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ORIGINAL ARTICLE

Application of differential transformation method in micropolar fluid flow and heat transfer through permeable walls

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Abstract In this paper, we applied Differential Transformation Method (DTM) to study micropolar fluid flow and heat transfer through a channel with permeable walls. In order to verify the accuracy and validity of the application of this method to this problem, comparison with numerical method (NUM) is taken into account. Results reveal that DTM is an appropriate method for approximating solutions of the problem while it is smooth and straightforward to implement. The effect of significant parameters such as the Reynolds number, micro rotation/angular velocity and the Peclet number on the stream function, temperature distribution and concentration characteristics of the fluid, is discussed.

1. Introduction

Micropolar fluids are fluids with microstructure. Micropolar fluids consist of rigid, randomly oriented particles with their own and spins and microrotations, suspended in a viscous medium. In micropolar fluids, rigid particles contained in a small element can rotate about the center of the volume element described by a micro rotation vector. Beside this type of fluid, an interesting phenomenon is nanofluid, that is applicable on heat transfer enhancement, thus attracts many researchers [1–6]. The theory of a micropolar fluid derives from the need to model the flow of fluids that contain rotating micro constituents. A micropolar fluid is a fluid with internal structures which is coupling between the spin of each particle and the macroscopic velocity field is taken into account. It is a hydro dynamical framework suitable for granular systems which consist of particles with macroscopic size. An interesting feature of this class of fluid is the sustenance of couple stress. Some anisotropic fluids, animal blood, and liquid crystals are the examples of micropolar fluids. The micropolar fluid theory is applicable to certain polymer solutions, lubricant fluids, colloidal expansions, and complex biological structures. Eringen [7] was the first pioneer of formulating the theory of micropolar fluids. His theory introduced new material parameters, an additional independent vector field – the microrotation – and new constitutive equations which must be solved simultaneously with the usual equations for Newtonian fluid flow. The microrotation vector is a feature of this type of fluid that makes it applicable in the literature of modeling blood flow

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Nomenclature

C	species concentration (mol/m^3)
k_1	thermal conductivity (W/m k)
g	dimensionless microrotation
DTM	Differential Transformation Method
(u, v)	Cartesian velocity components (m/s)
$N_{1,2,3}$	dimensionless parameters
Sh	Sherwood number
p	pressure (Pa)
Pe	Peclet number
T	fluid temperature (k)
(x, y)	Cartesian coordinate components parallel and normal to channel axis, respectively

Greek symbols

η	similarity variable
μ	dynamic viscosity (Pa s)
ρ	Fluid density (kg/m^3)
ψ	stream function (m^2/s)
D^*	molecular diffusivity (m^2/s)
f	dimensionless stream function
h	half of channel width (m)
j	micro-inertia density (m^2)
$\vec{N}$	microrotation/angular velocity (m/s)
Nu	Nusselt number
Sc	Schmidt number
Pr	Prandtl number
Re	Reynolds number
s	microrotation boundary condition
θ	dimensionless temperature
κ	coupling coefficient (Pa s)
υ_s	microrotation/spin-gradient viscosity (N s)

in an artery. Although the field of micropolar fluids is rich in literature, some gaps can be observed and need more study in this field. For instance, Gorla [8], Rees and Bassom [9] investigated the flow of a micropolar fluid over a flat plate. Also, Kelson and Desseaux [10] studied the flow of micropolar fluids on stretching surfaces. Heat and mass transfer have an important role in many industrial and technological processes such as manufacturing and metallurgical processes in which heat and mass transfer occur simultaneously. The influence of a chemical reaction and thermal radiation on the heat and mass transfer in MHD micropolar flow over a vertical moving plate in a porous medium with heat generation was studied by Mohamed and Abo-Dahab [11]. Recently effect of using micropolar fluid, nanofluid, etc. on flow and heat transfer has been studied by several authors [12–23].

There are numerous amounts of publications about the application of semi-analytical methods on different phenomena. Such semi-analytical methods include Homotopy Analysis Method (HAM), Optimal Homotopy Asymptotic Method (OHAM), Adomian Decomposition Method (ADM), Homotopy Perturbation Method (HPM) and Differential Transformation Method (DTM) that are popular because of their high accuracy and simplicity in obtaining the solution. DTM has some advantages in comparison with other semi-analytical methods. HAM needs to calculate auxiliary parameter $\hbar$, through h-curves and initial guesses [24,25], but DTM does not need any auxiliary parameter and initial guess. DTM does not need any auxiliary function like $H(p)$ that is used in OHAM [26,27]. This method does not need to obtain Adomian polynomial that is difficult to access for highly nonlinear terms in ADM [28,29]. Also, DTM does not need any small parameter like "p" in (HPM) for discretization, perturbation or linearization [30–32]. Differential Transformation Method (DTM) is a powerful analytical method which is well known as a high accurate technique for solving the differential equations while it is straightforward and easy to implement. This approach constructs an analytical solution in the form of a polynomial and formulizes the Taylor series in a totally different manner. Zhou [33] first introduced this method for solving linear and nonlinear initial value problems. He used this method to obtain semi-analytical solution for the electrical circuit analysis. A considerable research revealed that this approach is appropriate for various problems [34–40]. For instance, Sheikholeslami et al. [39] used DTM to the governing equations for the MHD fluid flow, heat and mass transfer between two horizontal parallel plates to count in the effects of Brownian motion and thermophoresis in the nanofluid model.

With the above discussion in mind, in this study, we employed DTM to the governing coupled differential equations of micropolar fluid flow and heat transfer in a permeable channel. After that, we present a comparison with a numerical method to verify the accuracy and validity of this powerful method. As the Reynolds number (Re), Peclet number (Pe) and micro rotation/angular velocity play an important role in this problem, we focused on the effects of these parameters on the flow, heat transfer and concentration characteristics.

2. Problem description and governing equations

We considered the steady laminar flow of a micropolar fluid along a two-dimensional channel with porous walls through which fluid is uniformly injected or removed with speed v_0.

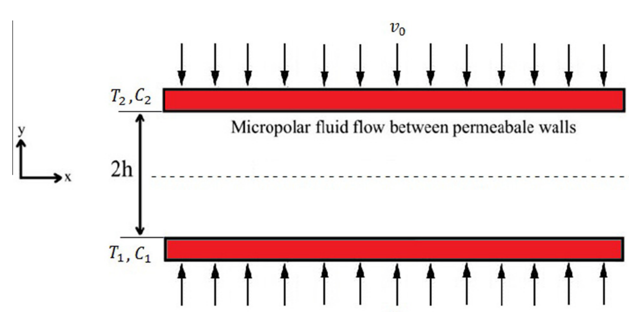

Figure 1 The geometry of the problem.

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