Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **2**, No. 1, pp. 76-85

DOI: 10.4208/aamm.09-m0941
February 2010

Numerical study of Natural Convection of Magnetic Fluids in a Cubic Cavity with a Heat Generating Object Inside by the Lattice Boltzmann Method

Xiao-Dong Niu[1,*], Hiroshi Yamaguchi[1], Xin-Rong Zhang[2,1] and Keisuke Yoshikawa[1]

[1] *Energy Conversion Research Center, Department of Mechanical Engineering, Doshisha University, Kyoto 630-0321, Japan*

[2] *Department of Energy and Resources Engineering, College of Engineering, Peking University, 100871, P. R. China*

Received 21 May 2009; Accepted (in revised version) 02 July 2009

Available online 31 December 2009

Abstract. In this article, natural convection of a magnetic fluid in a cubic cavity with a heat generating object inside and under a uniform magnetic field is simulated by the lattice Boltzmann method. Results obtained from the present simulations are shown to be agreed well with our experimental measurements, and reveal more of effects of the magnetic field on the flow and heat transfer of the magnetic fluids.

PACS: 47.65.cb

Key words: Magnetic fluids, natural convection, Lattice Boltzmann method.

1 Introduction

Magnetic fluids are super paramagnetic fluids formed by a stable colloidal suspension of ferromagnetic nanoparticles dispersed in carrier liquids such as water or kerosene [1]. Among various magnetic fluids, there is a so-called temperature-sensitive magnetic fluid (TSMF), whose magnetization strongly depends on the temperature. Becau-

*Corresponding author.
URL: `https://kenkyudb.doshisha.ac.jp/rd/search/researcher/108197/index-j.html`
Email: xniu@mail.doshisha.ac.jp (X.-D. Niu), hyamaguc@mail.doshisha.ac.jp (H. Yamaguchi), xrzhang@coe.pku.edu.cn (X.-R. Zhang), dth0319@mail4.doshisha.ac.jp (K. Yoshikawa)

se of its being operated easily in the room temperature range, the TSMF is considered as a promising fluid in energy conversion and heat transport systems with small length scale or under microgravity environment [2, 3]. Due to the important role of the convection mechanism in the energy conversion and heat transportation, a thorough understanding of relations between the applied magnetic field and the resulted convection is necessary.

Flow behaviors as well as the heat transfer characteristics associated with the natural convection of the TSMF have been studied by many researchers in the past years [4–8]. Finlayson [4] first studied the thermomagnetic convection of the TSMF and showed that there exists a critical parameter beyond which the thermomagnetic convection occurs. Schwab et al. [5] conducted an experimental investigation of the convective instability in a horizontal layer of the TSMF and characterized the influence of the magnetic Rayleigh number on the Nusselt number. Krakov and Nikiforov [6] addressed the influences of the relative orientation of the temperature gradient and the magnetic field on thermomagnetic convection in a square cavity. Yamaguchi et al. [7, 8] performed experiments and numerical analyses in a square enclosure and characterized the heat transfer in terms of the magnetic Rayleigh number.

However, in most of practical situations, a container with heat generating objects inside is often encountered, and studying the convection of such a case is fewer but nontrivial in both academics and engineering. For this reason, in our recent study [9], the natural convection of the TSMF in a cubic container with a heat generating square cylinder object inside was investigated under a uniform magnetic field experimentally. The experimental results showed that the heat transfer characteristic of the TSMF is enhanced when the magnetic field is applied. The stronger the magnetic field, the better the heat transfer characteristic can be achieved.

As a compensation of the above experimental research, and in order to disclose more physics behind the experimental findings, in this paper the natural convection of the TSMF in a cubic cavity with a heat generating object inside under a uniform magnetic field is numerically carried out by using the lattice Boltzmann method (LBM) [10, 11]. The LBM [10, 11] is formulated based on a derived scalar magnetic potential advection-diffusion equation at the first-order time accuracy. By defining an effective velocity, which is a function of the temperature gradient, a lattice Boltzmann scheme for the magnetic field is straightforwardly constructed in a similar fashion of that of modeling the temperature transport equation. To ensure the scheme close to the original elliptic scalar potential equation, the time derivative in the advection-diffusion equation is multiplied by an adjustable preconditioning parameter. In the present study, using the LBM [10, 11], we particularly focus on investigating the effects of the magnetic field on the characteristics of the flow and heat transfer as well as the temperature behaviors in the considered flow field.

The rest of the paper is organized as follows. In Section 2, the LBM [10, 11] with numerical implementations is introduced briefly. Section 3 is devoted to results and discussions of the present study. The results obtained are compared to experimental measurements conducted in our labs. A conclusion is given in Section 4.