Available online at www.sciencedirect.com
ScienceDirect
Journal of the Nigerian Mathematical Society 35 (2016) 1–17
Journal of the Nigerian Mathematical Society
www.elsevier.com/locate/jnnms

Casson fluid flow with variable thermo-physical property along exponentially stretching sheet with suction and exponentially decaying internal heat generation using the homotopy analysis method

I.L. Animasaun*, E.A. Adebile, A.I. Fagbade

Department of Mathematical Sciences, Federal University of Technology Akure, Ondo State, Nigeria

Received 12 July 2014; received in revised form 27 September 2014; accepted 17 January 2015
Available online 23 February 2015

Abstract

This article studies the motion of temperature dependent plastic dynamic viscosity and thermal conductivity of steady incompressible laminar free convective magnetohydrodynamic (MHD) Casson fluid flow over an exponentially stretching surface with suction and exponentially decaying internal heat generation. It is assumed that the natural convection is driven by buoyancy and space dependent heat generation. The viscosity and thermal conductivity of Casson fluid is assumed to vary as a linear function of temperature. By using suitable transformation, the governing partial differential equations corresponding to the momentum and energy equations are converted into non-linear coupled ordinary differential equations and solved by the Homotopy analysis method. A new kind of averaged residual error is adopted and used to find the optimal convergence control parameter. A parametric study is performed to illustrate the influence of Prandtl number, Casson parameter, temperature dependent viscosity, temperature dependent thermal conductivity, Magnetic parameter and heat source parameter on the fluid velocity and temperature profiles within the boundary layer. The flow controlling parameters are found to have a profound effect on the resulting flow profiles.

Keywords: Casson fluid; Variable viscosity; Variable thermal conductivity; Boundary value problem; Homotopy analysis method

1. Introduction

As fluid flows on continuous moving surface, boundary layer is formed and it's of important in nature due to its influence on the transport phenomena. Natural convection arises within the fluid when temperature changes cause density variation leading to buoyancy forces which act directly on the fluid elements. Theoretical and experimental study on heat transfer MHD free convection flow with thermal radiation effects on a vertical plate has received

Peer review under responsibility of Nigerian Mathematical Society.
* Corresponding author.
E-mail addresses: anizakph2007@gmail.com (I.L. Animasaun), eaadebiletri@gmail.com (E.A. Adebile), yemi2favours@yahoo.co.uk (A.I. Fagbade).

http://dx.doi.org/10.1016/j.jnnms.2015.02.001

deep interest during the last decades. The study of magnetohydrodynamics flow and heat transfer over a continuous stretching sheet is one of the very important problems in fluid dynamics due to its numerous applications in industrial manufacturing processes such as paper production, manufacturing of ceramic polymer extrusion and production of plastic. Sakiadis [1,2] started a research on boundary layer behavior when fluid flows on a continuous solid surface. Crane [3] furthered the research and considered the boundary layer flow caused by a stretching sheet which moves with a velocity varying linearly with the distance from a fixed point. Carragher and Crane [4] continued this research and studied heat transfer aspect under the conditions when the temperature difference between the surface and the ambient fluid is proportional to a power of the distance from a fixed point. Ibrahim [5] adopted numerical analysis method in order to study heat and mass transfer effects on steady two dimensional flow of a viscous incompressible, electrically conducting dissipating fluid past an exponentially stretching surface in the presence of magnetic field, heat generation and radiation. In the governing equation, the author considered magnetic field term and square of velocity component in x-direction. Miansari et al. [6] applied the Homotopy analysis method together with Pade-Approximation to solve dimensionless momentum and energy equations considering the case of a two dimensional incompressible flow passing over a wedge. They also presented efficiency of HAM together with trial and error method for solving the momentum equation. They also solved the momentum equation by considering the Pade-Approximation with HAM. The flow and heat transfer over an exponentially stretching surface have been studied by many researchers. Elbashbeshy [7] investigated wall mass suction, Khan and Sanjayanand [8] presented the boundary layer flow of viscoelastic fluid and heat transfer over an exponentially stretching sheet with viscous dissipation effect, Partha et al. [9] reported a similarity solution for mixed convection flow past an exponentially stretching surface. Ishak [10] studied the magnetohydrodynamic (MHD) boundary layer flow over an exponentially shrinking sheet in the presence of thermal radiation, Bhattacharyya [11] discussed the boundary layer flow and heat transfer caused due to an exponentially shrinking sheet and Bhattacharyya and Pop [12] showed the effect of external magnetic field on the flow over an exponentially shrinking sheet. Recently, Bhattacharyya and Vajravelu [13] described the stagnation point boundary layer flow due to exponentially shrinking sheet for Newtonian fluid.

The study of non-Newtonian fluids has attracted much attention because of their extensive variety of applications in engineering and industry especially in extraction of crude oil from petroleum products, production of plastic materials and syrup drugs. In the category of non-Newtonian fluids, Casson fluid has distinct features. Casson fluid is one of the types of such non-Newtonian fluids, which behaves like an elastic solid, and for this kind of fluid, a yield shear stress exists in the constitutive equation. Non-Newtonian transport phenomena arise in many branches of mechanical and chemical engineering and also in food processing. Some materials e.g. muds, condensed milk, glues, printing ink, emulsions, paints, sugar solutions, shampoos and tomato pastes exhibit almost all the properties of non-Newtonian fluid. This rheological model was introduced originally by Casson [14] in his research on a flow equation for pigment oil-suspensions of printing ink. Casson model constitutes a plastic fluid model which exhibits shear thinning characteristics, yield stress, and high shear viscosity. According to a research conducted by Rao et al. [15], it is stated that Casson fluid model is reduced to a Newtonian fluid at a very high wall shear stress, i.e., when the wall stress is much greater than yield stress. This fluid model also approximates reasonably well the rheological behavior of other liquids including physiological suspensions, foams, cosmetics, syrups, etc. Although different models are proposed to explain the behavior of non-Newtonian fluids, the most important non-Newtonian fluid possessing a yield value is the Casson fluid. Bird et al. [16] investigated the rheology and flow of visco-plastic materials and reported that the Casson model constitutes a plastic fluid model which exhibits shear thinning characteristics, yield stress, and high shear viscosity. In 2007, Evan Mitsoulis discussed in detail on the stress-deformation behavior of viscoplastic models (i.e. Bingham models, Herschel–Bulkley model and the Casson model) and different constitutive equations proposed in [16]. Mitsoulis [17] further reviews several benchmark problems of viscoplastic flows, such as entry and exit flows from dies, flows around a sphere and a cylinder and squeeze flows. The fundamental analysis of the flow field of non-Newtonian fluids in a boundary layer adjacent to a stretching sheet or an extended surface is very important and is an essential part in the study of fluid dynamics and heat transfer [18]. Hayat et al. [19] investigated Soret and Dufour effects on magnetohydrodynamic (MHD) flow of Casson fluid. Fredrickson [20] investigated the steady flow of a Casson fluid in a tube. The unsteady boundary layer flow and heat transfer of a Casson fluid over a moving flat plate with a parallel free stream were studied by Mustafa et al. [21] and they solved the problem analytically using the Homotopy analysis method (HAM). Recently, Animasaun [22] presented the effects of some thermo-physical parameters on non-darcian MHD dissipative Casson fluid flow along linearly stretching vertical surface when there exists migration of colloidal particles in response to a macroscopic temperature.