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Full Length Article

Effects of induced magnetic field and homogeneous–heterogeneous reactions on stagnation flow of a Casson fluid

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ABSTRACT

In this study, we analyzed the induced magnetic field effect on the stagnation-point flow of a non-Newtonian fluid over a stretching sheet with homogeneous–heterogeneous reactions and non-uniform heat source or sink. The transformed ordinary differential equations are solved numerically using Runge–Kutta and Newton's method. For physical relevance we analyzed the behavior of homogeneous and heterogeneous profiles individually in the presence of induced magnetic field. The effects of different non-dimensional governing parameters on velocity, induced magnetic field, temperature and concentration profiles, along with the skin friction coefficient and local Nusselt number, are discussed and presented through graphs. The results of the present study are validated by comparing with the existed literature. Results indicate that induced magnetic field parameter and stretching ratio parameter have the tendency to enhance the heat transfer rate.

1. Introduction

The study of convection flows over stretching sheet has extensive applications in the field of manufacturing production of plastic, polythene, paper, polymer extrusion, cooling of elastic sheets, and fiber technology, science and engineering technology. The applications of stretching surface were broadly discussed by Chaim [1]. The flow of a non-Newtonian fluid over a stretching sheet has potential applications in the biosciences, blood flows, jelly and engineering. Casson is a shear thinning liquid. It can exhibit yield stress. If applied yield stress is greater than the shear stress, then it acts as solid, whereas if yield stress is lesser than the applied shear stress then it starts to move. The application of Casson fluid was discussed by Hayat et al. [2]. The homogeneous–heterogeneous reactions on stagnation-point flow past a stretching surface was discussed by Bachok et al. [3]. Peristaltic flow of a Carreau fluid flow with convective boundary conditions was analyzed by Hayat et al. [4], and concluded that brinkman number and hall parameters help to enhance the thermal boundary layer thickness. Khan and Pop [5] investigated the viscoelastic fluid flow through a stretching surface with homogeneous–heterogeneous effects. Hayat et al. [6] illustrated the three-dimensional MHD bidirectional flow of a nanofluid past a permeable stretching sheet in the presence of slip condition and homogeneous–heterogeneous reactions.

Heat transfer analysis of magneto hydrodynamic stagnation-point flow toward a stretching surface in the presence of induced magnetic field was done by Ali et al. [7]. Abbas et al. [8] considered the slip conditions and homogeneous–heterogeneous effects on MHD stagnation-point flow of viscous fluid past a stretching or shrinking surface. Sandeep and Sulochana [9] discussed the mixed convection flow of an unsteady micropolar fluid flow over a stretching or shrinking sheet in the presence of magnetic and non-uniform heat source/sink. Raju et al. [10] analyzed the non-uniform heat source or sink effects on ferrofluid flow through a flat plate with thermal radiation and aligned magnetic field effects. The stagnation-point flow toward a vertical stretching surface was explained by Ishak et al. [11]. Mallikarjuna et al. [12] investigated the variable porosity regime on convection flow over a vertical cone with chemical reaction and magnetic field effect. An unsteady MHD nanofluid flow through a stretching surface in the presence of non-uniform heat source/sink and magnetic field effect was studied by Sandeep et al. [13]. Pal and Mandal [14] analyzed the induced magnetic field effect on stagnation point flow of a nanofluid past a non-isothermal stretching surface.

Heat transfer analysis of a stagnation point viscoelastic fluid flow toward a stretching sheet was investigated by Mahapatra

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and Gupta [15]. Gorla [16] depicted the stagnation point flow of non-Newtonian fluid flow in the presence of transverse magnetic field. Heat transfer characteristics of MHD Casson fluid flow past a permeable an exponentially stretching sheet was considered by Raju et al. [17]. Hayat et al. [18] analyzed the two-dimensional flow of Eyring–Powell fluid flow toward a stretching sheet with homogeneous–heterogeneous reactions and concluded that the Eyring–Powell fluid material parameter enhances the boundary layer thickness. Heat transfer characteristics of Casson fluid flow past a permeable exponentially stretching sheet in the presence of thermal radiation was discussed by Pramanik [19] and concluded that an increasing value of Casson parameter suppresses the velocity profiles. Animasaun [20] discussed the MHD Casson fluid flow in the presence of viscous dissipation. Stagnation point flow of optimized exact solution for oblique flow of Casson-nanofluid with convective boundary conditions was discussed by Nadeem et al. [21]. Makinde and Aziz [22,23] examined the boundary layer analysis of a nanofluid flow through a stretching surface in the presence of convective boundary conditions and buoyancy effects. MHD heat transfer characteristics of an electrically conducting nanofluid flow through nonlinearly stretching surface in the presence of viscous dissipation was examined numerically by Mabood et al. [24]. Nadeem and Saleem [25] proposed an analytical solution for an unsteady mixed convection MHD flow on a rotating cone. Dissipation and magnetic field effects on the boundary layer flow of a power-law nanofluid induced by a permeable stretching/shrinking sheet were investigated numerically by Dhanai et al. [26]. Chaudhary and Merkin [27] proposed a simple isothermal model for homogeneous–heterogeneous reactions for boundary layer flow. Very recently, Hayat et al. [28] and Mahanta and Shaw [29] investigated the heat transfer characteristics of Casson fluid through different channels. Hayat et al. [30] studied the homogeneous and heterogeneous reactions on the flow over a nanotube with homogeneous heating. Further, Farooq et al. [31] discussed the homogeneous–heterogeneous characteristics on the flow of Jeffrey fluid.

In this study, we investigated the induced magnetic field and non-uniform heat source or sink effects on the stagnation-point flow of a non-Newtonian fluid toward a stretching sheet in the presence of homogeneous–heterogeneous reactions. The emerging set of governing nonlinear partial differential equations is transformed into a set of ordinary differential equations using similarity transformation, which are then solved numerically using Runge–Kutta and Newton's method. The effects of different non-dimensional governing parameters on velocity, induced magnetic field, temperature and concentration profiles, along with the friction factor and local Nusselt number, are discussed and presented through graphs and tables.

2. Flow analysis

Consider a steady, incompressible, electrically conducting stagnation point flow of a Casson fluid toward a stretching sheet in the presence of induced magnetic field, non-uniform heat source/sink and homogeneous–heterogeneous reactions. The stretching sheet is considered along the x-axis and y-axis is normal to it as displayed in Fig. 1.

The governing boundary layer equations for the flow and induced magnetic field profiles are given by [7].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\frac{\partial I_1}{\partial x}+\frac{\partial I_2}{\partial y}=0, \tag{2}$$

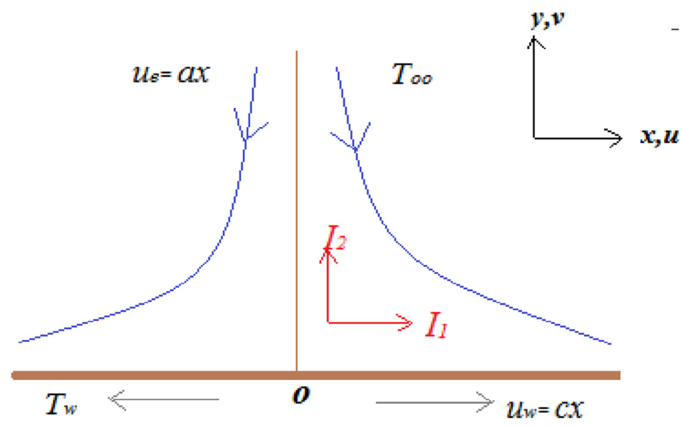

Fig. 1. Physical model and coordinate system.

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=u_e(x)\frac{\partial u_e(x)}{\partial x}+\nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+\frac{\mu}{4\pi}\left(I_1\frac{\partial I_1}{\partial x}+I_2\frac{\partial I_1}{\partial y}-I_e\frac{\partial I_e}{\partial x}\right), \tag{3}$$

$$u\frac{\partial I_1}{\partial x}+v\frac{\partial I_1}{\partial y}=I_1\frac{\partial u}{\partial x}+I_2\frac{\partial u}{\partial y}+\mu_e\frac{\partial^2 I_1}{\partial y^2}, \tag{4}$$

Subjected to the boundary conditions

$$\left.\begin{aligned}&u=u_w(x)=cx,\ v=0,\ \frac{\partial I_1}{\partial y}=I_2=0, && \text{at } y=0,\\ &u=u_e(x)=ax,\ \frac{\partial u}{\partial y}\to 0,\ \frac{\partial v}{\partial y}\to 0,\ I_1=I_e(x)=I_0 x, && \text{as } y\to\infty,\end{aligned}\right\} \tag{5}$$

where μ_e is the magnetic diffusivity of the fluid, which is given by $\mu_e = 1/4\pi\sigma$, u and v are the velocity components along the x and y directions, respectively, ρ is the density, and ν is the viscosity.

To convert the governing equations of the flow into a set of nonlinear ordinary differential equations, we now introduce the following similarity transformation:

$$\left.\begin{aligned}&u=cxf'(\eta),\ v=-\upsilon_f^{1/2}c^{1/2}f(\eta),\ \eta=\upsilon_f^{-1/2}c^{1/2}y,\\ &I_1=I_0xg'(\eta),\ I_2=-I_0\upsilon_f^{1/2}c^{-1/2}g(\eta),\end{aligned}\right\} \tag{6}$$

Equation (6) identically satisfies the continuity equations (1) and (2), and equations (3) and (4) become

$$\left(1+\frac{1}{\beta}\right)f'''-(f'^2-ff'')+\Lambda(g'^2-gg''-1)+\left(\frac{a}{c}\right)^2=0, \tag{7}$$

$$\lambda g'''+fg''-f''g=0, \tag{8}$$

Subjected to the transformed boundary conditions

$$\left.\begin{aligned}&f=g=0,\ f'=1,\ g''=0, && \text{at } \eta=0,\\ &f'=a/c,\ g'=1,\ g''=f''=0, && \text{as } \eta\to\infty,\end{aligned}\right\} \tag{9}$$

where β is the Casson parameter, Λ is the magnetic parameter, and λ is the reciprocal magnetic Prandtl number, which are given by $\Lambda=\frac{\mu H_0^2}{4\pi\rho c^2},\ \lambda=\frac{1}{4\pi\sigma\upsilon}$.

3. Heat transfer analysis

The governing equation for energy in the presence of no-uniform heat source/sink is given by