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Casson fluid flow and heat transfer past an exponentially porous stretching surface in presence of thermal radiation

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Abstract The present paper aims at investigating the boundary layer flow of a non-Newtonian fluid accompanied by heat transfer toward an exponentially stretching surface in presence of suction or blowing at the surface. Casson fluid model is used to characterize the non-Newtonian fluid behavior. Thermal radiation term is incorporated into the equation for the temperature field. With the help of similarity transformations, the governing partial differential equations corresponding to the momentum and heat transfer are reduced to a set of non-linear ordinary differential equations. Numerical solutions of these equations are then obtained. The effect of increasing values of the Casson parameter is seen to suppress the velocity field. But the temperature is enhanced with increasing Casson parameter. Thermal radiation enhances the effective thermal diffusivity and the temperature increases. It is found that the skin-friction coefficient increases with the increase in suction parameter.

1. Introduction

The study of laminar flow and heat transfer occurring over a stretching sheet in a viscous fluid is of considerable interest because of their ever increasing industrial applications and important bearings on several technological processes. Most of the available literature deals with the study of boundary layer flow over a stretching surface where the velocity of the stretching surface is assumed to be linearly proportional to the distance from the fixed origin. However, it is often argued that (Gupta and Gupta [1]) stretching of plastic sheet may not necessarily be linear. A few years later, several researchers like Magyari and Keller [2], Elbashbeshy [3], Partha et al. [4], Khan [5], and Sanjayanand and Khan [6,7] focused on heat mass transfer on boundary layer flow due to the presence of an exponentially, continuous stretching sheet under different thermo-physical conditions. Flow and heat transfer characteristics past an exponentially stretching sheet has a wider applications in technology. For example, in case of annealing and thinning of copper wires, the final product depends on the rate of heat transfer at the stretching continuous surface with exponential

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Nomenclature

c_p	specific heat at constant pressure	β	Casson fluid parameter
N	radiation parameter	η	similarity variable
Pr	Prandtl number	κ	coefficient of thermal diffusivity
S	suction/blowing parameter	ρ	density of the fluid
T	temperature of the fluid	ν	kinematic viscosity
T_w	temperature of the wall of the surface	θ	non-dimensional temperature
T_∞	free-stream temperature		
U_0	reference velocity		

variations in stretching velocity and temperature distribution. During such processes, both the kinematics of stretching and the simultaneous heating or cooling have a decisive influence on the quality of the final products. Al-Odat et al. [8] discussed the effects of magnetic field on fluid flow and heat transfer past an exponentially stretching surface. Later, Sajid and Hayat [9] considered the influence of thermal radiation on the boundary layer flow due to an exponentially stretching sheet by solving the problem analytically via homotopy analysis method (HAM). Recently, Bidin and Nazar [10] analyzed the effect of thermal radiation on the steady laminar two-dimensional boundary layer flow and heat transfer over an exponentially stretching sheet. Bararnia et al. [11] analytically studied the boundary layer flow and heat transfer on continuously stretching surface taking exponential surface velocity and temperature distributions. On the other hand, El-Aziz [12] investigated the mixed convection flow of micropolar fluid past an exponentially stretching sheet. Pal [13] carried out his investigation to report mixed convection flow past an exponentially stretching surface in presence of a magnetic field. Recently, Nadeem et al. [14] analyzed the flow of Jeffrey fluid and heat transfer past an exponentially stretching sheet. Combined effects of magnetic field and thermal radiation on flow and heat transfer over an exponentially stretching sheet were discussed by Ishak [15]. Of late, the effects of slip on third grade fluid past an exponentially stretching sheet were analyzed by Sahoo and Poncet [16]. Mukhopadhyay and Gorla [17] discussed the effects of partial slip on flow past an exponentially stretching sheet.

Convective heat transfer plays a vital role during the handling and processing of non-Newtonian fluid flows. Mechanics of non-Newtonian fluid flows present a special challenge to engineers, physicists, and mathematicians. Because of the complexity of these fluids, there is not a single constitutive equation which exhibits all properties of such non-Newtonian fluids. In the process, a number of non-Newtonian fluid models have been proposed. Amongst these, the fluids of viscoelastic type have received much attention. In the literature, the vast majority of non-Newtonian fluid are concerned of the types, e.g., like the power law and grade two or three (Andersson and Dandapat [18], Hassanien [19], Sadeghy and Sharifi [20], Serdar and Salih Dokuz [21], Sajid et al. [22,23]). These simple fluid models have the shortcomings that render results that are not in accordance with the fluid flows in reality. Power-law fluids are by far the most widely used model to express non-Newtonian behavior in fluids. The model predicts shear thinning and shear thickening behavior. However, it is inadequate in expressing normal stress behavior as observed in die swelling and rod climbing behavior in some non-Newtonian fluids. The second grade fluid model is the simplest subclass of viscoelastic fluids for which one can reasonably hope to obtain the analytic solution. Normal stress effects can be expressed in second grade fluid model, a special type of Rivlin–Ericksen fluids, but this model is incapable of representing shear thinning/thickening behavior (Aksoy et al. [24]). The non-Newtonian fluids are mainly classified into three types, namely differential, rate, and integral. The simplest subclass of the rate type fluids is the Maxwell model which can predict the stress relaxation. This rheological model, also, excludes the complicated effects of shear-dependent viscosity from any boundary layer analysis (Hayat et al. [25]). There is another type of non-Newtonian fluid known as Casson fluid. Casson fluid exhibits yield stress. It is well known that Casson fluid is a shear thinning liquid which is assumed to have an infinite viscosity at zero rate of shear, a yield stress below which no flow occurs, and a zero viscosity at an infinite rate of shear, i.e., if a shear stress less than the yield stress is applied to the fluid, it behaves like a solid, whereas if a shear stress greater than yield stress is applied, it starts to move. The examples of Casson fluid are of the type are as follows: jelly, tomato sauce, honey, soup, concentrated fruit juices, etc. Human blood can also be treated as Casson fluid. Due to the presence of several substances like, protein, fibrinogen, and globulin in aqueous base plasma, human red blood cells can form a chainlike structure, known as aggregates or rouleaux. If the rouleaux behave like a plastic solid, then there exists a yield stress that can be identified with the constant yield stress in Casson's fluid (Fung [26]). Casson fluid can be defined as a shear thinning liquid which is assumed to have an infinite viscosity at zero rate of shear, a yield stress below which no flow occurs, and a zero viscosity at an infinite rate of shear (Dash et al. [27]).

The process of suction and blowing has also have their importance in many engineering activities, for example, in the design of thrust bearing and radial diffusers, and thermal oil recovery. Suction is applied to chemical processes to remove reactants (Mukhopadhyay [28,29]). Blowing is used to add reactants, which cool the surface, prevent corrosion or scaling and reduce the drag (Mukhopadhyay and Vajravelu [30]).

The radiative effects have important applications in physics and engineering processes. The radiations due to heat transfer effects on different flows are very important in space technology and high temperature processes. But very little is known about the effects of radiation on the boundary layer. Thermal radiation effects may play an important role in controlling heat transfer in polymer processing industry where the quality of the final product depends, to some extent to the heat