Journal of Molecular Liquids 194 (2014) 13–19

Contents lists available at ScienceDirect

Journal of Molecular Liquids

journal homepage: www.elsevier.com/locate/molliq

Numerical investigation for two phase modeling of nanofluid in a rotating system with permeable sheet

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ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form 1 January 2014
Accepted 7 January 2014
Available online 21 January 2014

Keywords:
Nanofluid
Porous plate
Brownian
Thermophoresis
Schmidt number
Rotating disk

ABSTRACT

Nanofluid flow and heat transfer in a rotating system is studied numerically using fourth-order Runge–Kutta method. The important effects of Brownian motion and thermophoresis have been included in the model of nanofluid. The numerical investigation is carried out for different governing parameters namely: Reynolds number, Rotation parameter, injection parameter, Schmidt number, Thermophoretic parameter and Brownian parameter. The results indicate that skin friction parameter increases with augment of Reynolds number and Rotation parameter but it decreases with increase of injection parameter. Also it can be found that Nusselt number has a direct relationship with Reynolds number and injection parameter while it has a reverse relationship with Rotation parameter, Schmidt number, Thermophoretic parameter and Brownian parameter.

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1. Introduction

The fluid dynamics due to a stretching sheet are important from theoretical as well as practical point of view because of their wide 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. Crane [1] 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, magneto-hydrodynamics, etc. [2–9].

In most of the available studies, the base fluid is a common fluid with low thermal conductivity. The resulting performances of such thermal systems are poor. A recent way of improving the performance of these systems is to suspend metallic nanoparticles in the base fluid. Rashidi et al. [10] considered the analysis of the second law of thermodynamics applied to an electrically conducting incompressible nanofluid flowing over a porous rotating disk. They concluded that using magnetic rotating disk drives has important applications in heat transfer enhancement in renewable energy systems. MHD effect on natural convection heat transfer in an inclined L-shape enclosure filled with nanofluid was studied by Sheikholeslami et al. [11]. They found that enhancement in heat transfer has reverse relationship with Hartmann number and Rayleigh number. Ellahi [12] studied the magnetohydrodynamic (MHD) flow of non-Newtonian nanofluid in a pipe. He observed that the MHD parameter decreases the fluid motion and the velocity profile is larger than that of temperature profile even in the presence of variable viscosities. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in the presence of magnetic field was investigated by Sheikholeslami et al. [13]. They found that the

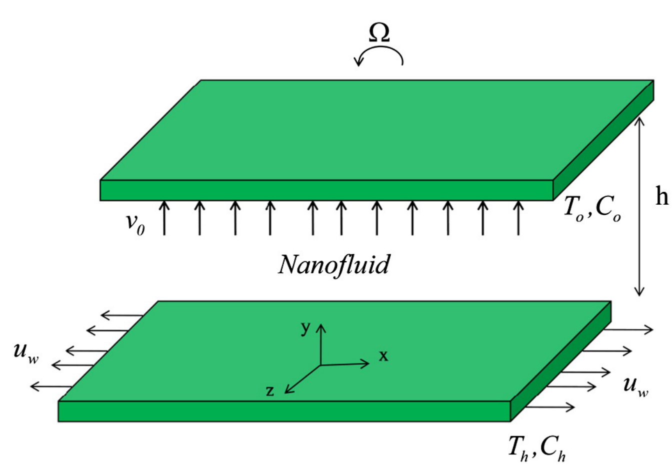

Fig. 1. Geometry of problem.

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0167-7322/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.molliq.2014.01.003

Nomenclature

C	Nanofluid concentration
$C_f, \widetilde{C}_f$	Skin friction coefficients
C_p	Specific heat at constant pressure
D_B	Diffusion coefficient
H	Distance between the plates
K	Thermal conductivity
K_r	Rotation parameter
Nu	Nusselt number
P^*	Modified fluid pressure
Pr	Prandtl number
R	Reynolds number
Sc	Schmidt number
Nb	Brownian motion parameter
Nt	Thermophoretic parameter
u, v, w	velocity components along x, y, z axes, respectively

Greek symbols

α	thermal diffusivity
ϕ	Dimensionless concentration
η	Dimensionless variable
λ	Dimensionless suction/injection parameter
μ	Dynamic viscosity
υ	Kinematic viscosity
Θ	Dimensionless temperature
P	Fluid density
Ω	Constant rotation velocity

Subscripts

h	Hot
o	Cold

enhancement in heat transfer increases as Hartmann number increases but it decreases with the increase of Rayleigh number. Sheikholeslami et al. [14] 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.

All the above studies assumed that there are no slip velocities between nanoparticles and fluid molecules and assumed that the nanoparticle concentration is uniform. It is believed that in natural convection of nanofluids, the nanoparticles could not accompany fluid molecules due to some slip mechanisms such as Brownian motion and thermophoresis, so the volume fraction of nanofluids may not be uniform anymore and there would be a variable concentration of nanoparticles in a mixture. Nield and Kuznetsov [15] studied the natural convection in a horizontal layer of a porous medium. Their analysis revealed that for a typical nanofluid (with large Lewis number) the prime effect of the nanofluids is via a buoyancy effect coupled with the conservation of nanoparticles, the contribution of nanoparticles to the thermal energy equation being a second-order effect. Khan and Pop [16] published a paper on boundary-layer flow of a nanofluid past a stretching sheet. They indicated that the reduced Nusselt number is a decreasing function of each dimensionless number. Hassani et al. [17] investigated the problem of boundary layer flow of a nanofluid past a stretching sheet. They found that the reduced Nusselt number decreases with the increase of Prandtl number. Recently, there have been published several numerical studies on the modeling of natural convection heat transfer and effect of using nanofluids on heat transfer enhancement [18–32].

The main purpose of this work is to apply two phase model for simulating nanofluid flow and heat transfer in a rotating system. The reduced ordinary differential equations are solved numerically. The effects of Reynolds number, Rotation parameter, injection parameter, Schmidt number, Thermophoretic parameter and Brownian parameter on flow, heat and mass transfer are examined.

2. Governing equations

Consider the steady nanofluid flow between two horizontal parallel plates when the fluid and the plates rotate together around the y-axis which is normal to the plates with an angular velocity. A cartesian coordinate system 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 (see Fig. 1). The upper plate is subjected to a constant wall injection velocity $v_0(>0)$, respectively. The plates are located at $y = 0$ and $y = h$. The lower plate is being stretched by two equal and opposite forces so that the position of the point $(0,0,0)$ remains unchanged. The upper plate is

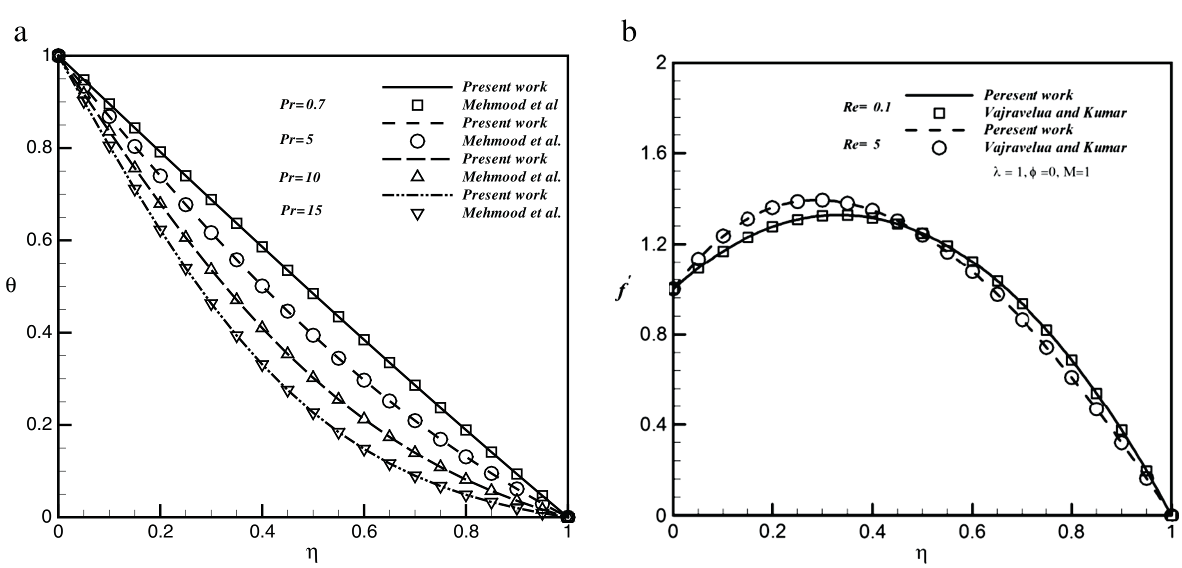

Fig. 2. Comparison of (a) the temperature profiles between the present work and [33] when $\lambda = 0.5$, $M = 1$, $R = 0.5$ and $Kr = 0.5$; (b) velocity profile between the present work and [34] when $\phi = 0$, $Kr = 0$, $M = 1$ and $\lambda = 1$.

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