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Magnetic field effect on natural convection in a nanofluid-filled square enclosure

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ABSTRACT

This paper examines the natural convection in an enclosure that is filled with a water-Al_2O_3 nanofluid and is influenced by a magnetic field. The enclosure is bounded by two isothermal vertical walls at temperatures T_h and T_c and by two horizontal adiabatic walls. Based upon numerical predictions, the effects of pertinent parameters such as the Rayleigh number ($10^3 \le Ra \le 10^7$), the solid volume fraction ($0 \le \phi \le 0.06$) and the Hartmann number ($0 \le Ha \le 60$) on the flow and temperature fields and the heat transfer performance of the enclosure are examined. Prandtl number is considered to be $Pr = 6.2$. The results show that the heat transfer rate increases with an increase of the Rayleigh number but it decreases with an increase of the Hartmann number. An increase of the solid volume fraction may result in enhancement or deterioration of the heat transfer performance depending on the value of Hartmann and Rayleigh numbers.

1. Introduction

The classical problem of natural convection in square enclosures has many engineering applications such as the cooling systems of electronic components, the building and thermal insulation systems, the built-in-storage solar collectors, the nuclear reactor systems, the food storage industry and the geophysical fluid mechanics [1]. In some practical cases such as the crystal growth in fluids, the metal casting, the fusion reactors and the geothermal energy extractions, the natural convection is under the influence of a magnetic field [2]. There has been an increasing interest to understand the flow behaviour and the heat transfer mechanism of enclosures that are filled with electrically conducting fluids and are in the influence of a magnetic field [3–7]. The common finding of all these studies is that the fluid within the enclosure, which is under the magnetic effects, experiences a Lorentz force. This force, in turn, affects the buoyant flow field and the heat transfer rate.

Ece and Buyuk [8] examined the steady and laminar natural-convection flow in the presence of a magnetic field in an inclined rectangular enclosure heated and cooled on adjacent walls. They found that the magnetic field suppressed the convective flow and the heat transfer rate. They also showed that the orientation and the aspect ratio of the enclosure and the strength and direction of the magnetic field had significant effects on the flow and temperature fields. Dulikravich and Colaco [9] also found that the convective heat transfer can be controlled by the magnetic field. A numerical investigation on the double-diffusive convective flow in a rectangular enclosure by Teamah [10] also concluded that the heat and mass transfer mechanisms and the flow characteristics inside the enclosure strongly depend on the strength of the magnetic field and the heat generation. Sivasankaran and Ho [11] numerically studied the effects of temperature dependent properties on the natural convection of water in a cavity under the influence of a magnetic field. They showed that the heat transfer rate is influenced by the direction of the external magnetic field and decreases with an increase of the magnetic field. Kahveci and Oztuna [12] numerically simulated the natural-convection flow in a laterally heated partitioned enclosure and concluded that the magnetic field and its direction affect the heat transfer performance of the enclosure. Sathiyamoorthy and Chamkha [13] used different thermal boundary conditions to examine the steady laminar two-dimensional natural convection in the presence of inclined magnetic field in a square enclosure filled with a liquid gallium. They found that the heat transfer decreases with an increase of the magnetic field and that the vertically and horizontally-applied magnetic fields affect the heat transfer differently.

Most of the studies on the natural convection in enclosures with the magnetic effects have considered the electrically conducting fluid with a low thermal conductivity. This, in turn, limits the enhancement of heat transfer in the enclosure particularly in the

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