



# New correlation for Nusselt number of nanofluid with Ag / Al<sub>2</sub>O<sub>3</sub> / Cu nanoparticles in a microchannel considering slip velocity and temperature jump by using lattice Boltzmann method



Arash Karimipour

Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran

## ARTICLE INFO

### Article history:

Received 20 April 2014

Received in revised form

10 January 2015

Accepted 12 January 2015

Available online 16 February 2015

### Keywords:

Different nanoparticles

Slip velocity

Temperature jump

LBM

Microflow

## ABSTRACT

Forced convection heat transfer of water-Ag, water-Cu and water-Al<sub>2</sub>O<sub>3</sub> nanofluid in a microchannel is studied numerically by using lattice Boltzmann method. Temperature of microchannel walls is higher than that of the inlet fluid. Effects of change in nanoparticles volume fraction and slip coefficient are investigated. Slip velocity, temperature jump and velocity and temperature profiles are presented at different cross sections. Moreover, a correlation is developed to predict nanofluid Nusselt number through the microchannel. As a result, higher value of slip coefficient corresponds to less Nusselt number and more slip velocity and temperature jump.

© 2015 Elsevier Masson SAS. All rights reserved.

## 1. Introduction

Investigation of fluid flow and heat transfer in micro scales has become one of the most attractive topics in recent years. Micro-pumps, microvalves, microchannels, etc. are a few examples of micro-devices which many researches have reported on [1–3]. Higher efficiency along with their small sizes increases the application of these micro devices more than before. Cooling the hot walls of a microchannel is a fundamental topic in the area of microflows due to its widespread applications. Surface effect is more important in the micro scale level, so that the well-known no-slip boundary condition fails and slip flow regime must be considered [4–7]. As a result, slip velocity and temperature jump can be observed along the fluid-solid boundaries. In addition to the slip flow, the transient and free molecular regimes might occur in the micro gas flows. It should be mentioned that Navier Stokes equations work well only for slip flow; however particle-based methods must be used for other flow regimes. Molecular dynamic (MD), lattice Boltzmann method (LBM) and direct simulation of Monte Carlo (DSMC) are some of these approaches [8–10]. LBM requires lower computation cost and uses easier equations

compared with MD or DSMC; it also deals with simple parallel algorithms and well describes the complex boundaries.

One time step of LBM is achieved by Collision and propagation between the fictive fluid particles located on a specified lattice points [11–17]. Collision must satisfy the conservation laws for which several models have been presented so far. Among them, BGK model shows suitable stability and accuracy [18–21]. He et al. [22] presented the thermal lattice Boltzmann method (TLBM) to simulate fluid flow and heat transfer. They introduced TLBM based on the internal energy distribution function. TLBM is able to take into account the pressure work and viscous heat dissipation terms [23]. Karimipour et al. [24] showed that TLBM worked well for the mixed convection of air in a microchannel. Investigations on LBM are still going on in order to attain more progress for better simulation of fluid flow and heat transfer. Thus, several researchers have been trying to find out if it is applicable for different conditions and geometries [25,26].

An innovative approach to increase heat transfer rate is using “nanofluids” which is a homogeneous mixture of liquid and solid nanoparticles. Nanofluid conduction is higher than that of the base fluid due to the large thermal conductivity of nanoparticles. Suitable performance of nanofluid at macro scales levels have been shown in several previous works [27–29]. Santra et al. [30] studied the heat transfer of laminar copper–water nanofluid flow through two isothermally heated parallel plates and also Esfe et al. [31]

E-mail addresses: [arashkarimipour@gmail.com](mailto:arashkarimipour@gmail.com), [arash.karimipour@pmc.iaun.ac.ir](mailto:arash.karimipour@pmc.iaun.ac.ir), [arash.karimipour@uniroma1.it](mailto:arash.karimipour@uniroma1.it), [arash.karimipour@yahoo.com](mailto:arash.karimipour@yahoo.com).

**Nomenclature**

|                                   |                                                       |
|-----------------------------------|-------------------------------------------------------|
| $B = \beta/h$                     | non-dimensional slip coefficient                      |
| $\mathbf{c}=(c_x, c_y)$           | microscopic velocity                                  |
| $C_p$                             | heat capacity, $\text{J kg}^{-1} \text{K}^{-1}$       |
| $D_H = 2h$                        | hydraulic diameter, m                                 |
| $d_p$                             | diameter of nanoparticles, nm                         |
| $f$                               | density-momentum distribution function                |
| $g$                               | internal energy distribution function                 |
| $h, l$                            | height and length of microchannel, m                  |
| $H = h/h, L = l/h$                | non-dimensional height and length                     |
| $k$                               | thermal conductivity, $\text{W m}^{-1} \text{K}^{-1}$ |
| $L_s$                             | length of slip, m                                     |
| $Nu$                              | Nusselt number                                        |
| $Pr = \nu_{nf}/\alpha_{nf}$       | Prandtl number                                        |
| $Re = \rho_{nf} u_i D_H/\mu_{nf}$ | Reynolds number                                       |
| $t$                               | time, s                                               |
| $T$                               | temperature, K                                        |
| $T_i$                             | inlet temperature, K                                  |
| $T_w$                             | wall temperature, K                                   |
| $\mathbf{u} = (u, v)$             | macroscopic velocity, $\text{m s}^{-1}$               |
| $(U, V) = (u/u_i, v/u_i)$         | non-dimensional velocity                              |
| $u_i$                             | inlet velocity, $\text{m s}^{-1}$                     |
| $U_s$                             | slip velocity                                         |
| $x, y$                            | coordinates, m                                        |

|                       |                             |
|-----------------------|-----------------------------|
| $(X, Y) = (x/h, y/h)$ | non-dimensional coordinates |
| $Z$                   | heat dissipation            |

**Greek symbols**

|                  |                                                  |
|------------------|--------------------------------------------------|
| $\alpha$         | thermal diffusivity, $\text{m}^2 \text{s}^{-1}$  |
| $\beta$          | slip coefficient                                 |
| $\phi$           | volume fraction of nanoparticles                 |
| $\mu$            | dynamic viscosity, Pas                           |
| $\theta = T/T_i$ | non-dimensional temperature                      |
| $\theta_s$       | temperature jump                                 |
| $\rho$           | density, $\text{kg m}^{-3}$                      |
| $\tau_f, \tau_g$ | momentum and internal energy relaxation times    |
| $\nu$            | kinematics viscosity, $\text{m}^2 \text{s}^{-1}$ |
| $\zeta$          | temperature jump distance                        |
| $\Omega$         | collision                                        |

**Super- and Sub-scripts**

|          |                                |
|----------|--------------------------------|
| $e$      | equilibrium                    |
| $f$      | fluid (water)                  |
| $i$      | inlet, lattice directions      |
| $nf$     | nanofluid                      |
| $out$    | outlet                         |
| $s$      | solid nanoparticles            |
| $w$      | wall                           |
| $\alpha$ | $x$ – $y$ direction components |

investigated the natural convection around an obstacle placed in an enclosure filled with different types of nanofluids.

The slip flow regime might happen for the liquid flows at micro scales. Aminossadati et al. [32] studied the effects of magnetic field on nanofluid forced convection in a partially heated microchannel; however without taking into account the slip velocity and temperature jump boundary conditions. The investigation of nanofluid flow in a microchannel in the absence of slip flow regimes along the walls can also be referred in other works [33,34]. However, in several of them the slip velocity (not the temperature jump) was presented for different states of nanofluid microflow [35,36]. Simulation of nanofluid flow using LBM has become an attractive topic for researchers at last few years [37,38]. Among these works, some are concerned with the investigation of nanofluid flow through a microchannel by LBM; however they all ignored the simulation of slip velocity and temperature jump by lattice Boltzmann method for the nanofluid [39,40,50,51].

Therefore, the force convection of nanofluid through a microchannel is studied here for the first time by using LBM considering slip velocity and temperature jump boundary conditions. To the best of authors' knowledge, this approach has not been implemented in any previous works.

**2. Problem statement**

Fig. 1 shows the physical geometry of microchannel. The inlet temperature of the Newtonian nanofluid is less than that of the walls ( $T_i = 0.5T_w$ ); while Reynolds number is kept fixed as  $Re = \rho_{nf} u_i D_H/\mu_{nf} = 0.01$ . At micro scales levels, the effects of gravity can be ignored due to very small value of characteristic length; hence the gravity effects and buoyancy motions are not involved. To exert the fully developed condition for both hydrodynamic and thermal domains, microchannel length is chosen long enough in comparison with its height. The incompressible flow regime is laminar and it is assumed that the spherical nanoparticle diameter is

$d_p = 10$  nm. The mixture is a homogeneous substance of water and nanoparticles. Nanofluid forced convection is studied numerically by applying LBM-BGK and using hydrodynamic ( $f$ ) and thermal ( $g$ ) distribution functions.

The effects of different kinds of nanofluid such as water-Ag, water-Cu and water- $\text{Al}_2\text{O}_3$  are investigated for three values of nanoparticles volume fraction ( $\phi = 0, \phi = 0.02$  and  $\phi = 0.04$ ). The slip coefficient value is taken into account as  $0.005 < B < 0.05$  in order to illustrate the slip velocity and temperature jump. Simulation of nanofluid temperature jump by LBM is presented for the first time. Moreover, it will be tried to develop a correlation for prediction of nanofluid Nusselt number through the microchannel.

The present work nanofluid is supposed as a homogeneous single phase mixture of water and nanoparticles. As a result, some characteristics of nanofluid such as local variations of volume fraction and actions and re-actions of nanoparticles are ignored. However the nanoparticles' Brownian motion effects on the thermal conductivity are considered here by using Eq. (5).

**3. Mathematical formulation****3.1. Nanofluid**

A homogeneous mixture of liquid as the base fluid and suspended solid nanoparticles inside, is called nanofluid. Using mixture model, the effective density and heat capacity can be achieved as follows:

$$\rho_{nf} = \phi \rho_s + (1 - \phi) \rho_f \quad (1)$$

$$(\rho C_p)_{nf} = (1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_s \quad (2)$$

where subscripts  $f$  and  $s$  show the fluid and solid nanoparticles, respectively. The subscript  $nf$  is also referring to nanofluid while  $\phi$

Download English Version:

<https://daneshyari.com/en/article/7060975>

Download Persian Version:

<https://daneshyari.com/article/7060975>

[Daneshyari.com](https://daneshyari.com)