Magnetohydrodynamic Flow of Casson and Carreau Fluids through a Porous Medium with Variable Thermal Conductivity in the Context of Suction or Injection.

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Abstract

The central focus of this study is to explore the implications of magnetohydrodynamics on the heat transfer characteristics of Casson and Carreau fluids flowing through a porous medium along a stretching sheet. The influence of variable thermal conductivity and suction/injection parameters is also considered. Employing similarity transformations, the governing equations of magnetohydrodynamics for the Casson and Carreau fluid models are transformed into dimensionless nonlinear ordinary differential equations. The study examines velocity, concentration, and temperature profiles, as well as surface drag, Nusselt number, and Sherwood number, considering a range of flow parameters. The findings are presented through visual plots and tables. The fluid flow behavior is analyzed for various suction and injection scenarios. Analysis reveals that the velocity profile diminishes with an increase in the magnetic parameter, while the reverse trend is observed for rising Weissenberg numbers in both suction and injection cases.

Introduction

"Non-Newtonian fluids have garnered substantial attention in recent decades due to their wide-ranging applications in engineering, environmental sciences, and geophysics. The study of fluid motion and heat transfer of non-Newtonian fluids past a stretching sheet has also regained considerable interest among researchers [1]. This is owing to its significance in various industrial and engineering contexts, including solidification of liquid crystals, specialty lubricants, wire drawing, fiber spinning, petroleum extraction, continuous cooling processes, and glass-fiber production, among others. In recent years, multiple researchers [2] (in 2016, 2017, and 2018) have published their work concerning flow past a stretching sheet under diverse conditions. The concept of magnetohydrodynamics (MHD) has found application in the design of pumps, heat exchangers, space vehicles, and thermal systems [3]. The study of MHD non-Newtonian fluid flow through a permeable medium has captured the interest of researchers due to its potential roles in applications such as alloy and metal solidification, nuclear fuel debris treatment, and beyond (notable works in 2020, 2021, 2019, 2020, 2023, 2022, and 2014) [4].

Given the significance of Soret and Dufour effects on fluids with varying molecular weights, researchers have produced numerous studies. For instance, Alam et al. (2005) explored the influence of Soret and Dufour effects on free convection MHD and mass transport flow using numerical methods [5]. Hasanuzzaman et al. (2021) investigated Soret and Dufour effects on MHD unsteady mixed convection flow past a radiative porous vertical plate. Cheng (2011) examined the impact of Soret and Dufour effects on mixed convection heat and mass transport along a downward-pointing vertical wall [6]. Sharma et al. (2014) studied the influence of Soret and Dufour effects on heat and mass transport in MHD mixed convection flow with Ohmic heating [7]. The complex interplay of mixed convective flow and incompressible flow in the presence of buoyancy and a transverse magnetic field, along with Soret and Dufour effects, has been investigated by Makinde (2011)."

Mathematical formulation

Consider two-dimensional steady, MHD boundary layer flow of viscous, incompressible Casson and Carreau nanofluid over the heated permeable porous elongated sheet in the presence of chemical reaction were examined [8].

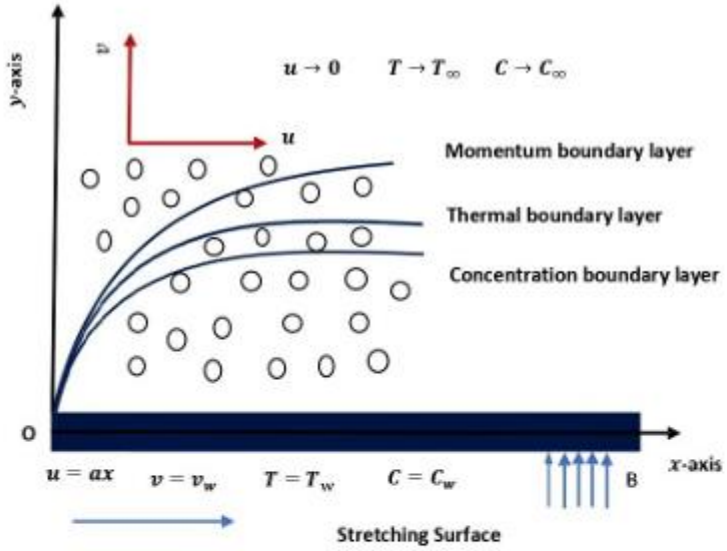

Fig-1. Schematic diagram of the flow

The governing equations for the fluid flow of the model are formulated as [2022]:

$$u_x + v_y = 0\,, \tag{1}$$

$$uu_x + vu_y = \nu\left(\left(1+\frac{1}{\gamma}\right)+\frac{3(n-1)}{2}\Gamma^2\left(u_x\right)^2\right)u_{yy} - \left(\frac{\sigma B_0^2}{\rho}+\frac{\nu}{K^*}\right)u\,, \tag{2}$$

$$uT_x + vT_y = \frac{1}{\rho c_p}\left(k(T)\,T_{yy}\right) - \frac{1}{\rho c_p}q_{ry} + D_{TC}C_{yy}\,, \tag{3}$$

$$uC_x + vC_y = D_{SM}C_{yy} + D_{CT}T_{yy} - Kr^*\left(C - C_\infty\right)\quad , \tag{4}$$

with the following boundary conditions that physically go along

$$\begin{aligned} &u = u_w = ax, v = v_w, T = T_w, C = C_w \quad \text{at} \quad y = 0,\\ &\qquad u \to 0, T \to T_\infty, C \to C_\infty \quad \text{as} \quad y \to \infty. \end{aligned} \tag{5}$$

In this study we incorporated the variable thermal conductivity, and it is expressed as $k(T) = k\left(1+\beta\left(\frac{T-T_\infty}{T_w - T_\infty}\right)\right)$.

Results

The main goal of this research is to investigate and discuss a complete analysis of the steady, MHD boundary layer CCF flow past an infinite stretching sheet embedded with porous media. Similarity and shooting schemes were employed to obtain the solutions for velocity, temperature, and concentration profiles [9]. Thermal radiation, suction/injection, and variable thermal conductivity effects are considered in the study. The variation of non-dimensional fluid motion, concentration, and temperature is discussed in detail for different physical parameter values, including the magnetic parameter, Weissenberg number, porous parameter.

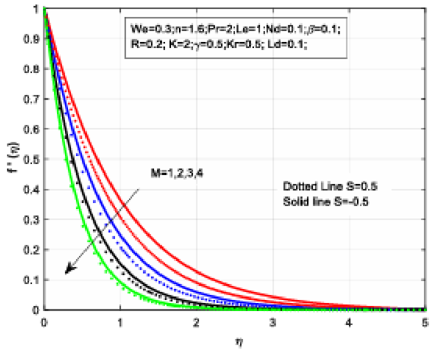

Fig. 2. Velocity profile versus magnetic parameter.

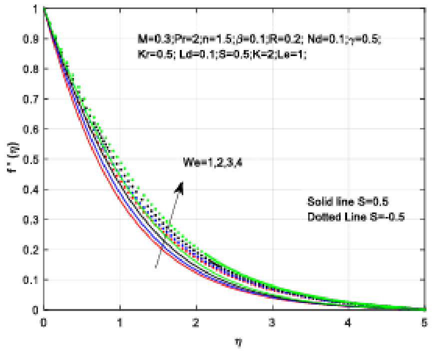

Fig. 3. Velocity profile versus Weissenberg number

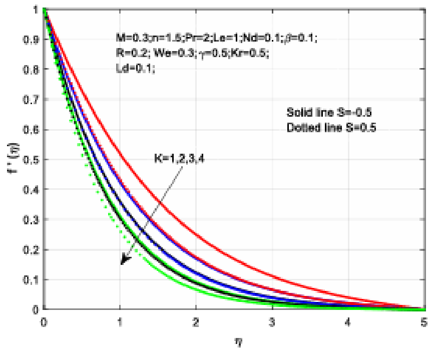

Fig. 4. Velocity profile versus porous parameter.

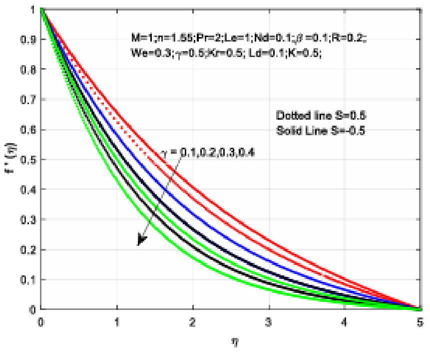

Fig. 5. Velocity profile versus Casson fluid parameter.

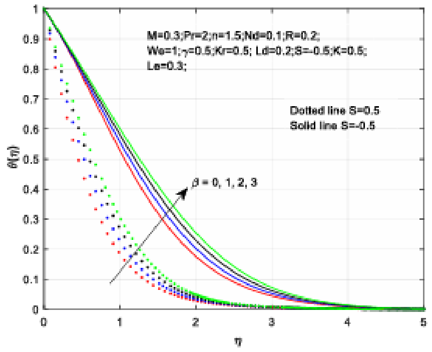

Fig. 6. Temperature profile versus thermal conductivity parameter.

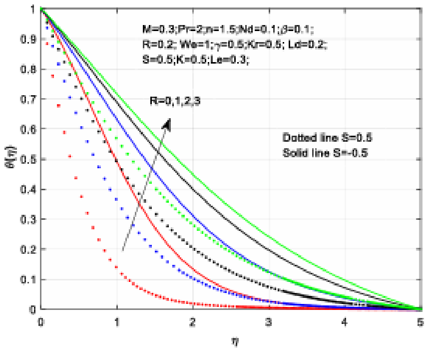

Fig. 7. Temperature profile versus radiation parameter.

Conclusions

The numerical investigation delves into the MHD boundary layer flow, heat, and mass transport characteristics of Carreau fluid (CCF). Notably, the study accounts for the influences of thermal radiation, suction/injection, and variable thermal conductivity. The key findings derived from the study are as follows:

- The fluid motion diminishes as the magnetic parameter, porous parameter, and time constant parameter increase, while it intensifies with higher Weissenberg numbers.

- Fluid concentration drops with higher chemical reaction parameters but rises with an increase in Dufour number and Dufour solutal Lewis number.

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