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Semi-analytical investigation on micropolar fluid flow and heat transfer in a permeable channel using AGM

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Abstract In this paper, micropolar fluid flow and heat transfer in a permeable channel have been investigated. The main aim of this study is based on solving the nonlinear differential equation of heat and mass transfer of the mentioned problem by utilizing a new and innovative method in semi-analytical field which is called Akbari–Ganji's Method (AGM). Results have been compared with numerical method (Runge–Kutte 4th) in order to achieve conclusions based on not only accuracy and efficiency of the solutions but also simplicity of the taken procedures which would have remarkable effects on the time devoted for solving processes.

Results are presented for different values of parameters such as: Reynolds number, micro rotation/angular velocity and Peclet number in which the effects of these parameters are discussed on the flow, heat transfer and concentration characteristics. Also relation between Reynolds and Peclet numbers with Nusselts and Sherwood numbers would found for both suction and injection

Furthermore, due to the accuracy and convergence of obtained solutions, it will be demonstrating that AGM could be applied through other nonlinear problems even with high nonlinearity.

1. Introduction

Micropolar fluids are fluids with microstructure. They belong to a class of fluids with nonsymmetrical stress tensor that we shall call polar fluids, which could be mentioned as the well-established Navier–Stokes model of classical fluids. These fluids respond to micro-rotational motions and spin inertia and therefore, can support couple stress and distributed body couples. Physically, a micropolar fluid is one which contains suspensions of rigid particles. The theory of micropolar fluids was first formulated by Eringen (1966). Examples of industrially relevant flows that can be studied with accordance to this theory include flow of low concentration suspensions, liquid crystals, blood, lubrication and so on. The micropolar theory has recently been applied and considered in different aspects of sciences and engineering applications. For instance, Gorla (1989), Gorla (1988), Gorla (1992) and Arafa and Gorla (1992) have considered the free and mixed convection flow of a micropolar fluid from flat surfaces and cylinders. Raptis (2000) studied boundary layer flow of a micropolar fluid through a porous medium by using the generalized Darcy

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law. 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 (2009).

It would be worthy to mention the fact that many scientists and researchers all around the world are working on the effects of using micropolar fluids and nanofluids on flow and heat transfer problems (Kelson and Desseaux, 2001; Sheikholeslami et al., 2016a,b; Rashidi et al., 2011; Sheikholeslami et al., 2015; Turkyilmazoglu, 2014c; Turkyilmazoglu, 2016b) which will lead to suitable perspective for future industrial and research applications such as: pharmaceutical processes, hybrid-powered engines, heat exchangers and so on.

In many engineering problems solving procedures will finally lead to whether mathematical formulation or modeling processes. For obtaining better understanding in both of these factors, many researchers from different fields devote their time to expand relevant knowledge. As one of the most important type of these knowledge, we could mention analytical, semi-analytical methods and numerical technics in solving nonlinear differential equations. By utilizing analytical and semi-analytical methods, solutions for each problem will approach to a unique function. Most of the heat transfer and fluid mechanics problems would engage with nonlinear equation which finding accurate and efficient solutions for these problem have been considered by many researchers recently. Therefore, for the purpose of achieving the mentioned facts, many researchers have tried to reach acceptable solution for these equations due to their nonlinearity by utilizing analytical and semi-analytical methods such as: Perturbation Method by Ganji et al. (2007), Homotopy Perturbation Method by Turkyilmazoglu (2012), Sheikholeslami et al. (2013) and Mirgolbabaei et al. (2009), Variational Iteration Method by Turkyilmazoglu (2016a), Mirgolbabaei et al. (2009) and Samaee et al. (2015), Homotopy Analysis Method by Sheikholeslami et al. (2014), Sheikholeslami et al. (2012) and Turkyilmazoglu (2011), Parameterized Perturbation Method (PPM) by Ashorynejad et al. (2014), Collocation Method (CM) by Hoshyar et al. (2015), Adomian Decomposition Method by Sheikholeslami et al. (2013), Least Square Method (LSM) by Fakour et al. (2014), Galerkin Method (GM) by Turkyilmazoglu (2014a,b) so on.

Its noteworthy to mentioned the fact that Semi-Analytical methods could be categorized into two perspectives due to their solving procedures as for simplicity we would call them as: Iterate-Base Method and Trial Function-Base Method. In Iterate-Base Method such as: HPM, VIM, ADM and etc., the important factor which affect the solving procedures is number of iterations. Although in this methods we may assume a trial functions, which are based on our in depended functions, however, in order to achieve solution in each step we have to solve previous steps at first. According to mentioned explanations, it's obvious that whilst the iteration results in higher steps can't be obtain by related software, we will face problem which will interrupt our solving procedures. Also these methods usually take more time for obtaining solutions. In Trial Function-Base Method such as: CM, LSM, Akbari–Ganji's Method (AGM) and etc., the main factor which affect the solving procedures is trial function. In this methods we will assume an efficient trial function base on the problem's boundary and initial conditions which contains different constant coefficients. Afterward, due to the basic idea of each method, we are obligated for solving the constant coefficients. In most cases the constant coefficients will be obtain easily by solving set of polynomials. Although in these methods, number of terms in our trial function could be referred as needed iterations, however, it's essential to mention the fact that utilized constants will obtain simultaneously in solving procedures. So in these methods the iteration problems have been eliminated.

In this article attempts have been made in order to obtain approximate solutions of the governing nonlinear differential equations of micropolar fluid flow. We have utilized a new and innovative semi-analytical method calling Akbari–Ganji's Method which is developed by Akbari and Ganji by Akbari et al. (2014) and Rostami et al. (2014) in 2014 for the first time. Since then this method has been investigated by many authors to solve highly nonlinear equations in different aspects of engineering problems such as: Fluid Mechanics, Nonlinear Vibration Problems, Heat Transfer Applications, Nanofluids and etc. Some of the excellence of proposed method could be referred as Ledari et al. (2015) and Mirgolbabaee et al. (2016a,b).

Due to recently achievements from this method and also the Trial Function-Base characteristics of this method, it could precisely conclude that AGM has high efficiency and accuracy for solving nonlinear problems with high nonlinearity. It is necessary to mention that a summary of the excellence of this method in comparison with the other approaches can be considered as follows: Boundary conditions are needed in accordance with the order of differential equations in the solution procedure but when the number of boundary conditions is less than the order of the differential equation, this approach can create additional new boundary conditions in regard to the own differential equation and its derivatives.

2. Mathematical formulation

We consider the steady laminar flow of a micropolar fluid along a two-dimensional channel with parallel porous walls through which fluid is uniformly injected or removed with speed v_0 which is represented in Fig. 1. The geometry of problem has defined clearly in Fig. 1. By utilizing Cartesian coordinates, the governing equations for flow are Sibanda and Awad (2010):

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial P}{\partial x}+(\mu+\kappa)\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial^2 y}\right)+\kappa\frac{\partial N}{\partial y} \tag{2}$$

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial x}+(\mu+\kappa)\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial^2 y}\right)-\kappa\frac{\partial N}{\partial x} \tag{3}$$

$$\rho\left(u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}\right)=-\frac{\kappa}{j}\left(2N+\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}\right)+\left(\frac{\upsilon_s}{j}\right)\left(\frac{\partial^2 N}{\partial x^2}+\frac{\partial^2 N}{\partial^2 y}\right) \tag{4}$$