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Multiple-Relaxation-Time Lattice Boltzmann Simulation of Magnetic Field Effect on Natural Convection of Non-Newtonian Nanofluid in Rectangular Enclosure

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Abstract. The magnetic field effects on natural convection of a non-Newtonian power-law nanofluid in the rectangular enclosure have been investigated using the graphics process unit (GPU) accelerated multiple-relaxation-time (MRT) lattice Boltzmann method (LBM). The enclosure is filled up with a power-law non-Newtonian nanofluid with a proper percentage of the nanoparticle volume fraction. The height of the enclosure is twice its width. The left and right walls are heated with constant temperature, and the top and bottom walls are thermally adiabatic. Initially, the code is validated for the Newtonian nanofluid, and then validation is done with non-Newtonian power-law fluids. The numerical results with the effects of magnetic fields are presented in terms of the streamlines, isotherms, temperature distribution, local and average Nusselt number for the shear thinning and thickening nanofluid. The heat transfer rate gets augmented for the shear-thinning fluids ($n<1$) while that becomes attenuated for the shear-thickening fluids ($n>1$). Besides, the magnetic field effects reduce the heat transfer rate from the wall to the fluid region.

AMS subject classifications: 65M10, 78A48

Key words: Non-Newtonian nanofluid, magnetic field effect, multiple-relaxation-time, lattice Boltzmann Method, average rate of heat transfer.

1 Introduction

In the numerical study, the lattice Boltzmann method has proved to be a very promising simulation tool for studying behavioral properties of complex fluid flows [1–3]. Enhanc-

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ing heat transfer in this system is one of the most vital issues in respect to energy saving. Air, water, ethylene glycol, and engine oil are examples of conventional heat transfer fluids. These fluids have comparatively low thermal conductivity values, meaning these fluids have a property to limit the heat transfer rates [4]. Therefore, to increase efficiency and to maintain high performance of the thermal system, researchers have started adding nano-sized metallic or non-metallic particles into the base fluid in their experiments [5,6].

Different researches have been performed both experimentally and numerically over the last few years to study nano-particles' basic characteristics in the enhanced heat transfer system. Khanafer et al. [7] studied the natural convection flow of a copper-water nanofluid in a side heated square cavity numerically. They found that nanofluid enhanced the rate of heat transfer significantly. Sidik et al. [8] gave an idea on simulation of natural convection heat transfer in an enclosure using the LBM, where they showed that the flow pattern and heat transfer mechanism are significantly affected by the value of Rayleigh number. Chen and Gary [9] used the lattice Boltzmann method to simulate single-phase and multiphase fluid flows, and to incorporate additional physical complexities. Previously, researchers focused on investigating relevant findings related to the effects of various parameters on flow structure and heat transfer. But now some researchers are interested in working with the influence of the magnetic field. Few works have been performed related to the influence of the magnet field with Newtonian nanofluids.

Considering the work on the influence of magnetohydrodynamics (MHD), Sheikholeslam performed some remarkable works. Lattice Boltzmann method for MHD natural convection heat transfer using nanofluid has been employed by Sheikholeslam et al. [10]. Furthermore, Sheikholeslam et al. [11] worked on lattice Boltzmann simulation of magnetohydrodynamics natural convection heat transfer of Al_2O_3-water nanofluid in a horizontal cylindrical enclosure with an inner triangular cylinder. The subsequent study focused on the numerical investigation of MHD free convection of Al_2O_3-water Newtonian nanofluid considering the thermal radiation [12]. The obtained results from Sheikholeslami et al. [12] showed that the Nusselt number directly relates to nanoparticle volume fraction, Rayleigh number, and it has an inverse relationship with the Hartmann number (Ha).

Moreover, Sheikholeslami and Chamkha [13] investigated electrohydrodynamic (EHD) free convection heat transfer of a nanofluid in a semi-annulus enclosure with a sinusoidal wall where several values of Rayleigh number, nanoparticle volume fraction, and the voltage are supplied for the experiment. A new numerical procedure CVFEM, is used to solve the governing equations. The result shows that the voltage used can change the flow structure. Also, heat transfer rises with an increase in the voltage supplied and Rayleigh number. The effect of the electric field on heat transfer works better at low Rayleigh numbers. Further work was done on numerical simulation for forced convection flow of MHD $CuO-H_2O$ nanofluid inside a cavity employing LBM by Sheikholeslami et al. [14]. Also, Sheikholeslami et al. [15] worked on nanofluid forced convection heat transfer in the presence of the magnetic field. The obtained results show that the velocity of nanofluid increases with the increment of Reynolds number and Al_2O_3