



Analysis of turbulent MHD Couette nanofluid flow and heat transfer using hybrid DTM–FDM



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ABSTRACT

Unsteady turbulent magnetohydrodynamic nanofluid hydrothermal treatment is studied. The zero-equation turbulence model is used to simulate turbulent flow. The modeling results obtained by applying the hybrid differential transformation method–finite difference method to solve this problem confirm its viability. An analytical procedure is used for finding the effects of the problem parameters. Results indicate that the average Nusselt number over the lower plate depends linearly on volume fraction of nanofluid, Hall parameter, turbulent Eckert number, and Reynolds number whereas it is inversely proportional on the Hartmann number and the turbulent parameter.

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Introduction

There exist various turbulence models. The simple kind of them is zero-equation model which is suitable for simple flow where mixing length exists. This method has several advantages such as ease of implementation and small CPU times (Biswas & Eswaran, 2002).

Zhou (1986) applied differential transformation method to solve some problems analytically. A hybrid numerical technique that combines the finite difference method (FDM) and differential transformation method (DTM) is used in many studies (Rashidi, Chamkh, & Keimanesh, 2011; Odibat, Bertelle, Aziz-Alaoui, & Duchamp, 2010; Gökdoğan, Merdan, & Yildirim, 2012). It is a suitable and efficient method for solving the time-dependent problem in heat and mass transfer subjects. For instance, Peng and Chen (2011) investigated an annular fin using this hybrid-DTM. They supposed that thermal conductivity is a function of temperature. Chu and Lo (2007) developed this method to investigate transient nonlinear heat conduction problems. Motivated by these works, the main objective of our study is to introduce the hybrid-DTM as

an efficient method for the unsteady magnetohydrodynamic Couette nanofluid. Outcomes reveal that the hybrid-DTM as an explicit method can overcome all nonlinearity terms of the problem without needing linearization. Peng and Chen (2011) showed that convection heat transfer is dominating mechanism when heat dissipation considered.

Mixing solid nanoparticles with base fluid can generate new fluid called nanofluid (Choi, 1995). These fluids have greater thermal conductivity, so they can enhance heat transfer behavior. Nanofluid as a passive method for augmentation heat transfer became popular in the last decade (Hatami & Ganji, 2014; Domairry & Hatami, 2014; Hatami, Sheikholeslami, & Ganji, 2014a,b; Sheikholeslami, Gorji-Bandpay, & Ganji, 2012; Sheikholeslami, Gorji-Bandpy, & Ganji, 2013a, 2014a; Sheikholeslami, Gorji-Bandpy, Ganji, Rana, & Soleimani, 2014f; Sheikholeslami & Gorji-Bandpy, 2014; Sheikholeslami & Ganji, 2013; Sheikholeslami & Ganji, 2014a,b; Sheikholeslami, Gorji-Bandpy, & Domairry, 2013d). Various methods developed to predict thermal conductivity nanofluid. Putra, Roetzel, and Das (2003) conducted experiments to observe the free convective behavior of Al₂O₃–water. They reported that buoyancy forces reduce with rise of nanofluid volume fraction. Sheikholeslami, Gorji-Bandpy, Ganji, and Soleimani (2014d) conduct a procedure for Lorentz force impacts on nanofluid free convection behavior in an inclined cavity. They indicated that heat transfer improvement is directly proportional to the Lorentz forces. Sheikholeslami, Gorji-Bandpy, and Soleimani (2013c) reported the heatline analysis of nonhomogeneous simulations of

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Nomenclature

$A_i (i = 1 \dots 5)$	constant parameters
c_p	specific heat capacity of the fluid
B_0	magnetic field
Ec	Eckert number
Ec_t	turbulent Eckert number
Ha	Hartmann number

temperature

k	thermal conductivity
L_t	turbulent parameter
m	hall parameter
p	pressure
q_w	surface heat flux
Re	Reynolds number
S	suction parameter
T	fluid temperature
u	fluid velocity on the x -coordinate
v	fluid velocity on the y -coordinate
w	fluid velocity on the z -coordinate

Greek symbols

α	thermal diffusivity
β_1	hall factor
μ_t	turbulent viscosity
σ	electrical conductivity
θ	dimensionless
ν	kinematic viscosity
ρ	fluid density

Subscripts

ω	condition at the surface
nf	nanofluid
f	base fluid
s	nano-solid-particles

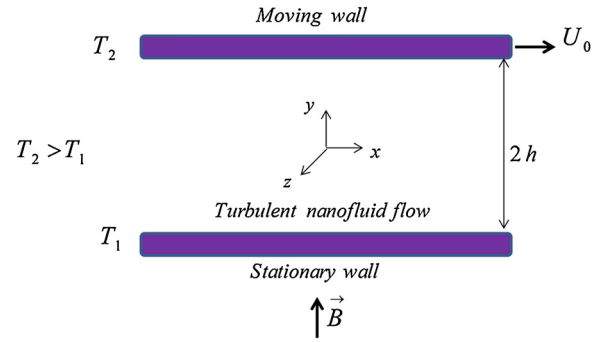


Fig. 1. Schematic of turbulent nanofluid flow.

Problem description

Turbulent nanofluid hydrothermal behavior through two plates is studied. Plates situated at planes $y = \pm h$. Top plate moves with a constant velocity U_0 with respect to a stationary bottom plate. The temperature of each plate is shown in Fig. 1. A horizontal uniform pressure gradient is considered. A constant magnetic field B_0 is considered in the positive vertical direction but the induced magnetic field is presumed negligible as a very small magnetic Reynolds number is assumed (see Fig. 1). A constant suction applied in vertical direction; the nanofluid velocity vector can be obtained as $\vec{v}(y, t) = +v_0 j + \vec{u}(y, t) i + \vec{w}(y, t) k$. The CuO and water properties are given in Table 1 (Koo & Kleinstreuer, 2005).

The momentum governing equations are:

$$\rho_{nf} \left(\frac{\partial \vec{u}}{\partial t} + v_0 \frac{\partial \vec{u}}{\partial y} \right) = -\frac{d\vec{P}}{dx} + (\mu_{nf} + \mu_t) \frac{\partial^2 \vec{u}}{\partial y^2} - \frac{\sigma_{nf} B_0^2}{1 + m_{nf}^2} (\vec{u} + m_{nf} \vec{w}), \quad (1)$$

$$\rho_{nf} \left(\frac{\partial \vec{w}}{\partial t} + v_0 \frac{\partial \vec{w}}{\partial y} \right) = (\mu_{nf} + \mu_t) \frac{\partial^2 \vec{w}}{\partial y^2} - \frac{\sigma_{nf} B_0^2}{1 + m_{nf}^2} (\vec{w} - m_{nf} \vec{u}), \quad (2)$$

where $m_{nf} = \sigma_{nf} \beta_1 B_0$ is Hall parameter and μ_t the turbulent viscosity given by $\mu_t = \rho_{nf} \ell_m^2 \left| \frac{\partial \vec{u}}{\partial y} \right|$. The energy equation is:

$$k_{nf} \frac{\partial^2 T}{\partial y^2} + (\mu_{nf} + \mu_t) \left[\left(\frac{\partial \vec{u}}{\partial y} \right)^2 + \left(\frac{\partial \vec{w}}{\partial y} \right)^2 \right] + \frac{\sigma_{nf} B_0^2}{(1 + m_{nf}^2)} (\vec{u}^2 + \vec{w}^2) = (\rho c_p)_{nf} \left(\frac{\partial T}{\partial t} + v_0 \frac{\partial T}{\partial y} \right), \quad (3)$$

where T denotes the temperature of the fluid. (ρ_{nf}) and $(\rho c_p)_{nf}$ are calculated from (Khanafer, Vafai, & Lightstone, 2003)

$$\begin{aligned} \rho_{nf} &= \rho_f (1 - \phi) + \rho_s \phi, \\ (\rho c_p)_{nf} &= (\rho c_p)_f (1 - \phi) + (\rho c_p)_s \phi. \end{aligned} \quad (4)$$

Also, σ_{nf} as given by Maxwell (Sheikholeslami, Ganji, Gorji-Bandpy, & Soleimani, 2014e) is:

$$\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3(\sigma - 1)\phi}{-(\sigma - 1)\phi + (\sigma + 2)}, \quad \frac{\sigma_s}{\sigma_f} = \sigma\sigma. \quad (5)$$

In this study, the Brownian motion impacts on (k_{nf}) and (μ_{nf}) has been considered (Koo & Kleinstreuer, 2005) as follows,

nanofluid hydrothermal behavior. They confirmed that the Nusselt number reduces to a minimum value as buoyancy ratio number increases and then starts increasing. Sheikholeslami, Hatami, and Ganji (2014g) analyzed magnetohydrodynamic (MHD) nanofluid hydrothermal behavior in a rotating system. They concluded that, the Nusselt number enhances with adding nanoparticle. Second law of thermodynamics has been applied for analysis of nanofluid flow over a rotating porous plate by Rashidi, Abelman, and Freidooni-Mehr (2013).

Fluid droplets sprays, petroleum industry, aerodynamics heating, and MHD pumps can be mentioned as various application of Couette flow. This flow has been studied by several scientists (Tani, 1962; Tao, 1960; Attia, 2006, 2008a, 2008b; Nigam & Singh, 1960; Eguía, Zueco, Granada, & Patiño, 2011; Alpher, 1961). Attia (1998) has investigated the Hall impact on hydrothermal behavior between two permeable plates. Magnetic field effects on nanofluid hydrothermal behavior have been considered by different scientists (Sheikholeslami, Gorji-Bandpy, & Ganji, 2013b, 2014b; Sheikholeslami, Gorji-Bandpy, Ellahi, & Zeeshan, 2014c; Sheikholeslami & Ganji, 2014c; Sheikholeslami et al., 2014d).

The purpose of this paper is to study turbulent unsteady nanofluid hydrothermal behavior two parallel disks. The Hall effect is taken into account in heat transfers. Influences of Eckert number, Hall and turbulent parameter, nanoparticle volume fraction, Reynolds and Hartmann numbers, and turbulent Eckert number on the style of velocity and temperature profiles are discussed.

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