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Thermal analysis of rotating system with porous plate using nanofluid

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ABSTRACT

In this study homotopy perturbation method is used to investigate nanofluid flow and heat transfer between two horizontal plates in a rotating system. The lower plate is a stretching sheet and the upper one is a solid porous plate. Copper (Cu) as nanoparticle and water as its base fluid have been considered. Comparison between HPM and numerical solution results showed an excellent agreement. The results for the flow and heat transfer characteristics are obtained for various values of the nanoparticle volume fraction, suction/injection parameter, rotation parameter and Reynolds number. The results show that for both suction and injection, the heat transfer rate at the surface has direct relationship with nanoparticle volume fraction, Reynolds number and injection/suction parameter but it is a decreasing function of power of rotation parameter.

1. Introduction

The term "nanofluid" which was first proposed by Choi [1] to indicate engineered colloids composed of nanoparticles dispersed in a base fluid. Sheikholeslami et al. [2] used heatline analysis to simulate two phase simulation of nanofluid flow and heat transfer. Their results indicated that the average Nusselt number decreases as buoyancy ratio number increases until it reaches a minimum value and then starts increasing. Abu-Nada et al. [3] investigated natural convection heat transfer enhancement in horizontal concentric annuli field by nanofluid. They found that for low Rayleigh numbers, nanoparticles with higher thermal conductivity cause more enhancement in heat transfer. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in presence of magnetic field was investigated by Sheikholeslami et al. [4]. They found that the enhancement in heat transfer increases as Hartmann number increases but it decreases with increase of Rayleigh number.

Soleimani et al. [5] studied natural convection heat transfer in a semi-annulus enclosure filled with nanofluid using the Control Volume based Finite Element Method. They found that the angle of turn has an important effect on the streamlines, isotherms and maximum or minimum values of local Nusselt number. Saleh et al. [6] studied the effect of inclination angles of the sloping wall on the flow and temperature fields in a trapezoidal enclosure filled with nanofluids. It was found that acute sloping wall and Cu nanoparticles with high concentration are effective to enhance the rate of heat transfer. Three dimensional heat and mass transfer in a rotating system using nanofluid were investigated by Sheikholeslami and Ganji [7]. They concluded that Nusselt number has direct relationship with Reynolds number while it has reverse relationship with rotation parameter, magnetic parameter, Schmidt number, Thermophoretic parameter and Brownian parameter. Sheikholeslami et al. [8] analyzed the magnetohydrodynamic nanofluid flow and heat transfer between two horizontal plates in a rotating system. Their results indicated that, for both suction and injection Nusselt number has a direct relationship with nanoparticle volume fraction. Recently several authors investigated about natural convection and effect of adding nanoparticle in the base fluid on flow and heat transfer [9–27].

The fluid dynamics due to a stretching sheet is important from theoretical as well as practical point of view because of their wider applications to polymer technology and metallurgy. During many mechanical forming processes, such as extrusion, melt-spinning, cooling of a large metallic plate in a bath, manufacture of plastic and rubber sheets, glass blowing, continuous casting, and spinning of fibers, the extruded material issues through a die. Provoked by the process of polymer extrusion in which extradite emerges from a narrow slit: Crane [28] first analyzed the two-dimensional fluid flow over a linearly stretching surface. Later, this problem has been extensively studied in various directions: For example, for non-Newtonian fluids, porous space and magneto-hydrodynamics [29–31].

Most of engineering problems, especially some of heat transfer equations are nonlinear, therefore some of them are solved using

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Nomenclature

A_1, A_2, A_3 Dimensionless constants
C_p Specific heat at constant pressure
$C_f, \widetilde{C}_f$ Skin friction coefficients
$f(\eta), g(\eta)$ Similarity functions
L_1, L_2, L_3 Auxiliary linear operators
h Distance between the plates
k Thermal conductivity
Kr Rotation parameter
Nu Nusselt number
p^* Modified fluid pressure
Pr Prandtl number
q_w Heat flux at the lower plate
R Reynolds number
u, v, w Velocity components along x, y, and z axes, respectively
$u_w(x)$ Velocity of the stretching surface
v_0 Suction/injection velocity

Greek symbols
α Thermal diffusivity
η Dimensionless variable
θ Dimensionless temperature
ρ Density
ϕ Nanoparticle volume fraction
λ Dimensionless suction/injection parameter
μ Dynamic viscosity
υ Kinematic viscosity
τ_w Skin friction or shear stress along the stretching surface
Ω Constant rotation velocity

Subscripts
∞ Condition at infinity
nf Nanofluid
f Base fluid
s Nano-solid-particles

numerical solution and some are solved using the different analytic method, such as perturbation method, homotopy perturbation method, and variational iteration method introduced by He [32]. Therefore, many different methods have recently introduced some ways to eliminate the small parameter. One of the semi-exact methods which do not need small parameters is the homotopy perturbation method. The homotopy perturbation method, proposed first by He in 1998 and was further developed and improved by He. The method yields a very rapid convergence of the solution series in the most cases. The HPM proved its capability to solve a large class of nonlinear problems efficiently. Usually, few iterations lead to high accuracy solution. Heat transfer of a nanofluid flow which is squeezed between parallel plates was investigated analytically using homotopy perturbation method by Sheikholeslami and Ganji [33]. They reported that Nusselt number has direct relationship with nanoparticle volume fraction, the squeeze number and Eckert number when two plates are separated but it has reverse relationship with the squeeze number when two plates are squeezed. Sheikholeslami et al. [34] studied the problem of laminar nanofluid flow in a semi-porous channel. They found that the velocity boundary layer thickness decreases with increasing Reynolds number and nanoparticle volume fraction, and it increases while Hartmann number increases. Recently analytical methods are employed for many researches in engineering sciences [35–42].

The main idea of the present study is to study the nanofluid flow and heat transfer. The reduced ordinary differential equations are solved analytically using homotopy perturbation method. The effects of the parameters governing the problem are studied and discussed.

2. Flow analysis

2.1. Governing equations

Consider the steady flow of nanofluid between two horizontal parallel plates when the fluid and the plates rotate together around the axis which is normal to the plates with a constant angular velocity Ω. A Cartesian coordinate system (x, y, z) is considered as follows: the x-axis is along the plate, the y-axis is perpendicular to it and the z-axis is normal to the x–y plane (Fig. 1). The origin is located at the lower plate, and the plates are located at $y = 0$ and $y = h$. The lower plate is being stretched by two equal opposite forces so that the position of the point $(0, 0, 0)$ remains unchanged. The upper plate is subjected to a constant wall suction velocity $v_0(<0)$ or a constant wall injection velocity $v_0(>0)$, respectively. The fluid is a water based nanofluid containing Cu (copper). The nanofluid is a two component mixture with the following assumptions: (i) incompressible; (ii) no-chemical reaction; (iii) negligible viscous dissipation; (iv) negligible radiative heat transfer; and (v) nano-solid-particles and the base fluid are in thermal equilibrium and no slip occurs between them. The thermo physical properties of the nanofluid are given in Table 1. Under these assumptions, the governing equations of motion in a rotating frame of reference are:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+2\Omega w=-\frac{1}{\rho_{nf}}\frac{\partial p^*}{\partial x}+\upsilon_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$u\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p^*}{\partial y}+\upsilon_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}-2\Omega w=\upsilon_{nf}\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}\right) \tag{4}$$

where u, v and w denote the fluid velocity components along the x, y and z directions, p^* is the modified fluid pressure and the physical meanings of the other quantities are mentioned in the Nomenclature.

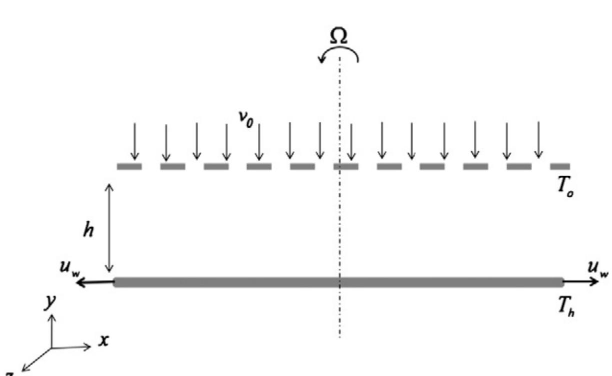

Fig 1. Schematic theme of the problem geometry.