Journal of the Taiwan Institute of Chemical Engineers 000 (2016) 1–9

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Unsteady squeezing nanofluid simulation and investigation of its effect on important heat transfer parameters in presence of magnetic field

M. Rahimi-Gorji [a,*], O Pourmehran [a], M. Gorji-Bandpy [b], D.D. Ganji [a]

[a] Young Researchers and Elite Club, Gorgan Branch, Islamic Azad University, Gorgan, Iran
[b] Professor of Mechanical Engineering, Department of Mechanical Engineering, Babol University of Technology, Babol, Iran

ARTICLE INFO

Article history:
Received 23 May 2016
Revised 23 July 2016
Accepted 1 August 2016
Available online xxx

Keywords:
Flow analysis
Squeezing nanofluid flow
Heat transfer
Galerkin Method (GM)

ABSTRACT

This paper presents a thermal and flow analysis of an unsteady squeezing nanofluid flow and heat transfer using nanofluid based on Brinkman model in presence of variable magnetic field. Galerkin Method (GM) is used to solve the nonlinear differential equations governing the problem. Squeezing flow between parallel plates are very applicable in the many industries and it means that one or both of the parallel plates have vacillation. The effects of active parameters such as the Hartman number, squeeze number and heat source parameter are discussed. Results for temperature distribution and velocity profile, Nusselt number and skin friction coefficient by Galerkin Method (GM) are presented. As can be seen in results, the values of Nusselt number and skin friction coefficient for CuO is better than Al_2O_3's. Also, according to figures, as nanofluid volume fraction increases, Nusselt number increases and skin friction coefficient decreases, increase in the Hartman number results in an increase in velocity and temperature profiles and an increase in squeeze number can be associated with the decrease in the velocity.

1. Introduction

Nanofluids are fluids consist of nanoparticles (nanometer-sized particles of metals, oxides, carbides, nitrides, or nanotubes). Nanofluids demonstrate increased thermal properties, amongst them; higher thermal conductivity and heat transfer coefficients compared to the base fluid. The nanofluid can be applied to engineering problems, such as cooling of electronic equipment, heat exchangers and chemical processes. Nanofluid contains a base fluid usually water, ethylene glycol, oil or engine oil and nano-powders such as Cu, CuO, Al_2O_3, TiO_2 or nano-diamond and usually a dispersant or surfactant to keep the nanoparticles' suspension stable. The main features of using nanofluids are increasing the heat transfer and viscosity improvement. Nanoparticles that are immersed in the base fluid will transfer heat with their Brownian motion and interactions. This advanced technique, which utilizes a mixture of nanoparticles and the base fluid, was first suggested by Choi [1] in order to develop heat transfer fluids with considerably higher conductivities. An admirable collection of the published papers on nanofluids can be found in the book by Das et al. [2].

Lately, the concept of a nanofluid has been proposed as a route for increasing the performance of the heat transfer rates in the liquids that are currently applied. Materials with sizes of nanometers have unique physical and chemical properties [2] It has been understood that the presence of nanoparticles within the fluid can extremely increase the effective thermal conductivity of the fluid and, as a consequence, increase the heat transfer characteristics. An excellent collection of works on this topic can be found in the book by Das et al. [2] and in the review papers by Kakac and Pramuanjaroenkij [3] and Fan and Wang [4]. Rahimi-Gorji et al. [5] studied the optimization of microchannel heat sink geometry cooled by different nanofluids using RSM analysis. Several studies have been performed on prediction of thermal conductivity of nanofluids [6–10].

Today numerical methods are applied for simulation many phenomena such as [11–15]. A numerical investigation on the heat transfer increasing due to adding nanoparticles in a differentially heated compound is reported by Khanafer et al. [16]. Hatami and Ganji [17] applied a numerical method to find the most accurate solution for the natural convection of the sodium alginate non-Newtonian nanofluid flow between two vertical plates. As a main result from their work, it is observed that by increasing the *Pr* number, velocity profiles and temperature values increased significantly, also Cu as nanoparticles had larger velocity and temperature values than Ag. Pourmehran et al. [18] examined the

* Corresponding author.
E-mail address: am69.rahimi@yahoo.com, m69.rahimi@stu.nit.ac.ir, mr.gorji@hotmail.com (M. Rahimi-Gorji).

http://dx.doi.org/10.1016/j.jtice.2016.08.001

Nomenclatures

u	Velocity in x direction
v	Velocity in y direction
P	Pressure
ρ_{nf}	Effective density of nanofluid
$(\rho C_p)_{nf}$	Effective heat capacity of nanofluid
σ_{nf}	Effective electrical conductivity of nanofluid
k_{nf}	Effective thermal conductivity of nanofluid
μ_{nf}	Viscosity of nanofluid
A_1, A_2, A_3, A_4 and A_5	Dimensionless constants
Pr	Prandtl number
Ha	Hartman number
S	Squeeze number
Hs	Heat source parameter
Nu	Nusselt number
D	Differential operator
C_f	Skin friction factor

Greek symbols

α	Constant rotational velocity
ϕ	Dimensionless concentration
μ	Dynamic viscosity
υ	Kinematic viscosity
θ	Dimensionless temperature
ρ	Fluid density

Subscripts

F	Base fluid
Nf	Nanofluid
P	Nano particle

optimization of microchannel heat sink performance cooled by KKL based in saturated porous medium.

Joneidi et al. [19] studied the effect of chemical reaction on free convective flow and mass transfer of a viscous, incompressible and electrically conducting fluid over a stretching surface in the presence of a constant transverse magnetic field. Their results showed that the velocity, temperature and concentration have direct relationship with chemical reaction parameter. Also magnetic parameter has direct relationship with temperature and concentration.

The second law of thermodynamics applied to an electrically conducting incompressible nanofluid fluid flowing over a rotating disk by Rashidi et al. [20]. They demonstrated that using magnetic rotating disk drives has important applications in heat transfer increasing in renewable energy systems. Khan and Pop [21] carried out research on boundary-layer flow of a nanofluid past a stretching sheet. Their model used for the nanofluid incorporates the effects of Brownian motion and thermophoresis. The heat transfer characteristics in the squeezed flow over a porous surface analyzed by Mahmood et al. [22]. Domairy and Aziz [23] investigated Magnetohydrodynamic squeezing flow of a viscous fluid between parallel disks. In recent years, much attention has been dedicated to the newly developed methods to construct an analytic solution of equation such as Collocation Method (CM), Least Square Method (LSM) and Galerkin Method (GM) which are introduced by Ozisik [24] for using in the heat transfer problems. Many of equations in the heat transfer problems [25,26] can be solved by these analytical methods that called the Weighted Residuals Methods (WRMs). Rahimi-Gorji et al. [27] performed an analytical analysis of particle motion in the non-Newtonian fluid using CM. Pourmehran et al. [28] analytically investigated the heat transfer of nanofluid flow between two parallel plates in order to show the influence of different nano particles on heat transfer by LSM, CM and numerical method. Hendi and Albugami [29] solved Fredholm–Volterra integral equation using Collocation and Galerkin methods. Legendre wavelet Galerkin method has been used for solving ordinary differential equations with non-analytic solution by Mohammadi et al. [30]. Hatami et al. [31] has investigated heat transfer and flow analysis for a non-Newtonian third grade nanofluid flow in porous medium of a hollow vessel in presence of magnetic field by using LSM, GM and numerical method.

In this paper, the viscosity of nanofluid and effective thermal conductivity are calculated by Brinkman correlation [32]. Also in the present paper, Galerkin method is used to solve nonlinear differential equations governing the problem of unsteady squeezing nanofluid flow and heat transfer using nanofluid based on Brinkman model in presence of variable magnetic field. Nusselt number and skin friction coefficient are presented. The effects of active parameters such as the Hartman number, squeeze number and heat source parameter are discussed. Heat transferring

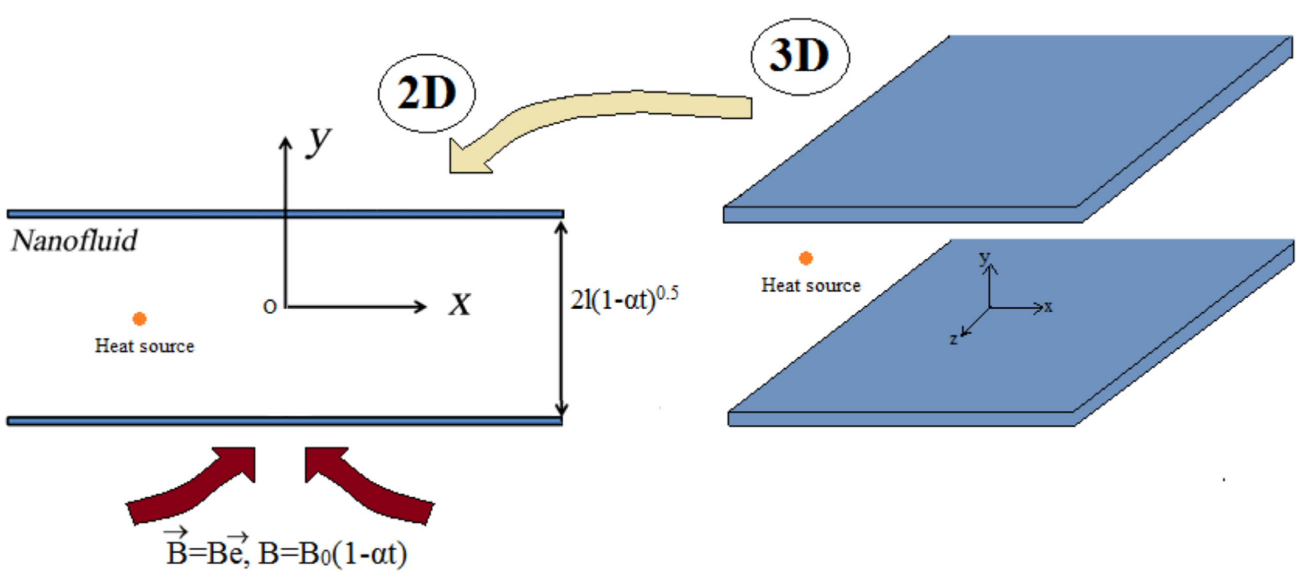

Fig. 1. Schematic of the problem (nanofluid between parallel plates).