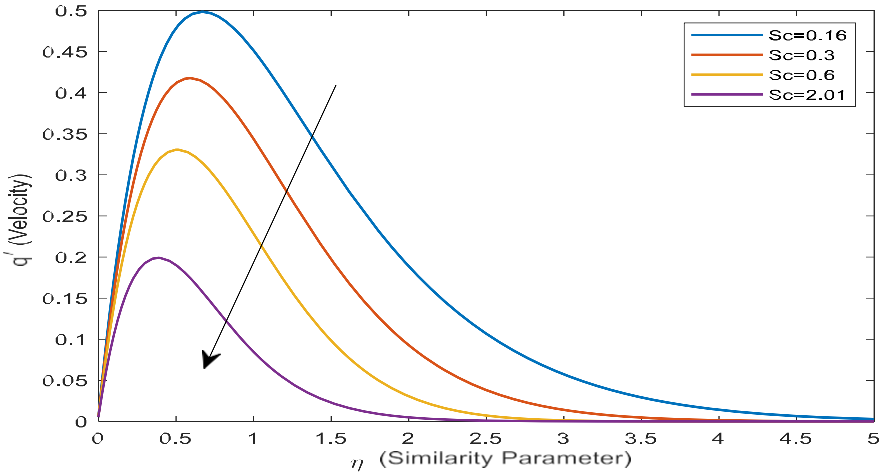

Fig.7 Velocity profile for different values of Sc

The influence of the Schmidt number Sc on the velocity profiles is shown in Fig.7. It can be seen that the velocity of the fluid decreases with increasing values of Sc. This is due to the fact that an increase in Sc leads to a decrease in molecular diffusivity, which results in a decrease in the concentration and velocity boundary layer thickness.

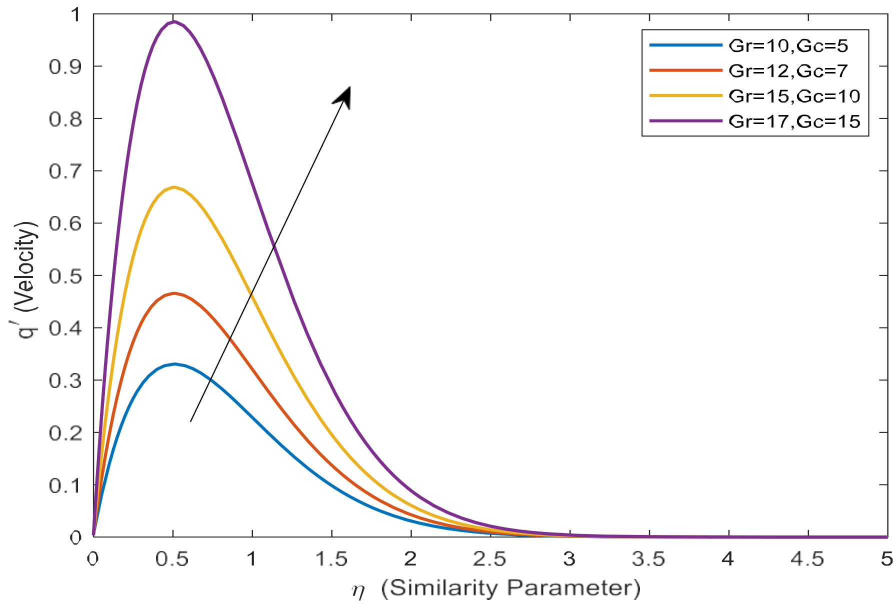

Fig.8 Velocity profile for different values of Gr and Gc

The variation of the velocity profiles with Grashof number Gr is presented in Fig. 8. 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 an increase in the value of the Grashof number.

5. Conclusion

The goal of this study was to find exact analytical solutions for the unsteady natural convection flow of a Casson fluid that is moving in a parabolic shape. These solutions had to take into account the effects of thermal radiation and heat generation over an infinite vertical plate that is embedded in a porous medium and is subject to a transverse uniform magnetic field. Different physical and non-dimensional factors have been looked at and shown to have effects on velocity, temperature, and concentration profiles. The following important conclusions can be made from the results. The temperature profile goes up as the heat production parameter (Q) and time (t) values go up, but it goes down as the Prandtl number (Pr) and thermal radiation parameter (R) values go up. As the Schmidt number (Sc) goes up, the concentration boundary layer gets thinner, which means that mass diffusion slows down. Increasing the permeability of the porous material (K), the thermal Grashof number (Gr), the mass Grashof number (Gc), and the Casson fluid parameter (γ) all make the Casson fluid move faster. But as the Prandtl number (Pr), the thermal radiation measure (R), and the Schmidt number (Sc) go up, the speed goes down. These results teach us a lot about how fluids behave when thermal, magnetic, and porous media effects are mixed. They could be used in heat exchangers in industry, the processing of polymers, and the study of biomedical fluid dynamics.

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