



Double MRT Lattice Boltzmann simulation of 3-D MHD natural convection in a cubic cavity with sinusoidal temperature distribution utilizing nanofluid

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ARTICLE INFO

Article history:

Received 6 April 2018

Received in revised form 10 May 2018

Accepted 11 May 2018

Keywords:

Double MRT-LBM

Nanofluid

3-D Natural convection

MHD

Sinusoidal boundary condition

ABSTRACT

In this work numerical simulation of magneto hydrodynamics (MHD) natural convection in a three-dimensional cubic cavity with sinusoidal temperature distribution on one side wall has been considered. New means of the Lattice Boltzmann method with double Multi-Relaxation-Time (MRT) model has been applied utilizing cu/water nanofluid. D3Q19 and D3Q7 models have been used to solve the momentum and energy equations, respectively. Different Rayleigh numbers ($Ra = 10^3$ – 10^5) and various Hartmann numbers ($Ha = 0$ – 100) for volumetric fraction of the nanoparticles (ϕ) between $\phi = 0$ and 12% have been investigated. Also, phase deviation varied from $\theta = 0$ to π with interval $\pi/2$. The magnetic field is considered horizontally and the results have been shown at different planes and lines of the 3-D enclosure. Based on the results, the double MRT-LBM method is a proper method for simulating the 3-D flows with complex boundary conditions. The results show that augmentation of the Hartmann number decreases the heat transfer rate whereas the increase of the Rayleigh number and nanoparticles' volumetric fraction enhance the heat transfer rate. The highest effect of magnetic field is obtained at $Ra = 10^4$ and the lowest effect is seen at $Ra = 10^3$. Also, the greatest effect of Rayleigh number is captured at $Ha = 0$ for all volumetric fraction of the nanoparticles.

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1. Introduction

For the last three decades, the lattice Boltzmann method (LBM) has been used extensively as a promising alternative method for simulating complex flows, such as turbulent flows, multiphase flows, MHD flows, and Nanofluids [1–6]. The most common model to do the collision step in this method is Lattice Bhatnagar–Gross–Krook (LBGK) that a single relaxation time (SRT) has been used and investigator showed some instability when this model is used to solve the energy equation [7,8]. So, to overcome this issue some other models such as two-relaxation-time (TRT), multiple-relaxation-time (MRT), and the entropic lattice Boltzmann equation (ELBE) have been investigated [9–11], and has been concluded that the MRT model is more accurate, stable and efficient to solve the flow and temperature field. Recently Li et al. [12] investigated double MRT model in the framework of LBM for simulating 3-D natural convection for the first time. They solved three types of

cubic natural convection problems with a new method at various Rayleigh numbers and used the MRT model for both momentum and energy equations. They showed that this new method is a proper method to solve the 3-D flow field and heat transfer but need more development for complex flow.

Natural convection flow is one of the important problems in fluid mechanics and is used for various applications [13,14]. Adding the magnetic field can control the heat transfer rate, so the simulation of the magneto hydrodynamics (MHD) natural convection has been developed and applied considerably in last decades [15–19]. Sivasankaran et al. [20] solved a 2-D mixed convection in an enclosure utilizing the finite-volume method. They considered sinusoidal boundary condition for temperature field and reported the effect of amplitude ratio, phase deviation, Richardson number, and Hartmann number on heat transfer rate. Their results showed that Nusselt number increases on increasing the amplitude ratio. In addition, the Nusselt number increases with the phase deviation up to $\phi = \pi/2$ and then it decreases for further increase in the phase deviation. Oztop et al. [21] reported the results for laminar mixed convection flow in the presence of the

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Nomenclature

f_i	distribution function for velocity field	F_l	Lorentz force
g_i	distribution function for temperature field	g	gravity
β	thermal expansion coefficient	T	temperature
B	applied magnetic field	Ra	Rayleigh number
σ	electrical conductivity	Pr	Prandtl number
ρ	density	Ha	Hartmann number
u	velocity in x direction	Gr	Grashof number
v	velocity in y direction	Nu	Nusselt number
w	velocity in z direction	μ	dynamic viscosity
ν	kinematic viscosity	C_p	heat capacitance

magnetic field in a top-sided lid-driven cavity heated by a corner heater for various Grashof and Hartmann numbers. They used finite volume method to simulate the equations and concluded that heat transfer rate declines with augmentation of Hartmann number. Bhuvaneswari et al. [22] studied convective flow and heat transfer in a cavity with sinusoidal temperature distributions on both side walls in the presence of a uniform magnetic field. They also used the finite volume method and reported that the heat transfer rate is increased first and then decreased by increasing the phase deviation. Zhang and Che [23] used the LBM method to solve a 2-D MHD flow in an inclined cavity with four heat sources. They considered double MRT model to simulate the momentum and energy equations, and investigated the effects of the Hartmann number on the fluid flow and heat transfer. They showed that the average Nusselt number declines by augmentation of Hartmann number for all Rayleigh numbers.

Nanoparticles are used to improve the thermal conductivity of pure fluids and addition of them to base fluid will increase the Nusselt number significantly. In this respect, nanofluid has attracted much attention as a way to increase heat transfer rate [24,25]. Kefayati [26] studied the effect of a magnetic field on 2-D natural convection flow in a nanofluid-filled cavity with sinusoidal temperature distribution on one side wall. He considered the effect of the different parameters such as; Rayleigh number, volumetric fraction of the nanoparticles, phase deviation and Hartmann number and showed that the greatest effects of nanoparticles are obtained at $\theta = 3\pi/4$, 0 and $\pi/2$ for $Ra = 10^3$, 10^4 and 10^5 , respectively. Sheikholeslami et al. [27] have done a numerical work for simulating flow and heat transfer of CuO–water nanofluid in presence of magnetic field in a cavity with a sinusoidal wall under constant heat flux using control volume based finite element method (CVFEM). They demonstrated that the Nusselt number increases by augmentation of nanoparticles volume fraction and dimensionless amplitude of the sinusoidal wall. Alsabery et al. [28] investigated 2-D natural convection in a square cavity filled with a nanofluid with sinusoidal temperature variations on both horizontal walls utilizing the finite difference method. They choose water-based nanofluids with Ag, Cu, Al₂O₃, or TiO₂ nanoparticles and worked on effect of various parameters. They exhibited that the heat transfer rate is significantly increased by incrementing the solid wall thickness. Tang et al. [29] considered natural convection heat transfer in an enclosure with two sinusoidal wavy walls which is filled with nanofluids. They reported that phase deviation between the inner and outer walls had significant effects on surface heat transfer coefficient. Also, heat transfer rate enhances as the volume fraction increasing from 0.1% to 0.9%.

It is seen in literature that most of the previous investigations were limited to two-dimensional geometries due to difficulty of 3-D flows simulation. So, to simulate more real flow, the numerical

simulations of three-dimensional geometry are necessary. Also, the ability of MRT model is mentioned in literature and the double MRT model as a proper and new model was not developed for complex flow fields and geometries by investigators. Therefore the main aim of this study is developing the double MRT Lattice Boltzmann method to simulate the MHD and nanofluid flow and heat transfer in a 3-D cavity with sinusoidal temperature distribution on one side wall. For the double MRT model D3Q7 and D3Q19 lattices are used to solve the temperature and flow fields respectively. Various parameters such as; phase deviation, volumetric fractions of the nanoparticles, Hartmann numbers and Rayleigh numbers have been considered and the results of new method have been validated by previous ones.

2. Problem statement

The 3-D enclosure which is solved in this work is shown in Fig. 1. The temperature of the left wall of the cavity ($X = 0$) in the dimensionless form is fixed at 1, the right wall ($X = L$) is heated sinusoidal like $T = T_0 + A \sin(\frac{2\pi y}{L} + \theta)$ and other four walls are all adiabatic. No-slip boundary conditions are used for all walls and a uniform magnetic field (B) is applied along the X direction, perpendicular to gravity. The enclosure is filled with cu/water nanofluid and assumed as a Newtonian and incompressible fluid. When the magnetic field (B) is applied in the X-direction, the hydromagnetic force acts along the Z and Y directions. In addition, Boussinesq approximation is used in this work and it is assumed that the viscous dissipation and Joule heating are neglected [15].

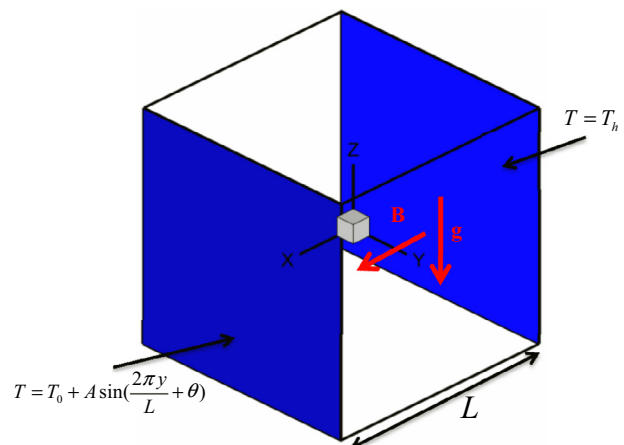


Fig. 1. Geometry of the present study.

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