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Similarity solution of 3D Casson nanofluid flow over a stretching sheet with convective boundary conditions

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Abstract

In this study, we analyzed the three-dimensional magnetohydrodynamic Newtonian and non-Newtonian fluid flow. Heat and mass transfer over a stretching surface in the presence of thermophoresis and Brownian motion is investigated. The transformed governing equations are solved numerically via Runge–Kutta based shooting technique. We obtained good accuracy of the present results by comparing with the exited literature. The influence of dimensionless parameters on velocity, temperature and concentration profiles along with the friction factor, local Nusselt and Sherwood numbers are discussed with the help of graphs and tables. It is found that an increase in the stretching ratio parameter enhances the heat and mass transfer rate. The heat and mass transfer rate in non-Newtonian fluid is comparatively high while compared with the heat and mass transfer rate in Newtonian fluid.

Keywords: Newtonian and Non-Newtonian fluids; Thermophoresis; Brownian motion; Stretching sheet

1. Introduction

The study of boundary layer flow and heat transfer over a stretching surface has attracted the attention of many researchers due to its huge industrial and engineering applications. In the field of industry, metallurgical processes such as drawing of continuous filaments through quiescent fluids, annealing and tinning of copper wires, manufacturing of plastic and rubber sheets, crystal growing, and continuous cooling and fiber spinning, in addition to wide-ranging applications in many engineering processes, such as extrusion of polymer, wire drawing, manufacturing foods and paper, in textile and glass fiber production etc. During the manufacturing of these sheets, the melt issues from a slit and it is stretched to achieve the desired thickness. The final product depends on two characteristics first is the rate of cooling in the process and the other is stretching rate. In view of these applications, Sakiadis [1] initiated the study of boundary layer flow past a stretching surface. Later, Crane [2] extended the idea for the two-dimensional

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boundary layer flow of an incompressible viscous fluid flow past a linearly stretching surface. This problem was later extended by Wang [3] and discussed for three-dimensional case. Afterwards, many investigations were made to gain insight information regarding the flow over a stretching/shrinking sheet in various situations. Such situations include the considerations of porous surfaces, MHD, suction/injection, thermal radiation, slip effects, convective boundary condition, etc. was studied by Samir et al. [4], Vajravelu et al. [5], Mohan Krishna et al. [6], Mabood et al. [7], Raju et al. [8], Mahapatra et al. [9], Sandeep and Sulochana [10]. Magyari and Keller [11] studied the boundary layer flow due to a non-linearly stretching surface. Ishak et al. [12] presented the concept of unsteady two dimensional mixed convection boundary layer flow and heat transfer through vertical stretching surface. Wubshet and Bandari [13] analyzed the boundary layer flow and heat transfer on a penetrable stretching surface due to a nanofluid with the influence of magnetic field and slip boundary conditions.

The study of non-Newtonian fluids has keen interest among the researchers because of its variety of applications in engineering, chemical and petroleum industries. In the class of non-Newtonian fluids, Casson fluid has unique characteristics, which have wide application in food processing, in metallurgy, drilling operation and bio-engineering operations, etc. Hayat et al. [14] elaborated the concept of mixed convection stagnation point flow of Casson fluid under the effect of convective boundary conditions. Flow through a porous linearly stretching surface of MHD three-dimensional Casson fluid was analyzed by Nadeem et al. [15]. Hayat et al. [16] studied the variable thermal radiation effect over a three-dimensional stretched flow of Jeffery fluid. Nadeem et al. [17] examined the magneto-hydrodynamic boundary layer flow of a Casson fluid past an exponentially shrinking surface. Haq et al. [18] investigated the effect of MHD and convective heat transfer on Casson nanofluid flow past a linearly shrinking surface.

Jayachandra Babu et al. [19] discussed the effect of radiation on stagnation-point flow of a micropolar fluid over a nonlinearly stretching surface with suction/injection effects. Pramanik [20] presented the concept of Casson fluid flow and heat transfer over a porous exponentially stretching sheet in the presence of thermal radiation. Bhattacharyya [21] studied the Boundary layer stagnation point flow of a Casson fluid and heat transfer over a stretching/shrinking surface. The effect of a convective boundary condition on the two-dimensional boundary layer flow of a nanofluid over a linear stretching surface is numerically presented by Makinde and Aziz [22]. Zaimi et al. [23] illustrated the two-dimensional boundary layer flow and heat transfer of a nanofluid over a nonlinearly permeable stretching/shrinking surface with Brownian motion and thermophoresis effects. Nadeem and Lee [24] discussed the effects of Brownian motion parameter and thermophoresis parameter on the steady boundary layer flow of a nanofluid past an exponential stretching surface. Hayat et al. [25] discussed the effects of convective boundary conditions on MHD flow of nanofluids in porous medium past an exponentially stretching surface. Ferdows et al. [26] examined the effect of Brownian motion parameter and thermophoresis parameter on MHD mixed convective boundary layer flow of a nanofluid over a porous exponentially stretching sheet. The researchers [27,28] studied the heat and mass transfer characteristics of non-Newtonian fluid through stretching sheet. Makinde et al. [29] elaborated the influence of thermophoresis and radiation on heat transfer of MHD flow with varying viscosity past a heated plate immersed in a porous medium. Khan et al. [30] and Khan et al. [31] discussed the mixed convective heat and mass transfer of power law nanofluid and third grade nanofluid past on a heated vertical surface and heated stretching surface.

In this study, we analyzed the three-dimensional magnetohydrodynamic Newtonian and non-Newtonian fluid flow, heat and mass transfer over a stretching surface in the presence of thermophoresis and Brownian motion is investigated. The transformed governing equations are solved numerically via Runge–Kutta based shooting technique. The influence of dimensionless parameters on velocity, temperature and concentration profiles along with the friction factor, local Nusselt and Sherwood numbers are discussed with the help of graphs and tables.

2. Mathematical formulation

Consider a three-dimensional, steady, incompressible flow of a Casson fluid over a stretching sheet. It is considered that the sheet is stretched along xy-plane while fluid is placed along the z-axis. It is assumed that induced magnetic field is negligible. Thermophoresis and Brownian motion effects are taken into account. Here, we assumed that the sheet has stretched with the linear velocities $u = ax$ and $v = by$ along the xy-plane, respectively, with constants a and b (see Fig. 1). Moreover, it is considered that a constant magnetic field is applying normal to the fluid flow. The heat and mass transfer process is taken in to account. The rheological equation of state for an isotropic flow of a Casson