Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

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

Mixed convection of copper–water nanofluid in a shallow inclined lid driven cavity using the lattice Boltzmann method

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HIGHLIGHTS

- Nanofluid LBM simulation in a shallow inclined driven cavity for the first time.
- Showing appropriate ability of LBM to simulate nanofluid mixed convection.
- Sharp increasing in Nu_m with γ and φ especially at higher Ri.
- More Nu_m is observed at $\mathrm{Re} = 100$ than the state of $\mathrm{Re} = 10$.
- Obtaining higher Nu_m at a vertical position of free convection in higher Re and φ.

ARTICLE INFO

Article history:
Received 5 July 2013
Received in revised form 1 January 2014
Available online xxxx

Keywords:
Shallow inclined cavity
Nanofluid
Lattice Boltzmann
Mixed convection

ABSTRACT

The goal of this work is to study the laminar mixed convection of water–Cu nanofluid in an inclined shallow driven cavity using the lattice Boltzmann method. The upper lid of the cavity moves with constant velocity, U_0, and its temperature is higher than that of the lower wall. The side walls are assumed to be adiabatic. The effects of different values of the cavity inclination angle and nanoparticles volume fraction at three states of free, force and mixed convection domination are investigated while the Reynolds number is kept fixed as $\mathrm{Re} = 100$ and $\mathrm{Re} = 10$. Validation of present results with those of other available ones shows a suitable agreement. Streamlines, isotherms, Nusselt numbers, and velocity and temperature profiles are presented. More Nusselt numbers can be achieved at larger values of the inclination angle and nanoparticles volume fraction at free convection domination. Results imply the appropriate ability of LBM to simulate the mixed convection of nanofluid in a shallow inclined cavity.

1. Introduction

Lattice Boltzmann method (LBM) is a type of CFD methods which is applied for the numerical simulation of flow and heat transfer. LBM can be used for macro, micro and nano flows (MEMS & NEMS) and its suitable performance has led to an increase in its usage in different conditions. Basically, LBM is a compressible model of ideal gas; so, it is able to satisfy the compressible Navier–Stokes (NS) equations. However, by using the Chapman–Enskog expansion, the incompressible NS equations would be achieved; and also, at low values of the Mach number, the compressibility error of LBM is negligible [1–8].

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0378-4371/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.physa.2014.01.057

Nomenclature

BGK Bhatnagar Gross Krook
$\mathbf{c} = (c_x, c_y)$ Microscopic velocity vector
Cu copper
C_p Heat capacity, J kg^{-1} K^{-1}
d_p Nanoparticle diameter, nm
DSMC Direct simulation Monte Carlo
e Internal energy density
f, g Density-momentum and internal energy density distribution functions
$\mathbf{g}$ Gravity vector
$\mathrm{Gr} = g\beta_{nf}H^3\Delta T/\upsilon_{nf}^2$ Grashof number
GPTBC General purpose thermal boundary condition
h, l Cavity height and length, m
$H = h/h, L = l/h$ Dimensionless height and length
k Thermal conductivity coefficient, Wm^{-1} K^{-1}
LBM Lattice Boltzmann method
Ma Mach number
MEMS Microelectromechanic systems
MD Molecular dynamic
Nu_X, Nu_m Local and averaged Nusselt number
NS Navier–Stokes
$\mathrm{Pr} = \upsilon_{nf}/\alpha_{nf}$ Prandtl number
$\mathrm{Re} = \rho_{nf}U_0h/\mu_{nf}$ Reynolds number
$\mathrm{Ri} = \mathrm{Gr}/\mathrm{Re}^2$ Richardson number
t Time, s
T_H, T_C Hot and cold Temperature, K
$\mathbf{u} = (u, \upsilon)$ Macroscopic flow velocity vector, ms^{-1}
$(U, V) = (u/U_0, \upsilon/U_0)$ Dimensionless flow velocity in x–y direction
U_0 Cavity lid velocity, ms^{-1}
x, y Cartesian coordinates, m
$(X, Y) = (x/h, y/h)$ Dimensionless coordinates
Z Heat dissipation

Greek symbols

α Thermal diffusivity, m^2 s^{-1}
φ Nanoparticles volume fraction
μ Dynamic viscosity, Pa s
$\theta = (T - T_C)/(T_H - T_C)$ Dimensionless temperature
ρ Density, kg m^{-3}
τ_f, τ_g Relaxation times for momentum and internal energy
υ Kinematics viscosity, m^2 s^{-1}
γ Cavity inclination angle
Ω Collision operator

Super- and sub-scripts

e Equilibrium
f Base fluid (pure water)
i Lattice directions
nf Nanofluid
s Solid nanoparticles
w Wall
α x–y geometry components

LBM is also more appropriate to simulate the multiphase flows compared to the Navier–Stokes equations. LBM uses the first-order PDEs which makes it a simple approach in discretization and programming. Applying parallel processing and not needing additional system of equations for the pressure field are some other advantages of LBM. Moreover, it is less time-consuming than the other particle based methods such as molecular dynamic, MD, or direct simulation Monte Carlo,

Please cite this article in press as: A. Karimipour, et al., Mixed convection of copper–water nanofluid in a shallow inclined lid driven cavity using the lattice Boltzmann method, Physica A (2014), http://dx.doi.org/10.1016/j.physa.2014.01.057