Alexandria Engineering Journal (2016) 55, 973–982

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Entropy generation in a micropolar fluid flow through an inclined channel

D. Srinivasacharya *, **K. Hima Bindu**

Department of Mathematics, National Institute of Technology, Warangal 506004, India

Received 6 December 2015; revised 9 February 2016; accepted 29 February 2016
Available online 25 March 2016

KEYWORDS

Micropolar fluid;
Spectral quasilinearization;
Entropy;
Bejan number

Abstract In this paper the entropy generation is studied due to micropolar fluid flow through an inclined channel of parallel plates with constant pressure gradient. The lower plate is maintained at constant temperature and upper plate at a constant heat flux. The governing equations are solved by applying the spectral quasilinearization method. The velocity, microrotation and temperature profiles are obtained numerically and are used to calculate the entropy generation number. The influence of pertinent parameters on velocity, microrotation, temperature, entropy generation and Bejan number is discussed with the help of graphs. The results reveal that the entropy generation number increases with the increase in Brinkman number and angle of inclination. Further, it is observed that the increase in coupling number, Prandtl number and Reynolds number reduces the entropy generation number.

1. Introduction

The production of thermal and engineering devices is concerned by irreversible losses that lead to increase the entropy and decrease system efficiency. Thus it is important to find the factors that minimize the entropy generation and maximize the flow system efficiency. To analyze the irreversibilities in the form of entropy generation, the second law of thermodynamics is applied. Factors that are responsible for the irreversibility are heat transfer across finite temperature gradients, characteristics of convective heat transfer and viscous dissipation. Most of the energy related applications such as cooling of modern electronic systems, solar power collectors, and geothermal energy systems depend on entropy generation. Several investigations ([1–3]) were carried out on entropy generation under various flow configurations.

Fluid flow and heat transfer inside channels with simple geometry and different boundary conditions is one of the fundamental areas of research in engineering. It has wide range of applications such as thermal insulation engineering, electronics cooling and water movement in geothermal reservoirs. Recently, a wide literature on fluid flow, heat transfer and entropy generation in various channels has been developed. Havzali et al. [4] investigated the entropy generation of incompressible, viscous fluid flow through an inclined channel with isothermal boundary conditions. They observed that the entropy generated in a small section is dominant on the total entropy produced in the entire system. Komurgoz et al. [5] discussed the entropy generation of porous-fluid layers contained in an inclined channel by using the differential transform

* Corresponding author.
E-mail addresses: dsc@nitw.ac.in, dsrinivasacharya@yahoo.com (D. Srinivasacharya).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.02.027
1110-0168 © 2016 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

method. Karamallah et al. [6] studied the consequence of differential heat isothermal walls on entropy generation of a vertical square channel saturated with porous media. Liu and Lo [7] performed a numerical analysis on the entropy generation within a mixed convection magneto hydrodynamic (MHD) flow in a parallel-plate vertical channel. They observed that the minimum entropy generation number and the maximum Bejan number occur at centerline region of the channel under asymmetric heating conditions. Makinde and Eegunjobi [8] addressed the irreversibility analysis in the flow of couple stress fluid through a porous medium. Damseh et al. [9] studied the presence of transverse magnetic field on entropy generation due to laminar forced convection flow in a channel. Das and Jana [10] investigated the combined effects of Navier slips, suction/injection and magnetic field on entropy generation in a porous channel by considering the constant pressure gradient. Chen and Liu [11] numerically investigated the viscous dissipation effect on entropy generation due to mixed convection nanofluid flow within a vertical channel.

The study of heat transfer has much importance in high temperature processes such as nuclear plants, gas turbines, thermal energy storage. Different kinds of boundary conditions are applied in heat transfer processes. Thermal boundary conditions, heat flux boundary conditions and convective boundary conditions are commonly encountered in heat transfer processes. The effects of these boundary conditions on entropy generation for any fluid flow of different geometries have been studied by several authors. Mahmud and Fraser [12] applied second law of thermodynamics to analyze the heat transfer and fluid motion in rotating concentric cylinders using heat flux boundary conditions. Iman [13] investigated the importance of thermal boundary conditions of the heated/cooled walls in the development of flow and heat transfer, and observed the characteristics of entropy generation in a porous enclosure. Antar and El-Shaarawi [14] investigated the effects of uniform heat flux boundary conditions on entropy generation over a rotating solid sphere with forced convection. Butt et al. [15] presented the effects of hydrodynamic slip on entropy generation in a viscous flow over a vertical plate with convective boundary conditions. Anandalakshmi and Basak [16] studied the effect of various heating patterns (different heating and Rayleigh–Benard convection) on entropy generation in a porous rhombic enclosure for different *Pr* and inclination angles. Anand [17] discussed the velocity slip effect on heat transfer and entropy generation of fully developed power law fluid flow in a micro channel. Mostafa and Ali [18] presented the effect of slip boundary condition on entropy generation for Newtonian and non-Newtonian fluid flows through a parallel plates channel. Ibanez [19] studied the combined effects of magnetic field, suction/injection Reynolds number and hydrodynamic slip on the entropy generation subjected to convective boundary conditions.

The majority of these studies deal with the traditional Newtonian fluids. The study of Newtonian fluids is not sufficient to characterize the flow properties of polymeric fluids, animal blood, coal slurries, mine tailings and mineral suspensions. Such properties are described in non-Newtonian fluid flow model. Many fluids in nature and industrial processes show a non-Newtonian fluid behavior. A number of mathematical models were proposed to explain the rheological behavior of non-Newtonian fluids. One among them is micropolar fluid introduced by Eringen [20] who exhibits certain microscopic effects arising from the local structure and micro-rotations of fluid elements. The Micropolar fluids accurately simulate the flow characteristics of geomorphological sediments, polymeric additives, colloidal suspensions, liquid crystals, lubricants, hematological suspensions, etc. The rotation of fluid particles in micropolar fluid model is governed by independent kinematic vector called the microrotation vector, which makes it different from other non-Newtonian fluids. Heat transfer in micropolar fluids is also important in the context of industrial manufacturing processes and aerospace engineering and also in chemical engineering.

Although the analysis of entropy generation in a micropolar fluid is important, very little work has been reported in the literature. Ramana Murthy and Srinivas [21] considered the problem of First and Second Law Analysis for the MHD Flow of Two Immiscible Couple Stress Fluids between Two Parallel Plates. Jangili and Murthy [22] analyzed the entropy generation on the steady Poiseuille flow of two immiscible incompressible micropolar fluids between two horizontal parallel plates of a channel with constant wall temperatures in terms of entropy generation. Though most of the work has been done on entropy generation, to the best of the authors' knowledge, entropy generation analysis for micropolar fluid flow with heat flux boundary condition has not yet been addressed in the literature. Therefore, the objective of the present paper is to investigate the characteristics of micropolar fluid flow, heat transfer and entropy generation inside an inclined channel with constant pressure gradient and constant flux on the upper plate. The governing equations are solved using spectral quasi-linearization method. The behavior of flow characteristics with pertinent flow parameters is discussed through graphs.

2. Mathematical formulation

Consider a steady laminar incompressible micropolar fluid flow bounded by two infinite inclined parallel plates separated by a distance $2h$. The channel is inclined at an angle α. Choose the cartesian coordinate system with x-axis aligned at the center of the channel in the direction of the flow and the y-axis perpendicular to the plates. The plates are of infinite length in x-direction so that the physical quantities do not depend on x. Therefore the physical variables are depending on y only. Assume that the properties of the fluid are constant other than the variations of density in the buoyancy force term. Let $(u, v, 0)$ be the fluid velocity vector. The transpiration cross flow velocity v_0 is constant, where $v_0 > 0$ is the injection velocity and $v_0 < 0$ is the suction velocity. In this study the upper plate of the channel is subjected to a constant uniform heat flux q (isoflux) while the lower plate of the channel is kept at constant temperature T_1 (isothermal).

Under these assumptions and Boussinesq approximations the governing equations for the steady flow of micropolar fluid are

$$v = v_0 \tag{1}$$

$$(\mu+\kappa)\frac{d^2u}{dy^2} - \rho v_0\frac{du}{dy} + \kappa\frac{d\sigma}{dy} + \rho g^*\beta(T-T_1)\sin(\alpha) - \frac{\partial p}{\partial x} = 0 \tag{2}$$

$$\gamma\frac{d^2\sigma}{dy^2} - \rho j^* v_0\frac{d\sigma}{dy} - 2\kappa\sigma - \kappa\frac{du}{dy} = 0 \tag{3}$$

$$K_f\frac{d^2T}{dy^2} - \rho C_p v_0\frac{dT}{dy} + (\mu+\kappa)\left(\frac{du}{dy}\right)^2 + 2\kappa\left(\sigma^2 + \sigma\frac{du}{dy}\right) + \gamma\left(\frac{d\sigma}{dy}\right)^2 = 0 \tag{4}$$