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Technical Note

Flow of a micropolar fluid past a continuously moving plate by the presence of radiation

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1. Introduction

Eringen [1] first derived the constitutive equations for fluids with micro-structures. The boundary layer flow of such a micropolar fluid past a semi-infinite plate has been studied by Peddieson and McNitt [2], whereas a similarity solution for boundary layer flow near a stagnation point was presented by Ebert [3]. On taking into account the gyration vector normal to the xy-plane and the micro-inertia effects, the boundary layer flow of micropolar fluids past a semi-infinite plate was studied by Ahmadi [4]. Willson [5] obtained the solution in the stagnation region of the micropolar fluid. The flow of a micropolar fluid past a wedge was studied by Nath [6]. Takhar and Soundalgekar [7] studied the heat transfer aspect of the flow of a micropolar fluid past a semi-infinite plate. Recently Perdikis and Raptis [8] studied the heat of a micropolar fluid by the presence of radiation.

In all these paper studies, the plate was assumed to be stationary and the micropolar fluid moved over this plate. Another situation commonly observed is the flow of a micropolar stationary fluid past a continuously moving plate. It is now proposed to study the flow of a micropolar fluid past a moving plate by the presence of radiation.

2. Analysis

We consider a steady two dimensional flow of a micropolar fluid past a continuously moving plate with a constant velocity. The origin is located at the spot through which the plate is drawn in the fluid medium, the x-axis is chosen along the plate and y-axis is taken normal to it.

The fluid is considered to be a gray, absorbing–emitting radiation but non-scattering medium and the Rosseland approximation is used to describe the radiative heat flux in the energy equation. The radiative heat flux in the x-direction is considered negligible in comparison to the y-direction.

Then under the usual boundary layer approximation, the flow and heat transfer by the presence of radiation are governed by the following equations:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+K_1\frac{\partial \sigma}{\partial y} \tag{2}$$

$$G_1\frac{\partial^2 \sigma}{\partial y^2}-2\sigma-\frac{\partial u}{\partial y}=0 \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \tag{4}$$

and the boundary conditions are given by

$$u=U_0,\quad v=0,\quad T=T_w,\quad \sigma=0 \quad \text{at} \quad y=0$$

$$u\to 0,\quad T\to T_\infty,\quad \sigma\to 0 \quad \text{as} \quad y\to\infty. \tag{5}$$

Here u, v, are the velocity components along x, y coordinates respectively, $\nu=(\mu+S)/\rho$ is the apparent kinematic viscosity, μ the coefficient of dynamic viscosity, S a constant characteristic of the fluid, ρ the density, σ the microrotation component, $K_1=S/\rho$ ($K_1>0$) the coupling constant, G_1 (>0) the microrotation constant, T the temperature of the fluid, c_p the specific heat at constant pressure, k the thermal conductivity, q_r the radiative heat flux, U_0 the uniform velocity of the plate, T_w the temperature of the plate and T_∞ the temperature of the fluid far away from the plate.

By using Rosselant approximation we have

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

with σ^* the Stefan–Boltzmann constant and k^* the mean absorption coefficient.

We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms, thus

$$T^4\simeq 4T_\infty^3T-3T_\infty^4. \tag{7}$$

By using (6) and (7) equation (4) gives

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$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+\frac{v}{c_p}\left(\frac{\partial u}{\partial y}\right)^2+\frac{16\sigma^* T_\infty^3}{3\rho c_p k^*}\frac{\partial^2 T}{\partial y^2}. \qquad (8)$$

On introducing the following transformations

$$n=\left(\frac{U_0}{2vx}\right)^{1/2}y,\quad u=\frac{\partial\psi}{\partial y},\quad v=-\frac{\partial\psi}{\partial x},$$

$$\psi=(2vU_0x)^{1/2}f(n),\quad \sigma=\left(\frac{U_0}{2vx}\right)^{1/2}U_0g(n),$$

$$\theta=\frac{T-T_\infty}{T_w-T_\infty}$$

into equations (1), (2), (3) and (8) we get

$$f'''+ff''+Kg'=0 \qquad (9)$$

$$Gg''-2(2g+f'')=0 \qquad (10)$$

$$(3N+4)\theta''+3NPf\theta'+3NPEf''^2=0 \qquad (11)$$

with the corresponding boundary conditions

$$f(0)=0,\quad f'(0)=1,\quad \theta(0)=1,\quad g(0)=0,$$
$$f'(\infty)=0,\quad \theta(\infty)=0,\quad g(\infty)=0. \qquad (12)$$

Here

$E=\dfrac{U_0^2}{c_p(T_w-T_\infty)}$ (Eckert number)

$P=\dfrac{\rho v c_p}{k}$ (Prandtl number)

$K=\dfrac{K_1}{v}$ (coupling constant parameter)

$G=\dfrac{G_1U_0}{vx}$ (microrotation parameter)

$N=\dfrac{k^*k}{4\sigma^*T_\infty^3}$ (radiation parameter).

The system of equations (9)–(11) under the boundary conditions (12) is solved numerically and the temperature profiles are shown in Fig. 1 when $P=7$, $E=0.02$, $G=2$ and $K=0.1$. We observe from this figure that an increase in radiation parameter leads to a decrease of the temperature.

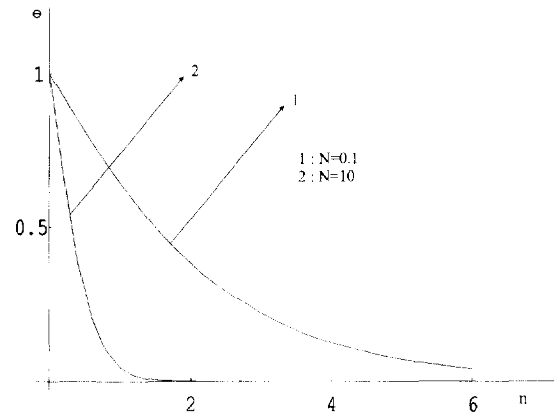

Fig. 1. Temperature profiles.

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