Chapter 9
Magnetic Field Dependent (MFD) Viscosity Effect on Nanofluid Treatment

ABSTRACT

In this chapter, the effect of magnetic field dependent (MFD) viscosity on free convection heat transfer of nanofluid in an enclosure is investigated. A single-phase nanofluid model is utilized considering Brownian motion. The control volume-based finite element method is applied to simulate this problem. The effects of viscosity parameter, Hartmann number, and Rayleigh number on hydrothermal behavior have been examined.

1. INTRODUCTION

Ferrohydrodynamics deals with the study of ferrofluids in the presence of magnetic field and it is a special branch of magnetohydrodynamics. During the last decades, an extensive research work has been done on these fluids since the effect of magnetization has yielded interesting information leading to their diverse fascinating technological applications (Rosensweig, 1985). Ferrofluids consist of colloidal suspensions of single domain magnetic nanoparticles and it has been recognized that they have promising potential for heat transfer applications in electronics, engines, micro and nanoelectromechanical systems (MEMS and NEMS), air-conditioning and ventilation systems (Ganguly, Sen and Puri, 2004). Under the circumstances, the study of thermal convection in ferrofluids is gaining much importance in the recent years. Moreover, many physical properties of these fluids can be tuned by varying the magnetic field. One of the well known phenomena generated by the influence of magnetic fields on ferrofluids is the change of their viscous behavior. Realizing the importance of magnetic field dependent (MFD) viscosity on ferrofluid flows, several studies have been undertaken in the past. The effect of a homogeneous magnetic field on the viscosity of a fluid with solid particles possessing intrinsic magnetic moments has been investigated by Shliomis (1972). The effect of MFD viscosity on the onset of ferroconvection in a rotating ferrofluid layer is discussed by Vaidyanathan et al. (2002). Nanjundappa et al. (2010) have investigated the effect of MFD viscosity on the onset of convection in a ferromagnetic fluid layer in the
presence of a vertical magnetic field by considering the bounding surfaces are either rigid-ferromagnetic or stress-free with constant heat flux conditions. Sheikholeslami et al. (2016) considered MFD viscosity effect on natural convection of ferrofluid. Sheikholeslami (2017) studied the magnetic field influence on nanofluid thermal radiation in a cavity with tilted elliptic inner cylinder. Sheikholeslami and Shehzad (2017) studied the thermal radiation of ferrofluid in existence of Lorentz forces considering variable viscosity. Sheikholeslami and Rokni (2017) reported the magnetic nanofluid natural convection in presence of thermal radiation. Sheikholeslami and Abelman (2018) presented the numerical analysis of the effect of magnetic field on Fe3O4-water ferrofluid convection with thermal radiation. Sheikholeslami et al. (2017) investigated the nanofluid radiation and natural convection in an enclosure with elliptical cylinders. Sheikholeslami and Sadoughi (2017) studied the Fe3O4-water nanofluid flow in porous medium considering MFD viscosity. Magnetic field effect on nanofluid treatment was investigated in recent decade.

2. NATURAL CONVECTION OF MAGNETIC NANOFLUID CONSIDERING MFD VISCOSITY EFFECT

2.1. Problem Definition

The geometry of this problem is shown in Figure 1(a). The heat source is centrally located on the bottom surface and its length L/3. The cooling is achieved by the two vertical walls. The heat source has constant heat flux \( q'' \) while the cooling walls have a constant temperature \( T_c \); all the other surfaces are adiabatic. Also, it is also assumed that the uniform magnetic field \( \vec{B} = B_x \vec{e}_x + B_y \vec{e}_y \) of constant magnitude \( B = \sqrt{B_x^2 + B_y^2} \) is applied, where \( \vec{e}_x \) and \( \vec{e}_y \) are unit vectors in the Cartesian coordinate system. The orientation of the magnetic field form an angle \( \theta_M \) with horizontal axis such that \( \theta_M = \cot^{-1} \left( \frac{B_x}{B_y} \right) \).

The electric current \( J \) and the electromagnetic force \( F \) are defined by \( J = \sigma \left( \nabla \times \vec{B} \right) \) and \( F = \sigma \left( \nabla \times \vec{B} \right) \times \vec{B} \), respectively.

2.2. Governing Equation

The flow is steady, two-dimensional, laminar and incompressible. The induced electric current and Joule heating are neglected. The magnetic Reynolds number is assumed to be small so that the induced magnetic field can be neglected compared to the applied magnetic field. Neglecting displacement currents, induced magnetic field, and using the Boussinesq approximation, the governing equations of heat transfer and fluid flow for nanofluid can be obtained as follows:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(1)
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