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RESEARCH ARTICLE

Graphical Study of Magneto Hydrodynamic Boundary Layer Flow of a Micropolar Fluid with Uniform Suction/Injection

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ABSTRACT

In the present study, a problem of heat transfer in a laminar stagnation point flow (steady) of an incompressible electrically conducting micropolar fluid is considered and which is impacting on a flat plate (permeable) with uniform suction or injection. A magnetic field of uniform strength is applied in normal direction to the plate and the effect of viscous dissipation is considered. Differential equations in the present study, which are in partial in nature are transformed into differential equations of ordinary nature. A numerical solution is obtained for the ordinary differential equations. Results are shown graphically. The results of effect of the magnetic and suction parameter on the flow are shown and discussed properly.

Keywords: micropolar fluid, laminar stagnation, suction

INTRODUCTION

The micropolar fluids can be categorized in the non-Newtonian fluids and that consists of a deferment of colloidal fluid elements and body fluids (small). For the study concerned with theory of micropolar fluids, the effects due to the intrinsic motion and microstructure of the fluid elements are important for consideration. The study of stagnation point flow of micropolar fluid have been analysed by researchers Nazar et al. [1] and Attia [2]. Arabay and Hassan [3] disscused the effect of suction/injection on the micropolar fluid flow in the presence of radiation. Salem and Odda [4] analysed the effects of thermal conductivity with variable viscosity on the micropolar fluid flow in presence of suction or injection. Attia [5] studied the stagnation point flow of a micropolar fluid with suction or blowing of uniform strength. Ishak and Nazar [6] and Kishan and Deepa [7] have analysed the micropolar fluid theory with suction or injection through diversed surfaces.

Formulation of the Problem

In the present problem, we consider a steady flow (two-dimensional) of a viscous incompressible electrically conducting micropolar fluid in the perpendicular direction to a horizontal flat plate with permeable nature and placed at y=0. It separates in two streams on the plate and leave in both directions around a stagnation point. A transverse magnetic field of strength Bo (uniform) is applied normal to the plate. The x-axis is taken along the plate and y-axis is chosen normal to it. Let u and v be the x- and y components of velocity near to stagnation point respectively and N be the component of the micro-rotation vector normal to the plane of xy. A uniform strength suction/injection is applied at the plate with a transpiration velocity at the boundary of the plate given by $-v_0$ (v_0 >0 is for suction). We consider potential flow velocity outer to the boundary layer as U(x) = ax. Fluid properties are assumed to be constant for the whole motion.
The governing equations in presence of viscous dissipation are given by:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad \text{(i)}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=U\frac{dU}{dx}+\frac{(\mu_0+r_0)}{\rho_0}\frac{\partial^2 u}{\partial y^2}+\frac{r_0}{\rho_0}\frac{\partial N_0}{\partial y}-\frac{1}{\rho_0}\sigma_0 B_0^2 u \qquad \text{(ii)}$$

$$\rho_0\left(u\frac{\partial N_0}{\partial x}+v\frac{\partial N_0}{\partial y}\right)=\frac{e_0}{j_0}\frac{\partial^2 N_0}{\partial y^2}-\frac{r_0}{j_0}\left(2N_0+\frac{\partial u}{\partial y}\right) \qquad \text{(iii)}$$

$$\rho_0 c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\kappa_0\frac{\partial^2 T}{\partial y^2}+(\mu_0+r_0)\left(\frac{\partial u}{\partial y}\right)^2+\sigma_0 B_0^2 u^2 \qquad \text{(iv)}$$

The boundary conditions are

$$y=0:\ u=0,\ v=-v_0,\ T=T_w,\ N_0=-m\frac{\partial u}{\partial y}$$

$$y\to\infty:\ u=U(x)=ax,\ T=T_\infty,\ N_0\to 0 \qquad \text{(v)}$$

T = Temperatures of fluid
T_w = Temperatures of plate
T_∞ = Temperature of the fluid far away from the plate
μ_0 = Viscosity
ρ_0 = Fluid density
σ_0 = Electrical conductivity
κ_0 = Thermal conductivity
c_p = Specific heat at constant pressure
j_0 = Micro-inertia per unit mass
e_0 = Spin gradient viscosity
r_0 = Vortex viscosity
m = Boundary parameter ($0\le m\le 1$)
Here e_0, j_0 and r_0 are assumed to be constants and e_0 is assumed to be given by Nazar et al. [1]

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$$e_0 = \left(\mu_0 + \frac{r_0}{2}\right) j_0 \qquad \text{(vi)}$$

We take $j_0 = \frac{\upsilon_0}{a}$ as a reference length, where υ_0 is called the kinematic viscosity.

Analysis

The equation (1) (continuity) is identically satisfied by stream function ψ_0 and defined as

$$u = \frac{\partial \psi_0}{\partial y}, \quad v = -\frac{\partial \psi_0}{\partial x} \qquad \text{(vii)}$$

For the solution of momentum, micro-rotation (spin) and the energy equation given by (ii) to (iv), the following similarity transformations are used to convert the partial differential equations into the ordinary differential equations

$$\psi_0(x,y) = x\sqrt{a\upsilon_0}\, f(\eta), \quad N_0(x,y) = ax\sqrt{\frac{a}{\upsilon_0}}\, g(\eta) \text{ and } \theta = \frac{T - T_\infty}{T_w - T_\infty},$$

where $\eta = y\sqrt{\frac{a}{\upsilon_0}}$ (viii)

Assumptions

$D = \frac{r_0}{\mu_0}$ (Material parameter)

$B = \frac{\sigma_0 B_0^2}{\rho_0 a}$ (Magnetic parameter)

$\Pr = \frac{\mu_0 c_p}{\kappa_0}$ (Prandtl number)

$C = -\frac{v_0}{\sqrt{a\upsilon_0}}$ (Suction/Injection parameter, +ive /-ive)

Skin-friction coefficient (C_f) and the Local Nusselt number (Nu) which are known as physical quantities of interest are given by

$$C_f = \frac{\tau_w}{\frac{\rho_0 U^2}{2}} \quad \text{and} \quad Nu = \frac{x q_w}{\kappa_0 \left(T_w - T_\infty\right)}$$

Here $U(x) = ax$ is called a characteristic velocity while τ_w is known as wall shear stress.

Using basic definitions of τ_w and q_w , we get

$$C_f = \frac{2\left(1+\frac{D}{2}\right)}{\sqrt{\text{Re}}} f''(0) \quad , Nu = -\sqrt{\text{Re}}\,\theta'(0)$$

where $\text{Re} = \frac{xU}{\upsilon_0}$ is known as the local Reynolds number.

RESULTS AND DISCUSSION

The reduced ordinary differential equations obtained from (ii) and (iii) subject to the reduced boundary conditions of (v) were solved by numerical procedure with the help of computer language Matlab. Velocity profiles are explained in figures (1) and (2). It is evident from these graphs that the velocity decreases with the increasing values of the magnetic parameter B and it increases with the increasing values of the suction/injection parameter C. Profiles of temperature distribution are shown in figure (3) and (4). It can be analysed from these graphs that the temperature decreases with the increasing values of the suction/injection parameter C but it increases with the increasing values of magnetic parameter B. Figure (5) shows the profile of the skin friction coefficient (which is proportional to $f''(0)$). It is clear from this graphs that the coefficient of skin friction increases with the increasing values of the parameter C. Figures (6) shows the profile of the Nusselt number (which is proportional to $-\theta'(0)$) and this graph shows that the Nusselt number decreases with the increasing values of the parameter B.

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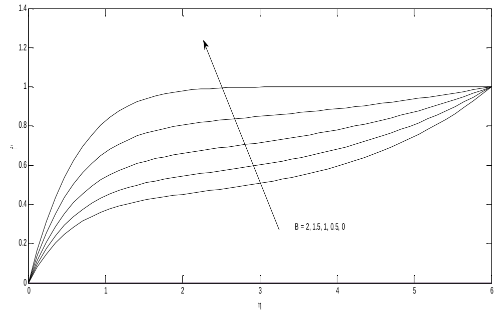

Figure1.Profile of Velocity against η for various values of magnetic parameter B when C=2 and D=2

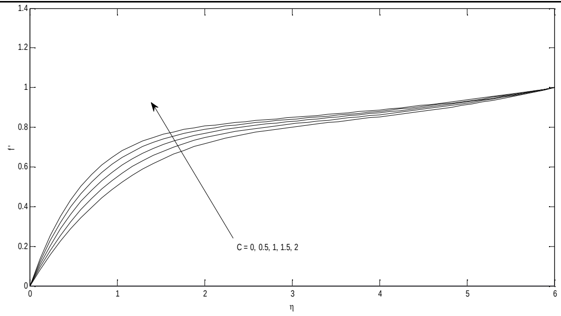

Figure 2. Profile of Velocity against η for various values of parameter C when B=0.5 and D=2

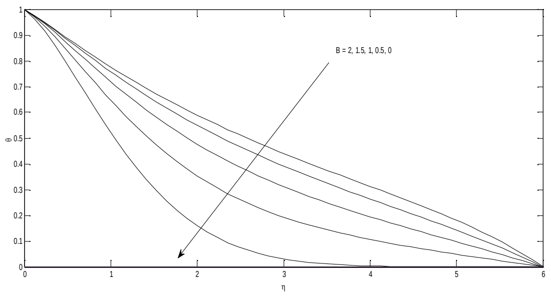

Figure 3. Profile of Temperature against η for various values of parameters B when D=2, Pr=0.5, Ec=0.5 and C=1

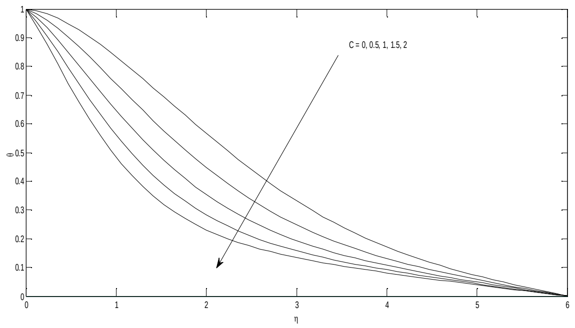

Figure 4. Profile of Temperature against η for various values of parameter C when B=0.5, D=2, Pr=0.5 and Ec=0.5

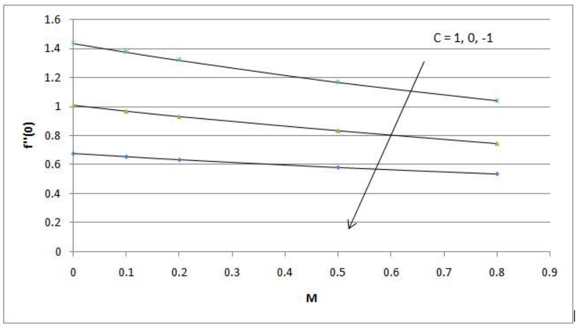

Figure 5. Profile of Skin friction coefficient ($f''(0)$) against M for various values of parameter C when D=1

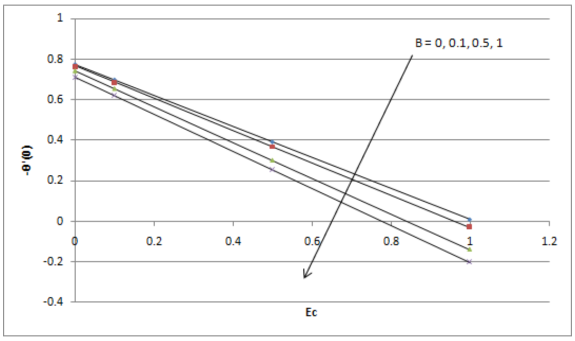

Figure 6. Profile of Nusselt Number (which is proportional to $-\theta'(0)$) against Ec for various values of parameter B when Pr =0.5, C=1, D=1.