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Hydromagnetic Hiemenz Slip Flow of Convective Micropolar Fluid Towards a Stretching Plate

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This paper is concerned with the effect of slip velocity on the steady two-dimensional flow of a micropolar fluid near a stagnation point at a stretching plate in the presence of a uniform transverse magnetic field and thermal radiation with the bottom surface of the plate is heated by convection from a hot fluid. The governing system of partial differential equations describing the problem is converted into a system of nonlinear ordinary differential equations using similarity transformation, and then solved numerically using the Chebyshev spectral method. Numerical results for the velocity, microrotation, and temperature are shown graphically and discussed for various values of different parameters. Moreover, the numerical values of the local skin-friction coefficient and the local Nusselt number for these parameters are also tabulated and discussed.

I. Introduction

MICROPOLAR fluids are those with a microstructure belonging to a class of fluids with nonsymmetrical stress tensor. The theory of micropolar fluids, first proposed by Eringen [1], who is capable of describing such fluids, and later [2] generalized the micropolar-fluid theory to include the thermal effects. This theory is expected to provide a mathematical model for non-Newtonian fluid behavior, which can be used to analyze the behavior of exotic lubricants, liquid crystals, polymeric fluids, colloidal fluids, real fluids with suspensions, and animal blood. Extensive reviews of this theory and its applications can be found in the review articles by Ariman et al. [3,4], and the books by Lukaszewicz [5] and Eringen [6]. Several researchers have studied the boundary-layer flow and heat transfer on a moving surface with and without a magnetic field under different boundary conditions [7–11].

For some industrial applications such as glass production and furnace design, nuclear-power plants, gas turbines, and in space-technology applications such as cosmical flight aerodynamic rocket-propulsion systems, plasma physics, and spacecraft-reentry aerothermodynamics that operate at higher temperature, radiation effects can be quite significant. In view of this, the effects of radiation on the flow and heat transfer of a micropolar fluid past a continuously moving plate have been studied by many authors [12–17].

Stagnation-point flow has attracted many investigations during the past several decades because of its wide applications in many practical problems like cooling of electronic devices by fans, cooling of nuclear reactors, and many hydrodynamic processes. Hiemenz [18] was the first one who studied the two-dimensional (2-D) flow of fluid near a stagnation point. This problem was extended numerically by Schlichting and Bussman [19], and analytically by Ariel [20] to include the effect of suction. Peddieson and McNitt [21] derived the boundary-layer equations for a 2-D micropolar flow at a stagnation point on a stationary wall. The stagnation-point flows toward a surface that is stretched have been considered, for example, by Nazar et al. [22] and recently by Ishak et al. [23]. Ramadan and Al-Nimr [24] numerically studied the impulsively started convection in planar and axisymmetric stagnation-point flow.

In the aforementioned studies, the effect of slip condition has not been taken into consideration, while the study of magnetomicropolar fluid flows in the slip-flow regimes with heat transfer has important engineering applications, such as in power generators, refrigeration coils, transmission lines, electric transformers, and heating elements. From the kinetic theory of gases of slightly rarefied flows, the no-slip boundary condition is replaced by a slip boundary condition, and for a prescribed surface temperature, a thermal-jump condition will occur [25]. Kiwan and Al-Nimr studied the effects of velocity slip and temperature-jump condition on 1) the convection heat transfer induced by a stretching flat plate [26], and 2) stagnation-point flow toward a stationary flat plate [27]. There is no kinetic theory for surface heat-flux boundary condition or convective surface heat-flux boundary condition, or liquid fluids or non-Newtonian fluids. Therefore, calculations for heat transfer at the microscale assume that there is no thermal jump comparing the velocity jump. If this is correct, then for surface heat fluxes, liquids, and non-Newtonian fluids, the temperature boundary condition at the wall will be the same as for nonslip flows. The previous researchers have assumed that there is a nonjump temperature [28–36].

Except for a few, the stagnation-point flows of a micropolar fluid have been studied using either a constant surface temperature or a constant heat-flux boundary condition. Very recently, the study of heat-transfer problem for the boundary layer concerning a convective boundary condition has received considerable attention because of its use in several engineering and industrial processes, such as transpiration-cooling process, material drying, laser-pulse heating, etc. Aziz [37] presented a similarity solution for laminar boundary layer over a flat plate with a convective boundary condition. Abraham and Sparrow [38] investigated the validity of the relative model for the problem of laminar fluid flow, which results from the simultaneous motion of a freestream and its bounding surface in the same direction. Sparrow and Abraham [39] developed a method for determining universal solutions for streamwise variation of the temperature of a moving sheet in the presence of an independently moving fluid. Ishak et al. [40] have studied the radiation effects within the thermal boundary over a moving plate under a convective boundary condition. Jafar et al. [41] studied the steady laminar 2-D stagnation-point flow and heat transfer of an incompressible viscous fluid impinging normal to a horizontal plate, with the bottom surface of the plate heated by convection from a hot fluid. Bataller [42] has presented the effects of radiation on Blasius and Sakiadis flows with convective boundary condition. Also, Makinde and Aziz [43] and Yao et al. [44] have investigated boundary-layer flows over a vertical plate and stretching/shrinking sheet, respectively, under the same convective boundary conditions. Motivated by the aforementioned investigations and applications, in this paper, the authors investigate a heat-transfer problem with a convective boundary condition for the

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