Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2020-0001

Vol. **29**, No. 1, pp. 292-318
January 2021

Natural Convection Heat Transfer in a Porous Cavity with Sinusoidal Temperature Distribution Using Cu/Water Nanofluid: Double MRT Lattice Boltzmann Method

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Received 1 January 2020; Accepted (in revised version) 16 May 2020

Abstract. In this study, natural convection flow in a porous cavity with sinusoidal temperature distribution has been analyzed by a new double multi relaxation time (MRT) Lattice Boltzmann method (LBM). We consider a copper/water nanofluid filling a porous cavity. For simulating the temperature and flow fields, D2Q5 and D2Q9 lattices are utilized respectively, and the effects of different Darcy numbers (Da) (0.001-0.1) and various Rayleigh numbers (Ra) (10^3-10^5) for porosity (ε) between 0.4 and 0.9 have been considered. Phase deviation (θ) changed from 0 to π and the volume fraction of nanoparticles ($\varnothing$) varied from 0 to 6%. The present results show a good agreement with the previous works, thus confirming the reliability the new numerical method proposed in this paper. It is indicated that the heat transfer rate increases at increasing Darcy number, porosity, Rayleigh number, the volume fraction of nanoparticles and phase deviation. However, the most sensitive parameter is the Rayleigh number. The maximum Nusselt deviation is 10%, 32% and 33% for Ra$=10^3$, 10^4 and 10^5, respectively, with $\varepsilon=0.4$ to $\varepsilon=0.9$. It can be concluded that the effect of Darcy number on the heat transfer rate increases at increasing Rayleigh number, yielding a maximum enhancement of the average Nusselt number around 12% and 61% for Ra$=10^3$ and Ra$=10^5$, respectively.

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AMS subject classifications: (or PACs) To be provided by authors

Key words: Porous media, double multi relaxation time-lattice Boltzmann method, nanofluid, natural convection, sinusoidal temperature distribution.

Nomenclature

f_i	Distribution function for velocity field
h_i	Distribution function for temperature field
β	Thermal expansion coefficient
α	Thermal diffusivity
ρ	Density
U	Velocity in x-direction
V	Velocity in y-direction
ε	Porosity
ν	Kinematic viscosity
G	Gravity
T	Temperature
Ra	Rayleigh number
μ	Dynamic viscosity
C_p	Heat capacitance
K	Thermal conductivity

1 Introduction

In the last decades, the Lattice Boltzmann method (LBM) has developed into a powerful mesoscopic technique to simulate a broad variety of complex flows, such as turbulent flows, flows in porous media, nanofluids, and many others [1–14].

The LBM is consisting of two main steps: collision and streaming, and various models are used to perform the collision step, the simplest and most common being the Lattice Bhatnagar-Gross-Krook (LBGK) [15–26]. Single relaxation time (SRT) has been utilized for the LBGK model, but researchers reported that the LBGK may suffer instability when applied to flows with energy conservation [27]. Ginzburg [29] concluded that two-relaxation-time (TRT) is a suitable model for collision step and this model can overcome the disadvantage of the SRT model. Chikatamarla et al. [29] investigated the Entropic Lattice Boltzmann Model for collision step and reported that the new model is stable and guarantees the thermodynamic consistency of the problem. Also, a comprehensive study on the models which are used for collision step has been down by Luo et al. [30]. They