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Lattice Boltzmann Simulation of Magnetic Field Effect on Natural Convection of Power-Law Nanofluids in Rectangular Enclosures

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Abstract. In this paper, the magnetic field effects on natural convection of power-law nanofluids in rectangular enclosures are investigated numerically with the lattice Boltzmann method. The fluid in the cavity is a water-based nanofluid containing Cu nanoparticles and the investigations are carried out for different governing parameters including Hartmann number ($0.0 \leq Ha \leq 20.0$), Rayleigh number ($10^4 \leq Ra \leq 10^6$), power-law index ($0.5 \leq n \leq 1.0$), nanopartical volume fraction ($0.0 \leq \phi \leq 0.1$) and aspect ratio ($0.125 \leq AR \leq 8.0$). The results reveal that the flow oscillations can be suppressed effectively by imposing an external magnetic field and the augmentation of Hartmann number and power-law index generally decreases the heat transfer rate. Additionally, it is observed that the average Nusselt number is increased with the increase of Rayleigh number and nanoparticle volume fraction. Moreover, the present results also indicate that there is a critical value for aspect ratio at which the impact on heat transfer is the most pronounced.

AMS subject classifications: 65M10, 78A48

Key words: magnetic field, nanofluid, power-law viscosity, lattice Boltzmann method.

1 Introduction

During the past decades, natural convection in enclosures has drawn considerable attention due to its importance and wide applications in various fields, such as heat exchangers, cooling of electronic systems and furnace engineering [1–3]. Heat transfer enhancement in these systems is usually an essential topic from an energy saving perspective. However, conventional heat transfer fluids like water, ethylene glycol and engine oil

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have relative low thermal conductivity values, which thus limit the heat transfer rates. Fortunately, due to recent process in nanotechnology, thermal conductivity values can be increased by adding nanometer-sized particles in conventional heat transfer fluids to form the so-called nanofluids [4] and this also explains why nanofluids have found such a wide applications in some engineering applications [5].

Over the last few years, many effective numerical and experimental studies have thus been performed to investigate the basic mechanism of the enhanced heat transfer characteristics in nanofluids. For instance, Nnanna [6] experimentally examined the heat transfer behavior of the natural convection in a differentially heated enclosures filled with Al_2O_3-water nanofluid. Based on the experimental data, the author developed an empirical correlation for Nusselt number as a function of the nanoparticle volume fraction and Rayleigh number. Khanafer et al. [7] numerically investigated buoyancy driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. It was observed that the heat transfer rate across the enclosure is increased with the increase of nanoparticle volume fraction for any Grashof number. Jahanshahi et al. [8] numerically investigated the influence of uncertainties due to adopting various formulas for the effective thermal conductivity of SiO_2-water on heat transfer characteristics for natural convection in a square enclosure. And the results show that heat transfer rate is increased with the addition of nanoparticle volume fraction when employing experimental thermal conductivity, whereas it is decreased when using theoretical thermal conductivity, to cite a few.

The aforementioned investigations show that previous studies are devoted to exploring the effects of various parameters on flow structure and heat transfer and the influence of magnetic field is usually ignored. However, in some practical cases such as the crystal growth in fluids, the metal casting and the geothermal energy extractions, the natural convection is under the influence of a magnetic field [9]. In view of these aspects, several studies have been conducted to evaluate the effect of the magnetic field on natural convection flow and heat transfer. Sathiyamoorthy and Chamkha [10] examined the steady laminar two-dimensional natural convection in the presence of an inclined magnetic field in a square enclosure filled with a liquid gallium. It was demonstrated that the orientation of the magnetic field has a great influence on the heat transfer rate. Sheikholeslami [11] studied the ferrofluid flow and heat transfer in the presence of an external variable magnetic field and the results indicated that the Nusslet number is an increasing function of Magnetic number, Rayleigh number and nanoparticle volume fraction while it is a decreasing function of the Hartmann number. The author [12] also investigated the magnetic field effect on natural convection of nanofluid in a cubic cavity heated from below. Kefayati [13] analyzed the effect of a magnetic field on natural convection flow in a nanofluid-filled cavity with sinusoidal temperature distribution by lattice Boltzmann method. The results showed that the heat transfer is decreased by the increment of Hartmann number for various Rayleigh numbers. Additionally, the magnetic field effect on entropy generation in nanofluid-filled enclosures has been revealed in the recent publications [14–16]. It was found that the intensity of magnetic field has a significant influence