Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **3**, No. 1, pp. 121-130

DOI: 10.4208/aamm.10-m1036
February 2011

Natural Convection of Temperature-Sensitive Magnetic Fluids in Porous Media

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Received 29 June 2010; Accepted (in revised version) 31 August 2010
Available online 15 October 2010

Abstract. In this article, natural convection of a temperature-sensitive magnetic fluid in a porous media is studied numerically by using lattice Boltzmann method. Results show that the heat transfer decreases when the ball numbers increase. When the magnetic field is increased, the heat transfer is enhanced; however the average wall Nusselt number increases at small ball numbers but decreases at large ball numbers due to the induced flow being more likely confined near the bottom walls with a high number of obstacles.

PACS (2006): 44.30.+v, 47.65.Cb, 44.25.+f

Key words: Temperature sensitive magnetic fluid, natural convection, porous media, lattice Boltzmann method.

1 Introduction

Ferrofluids are a mixture of ferromagnetic nanoparticles in suspension in a carrier fluid [1] which makes them reactive to the presence of a magnetic field. The ferrous particles are usually coated with a surfactant, which allows the suspension to remain in a stable state. Among these fluids, temperature-sensitive magnetic fluids (TSMF) have their magnetization strongly dependent of the temperature [2]. Thus, with properties such as energy transfers and flow which can be controlled with a magnetic field, TSMF have various promising applications, ranging from heat transfer technologies [3,4] to spatial engineering [5], and have been the subject of many researches

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during the past years [6–10]. Finlayson [6] first studied thermomagnetic convection of the TSMF and showed the existence of a critical parameter beyond which the thermomagnetic convection occurs. Schwab et al. [7] conducted an experimental investigation of the convective instability in a horizontal layer of the TSMF and characterized influences of the magnetic Rayleigh number on the Nusselt number. Krakov and Nikiforov [8] addressed influences of the relative orientation of the temperature gradient and magnetic field on thermomagnetic convection in a square cavity. Yamaguchi et al. [9, 10] performed experiments and numerical analyses in a square enclosure and characterized the heat transfer in terms of a magnetic Rayleigh number.

However, the behaviors of TMSF still lack studies in cases such as natural convection in porous media, though many practical situations involve a porous structure. Porous media flows have themselves a wide application, from sand filters to petroleum engineering and hydrogeology [11, 12]; therefore the understanding of the magnetic fluid flow in such media could yield useful applications. In the following, we will discuss the results of the numerical simulations of natural convection of TSMF in a porous cavity. To ensure accurate and fast calculations for the complicated magnetohydrodynamics equations in such cases, we used the lattice Boltzmann Method (LBM), a recently developed computational fluid dynamics (CFD) technique [13]. While conventional CFD methods use finite differences or volumes to discretize the continuous fluid dynamics equations, LBM emerges from the Boltzmann equation (BE), and describes the fluid dynamics by means of a density distribution in virtual mesoscopic-scale particles placed along a 2- or 3-dimensional regular lattice. Since then, efforts have been made to extend the basic lattice Boltzmann model to include effects such as heat transfer and convection, or magnetic influence in ferrofluids [14, 15]. For this study of thermal effects in magnetic fluids, the LBM for TMSF described in [15] has been successfully implemented in modeling the ordinary porous flow phenomena. The porous media itself is modeled by different sizes and numbers of spherical obstacles evenly spread across the cavity. The purpose of the present study is to study the effect of the magnetic field to the heat transfer characteristics of flows in the porous media, which is a prototype of a cooling system with porous structure adjacent to the heating wall.

The rest of the paper is organized as follows: in Section 2 we will discuss the methodology of the study, and in particular, the details of lattice Boltzmann method used for the simulation; Section 3 focuses on the results obtained and their explanation. Finally, a conclusion is given in Section 4.

2 Methodology and numerical simulation

2.1 Lattice Boltzmann models

In the theory of the magnetic fluids, as the flow under influences of the magnetic field, it undergoes magnetic force. The magnetic hydrodynamics for the non-conductive magnetic fluid in porous media can be described by the following governing equa-