ARTICLE IN PRESS
Ain Shams Engineering Journal (2015) **xxx**, xxx–xxx

Ain Shams University
Ain Shams Engineering Journal
www.elsevier.com/locate/asej
www.sciencedirect.com

MECHANICAL ENGINEERING

Homogeneous–heterogeneous reactions in stagnation point flow of Casson fluid due to a stretching/shrinking sheet with uniform suction and slip effects

Mariam Sheikh *, **Zaheer Abbas**

Department of Mathematics, The Islamia University of Bahawalpur, Bahawalpur 63100, Pakistan

Received 20 April 2015; revised 31 August 2015; accepted 27 September 2015

KEYWORDS
Dual solutions;
Non-Newtonian Casson fluid;
Slip condition;
Homogeneous–heterogeneous reactions

Abstract This study deals with the effects of homogeneous–heterogeneous reaction on boundary layer flow of a non-Newtonian fluid near a stagnation point over a porous stretching/shrinking sheet with a constant suction. In this analysis Casson fluid is used to indicate the non-Newtonian fluid behavior by taking diffusion coefficients of both reactant and autocatalysis equal. The basic flow equations in form of partial differential equations are converted into a system of ordinary differential equations and then solved numerically. The influences of physical and fluid parameters on the velocity and concentration profiles are analyzed, presented and discussed through graphs. An increase in fluid velocity slip parameter reduces the magnitude of the velocity as well as increases the concentration in the boundary layer region. Furthermore, a unique solution is possible for all values of the stretching parameter ($\lambda > 0$), while in case of shrinking parameter ($\lambda < 0$), solutions are possible only for its limited ranges.

1. Introduction

Due to an increasing interest in the flow of fluids, a number of materials are utilized whose flow qualities are not analyzed with the Newtonian fluid model. In this situation non-Newtonian fluid models are very important because of their applications in polymer processing industries, petroleum drilling and biofluids dynamics and many others. The Navier–Stokes theory is inadequate for such type of fluids, and no single constitutive equation is available which covers the properties of all fluids. The most popular subclass of these fluids is Casson [1] fluid which displays yield stress impact. This fluid can be considered as a shear thinning liquid which is supposed to have an infinite viscosity at zero rate of shear, a yield stress below which no flow exists and a zero viscosity at an infinite rate of shear. In other words, this type of fluids acts like a solid, when a shear stress lower than the yield stress

* Corresponding author.
E-mail addresses: mariam_sheikh23@yahoo.com (M. Sheikh), za_qau@yahoo.com (Z. Abbas).
Peer review under responsibility of Ain Shams University.
ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2015.09.010
2090-4479 © 2015 Faculty of Engineering, Ain Shams University. Production and hosting by Elsevier B.V.

is applied to it, while it starts to move when a shear stress more than the yield stress is applied. The constitutive equation of Casson fluid is nonlinear in nature and has been defined to describe properly the flow curves of suspensions of pigments in lithographic varnishes utilized for preparing printing inks and silicon suspension [2]. Oka [3] reported the characteristics of Casson fluid model in tubes and considered a generalized model for flow of non-Newtonian fluid in tubes from which the Casson fluid model was constructed as a special case. Eldabe and Salwa [4] discussed the effects of MHD and heat transfer analysis in non-Newtonian Casson fluid flow between two rotating cylinders. Dash et al. [5] investigated the analysis of a Casson fluid in a pipe filled with a homogeneous porous medium by considering the Brinkman model. Recently, Mustafa et al. [6] presented the flow of a Casson fluid near a stagnation-point over a stretching sheet and analytical solution is obtained by means of homotopy analysis method. Due to its wide range of applications, this non-Newtonian fluid model has gained much attention of many authors, see Hayat et al. [7], Bhattacharyya [8,9], Shehzad et al. [10], Bhattacharyya et al. [11], Mukhopadhyay et al. [12], Pramanik [13]. Recently, Rao et al. [14] analyzed the heat transfer analysis in a Casson rheological fluid on a semi-infinite vertical plate with partial slip condition at the wall.

In recent years, boundary layer flow of different fluids in the region of stagnation point on a stretching/shrinking surface has attracted many scientists and engineers due to its real world applications in industry engineering processes. Chiam [15] examined the flow of a viscous fluid near a stagnation-point due to a stretching sheet. Ishak et al. [16] studied the effects of applied magnetic field near a stagnation point flow over a stretching sheet. Wang [17] discussed the flow of viscous fluid toward a stretching sheet with partial slip condition at the wall and obtained exact solution of Navier–Stokes equations. In another paper, Wang [18] studied the stagnation point flow due to a shrinking sheet in the presence of applied magnetic field. A theoretical analysis for different values of power index of the wall velocity using exact and numerical solutions for boundary layer flow of a viscous fluid over a nonlinearly shrinking sheet was investigated by Fang [19]. Javed et al. [20] discussed the numerical solution of heat transfer in the MHD viscous fluid over a porous nonlinearly shrinking sheet using Keller-box method. Rosali et al. [21] contributed to the study of stagnation point and heat transfer over a stretching/shrinking sheet in a porous medium. Bhattacharyya [22] reported the dual solutions in the boundary layer flow and mass transfer near a stagnation point on a stretching/shrinking surface. Muhaimin and Hashim [23] studied the effects of suction, heat and mass transfer on a viscous fluid toward a shrinking sheet with chemical reaction and variable stream condition. Singh and Chamkha [24] investigated the viscous fluid flow and heat transfer with second-order slip at shrinking isothermal sheet in a quiescent medium.

Most chemically reacting system involves both homogeneous and heterogeneous reactions, with examples occurring in combustion, catalysis and biochemical systems. The interaction between the homogeneous reactions in bulk of the fluid and heterogeneous reactions taking place on some catalytic surfaces is usually very complicated, which is included in the generation and consumption of reactant species at different rates both within the fluid and on the catalytic surfaces. Chaudhary and Merkin [25] initially studied simple mathematical model for homogeneous–heterogeneous reactions in boundary layer flow near a stagnation point. They gave the formulation of homogeneous (bulk) reaction by isothermal cubic kinetics and the heterogeneous (surface) reaction by considering the first-order kinetics. Later, Chaudhary and Merkin [26] continued their previous work to include the effect of loss of autocatalyst. Merkin [27] reported the results to study a model for isothermal homogeneous–heterogeneous reactions in boundary layer flow of viscous fluid on a flat plate. Khan and Pop [28] discussed the two-dimensional stagnation-point flow past an infinite permeable wall with homogeneous–heterogeneous reactions and uniform suction/injection numerically. Bachok et al. [29] studied the boundary layer flow with combined effects of stagnation-point and homogeneous–heterogeneous reactions toward a stretching surface. Again, Khan and Pop [30] investigated the effects of homogeneous–heterogeneous reactions on viscoelastic fluid due to a stretching sheet numerically using an implicit finite difference method. Kameswaran et al. [31] presented the effects of homogeneous–heterogeneous reactions in a nanofluid flow over a porous stretching sheet embedded in a porous medium by considering copper–water and silver–water as nanofluids. In another paper, Kameswaran et al. [32] studied the homogeneous–heterogeneous reactions on stagnation-point flow of a nanofluid over a stretching/shrinking sheet and obtained dual solutions for particular values of fluid parameters numerically. Shaw et al. [33] discussed the homogeneous–heterogeneous reactions in micropolar fluid flow over a permeable stretching or shrinking sheet in a porous medium numerically. Most recently, Abbas et al. [34] studied the effect of homogeneous–heterogeneous reactions on MHD viscous fluid near the stagnation-point over stretching/shrinking sheet with generalized slip condition.

The aim of the present study is to investigate the effects of homogeneous–heterogeneous reaction on a non-Newtonian Casson fluid near a stagnation point due to a permeable stretching/shrinking sheet with uniform suction and slip velocity at the wall. In this study, we consider the diffusion coefficients of both reactant and autocatalysis are equal. A numerical solution is constructed from nonlinear similarity equations using a shooting technique with Runge–Kutta method of order 4. The physical significance of the controlling fluid parameters on the flow field and concentration profiles are analyzed, presented and discussed graphically.

2. Formulation of the problem

We consider steady, two-dimensional and incompressible flow of a non-Newtonian fluid near a stagnation point due to a linear stretching/shrinking surface. The flow is confined in the region ($y > 0$) toward a surface coinciding with the plane ($y = 0$) with a fixed stagnation point at $x = 0$, with the x-axis along the surface and the y-axis perpendicular to it. Two equal and opposite forces are applied along the surface so that the wall is stretched/shrunk in the x-direction with linear surface velocity $u_w(x) = mx$, where $m > 0$ and $m < 0$ are for stretching and shrinking sheets, respectively, and the velocity outside the boundary layer is $u_e(x) = cx$, where $c > 0$ is the strength of stagnation flow. Following Mustafa et al. [35] and Subba Rao et al. [36], we assume rheological model of an isotropic flow of a non-Newtonian Casson fluid as follows:

Please cite this article in press as: Sheikh M, Abbas Z, Homogeneous–heterogeneous reactions in stagnation point flow of Casson fluid due to a stretching/shrinking sheet with uniform suction and slip effects, Ain Shams Eng J (2015), http://dx.doi.org/10.1016/j.asej.2015.09.010