International Journal of Heat and Mass Transfer 108 (2017) 1870–1883

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Numerical simulation of nanofluid forced convection heat transfer improvement in existence of magnetic field using lattice Boltzmann method

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A R T I C L E I N F O

Article history:
Received 18 October 2016
Received in revised form 31 December 2016
Accepted 13 January 2017

Keywords:
Lattice Boltzmann Method
Nanofluid
MHD
Forced convection
KKL model

A B S T R A C T

In this paper, nanofluid forced convection heat transfer is investigated in existence of magnetic field. Three dimensional simulations are presented by means of Lattice Boltzmann Method. Koo-Kleinstreuer-Li (KKL) model is considered to estimate the properties of nanofluid. Roles of Hartmann number, Reynolds number, Al_2O_3 volume fraction are illustrated graphically. Outputs are depicted in forms of velocity, isokinetic energy, streamlines, isotherms contours and Nusselt number. Results demonstrate that velocity of nanofluid augments with rise of Reynolds number and Al_2O_3 volume fraction but it reduces with increase of Hartmann number. Convection mode reduces with enhance of Lorentz forces. Temperature gradient over the moving wall augments with augment of hot surface velocity and Al_2O_3 volume fraction.

1. Introduction

One of the great mesoscopic approaches for simulation of complicated problems is Lattice Boltzmann method. Pressure term can be easily calculated via equation of state. The base of LBM is kinetic theory. New types of fluid needed to obtain more efficient performance. So nanofluid has been introduced by researchers. Andreozzi et al. [1] investigated impact of nanofluid and ribs on heat transfer in a channel. They indicated that highest thermal performance belongs to triangular ribs. Sheikholeslami and Ganji [2] presented mesoscopic simulation for entropy production of magnetic nanofluid. Their outputs reveled that entropy production reduces with rise of Lorentz forces. LBM has been utilized for free convection by Mohamad and Kuzmin [3]. Nanofluid convection in 3D cavity has been simulated by Sheikholeslami and Ellahi [4]. They concluded that convection reduces through larger Hartmann number. Qi et al. [5] utilized LBM for two phase modeling of nanofluid free convection heat transfer. Nithyadevi et al. [6] investigated the influence of titled angle on nanofluid mixed convection. Hayat et al. [7] examined influence of radiation on concentration of nanofluid. They showed that temperature distribution enhances with augment of thermal radiation. Yadav et al. [8] investigated the adiabatic boundary conditions for nanoparticle in presence of Lorentz force. Alsabery et al. [9] utilized heatline analysis for conjugate free convection of nanofluid. Few more recent contributions in dynamics of nanofluids can be seen in the investigations [10–15].

Nanofluid conjugate heat transfer in an inclined cavity has been examined by Selimefendigil and Oztop [16]. Sheikholeslami and Ellahi [4] applied LBM to simulate Lorentz force influence on nanofluid temperature distribution. Sheikholeslami [17] investigated the influence of magnetic field on nanofluid motion in porous semi annulus. MHD nanofluid free convective hydrothermal analysis in a tilted wavy enclosure was presented by Sheremet et al. [18]. Their results indicated that change of titled angle causes convective heat transfer enhancement. Impact of variable Lorentz forces on nanofluid flow style was examined by Sheikholeslami [19]. He concluded that improvement in heat transfer reduces for larger Kelvin forces. Sheikholeslami and Vajravelu [20] reported the nanofluid behavior in existence of magnetic field. Thermal radiation and convective condition in flow of pseudoplastic nanofluid were addressed by Hayat et al. [21]. Hayat et al. [22] modeled viscoelastic nanofluid flow in the presence of mixed convection and temperature dependent thermal conductivity. They reported that temperature distribution enhances for larger thermophoresis and

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2017.01.044
0017-9310/

Nomenclature

Ha	Hartmann number ($= LB_0\sqrt{\sigma/\mu}$)
g^{eq}	equilibrium internal for temperature
f_k^{eq}	equilibrium distribution
u, v, w	x, y and z-directions velocities
B_0	magnetic flux density
g	internal energy distribution functions
k	thermal conductivity
e_α	discrete lattice velocity in direction
c_s	speed of sound in Lattice scale
T	fluid temperature
Pr	Prandtl number ($= \upsilon/\alpha$)
Nu	Nusselt number

Greek symbols

σ	electrical conductivity
ρ	fluid density
υ	kinematic viscosity
ϕ	volume fraction
α	thermal diffusivity
ψ	stream function
τ	lattice relaxation time

Subscripts

loc	local
h	hot
f	base fluid
c	cold
s	solid particles
nf	nanofluid
ave	average

Brownian motion parameters. Impact of inconstant magnetic field on forced convection was reported by Sheikholeslami et al. [23]. They illustrated that higher lid velocity has more sensible Kelvin forces effect. In recent years, several researchers published papers about heat transfer in flows for different concepts [24–34].

The purpose of present paper is to simulate impact of Lorentz forces on 3D forced convection in a cubic cavity with moving bottom surface. KKL model is selected to estimate μ_{nf}, k_{nf}. LBM is selected for mesoscopic simulation. Influence of Reynolds and Hartmann numbers, volume fraction of Al_2O_3 on hydrothermal behavior are examined.

2. Problem statement

As shown in Fig. 1, 3D lid driven cavity is studied. The cold and hot surfaces are placed at $Z = z/L = 1$ and $Z = z/L = 0$, respectively. The hot surface can move. It is supposed that the uniform magnetic field is applied. In present work, θ_x, θ_z are equal to 90°.

3. LBM formulae

3.1. Viscous fluid

f and g are two distribution functions which are utilized for velocity and temperature, respectively. Cartesian coordinate is used. f and g can be obtained by solving lattice Boltzmann equation. According to Bhatnagar, Gross, Krook (BGK) approximation, the governing equations are:

$$f_i(x,t) - f_i(x + c_i\Delta t, t + \Delta t) + \frac{\Delta t}{\tau_\upsilon}[f_i^{eq}(x,t) - f_i(x,t)] + \Delta t c_i F_k = 0 \quad (1)$$

$$g_i(x,t) + \frac{\Delta t}{\tau_C}[g_i^{eq}(x,t) - g_i(x,t)] - g_i(x + c_i\Delta t, t + \Delta t) = 0 \quad (2)$$

where τ_c, τ_υ, F_k, c_i and Δt represent relaxation times of temperature and flow fields, external forces, discrete lattice velocity and lattice time step, respectively.

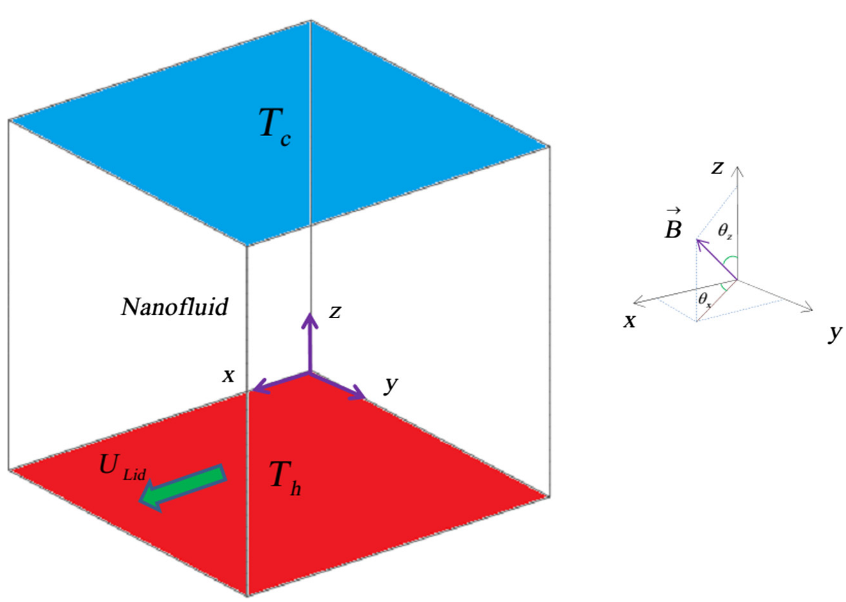

Fig. 1. Geometry of the problem.