Numerical study of Characterizing Spin Gradient Viscosity and Viscous Dissipation Effects on periodic flow of Micropolar Fluid through Tapered Wavy channel

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Abstract: The application of micropolar fluid theory extends to examining the characteristics of unique lubricants, polymeric suspensions, muddy and biological fluids, animal blood, colloidal solutions, as well as liquid crystals containing rigid molecules. The present study investigates the combined influence of viscous dissipation and chemical reaction on time-dependent MHD oscillatory micropolar fluid flow through a tapered asymmetric channel. The Boussinesq approximation and time-dependent flow model are modified and incorporated into the governing equations. The governing equations are non-dimensionalized by applying suitable non-similarity transformations and numerically solved using the implicit Crank-Nicolson finite difference method. The obtained results are compared to the numerical results generated by the ODE solver, bvp4c. The effects of spin gradient viscosity, Eckert number and Hartmann number on the velocity and microrotation profile are analyzed. This study shows that the microrotation and velocity profiles are strongly influenced by changes in the magnitude of the spin gradient viscosity.

1. INTRODUCTION & OBJECTIVE

The non-Newtonian characteristics of various physiological and industrial fluids have received significant attention in research. Among the different non-Newtonian fluid models, the theory of micropolar fluids, pioneered by Eringen [1], stands out as a prominent and cutting-edge theory over the last few decades. A micropolar fluid possesses internal structures, wherein the interaction between the spin of individual particles and the macroscopic velocity field is considered. In recent years, numerous researchers have investigated the unsteady free convection flow of a micropolar fluid through a porous medium, both in the presence and absence of a magnetic field. The electroosmotic flow of a micropolar fluid within a microchannel bounded by two parallel porous plates undergoing periodic vibration has been studied by Misra et al. [2]. Prakash and Muthtamilselvan [3] investigated the impact of thermal radiation on the fully developed flow of micropolar fluid between two infinite parallel porous vertical plates, considering the presence of a transverse magnetic field. Sheikholeslami et al. [4] discussed the behavior of micropolar fluid flow in a channel subjected to a chemical reaction. The theoretical analysis of boundary layer flow in an incompressible micropolar fluid subjected to a uniform magnetic field while buoyancy forces between vertical walls induce motion is studied by Hari et al. [5]. The objectives of the present study are as follows:

1. How does the interplay between viscous dissipation and Lorentz force contribute to the temperature and velocity profile of the micropolar fluid flow within the tapered asymmetric channel?

2. How does the variation in spin gradient viscosity affect the velocity and angular velocity profiles in time-dependent MHD oscillatory micropolar fluid flow through a tapered asymmetric channel?

2. MATHEMATICAL FORMULATION

The unsteady laminar flow of a viscous incompressible micropolar fluid through tapered asymmetric channel is considered. It is assumed that the fluid flow is normal to the strength of the constant magnetic field B_0. Since the magnetic Reynolds number is substantially lower than the external one, it is presumed that the generated magnetic fields are insignificant. The primary flow within the medium is solely induced by the buoyancy force, arising from the temperature difference between the wall and the medium. All fluid properties are assumed to be constant except for the density, which undergoes variations and consequently leads to the generation of the buoyancy force. The equations governing the flow, heat and mass transport of a viscous incompressible fluid can be expressed as follows,

$$\rho\left(\frac{\partial u}{\partial t} + \nu_0 \frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + (\mu + K')\frac{\partial^2 u}{\partial y^2} + \rho g \beta_T (T-T_0) + \rho g \beta_C (C-C_0) + K'\frac{\partial N'}{\partial y} - \left(\frac{\mu + K'}{k^*} + \sigma B_0^2\right)u \qquad (1)$$

$$\rho j\left(\frac{\partial N'}{\partial t} + \nu_0 \frac{\partial N'}{\partial y}\right) = \mu_s \left(\frac{\partial^2 N'}{\partial y^2}\right) - K'\left(2N' + \frac{\partial u}{\partial y}\right) \qquad (2)$$

$$\rho C_p\left(\frac{\partial T}{\partial t} + \nu_0 \frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} + (\mu + K')\left(\frac{\partial u}{\partial y}\right)^2 \qquad (3)$$

$$\frac{\partial C}{\partial t} + \nu_0 \frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - Kr^*(C-C_0) \qquad (4)$$

Boundary conditions are:

$$u = 0,\ N'=0,\ T = T_0 \text{ and } C = C_0 \text{ on } y = H_1 \qquad (5)$$

$$u = 0,\ N'=0,\ T = T_0 + (T_1 - T_0)\, e^{i\omega t} \text{ and } C = C_0 + (C_1 - C_0)\, e^{i\omega t} \text{ on } y = H_2 \qquad (6)$$

3. MEHODOLOGY

For solving the governing equations subjected to the boundary conditions, Crank–Nicolson implicit finite difference technique has been employed. It is a numerical technique used to solve partial differential equations (PDEs), particularly those that involve parabolic equations. The method discretizes both time and space domains, approximating derivatives using central differences.

4. CONCLUSIONS

1. In the angular velocity field, the spin gradient viscosity increases the angular velocity in the first half of the channel and decreases in the remaining.
2. An increase in the Eckert number decreases the fluid temperature.
3. An increase in the Lorentz force and micropolar parameter decreases the fluid velocity across the channel.

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