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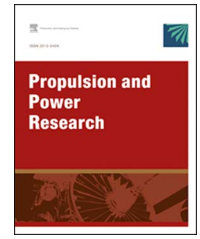

Flow and heat transfer of nanofluids over a rotating disk with uniform stretching rate in the radial direction

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Abstract This paper studies flow and heat transfer of nanofluids over a rotating disk with uniform stretching rate. Three types of nanoparticles-Cu, Al_2O_3 and CuO-with water-based nanofluids are considered. The governing equations are reduced by Von Karman transformation and then solved by the homotopy analysis method (HAM), which is in close agreement with numerical results. Results indicate that with increasing in stretching strength parameter, the skin friction and the local Nusselt number, the velocity in radial and axial directions increase, whereas the velocity in tangential direction and the thermal boundary layer thickness decrease, respectively. Moreover, the effects of volume fraction and types of nanofluids on velocity and temperature fields are also analyzed.

1. Introduction

The problem of fluid flow over a rotating disk is one of the classical problems in fluid mechanics, which has both theoretical and practical values. Many researches have been carried out on flow over a rotating disk in theoretical disciplines and due to numerous practical applications in some areas such as computer storage devices, rotating machinery, electronic devices and medical equipment, such flow is also very important in the engineering processes. Von Karman [1] originally investigated the hydrodynamic flow over an infinite rotating disk in 1921. In his work, Von Karman introduced his famous similarity transformations, which reduced the governing partial differential equations into ordinary differential equations. In recent years,

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Griffiths [2] considered the boundary-layer flow due to a rotating disk for a number of generalized Newtonian fluid models. Dandapat and Singh [3] studied the two-layer film flow over a non-uniformly rotating disk in the presence of uniform transverse magnetic field under the assumption of planar interface.

The flow due to stretching surfaces is important in the extrusion processes in plastic and metal industries [4–6]. The steady flow over a rotating and stretching disk was first studied by Fang [7]. Recently, Fang and Zhang [8] investigated the flow between two stretching disks. More recently, Turkyilmazoglu [9] studied the steady magnetohydrodynamic (MHD) laminar flow of an electrically conducting fluid on a radially stretchable rotating disk in the presence of a uniform vertical magnetic field. Fang and Tao [10] investigated the laminar unsteady flow over a stretchable rotating disk with deceleration. Rashidi et al. [11] considered the first and second law analyzes of an electrically conducting fluid past a rotating disk in the presence of a uniform vertical magnetic field. Asghar et al. [12] studied steady three dimensional flow and heat transfer of viscous fluid on a rotating disk stretching in radial direction. Turkyilmazoglu [13] investigated the traditional Bödewadt boundary layer of an incompressible viscous fluid flow and heat transfer over a stationary disk provided that the disk is allowed to radially stretch.

The term “nanofluids” was coined by Choi [14] in 1995 at the ASME Winter Annual Meeting. Nanofluid is a colloidal mixture by adding nanoparticles (<100 nm) in a base fluid, which can considerably change the transport and thermal properties of the base fluid and thus may improve thermal conductivity. A list of review papers on nanofluids can be found in Refs. [15–17]. Bachok et al. [18] studied the flow and heat transfer over a rotating porous disk in a nanofluid. Rashidi et al. [19] considered the entropy generation in steady MHD flow due to a rotating porous disk in a nanofluid. Turkyilmazoglu [20] investigated the flow and heat transfer characteristics over a rotating disk immersed in five distinct nanofluids.

The homotopy analysis method (HAM) introduced by Liao in 1992 [21–26], is an effective mathematical method which has been successfully employed to solve different types of nonlinear problems. Many studies have verified the validity and effectiveness of this method. In this work, we obtain the analytical solutions by using the homotopy analysis method.

Although the problem of fluid flow over a rotating disk that is stretching in the radial direction are already involved in some works as cited above, they have not yet been considered for nanofluids. In this paper we investigate the flow and heat transfer of nanofluid over a stretching rotating disk, three types of nanoparticles: Cu, CuO and Al_2O_3 are considered. Results show that with increasing in stretching strength parameter, the skin friction and the local Nusselt number, the velocity in radial and axial directions increase, whereas the velocity in tangential direction and the thermal boundary layer thickness decrease, respectively.

2. Formulation of the problem

Consider an incompressible, steady and axially symmetric nanofluid flow past a rotating disk that is placed at $z=0$ and rotates with an angular velocity Ω. The disk is further stretching at a uniform rate s in the radial direction r. Physical model of rotating disk is shown in Fig. 1 [13]. The governing equations of the nanofluid motion and energy in cylindrical coordinates can be presented, respectively, as follows

$$\frac{\partial u}{\partial r}+\frac{u}{r}+\frac{\partial w}{\partial z}=0 \tag{1}$$

$$u\frac{\partial u}{\partial r}-\frac{v^2}{r}+w\frac{\partial u}{\partial z}+\frac{1}{\rho_{nf}}\frac{\partial p}{\partial r}=\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}-\frac{u}{r^2}+\frac{\partial^2 u}{\partial z^2}\right) \tag{2}$$

$$u\frac{\partial v}{\partial r}+\frac{uv}{r}+w\frac{\partial v}{\partial z}=\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 v}{\partial r^2}+\frac{\partial}{\partial r}\left(\frac{v}{r}\right)+\frac{\partial^2 v}{\partial z^2}\right) \tag{3}$$

$$u\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial z}+\frac{1}{\rho_{nf}}\frac{\partial p}{\partial z}=\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 w}{\partial r^2}+\frac{1}{r}\frac{\partial w}{\partial r}+\frac{\partial^2 w}{\partial z^2}\right) \tag{4}$$

$$u\frac{\partial T}{\partial r}+w\frac{\partial T}{\partial z}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right) \tag{5}$$

The boundary conditions are given by

$$z=0: \quad u=sr,\ \ v=\Omega r,\ \ w=0,\ \ T=T_w \tag{6}$$

$$z\to\infty: \quad u\to 0,\ \ v\to 0,\ \ T\to T_\infty,\ \ P\to P_\infty \tag{7}$$

where T is the temperature of the nanofluid, T_∞ is the temperature of the ambient nanofluid, the pressure is P and the pressure of the ambient nanofluid is P_∞, μ_{nf} and α_{nf} are the dynamic viscosity and thermal diffusivity of

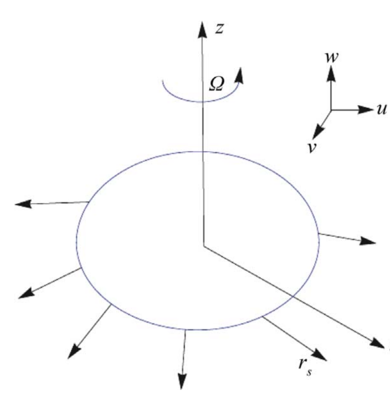

Fig. 1 Physical model of rotating disk.