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ORIGINAL ARTICLE

Investigation of the viscoelastic flow and species diffusion in a porous channel with high permeability

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Abstract In this study, effect of mass transfer on laminar flow of viscoelastic fluid in a porous channel with high permeability medium is investigated. The viscoelastic model used in this work is the upper convected Maxwell (UCM) model. Applying the similarity transformation, the governing partial equations are converted to ordinary differential equations. The problem is studied by a hybrid technique based on Differential Transformation Method (DTM) and iterative Newton's method (INM). Also a numerical solution is done to validate the present analytical method. The effects of active parameters such as Darcy number (Da), transpiration Reynolds number (Re_T) Deborah number (De) and Schmidt number (Sc) on the both velocity components and concentration function are discussed in this work. The results indicate that the stream function increases for large Deborah and Darcy numbers. The axial velocity is initially decreased by increasing the Deborah number but then increased while approaching the upper channel wall.

1. Introduction

In the current decade, the examination on the behavior of viscoelastic flows has attracted considerable interest due to their wide range of applications such as chemical process industries, food processing and biological systems. Viscoelastic fluids show both viscous and elastic properties, so because of this complexity of such fluids there is no specific model that indicates all of their properties, simultaneously. Some models have been proposed for such fluids which exhibit the non-linear relationship between stress and the rate of strain include second-grade model, Walters-B model, the Oldroyd model and upper convected Maxwell model (UCM). Many researchers studied the flow of all of these models. Fan et al. [1] utilized finite volume method to represent the viscoelastic flow which includes UCM and Oldroyd-B fluid in curved pipes. Sadeghi and Sharifi [2] studied the boundary layer flow of second-grade viscoelastic fluid above a moving plate. Nandeppanavar et al. [3] investigated the flow of Walters-B liquid fluid over an impermeable stretching sheet with the presence of non-uniform heat source/sink. The second-grade model is not suitable for flows of highly elastic fluids which occur at high Deborah number. Some studies show that the use of this kind of fluid is suitable only for slow flows with small level of elasticity [4,5] while there are some practical cases in which the Deborah

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Nomenclature

a_i	unknown parameter ($i = 1,2,3$)
C	concentration of species of fluid
C_H	concentration of channel center
C_W	concentration of channel wall
D	diffusion coefficient of the diffusing spices
Da	Darcy number
De	Deborah number
DTM	differential transformation method
$f(y)$	dimensionless normal velocity component
$f'(y)$	dimensionless axial velocity component
H	channel width
K	permeability of the porous medium
Re	Reynolds number
R_i	residual value ($i = 1,2,3$)
Sc	Schmidt number
U	fluid velocity along x-direction
V	fluid velocity along y-direction
X	coordinate along the channel
Y	coordinate perpendicular to the channel

Greek symbols

λ	relaxation time of the UCM fluid
ρ	density of the fluid
μ	dynamic viscosity of the fluid
ν	Kinetic viscosity of the fluid
ϕ	dimensionless concentration function

number is high [6]. So, the upper convected Maxwell model is proposed in simulating highly elastic fluids because it can predict the effects of stress relaxation. Khayat [7] analyzed the viscoelastic flow of UCM fluid between two parallel plates with moving free boundaries using perturbation method. Kumari and Nath [8] examined steady mixed convection flow of UCM fluids in the area of two-dimensional stagnation point with magnetic field by using boundary layer theory and finite difference method. The results are opposite of those reported for second-grade fluids. Frey et al. [9] utilized finite element method to study the flow of UCM fluids around a cylinder, and the model is approximated by a Galerkin least-squares formulation in extra-stress, pressure and velocity. Hayat et al. [10] employed homotopy analysis method (HAM) to investigate the influence of mass transfer on the two-dimensional stagnation point flow of UCM fluid over a stretching surface. Li et al. [11] studied viscoelasticity on lubricant thin film under the assumption that fluid belongs to the UCM model. The results show that the viscoelasticity that increases the lubricant pressure field has an influent effect on the lubrication performance. Abel et al. [12] used similarity transformation to investigate magnetohydrodynamic flow and heat transfer in a boundary layer of UCM flow over a stretching sheet applying numerical solution. Renardy and Wang [13] studied boundary layers arising in the high Weissenberg number limit of viscoelastic UCM flows using two mechanisms for the formation of viscoelastic boundary layer.

The study of heat and mass through a porous media is of special interest in many engineering fields such as chemical engineering, solar collectors processing and nuclear reactors. The phenomena of porous media in viscoelastic flow were investigated in some studies. Sivaraj and Kumar [14] investigated unsteady, MHD and chemically reacting dusty viscoelastic (Walter's liquid-B model) fluid Couette flow in a porous channel with convecting cooling and varying mass diffusion. Srinivas et al. [15] have studied the effects of chemical reaction and mass transfer on the flow of viscoelastic fluid in a porous channel with moving or stationary walls using HAM.

Most problems in the investigation of the flow of viscoelastic fluid are nonlinear. All these problems are modeled by partial or ordinary nonlinear equation. Hayat and Abbas [16] studied the flow of UCM fluid in a porous channel with chemical reaction, while Beg and Makinde [17] extended their study with considering species diffusion in a Darcian porous medium channel only using numerical solution. According to the above description, the main gain of this paper is to apply DTM to find the approximation solution of nonlinear differential equations governing the problem of flow of the UCM fluid in a porous channel with high-permeability. The main motivation of this study is to investigate both component of axial and normal velocity of the flow by using analytical solution. The influences of various parameters on velocity components and species concentration field are discussed.

In this paper, a new hybrid technique is used for solving the governing equations of the problem. The procedure of solution is based on the DTM and Newton's iterative method. Here, we can obtain the approximate solution of the problem using the proposed technique. Differential transform method is an iterative technique to obtain the semi analytical solution for differential equations by computing the components of Taylor series. Zhou [18] first introduced DTM for solving the linear and nonlinear initial value problems. He used this method to derive the semi analytical solution for the electrical circuit analysis. A considerable amount of researches have been done using DTM to investigate the solution of linear differential algebraic equations [19], nonlinear ordinary differential equations [20–24], partial differential equations [25], fractional differential equations [26] and integral equations [27]. DTM is a powerful and simple technique which is well known as a high accurate technique for solving the differential equations. Recently, most engineering problems have been analyzed using the analytical and approximate methods [28–35].

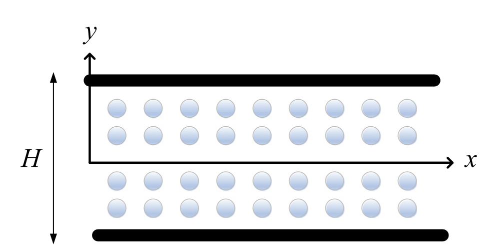

Figure 1 Schematic of the flow geometry in a channel with isotropic homogenous porous medium.

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