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Heat Transfer in an Upper Convected Maxwell Fluid with Fluid Particle Suspension

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Abstract. An analysis is carried out to study the magnetohydrodynamic (MHD) flow and heat transfer characteristics of an electrically conducting dusty non-Newtonian fluid, namely, the upper convected Maxwell (UCM) fluid over a stretching sheet. The stretching velocity and the temperature at the surface are assumed to vary linearly with the distance from the origin. Using a similarity transformation, the governing non-linear partial differential equations of the model problem are transformed into coupled non-linear ordinary differential equations and the equations are solved numerically by a second order finite difference implicit method known as the Keller-box method. Comparisons with the available results in the literature are presented as a special case. The effects of the physical parameters on the fluid velocity, the velocity of the dust particle, the density of the dust particle, the fluid temperature, the dust-phase temperature, the skin friction, and the wall-temperature gradient are presented through tables and graphs. It is observed that, Maxwell fluid reduces the wall-shear stress. Also, the fluid particle interaction reduces the fluid temperature in the boundary layer. Furthermore, the results obtained for the flow and heat transfer characteristics reveal many interesting behaviors that warrant further study on the non-Newtonian fluid flow phenomena, especially the dusty UCM fluid flow phenomena.

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1 Introduction

The heat transfer due to a continuously moving surface through an ambient liquid is one of the important areas of current research due to its extensive application in broad spectrum of science and engineering disciplines, for instance, in chemical engineering processes like metallurgical process and polymer extrusion process involving cooling of a molten liquid being stretched into a cooling system. The fluid mechanical properties desired for an outcome of such a process would mainly depend on two aspects, one is the cooling liquid used and the other is the rate of stretching. Liquids of non-Newtonian characteristics, which are electrically conducting, can be opted as a cooling liquid as the flow and the heat transfer can be regulated by some external agency. Rate of stretching is very important as rapid stretching results in sudden solidification there by destroying the expected properties of the outcome. This is a fundamental problem that arises frequently in many practical situations such as polymer extrusion process; other processes like drawing; annealing and tinning of copper wires; continuous stretching; rolling and manufacturing of plastic films and artificial fibers; heat treated materials traveling on conveyer belts; glass blowing; crystal growing; paper production and so on. Sakiadis [1] was the first among the others to study the boundary layer flow generated by a continuous solid surface moving with constant velocity. Crane [2] extended the work of Sakiadis [1] and analyzed a steady two-dimensional boundary layer flow caused by a stretching sheet moving with a velocity linearly varying with the distance from a fixed point on the sheet. Many investigators have extended the work of Crane to study heat and mass transfer under different physical situations [3–7].

All the above investigators restricted their analyses to flow and heat transfer in the absence of magnetic field. But, we find several applications in polymer industry. To be more specific, it may be pointed out that many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are sometimes stretched. Mention may be made of drawing, annealing, and thinning of copper wires. In these cases, the properties of final product depend to a great extent on the rate of cooling by drawing such strips in an electrically conducting fluid subject to a magnetic field. In view of these applications Pavlov [8] investigated the flow of an electrically conducting fluid caused solely by the stretching of an elastic sheet in the presence of a uniform magnetic field. Chakrabarti and Gupta [9] considered the flow and heat transfer of an electrically conducting fluid past a porous stretching sheet and presented analytical solution for the flow and numerical solution for the heat transfer problem. In this work the fluid was assumed to be Newtonian. However, many industrial fluids are non-Newtonian or rheological in nature: Such as molten plastics, polymers, suspension, foods, slurries, paints, glues, printing inks, blood. That is, they might exhibit dynamic deviation from Newtonian behavior depending upon the flow configuration and/or the rate of deformation. These fluids often obey non-linear constitutive equations and the complexity of these constitutive equations is the main culprit for the lack of exact analytical solutions. For example, visco-elastic