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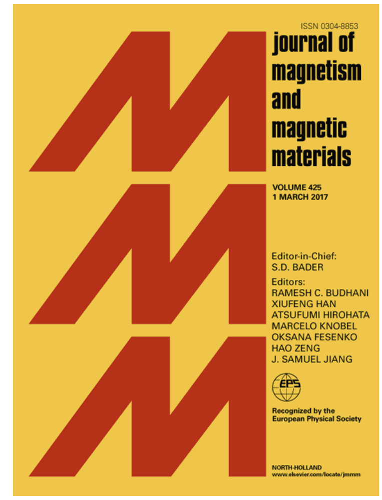

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The transition from natural convection to thermomagnetic convection of a magnetic fluid in a non-uniform magnetic field

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Abstract

Magnetic fluid flow and heat transfer by natural and thermomagnetic convection was studied numerically in a square enclosure. The aim was to investigate the transition from natural convection to thermomagnetic convection by exploring situations where buoyancy and the Kelvin body force would be opposing each other such that the magnetic effects would in some cases be the dominant factor throughout the domain and in other cases only in a part of the fluid. The numerical model coupled the solution of the magnetostatic field equation with the heat and fluid flow equations to simulate the fluid flow under a realistic magnetic field generated by a permanent magnet. The results suggest that the domain of influence over the flow field is largely aligned with the domain of dominance of the respective driving force. The result is that the transition from a single buoyancy-driven convection cell to a single thermomagnetically driven cell is via a two-cell structure and that the local effect on the flow field leads to a global effect on the heat transfer with a minimum of the Nusselt number in the transition region.

Keywords: Natural convection, Thermomagnetic convection, Magnetic fluid, Kelvin body force, Body force ratio

1. Introduction

Magnetic fluids are industrially manufactured colloidal suspensions of magnetic nano-particles with a typical equivalent diameter of about 10 nm. These particles are coated with a surfactant to prevent them from falling out of suspension when dispersed in a carrier fluid. Depending on the application, the carrier fluid could be water, kerosene or a silicone based fluid. Since the first manufactured magnetic fluid in the early to mid-1960s, the magnetic fluids industry has experienced substantial growth as ferrohydrodynamics began to develop [1]. Today, magnetic fluids are used in a range of industrial applications such as in anti-vibration devices or seals, in measurement technology, in medical technology for cancer treatment or targeted drug delivery in the body, and in heat transfer applications such as convection [2]. The electrical conductivity is largely determined by the carrier fluid, leading to the possibility of manufacturing electrically conducting or non-conduction magnetic fluids.

Heat transfer by convection is a key process and well known to transport or remove heat from processes or components by fluid flow in addition to heat conduction. It can be categorised into forced and passive convection. In forced convection, the fluid motion is induced by pumps or fans while in passive convection, changes in some fluid's properties lead to self-induced flow. The most common passive convection is natural or free convection, driven by buoyancy due to temperature-induced density changes. Natural convection in a nanofluid can be modified by a number of processes, such as internal heat generation in electrically conducting fluids or nanofluids with magnetic nanoparticles [3], by a strong variation of the viscosity with temperature [4], or by the shape of the nanoparticles [5], to name but a few. Magnetic fluids exhibit a different type of passive convection, in addition to natural convection, which is not driven by density variations but by changes in the magnetisation of the fluid. This type of convection is called thermomagnetic convection and is described in detail in §1.2. As thermomagnetic convection is not driven by buoyancy, it could be used as a passive cooling mechanism in micro-gravity environments or in situations where the heat source is above the cooling fluid [6]. Before describing thermomagnetic convection, modelling tools used to investigate convection in nanofluids are briefly introduced.

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