Alexandria Engineering Journal (2016) 55, 1025–1035

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

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

ORIGINAL ARTICLE

Unsteady Casson nanofluid flow over a stretching sheet with thermal radiation, convective and slip boundary conditions

Ibukun Sarah Oyelakin, Sabyasachi Mondal *, Precious Sibanda

School of Mathematics, Statistics and Computer Science, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa

Received 18 November 2015; revised 1 March 2016; accepted 3 March 2016
Available online 11 April 2016

KEYWORDS

Casson nanofluid;
Navier slip;
Soret and Dufour parameters;
Spectral relaxation method

Abstract In this paper we report on combined Dufour and Soret effects on the heat and mass transfer in a Casson nanofluid flow over an unsteady stretching sheet with thermal radiation and heat generation. The effects of partial slip on the velocity at the boundary, convective thermal boundary condition, Brownian and thermophoresis diffusion coefficients on the concentration boundary condition are investigated. The model equations are solved using the spectral relaxation method. The results indicate that the fluid flow, temperature and concentration profiles are significantly influenced by the fluid unsteadiness, the Casson parameter, magnetic parameter and the velocity slip. The effect of increasing the Casson parameter is to suppress the velocity and temperature growth. An increase in the Dufour parameter reduces the flow temperature, while an increase in the value of the Soret parameter causes increase in the concentration of the fluid. Again, increasing the velocity slip parameter reduces the velocity profile whereas increasing the heat generation parameter increases the temperature profile. A validation of the work is presented by comparing the current results with existing literature.

1. Introduction

The concept of nanofluids was introduced by Choi [1] where he proposed the suspension of nanoparticles in a base fluid such as water, oil, and ethylene glycol. Buongiorno [2] attempted to explain the increase in the thermal conductivity of such fluids and developed a model that took into account the particle Brownian motion and thermophoresis.

Noghrehabadi et al. [3] investigated the effects of the slip boundary condition on the heat transfer characteristics for a stretching sheet subjected to convective heat transfer in the presence of nanoparticles. They found that the flow velocity and the surface shear stress on the stretching sheet are strongly influenced by the slip parameter with a decrease in the momentum boundary layer thickness and increase in thermal boundary layer thickness. Khan and Pop [4] studied the problem of laminar fluid flow which results from a stretching of a flat surface in a nanofluid. They analyzed the development of the

* Corresponding author.
E-mail address: sabya.mondal.2007@gmail.com (S. Mondal).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.03.003
1110-0168

steady boundary layer flow, heat transfer and nanoparticle volume fraction over a stretching surface in the nanofluid. They observed that the reduced Nusselt number decreased while the reduced Sherwood number increased with the parameters considered in the study. They further obtained linear regression estimations in terms of Brownian and thermophoresis parameters for both the reduced Nusselt and Sherwood numbers. Nadeem et al. [5] studied two-dimensional boundary layer flow and heat transfer in steady incompressible Oldroyd-B nanofluid due to a stretching sheet. They showed that an increase in the Brownian motion parameter reduced the local Nusselt number while the local Sherwood number increased. Makinde et al. [6] studied the combined effects of buoyancy force, convective heating, Brownian motion, thermophoresis and a magnetic field on stagnation point flow and heat transfer due to a nanofluid flow from a stretching/shrinking sheet under the assumption that the magnetic Reynolds number was small. Their results showed that dual solutions exist for the shrinking case and an increase in the buoyancy force reduced both the skin friction coefficient and the local Sherwood number while the local Nusselt number increased. Haroun et al. [7] studied the heat and mass transfer in magnetohydrodynamic mixed convection flow of a nanofluid over an unsteady stretching/shrinking sheet. The flow considered was subject to a heat source and viscous dissipation. Soret and Dufour effects were assumed to be significant. They further assumed that the nanoparticle volume fraction at the wall could be actively controlled. The resulting fluid model equations were solved using the spectral relaxation method, an accurate technique for solving nonlinear boundary value problems. Recently, Haroun et al. [8] investigated magnetohydrodynamic nanofluid flow past an impulsively stretching surface with a chemical reaction and an applied magnetic field using the spectral relaxation method.

Casson fluid is classified as a non-Newtonian fluid due to its rheological characteristics in relation to the shear stress–strain relationship. It behaves like an elastic solid at low shear strain and above a critical stress value, it behaves like a Newtonian fluid. A Casson fluid can best be described as a shear thinning liquid with infinite viscosity at zero shear rate, and zero viscosity at an infinite rate of shear. Some common examples of liquids that exhibit Casson fluid characteristics include tomato sauce, honey, soup, orange juice and human blood.

Mustafa et al. [9] used the homotopy analysis method of solution to study the boundary layer flow of a Casson fluid near the stagnation-point on a stretching surface and presented results for the limiting case when the Casson parameter tends to infinity. Mustafa et al. [10] studied the momentum and thermal boundary layer development in a Casson fluid flow over a semi-infinite flat plate when both the ambient fluid and the flat plate are impulsively set in motion at the same time and the temperature of the flat plate is suddenly raised from that of the surrounding fluid. They derived parabolic partial differential equations which were solved analytically using the homotopy analysis method. Nandy [11] investigated the hydromagnetic boundary layer flow and heat transfer in a non-Newtonian Casson fluid with a stagnation point over a stretching surface in the presence of velocity and thermal slip boundary condition and the results indicated that the flow and temperature fields were greatly affected by the slip parameters on the velocity and thermal boundary conditions respectively. Makanda et al. [12] considered two-dimensional flow and diffusion of a chemically reactive species in Casson fluid from an unsteady stretching surface in the presence of magnetic field. It was generally noted that increasing the magnetic and permeability parameters reduced the velocity profiles, the coefficient of heat transfer and the concentration profiles while the skin friction increased. Bhattacharyya [13] considered two-dimensional magnetohydrodynamic stagnation point flow of an electrically conducting Casson fluid and heat transfer due to a stretching sheet under the effect of thermal radiation. They pointed out that the velocity boundary layer thickness for Casson fluid is larger than that of Newtonian fluids due to the plasticity of the Casson fluid. Mukhopadhyay et al. [14] studied Casson fluid flow over an unsteady stretching surface by extending the earlier work of Andersson et al. [15]. Hayat et al. [16] presented Soret and Dufour effects on two-dimensional flow of a Casson fluid induced by a stretching surface that is electrically conducting. They used the homotopy analysis method to solve the nonlinear system of ordinary differential equations. Nadeem [17] studied magnetohydrodynamic three dimensional Casson fluid flow past a porous linearly stretching sheet and they concluded that due to viscosity effects, the Newtonian fluid has less friction at the wall compared to the non-Newtonian fluid. Bhattacharyya [18] obtained analytical solutions for magnetohydrodynamic boundary layer flow of Casson fluid over a permeable stretching/shrinking sheet with wall mass transfer. Nadeem et al. [19] investigated the magnetohydrodynamic boundary layer flow of a Casson fluid over an exponentially permeable shrinking sheet. Nadeem et al. [20] discussed enhancement in the heat and mass transfer of a three dimensional magnetohydrodynamic Casson nanofluid and adjusted the hot fluid along the lower surface of the wall by introducing a convective boundary condition. They showed that a Newtonian nanofluid produces low skin friction at the wall compared to the Casson nanofluid and that there is low thermal conductivity for a higher Prandtl numbers. Mukhopadhyay [21] examined the effects of thermal radiation on Casson fluid flow and heat transfer over an unsteady stretching surface subjected to suction/blowing and they concluded that the Prandtl number can be used to increase the rate of cooling in the Casson fluid flow, temperature profile is intensified with increase in the radiation parameter, while the Casson parameter reduced the momentum boundary layer thickness and enhanced the thermal boundary layer thickness. Raju et al. [22] analyzed the flow, heat and mass transfer behavior of a Casson fluid past an exponentially permeable stretching surface in the presence of thermal radiation, a magnetic field, viscous dissipation, a heat source and chemical reaction, and they showed that increasing the heat source parameter reduced the temperature profiles in the boundary layer.

Recently, Kuznetsov and Nield [23] revisited their model on the natural convective boundary layer flow of a nanofluid over a vertical plate by including the effects of Brownian motion and thermophoresis. For the new model they argued that the nanofluid particle fraction at the boundary should be passively rather than actively controlled in order for the model to be physically realistic. This recent boundary condition provides one of the motivations for the present research.

The study of unsteady flow of Casson nanofluid has not been given much consideration so far. The aim of this paper is to study the fluid flow, heat and mass transfer in a Casson nanofluid, the Casson fluid being the base fluid. The