Journal of King Saud University – Science (2016) 28, 380–389

King Saud University
Journal of King Saud University – Science
www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Steady nanofluid flow between parallel plates considering thermophoresis and Brownian effects

M. Sheikholeslami [a], M.M. Rashidi [b,c], Dhafer M. Al Saad [d], F. Firouzi [e], Houman B. Rokni [f,*], G. Domairry [a]

[a] *Department of Mechanical Engineering, Babol University of Technology, Babol, Iran*
[b] *Shanghai Key Lab of Vehicle Aerodynamics and Vehicle Thermal Management Systems, Tongji University, 4800 Cao An Rd., Jiading, Shanghai 201804, China*
[c] *ENN-Tongji Clean Energy Institute of Advanced Studies, Shanghai, China*
[d] *School for Engineering of Matter, Transport and Energy, Arizona State University, Tempe, AZ 85287, USA*
[e] *Department of Electrical Engineering, Tennessee Technological University, Cookeville, TN 38505, USA*
[f] *University of Denver, Mechanical and Materials Engineering, Denver, CO 80208, USA*

Received 15 June 2015; accepted 15 June 2015
Available online 29 June 2015

KEYWORDS
Nanofluid;
Brownian;
MHD;
Thermophoresis;
Differential Transformation Method

Abstract In this article, heat and mass transfer behavior of steady nanofluid flow between parallel plates in the presence of uniform magnetic field is studied. The important effect of Brownian motion and thermophoresis has been included in the model of nanofluid. The governing equations are solved via the Differential Transformation Method. The validity of this method was verified by comparison of previous work which is done for viscous fluid. The analysis is carried out for different parameters namely: viscosity parameter, Magnetic parameter, thermophoretic parameter and Brownian parameter. Results reveal that skin friction coefficient enhances with rise of viscosity and Magnetic parameters. Also it can be found that Nusselt number augments with an increase of viscosity parameters but it decreases with augment of Magnetic parameter, thermophoretic parameter and Brownian parameter.

1. Introduction

Because of increment in energy price, heat transfer (HT) management is important in energy systems. Recently, nanofluid technology is planned and studied by some researchers experimentally or numerically in order to enhance HT process. The nanofluid can be applied to engineering problems, such as heat exchangers, cooling of electronic equipment and chemical processes. In most of the studies, it is assumed that nanofluid treats as the common pure fluid. Abu-Nada et al. (2008)

* Corresponding author.
E-mail addresses: m.sheikholeslami1367@gmail.com (M. Sheikholeslami), Houman.Babazadehrokni@du.edu (H.B. Rokni).
Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksus.2015.06.003
1018-3647

Nomenclature

C	nanofluid concentration	*Greek symbols*	
C_f	skin friction coefficients	α	thermal diffusivity
C_p	specific heat at constant pressure	ϕ	dimensionless concentration
h	distance between the plates	η	dimensionless variable
k	thermal conductivity	μ	dynamic viscosity
Nu	Nusselt number	υ	kinematic viscosity
p^*	modified fluid pressure	θ	dimensionless temperature
Pr	Prandtl number	ρ	fluid density
R	viscosity parameter	σ	electrical conductivity
u, v, w	velocity components along x, y, z axes respectively	τ_w	skin friction or shear stress along the stretching surface
$u_w(x)$	velocity of the stretching surface		

investigated the enhancement of natural convection in horizontal concentric annuli field. They concluded that as Rayleigh number decreases, the thermal conductivity effects of nanoparticles cause more HT enhancement. Jou and Tzeng (2006) numerically studied the natural convection enhancements of nanofluid within a two-dimensional enclosure. They analyzed HT performance using Khana-fer's model for various parameters, such as volume fraction, aspect ratio of the enclosure, and Grashof number. Results showed that increasing the buoyancy parameter and volume fraction of nanofluid causes an increase in the average HT coefficient. Rashidi et al. (2013) modeled the application of the second law of thermodynamics to an electrically conducting incompressible nanofluid fluid flowing over a porous rotating disk.

Malvandi and Ganji (2014a) studied the laminar flow and convective HT of alumina/water nanofluid inside a circular microchannel in the presence of a uniform magnetic field. For smaller nanoparticles, more uniform volume fraction is observed and abnormal variations in the HT rate are vanished. MHD effect on natural convection HT in an inclined L-shape enclosure filled with nanofluid was studied by Sheikholeslami et al. (2014). They found that enhancement in HT has reverse relationship with Hartmann number and Rayleigh number. They concluded that using magnetic rotating disk affects HT rate in renewable energy systems and industrial thermal management. Recently several authors investigated nanofluid flow and HT enhancement applications (Cortell, 2014; Mabood et al., 2014; Garoosi et al., 2015a,b,c; Ashorynejad et al., 2013a,b Hatami and Ganji, 2014a,b; Hatami et al., 2014a–c; Domairry et al., 2012; Sheikholeslami et al., 2013a; Sheikholeslami and Ganji, 2013; Sheikholeslami et al., 2013b–e; Kefayati, 2013a,b; Kefayati, 2013c; Sheikholeslami et al., 2012a–c; Shehzad et al., 2012; Shehzad et al., 2013a,b; Shehzad et al., 2014a,b; Sheikholeslami et al., 2014a; Sheikholeslami et al., 2014b–f; Sheikholeslami Kandelousi, 2014a,b; Sheikholeslami and Ganji, 2015a; Sheikholeslami et al., 2015a–c; Sheikholeslami and Rashidi, 2015; Ellahi, 2013; Ellahi et al., 2012, 2013, 2015; Raptis, 1998; Rashidi et al., 2015; Akbar et al., 2014a,b; Umavathi and Mohite, 2014: Zeeshan et al., 2014). In all the above articles, it is assumed that there are no slip velocities between nanoparticles and fluid molecules and assumed that the nanoparticle concentration is uniform. Nield and Kuznetsov (2009) studied the natural convection in a horizontal layer of a porous medium saturated by a nanofluid. Khan and Pop (2010) investigated boundary-layer flow of a nanofluid past a stretching sheet as a first paper in that field. Their model used for the nanofluid incorporates the effects of Brownian motion and thermophoresis. They have taken into account the Prandtl number, Lewis number, Thermophores number, and Brownian motion number. The investigation of heat and mass transfer unsteady squeezing viscous flow between two parallel plates in motion normal to their own surfaces independent of each other and arbitrary with respect to time has been regarded as one of the most important research topics due to its wide spectrum of scientific and engineering applications such as hydrodynamical equipment, lubrication system, polymer processing, chemical processing tool, materials damage due to freezing, food processing and cooling towers. Mahmood et al. (2007) investigated the HT characteristics in the squeezed flow over a porous surface. Differential Transformation Method is one of the semi-exact methods which do not have the limitation of the perturbation method. Against the traditional higher-order Taylor series procedure, this method applies a polynomial solution that is computationally expensive for higher orders. DTM is a substitute method and its main advantage is applying the nonlinear differential equations without discretization and linearization. This method was introduced by Zhou (1986), by applying the DTM method to different problems in electrical applications. Many researchers investigated Multi-step DTM in different applications, for example Hatami and his colleagues (2014d) studied spherical particles motion in plane Couette fluid flow (Yang and Baleanu, 2013; Cattani et al., 2015 El-Zahar, 2013; Sheikholeslami and Ganji, 2015b: Rashidi, 2009).

The main purpose of this study is to investigate the problem of unsteady nanofluid flow between parallel plates using the Differential Transformation Method. The influence of the radiation parameter, squeeze number, Hartmann number, Brownian motion parameter and thermophoretic parameter on temperature and concentration profiles is investigated.

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