Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 51(4) (2019) 1-4
DOI:

Investigation of 3 Dimensional Nano fluid Natural Convection in Presence of Magnetic Field using Double Multi Relaxation Time Lattice Boltzmann Method

H. Sajjadi*, A. Amiri Delouei

Department of Mechanical Engineering, University of Bojnord, Bojnord, Iran

ABSTRACT: In this work numerical simulation of magneto hydrodynamics natural convection in a three dimensional square cavity has been considered by new means of the Lattice Boltzmann method with double multi relaxation time model utilizing cu/water nanofluids. D3Q19 and D3Q7 models have been used to solve the momentum and energy equations, respectively and the effect of different Grashof numbers ($Gr=10^3$ _10^5) and various Hartmann numbers (Ha=0-100) for volumetric fraction of the nanoparticles between 0 and 12% have been investigated. The results have been shown at different planes and lines of the 3-D enclosure and based on the results the double multi-relaxation time - Lattice Boltzmann method is a proper method for simulating the complex 3-D flows. Also, the results show that augmentation of the Hartmann number decreases the heat transfer rate for base fluid and the maximum reduction of Nusselt number with increasing Hartmann number from 0 to 100 has been observed as 71% for $Gr=10^4$. While increasing the Grashof number and volumetric fraction of the nanoparticles enhance the heat transfer rate for all Hartmann number. The highest effect of nanoparticle is obtained at $Gr=10^4$ and Ha=50 as with increasing 12% of volumetric fraction of the nanoparticles Nusselt number enhances 43%.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Lattice Boltzmann method
Double multi relaxation time
Nanofluid
Magneto hydrodynamic
Natural convection

1- Introduction

The Lattice Boltzmann Method (LBM) has been developed as a useful and efficient numerical method extensively in the past decades [1]. This method has been applied to simulate turbulent flows, mix and natural convection, multi-phase flows and etc. [2-4]. This method consists of two main steps which are collision and streaming. To do the collision step in LBM, various models have been used that the most popular model is the Lattice Bhatnagar–Gross–Krook (LBGK) [5]. Single relaxation time (SRT) has been applied for the collision step in the LBGK model which has some instability when is used for solving thermal fluids [6]. So to overcome the disadvantage of this model various works have been conducted and reported that the Multi-Relaxation-Time (MRT) and Two-Relaxation-Time (TRT) models are better than the LBGK model in terms of accuracy and stability [7]. Recently a three-dimensional double MRT model has been used for simulating fluid flow and heat transfer for the first time and concluded that the new model can predict the results well in comparison with the experimental ones [8].

As an efficient way to increase the heat transfer rate, nanoparticles are added to pure fluid to improve the thermal conductivity of pure fluid, so the Nusselt number enhances considerably [9].

Magnetic fields affect the heat transfer rate and is used to control the natural convection in industry. A mix convection in a cavity in the presence of magnetic field has been considered by Sivasankaran et al. [10]. They solved the flow and heat transfer fields numerically and concluded that the Nusselt number decreases by augmentation of the magnetic field.

Corresponding author, E-mail: h.sajjadi@ub.ac.ir

The main aim of the present work is to develop the double MRT Lattice Boltzmann method to solve the complex three-dimensional flow such as Magneto Hydro Dynamics (MHD) nano fluid. Also the effect of different parameters such as Hartmann number, Grashof number and volumetric fraction of the nanoparticles on the Nusselt number has been investigated.

2- Methodology

2- 1- Problem statement

The geometry of the present work is shown in Fig. 1. It is a cubic cavity that the vertical walls (x=0 and $x=L$) are kept at constant temperature and the remained four walls are all adiabatic, also non-slip boundary conditions are used for all walls. The cavity is filled with a Newtonian nanofluid and the flow is laminar and incompressible. Magnetic field (B) is applied along the x direction, perpendicular to gravity.

2- 2- Double MRT Lattice Boltzmann method

In this study, MRT-LBM method with D3Q19 and D3Q7 models is used for the three dimensional flow simulations and energy equation, respectively. In this method to evaluate the distribution function for velocity and temperature the following distribution function are used [8]:

$$f_i(x+c_i\Delta t, t+\Delta t) = f_i(x,t) - M_{ij}^{-1}.S_{jk}.[m_k(x,t) - m_k^{eq}(x,t)] + F_i \quad (1)$$

$$h_i(x+e_i\Delta t, t+\Delta t) = h_i(x,t) - N_{ij}^{-1}Q_{jk}.[n_k(x,t) - n_k^{eq}(x,t)] \quad (2)$$

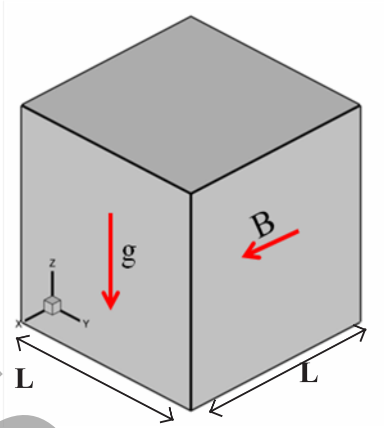

Fig. 1. Geometry of the present study

Where f_i and h_i is the velocity and temperature distribution functions, respectively. F_i in Eq. (1) is the force term and for MHD natural convection can be obtained as:

$$F_i = F_{yi} + F_{zi} \tag{3}$$

$$F_{zi} = 3\rho\omega_i g\beta\Delta T - \frac{3\omega_i (Ha^2)\mu w}{L^2} \tag{4}$$

$$F_{yi} = -\frac{3\omega_i (Ha^2)\mu v}{L^2} \tag{5}$$

3- Results and Discussion

A comparison of the average Nusselt number for different Hartmann numbers at a fixed Grashof number $Gr = 2\times10^5$ between the present results and the previous works [11, 12] has been illustrated in Table 1. As it is obvious in Table 1, average error between the present data and the previous works is less than 2.5% which is shown a good agreement.

Table 1. Comparison of the average Nusselt number for $Gr = 2\times10^5$

Ha	Present work	Rudraiah et al. [11]	Zhang and che [12]
0	5.02	4.92	5.08
50	2.99	2.84	2.99
100	1.44	1.43	1.46

To compare the present solution for nanofluid with the previous works, Fig. 2 shows a comparison between the present results by the data of Khanafer et al. [13] for different Grashof numbers, various volumetric fraction of the nanoparticles and Ha=0. Fig. 2 shows a good agreement between the present work and previous studies and the average error is less than 2%.

4- Conclusions

Magneto hydrodynamics natural convection in a cubic cavity has been studied by new means of the double Multi-Relaxation-Time Lattice Boltzmann method utilizing cu/water nanofluids. The effect of various parameters such as Grashof and Hartmann numbers and volumetric fraction of the nanoparticles on heat transfer rate have been investigated.

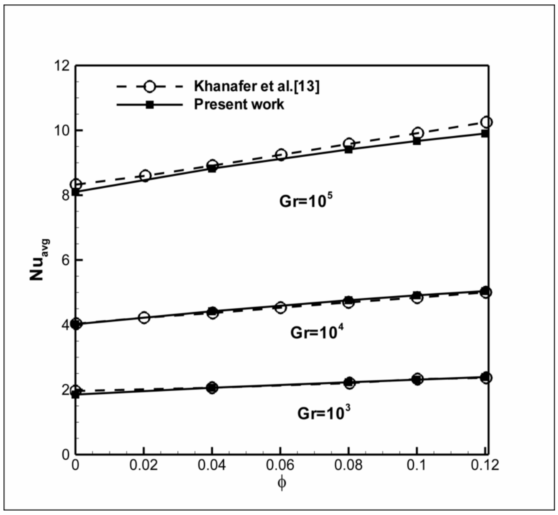

Fig. 2. Comparison of the average Nusselt number

The results showed that average and local Nusselt number decline by increasing of Hartmann number significantly. Also, heat transfer rate enhances by augmentation of Grashof number and it is gathered that the average Nusselt number increases by adding nanoparticle to the pure fluid.

References

[1] Sukop, M. C., and Thorne Jr, D. T., 2006. *Lattice Boltzmann Modeling: An Introduction for Geoscientists and Engineers*, Springer, Heidelberg, Berlin, New York.

[2] Sajjadi, H., Gorji, M., Kefayati, GH. R., and Ganji, D. D., 2012. "Lattice Boltzmann simulation of turbulent natural convection in tall enclosures using Cu/water nanofluid". *Numerical Heat Transfer Part A,* 62, pp. 512-530.

[3] Mohamad, A. A., Kuzmin, A. A., 2010. "Critical evaluation of force term in lattice Boltzmann method, natural convection problem", *International Journal of Heat Mass Transfer*, 53, pp. 990–996.

[4] Sajjadi, H., Salmanzadeh, M., Ahmadi, G., Jafari, S., 2017. "Turbulent Indoor Airflow Simulation Using Hybrid LES/RANS Model Utilizing Lattice Boltzmann Method". *Computers and fluids*, 150, pp. 66-73.

[5] Chen, S., Chen, H., Martnez, D., and Matthaeus, W., 1991. "Lattice Boltzmann model for simulation of magneto hydrodynamics", *Physics Review Letter,* 67 (27), pp. 3776– 3779.

[6] Lallemand, P., and Luo, L., 2000. "Theory of the lattice Boltzmann method: dispersion, dissipation, isotropy, Galilean invariance, and stability", *Physical Review E*, 61 (6), pp. 6546–6562.

[7] Luo, L., Liao, W., Chen, X., Peng, Y., and Zhang, W., 2011. "Numerics of the lattice Boltzmann method: effects of collision models on the lattice Boltzmann simulations", *Physical Review E*, 83 (5), pp. 056710.

[8] Li, Z., Yang, M., and Zhang, Y., 2016. "Lattice Boltzmann method simulation of 3-D natural convection with double MRT model", *International Journal of Heat and Mass Transfer*, 94, pp. 222–238.

[9] Kefayati, G.R., and Tang, H., 2017. "Simulation of natural convection and entropy generation of non-Newtonian nanofluid in a porous cavity using Buongiorno's

mathematical model", *International Journal of Heat and Mass Transfer*, 112, pp. 709– 744.

[10] Sivasankaran, S., Malleswaran, A., Lee, J., and Sundar, P., 2011. "Hydro-magnetic combined convection in a lid-driven cavity with sinusoidal boundary conditions on both sidewalls", *International Journal of Heat and Mass Transfer*, 54, pp. 512-525.

[11] Rudraiah, N., Barron, R., Venkatachalappa, M., and Subbaraya, C., 1995. "Effect of a magnetic field on free convection in a rectangular enclosure", *International Journal of Engineering Science*, 33, pp. 1075-1084.

[12] Zhang, T., and Che, D., 2016. "Double MRT thermal lattice Boltzmann simulation for MHD natural convection of nanofluids in an inclined cavity with four square heat sources", *International Journal of Heat and Mass Transfer*, 94, pp. 87-100.

[13] Khanafer, K., Vafai, K., and Lightstone, M., 2003. "Buoyancy driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids", *International Journal of Heat and Mass Transfer*, 46, pp. 3639-3653.

Please cite this article using:

H. Sajjadi, A. Amiri Delouei, Investigation of 3 Dimensional Nano fluid Natural Convection in Presence of Magnetic Field using Double Multi Relaxation Time Lattice Boltzmann Method, *Amirkabir J. Mech. Eng.*, 51(4) (2019) 1-4.

DOI: