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Magnetohydrodynamic Natural Convection in a Rotating Enclosure

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Abstract. Magnetohydrodynamic natural convection heat transfer in a rotating, differentially heated enclosure is studied numerically in this article. The governing equations are in velocity, pressure and temperature formulation and solved using the staggered grid arrangement together with MAC method. The governing parameters considered are the Hartmann number, $0 \leq Ha \leq 70$, the inclination angle of the magnetic field, $0^\circ \leq \theta \leq 90^\circ$, the Taylor number, $8.9 \times 10^4 \leq Ta \leq 1.1 \times 10^6$ and the centrifugal force is smaller than the Coriolis force and the both forces were kept below the buoyancy force. It is found that a sufficiently large Lorentz force neutralizes the effect of buoyancy, inertial and Coriolis forces. Horizontal or vertical direction of the magnetic field was most effective in reducing the global heat transfer.

AMS subject classifications: 65M06, 65M12, 76T05

Key words: Finite difference method, natural convection, MHD, rotating enclosure.

1 Introduction

Magnetohydrodynamics (MHD) deals with the dynamics of electrically conducting fluids, in which moving charge particles react to a magnetic field. MHD flow has been extensively studied due to its wide applications such as in controlling thermonuclear reactions in which the conducting fluid is a plasma confined by a magnetic field. The magnetohydrodynamic power generator is also an application of MHD flow. A magnetic field on thermally driven flow in a square enclosure was analytically studied by [6]. [18]

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numerically investigated the effect of the magnetic field inside a rectangular enclosure and found that a circulating flow is formed with a relatively weak magnetic field and the rate of convective heat transfer is decreased when the magnetic field strength increases. [2] showed that the convection modes inside the enclosure strongly depend on both the strength and orientation of the magnetic field. [17] concluded that the magnetic field considerably decreases the average Nusselt number. [1] showed the suppression effect of the magnetic field on convection currents and heat transfer is more significant for low inclination angles of the enclosure and high Grashof numbers. For the similar configuration, [16] found that the Nusselt number increases up to about inclination angle 45° and then decrease as the angle increases. [15] applied steady and rotating magnetic fields to control the heat and mass transfer and the temperature fluctuations within the melt. Surprisingly, the rotating magnetic field was found very effective to stabilize the buoyant flow.

The effect of enclosure rotation on heat transfer is particularly very important concerning the flow of liquid metals inside enclosure, which is the standard material for manufacture of single wafer crystals in the semiconductor industry. [5] firstly studied the thermally driven flows in a rotating enclosure by using numerical technique. They found that the cells orientation change with increasing the rotation speeds. The fluid flow and heat transfer characteristics of a rotating square enclosure were studied experimentally and numerically by [7]. They concluded that the Coriolis force arising from rotation may have a remarkable influence on heat transfer when compared with non-rotating results and a correlation of Nusselt number as function of Taylor and Rayleigh number were built. [13] and [11,12] studied a differentially heated rotating cubic enclosure. Significant flow modification was obtained when the rotational Rayleigh number greater than the Rayleigh number or the Taylor number greater than the Rayleigh number. A significant increasing or decreasing in heat transfer in a rotating and differentially heated square enclosure could be achieved due to rotational effects as reported by [3] and [4]. [10] studied numerically the rectangular enclosure with discrete heat sources. They found that rotation results in imbalance of clockwise and counterclockwise circulations, increases heat transfer in the worst stage, reduces the oscillation of Nusselt number and improves or reduces mean performance in each cycle. The effects of body forces in a rotating and differentially heated enclosure is considered by [19]. The centrifugal force effect on heat transfer was found to be negligible. Recently, [14] found that the inertial and non-inertial results match well only for low rotational speeds of the enclosure.

The previous studies of the thermally driven flows in the presence of a magnetic field in a square enclosures have dealt with stationary enclosure. The present study considers thermally driven flows in the presence of a magnetic field of an arbitrary direction with rotating enclosure. The effects of the strength and orientation of the magnetic field and the rotational speeds on characteristics of convective flow and heat transfer performance are considered. For example, by precisely controlling the flow stability using a magnetic field, it is possible to extract a large single-crystal from the melt in the crystal growth process.