Propulsion and Power Research ■■■■;■(■):■■■–■■■

HOSTED BY ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Natural convective flow of a magneto-micropolar fluid along a vertical plate

M. Ferdows[a,b,*], D. Liu[a]

[a]College of Engineering and Science, Louisiana Tech University, Ruston, Louisiana 71272, USA
[b]Department of Applied Mathematics, University of Dhaka, Dhaka-1000, Bangladesh

Received 13 September 2016; accepted 14 August 2017

KEYWORDS

Natural convection;
Thermal boundary layer;
Micropolar fluid;
Similarity transformation;
Internal heat generation

Abstract This paper presents a numerical study of natural convective flow of an electrically conducting viscous micropolar fluid past a vertical plate. Internal heat generation (IHG) versus without IHG in the medium are discussed in the context of corresponding similarity solutions. Results are presented in terms of velocity, angular velocity, temperature, skin friction in tabular forms, local wall-coupled stress, and Nusselt number. Computations have been accomplished by parametrizing the micropolar, micro-rotation, magnetic field, suction parameters, and the Prandtl number. Several critical issues are addressed at the end of the paper with reference to a previous study by El-Hakiem. The study is relevant to high-temperature electromagnetic materials fabrication systems.

1. Introduction

Micropolar fluids are those which contain micro-constituents that can undergo rotation, the presence of which can affect the hydrodynamics of the flow so that it can be distinctly non Newtonian. These fluids are fluids with microstructure belonging to a class of complex fluids with nonsymmetrical stress tensor referred to as microorphic fluids. It has many practical applications, for examples analyzing the behavior of exotic lubricants, the flow of colloidal suspensions or polymeric fluids, liquid crystals, additive suspensions, animal blood, body fluids, and turbulent shear flows.

Convective flow over bodies immersed in micropolar fluids has attracted an increasing amount of attention since the early studies of Eringen [1] since such fluids exhibit certain microscopic effect arising from the local structure and micromotions of the fluid elements. These fluids contain dilute suspensions with rigid micromolecules with

*Corresponding author.

E-mail addresses: ferdows@du.ac.bd (M. Ferdows).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

https://doi.org/10.1016/j.jppr.2018.01.005

Nomenclature

b	dimensionless material property
B	vortex viscosity parameter
B_0	strength of the uniform magnetic field
C_p	specific heat at constant pressure
f	nondimensional stream function
f_w	suction parameter
g	nondimensional angular velocity
g^*	acceleration due to gravity
K	vortex viscosity
Gr_x	local Grashof number
j	microinertia density
M	magnetic field parameter
N	angular velocity (component of the microrotation vector normal to the x-y plane)
Nu	Nusselt number
q'''	internal heat generation
u, v	velocity components along x and y-axis, respectively
T	temperature
x, y	vertical and horizontal coordinates

Greek symbols

α	thermal diffusivity
β	coefficient of thermal expansion
Δ	micropolar parameter
γ	spin gradient viscosity
κ	thermal conductivity of fluid
λ	temperature power-law parameter
η	dimensionless transformed variable
θ	nondimensionless temperature
μ	dynamic viscosity
ν	kinematic viscosity
ρ	density
ψ	stream function

Subscripts

w	wall conditions
∞	free stream conditions

individual motions, which supports stress and body moments and are influenced by spin inertia. Recent textbooks focusing on the theory and applications of micropolar fluids are those by Lukaszewicz [2] and Eringen [3].

A direction of advancement in the study of (external) flows of micropolar fluids was initiated by Peddiesen and McNitt [4] and Wilson [5], who, for the first time, used the boundary layer concept for such kind of flows.

Many investigators have studied and reported results for micropolar fluids in external flows. Since we are interested in the present paper on the standard vertical plate configuration, we will confine our literature survey on those studies related to this topic.

Jena and Mathur [6] presented similarity solution for laminar free convection flow of a thermo-micropolar fluid past a non-isothermal vertical plate. Wang and Liu [7] used spectral element and Runge-Kutta methods to study heat and mass transfer in free convection boundary layers near a vertical cylinder. A boundary layer solution for the steady free convection from a vertical isothermal plate in a strong cross magnetic field performed by Gorla et al. [8] lead to nonsimilar solutions. The case of uniform surface heat flux was analyzed by Gorla et al. [9] and they obtained nonsimilar solutions, which revealed the presence of a two-layer structure of the boundary layer as the distance from the leading edge increases. El-Hakiem [10] studied viscous dissipation effects on magnetohydrodynamic (MHD) free convection flow over a non iso-thermal surface in a micropolar fluid. In a further paper by the same author, [11], the natural convection in a micropolar fluid with thermal dispersion and internal heat generation. The coupling of conduction with mixed convection of micropolar fluids past a vertical plate was studied by Wang [12].

Although not of interest in the present context, we mention a number of papers on unsteady free convection flow of a micropolar fluid past a vertical plate, such as Refs. [13,14].

Starting from the paper by El-Hakiem [11], the objective of the present investigation is to study the MHD flow of a micropolar fluid over a vertical plate in the presence of internal heat generation (IHG) and suction. By allowing a variable wall temperature we will look for similarity solutions of the problem. The numerical results are discussed by systematically varying the model parameters.

2. Formulation of the problem

Let us consider a steady two-dimensional natural convective flow of viscous, incompressible micropolar fluid along a vertical plate. The temperature of the plate is held at the value T_w taken as a power-law of x, and the fluid has an internal volumetric heat generation denoted further by q'''. Physical model and co-ordinate system are shown below (Figure 1).

Taking the x axis along the plate from its leading edge and the y axis normal to it, and invoking the boundary layer and Boussinesq approximations, the flow can be described by the following equations

Continuity equation:

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

Momentum equation:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \left(\upsilon + \frac{K}{\rho}\right)\frac{\partial^2 u}{\partial y^2} + g^*\beta(T - T_\infty) + \frac{K}{\rho}\frac{\partial N}{\partial y} - \frac{\sigma B_0^2}{\rho}u \tag{2}$$

Please cite this article as: M. Ferdows, D. Liu, Natural convective flow of a magneto-micropolar fluid along a vertical plate, Propulsion and Power Research (2018), https://doi.org/10.1016/j.jppr.2018.01.005