Available online at www.sciencedirect.com
ScienceDirect
Journal of the Nigerian Mathematical Society 35 (2016) 199–207
Journal of the Nigerian Mathematical Society
www.elsevier.com/locate/jnnms

Magneto-hydrodynamic mixed convection of a non-Newtonian power-law nanofluid past a moving vertical plate with variable density

Macha Madhu, Naikoti Kishan*

Department of Mathematics, Osmania University, Hyderabad, Telangana, 500007, India

Received 5 November 2015; received in revised form 9 March 2016; accepted 9 March 2016
Available online 24 March 2016

Abstract

Present paper investigates the magnetohydrodynamic boundary layer mixed convection flow over a moving vertical plate in a non-Newtonian power-law nanofluid with variable density. The governing partial differential equations are transformed into a ordinary differential equations by suitable similarity transformations. The system of coupled non-linear ordinary differential equations are solved numerically using variational finite element method. The solutions for the flow and heat transfer characteristics are computed numerically for various values of flow controlling parameters. Investigation predict that an increase in the values of magnetic field parameter and thermophoresis parameter is to enhance the temperature and nanoparticle volume fraction profiles. Increasing power-law index reduces the velocity, temperature and nanoparticle volume fraction profiles. An increase in the Brownian motion and Lewis number is reduces the nanoparticle volume fraction profiles and temperature field is decreases with increasing Pradtl number. An increase in power-law index and thermophoresis is found to be increase in the skin friction co-efficient but decrease in the heat transfer co-efficient.

Keywords: Non-Newtonian; Nanofluid; Brownian motion; Thermophoresis; Power-law index; FEM

1. Introduction

Most of the fluids such as molten plastics, artificial fibers, petroleum, blood, dyes, ketchup, shampoo, paint, mud, clay coatings, polymer melts, certain oils and greases etc., are considered as non-Newtonian fluids. Such fluids do not obey the Newtons law of viscosity and are usually called as non-Newtonian fluids. The flows of such fluids occur in a wide range of practical problems having vital importance in polymer depolarization, bubble columns, fermentation, composite processing, boiling, plastic foam processing, bubble absorption and many others. Therefore, an analysis considering the non-Newtonian behavior of these fluids in such flows seems appropriate. These fluids can be divided into four groups: pseudo-plastic, dilatant, Bingham plastic and plastic. A dilatant (shear-thickening) fluid increases

Peer review under responsibility of Nigerian Mathematical Society.
* Corresponding author.
E-mail addresses: madhumaccha@gmail.com (M. Madhu), kishan_n@rediffmail.com (N. Kishan).

http://dx.doi.org/10.1016/j.jnnms.2016.03.001

resistance with increasing applied stress. Alternately, a pseudo-plastic (shear-thinning), fluid decreases resistance with increasing stress. Lots of non-Newtonian materials used in afore-mentioned applications exhibit shear-thinning and shear-thickening characteristics which are frequently approximated by power-law model. Its worth mentioning here that many of the inelastic non-Newtonian fluids encountered in chemical engineering processes, are known to follow the empirical Ostwaald-de-Waele model or the so-called power-law model in which the shear stress varies according to a power function of the strain rate.

Acrivos et al. [1], Shah [2] and Shah et al. [3] were probably the first to study heat transfer in laminar boundary layer flows of nowNewtonian fluids past external surfaces. The power-law model provides an adequate representation of many non-Newtonian fluids over the most important range of shear rates. This together with its apparent simplicity has made it a very attractive model for both analytical and numerical research. Andersson et al. [4] and Cortell [5] studied the boundary layer flow of an electrically conducting incompressible fluid obeying the power-law model in the presence of transverse magnetic field. Howell et al. [6] examined the momentum and heat transfer occurring in the laminar boundary layer on a continuously moving and stretching surface in a non-Newtonian power-law fluid. Hassanien et al. [7] studied the flow and heat transfer in a power-law fluid over a non-isothermal stretching sheet. Kishan and shashidhar reddy [8] investigated MHD effects on non-Newtonian power-law fluid past a continuously moving porous flat plate. Kavitha and Kishan [9]studied MHD flow and heat transfer of non-Newtonian power-law fluid over a stretching surface with viscous dissipation. Chen and Chen [10] have presented similarity solutions for free convection of non- Newtonian fluids over vertical surfaces in porous media. Mehta and Rao [11] have investigated buoyancy induced flow of non-Newtonian fluids over a non isothermal horizontal plate embedded in a porous medium. Jumah and Mujumdar [12] have considered free convection heat and mass transfer of non-Newtonian power-law fluids with yield stress from a vertical flat plate. [13] studied non- Newtonian power-law fluid flow over a continuously moving surface with species concentration and chemical reaction. Most studies of convective flow past a semi-infinite vertical plate were restricted, in general, to the case where the temperature difference between the plate and the ambient fluid is small. In this case, the Boussinesq approximations [14] can be used to treat the fluid density as a variable only in buoyancy term of the momentum equation.

The boundary layer flow and heat transfer of nanofluids have been the topic of extensive research due to its enhanced thermal conductivity. Excellent reviews on convective transport in nanofluids have been made by Buongiorno [15] and Kakac and Pramuanjaroenkij [16]. Kuznetsov and Nield [17,18] studied analytically the natural convective boundary-layer flow of a nanofluid past a vertical plate. The model used for the nanofluid incorporates the effects of Brownian motion and thermophoresis. Also, it is interesting to note that the Brownian motion of nanoparticles at molecular and nanoscale levels is a key nanoscale mechanism governing their thermal behaviors. In nanofluid systems, due to the size of the nanoparticles, the Brownian motion takes place, which can affect the heat transfer properties. As the particle size scale approaches to the nanometer scale, the particle Brownian motion and its effect on the surrounding liquids play an important role in the heat transfer. Makinde and Aziz [19], Das et al. [20], Makinde et al. [21] and Ibrahim and Makinde [22] give some research on the nanofluids considering the Brownian diffusion and thermophoresis. Khan et al. [23] investigated Non-aligned MHD stagnation point flow of variable viscosity nanofluids past a stretching sheet. The study of boundary layer flow of a power-law fluid over a stretching sheet extended to a power-law fluid with nanoparticles suspended in it is called power-law nanofluid. Due to a wide use of a nanofluid in modern technology, the study of the boundary layer flow of non-Newtonian based nanofluid over a stretching sheet has got a wide interest in recent times due to its enhanced thermal conductivity of nanofluids. The free convective heat transfer to the power-law non-Newtonian flow from a vertical plate in a porous medium saturated with nanofluid under laminar conditions is investigated by Hady et al. [24]. Vajravelu et al. Madhu and Kishan [25] investigated MHD mixed convection stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface. Nield [26] studied the onset of convection in a layer of a porous medium which is filled with non-Newtonian nanofluids of power-law type. Khan et al. [27] studied blasius flow of power-law nanofluids over a convectively heated vertical plate. Ellahi et al. [28] have elaborated that non-Newtonian nanofluids have potential roles in physiological transport as biological solutions and also in polymer melts, paints, etc. Rama and Goyal [29] have studied non-Newtonian nano fluid flow over a permeable sheet with heat generation and velocity slip in presence of magnetic field. Gorla and Kumari [30] utilized the Eringen micromorphic model in their analysis of mixed convection non-Newtonian nanofluid flow from a nonlinearly stretching sheet.

To the best of authors knowledge none of the papers deals with much more complicated problem of magneto hydrodynamic mixed convection non-Newtonian power-law nanofluid on a moving plate with variable density. In