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Nanofluid flow and heat transfer in a cavity with variable magnetic field

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ABSTRACT

Fe_3O_4–water nanofluid flow in a cavity with constant heat flux is investigated using a control volume based finite element method (CVFEM). Effects of Rayleigh and Hartmann numbers and volume fraction of Fe_3O_4 (nano-magnetite, an iron oxide) on flow and heat transfer characteristics are analyzed. Results indicate that the temperature gradient is an increasing function of the buoyancy force and the volume fraction of Fe_3O_4, but it is a decreasing function of the Lorentz force. Also, the rate of heat transfer is augmented with an increase in the Lorentz force. However, the opposite is true on the rate of heat transfer with the buoyancy force. Furthermore, the core vortex moves downward with an increase in the Lorentz force. It is expected that the results presented here will not only provide useful information for cooling of electronic components but also complement the existing literature.

1. Introduction

Magneto-hydrodynamic free convection has various applications such as cooling of electronic components, combustion modeling, fire engineering etc. In recent years, nanotechnology offered an innovative passive method for heat transfer improvement. Alsabery et al. [1] studied the nanofluid conjugate free convection with sinusoidal temperature variation. Pal et al. [2] examined the Soret impact on nanofluid thermal radiation in the presence of a magnetic field. They showed that the shear stress reduces with an increase in the Soret number. Brownian motion effects on the velocity field have been reported by Abdel-wahed et al. [3]. Peristaltic magnetic nanofluid flow in a duct was presented by Akbar et al. [4]. The effect of atherosclerosis on hemodynamics of stenosis has been analyzed by Nadeem and Ijaz [5]. They showed that the velocity gradient on the wall of stenosed arteries decreases with the augmentation of the Strommers number. Ahmad and Mustafa [6] investigated the rotating nanofluid flow induced by an exponentially stretching sheet. Their results revealed that the temperature gradient is a decreasing function of the angular velocity. Hayat et al. [7] presented the influence of radiation on mass transfer of a nanofluid. They showed that the temperature gradient decreases with an increase in the thermal radiation. Bhatti and Rashidi [8] presented the impact of thermo-diffusion on Williamson nanofluid flow over a sheet. Effect of magnetic nanofluid on film condensation was studied by Heysiattalab et al. [9]. They concluded that the Nusselt number increases with a reduction in the size of the nanoparticles.

Selimefendigil and Öztop [10] examined conjugate convection in a cavity with nanofluids. They showed that the temperature gradient increases with an increase in the Grashof number. Garoosi et al. [11] used the Buongiorno model for nanofluid

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Nomenclature

B	magnetic induction
C_p	specific heat at constant pressure
Ec	Eckert number
En	heat transfer enhancement
Gr_f	Grashof number
$\vec{g}$	gravitational acceleration vector
H_x, H_y	components of the magnetic field intensity
H	the magnetic field strength
Ha	Hartmann number
k	thermal conductivity
Nu	Nusselt number
Pr	Prandtl number $(=\upsilon_f/\alpha_f)$
Ra	Rayleigh number
T	fluid temperature
u, v	velocity components in the x-direction and y-direction
U, V	dimensionless velocity components in the X-direction and Y-direction
x, y	space coordinates
X, Y	dimensionless space coordinates

Greek symbols

α	thermal diffusivity
ϕ	volume fraction
γ	magnetic field strength at the source
σ	electrical conductivity
μ	dynamic viscosity
μ_0	magnetic permeability of vacuum $(=4\pi \times 10^{-7}$ Tm/A)
υ	kinematic viscosity
ψ and Ψ	stream function and dimensionless stream function
Θ	dimensionless temperature
ρ	fluid density
β	thermal expansion coefficient
ω, Ω	vorticity and dimensionless vorticity

Subscripts

c	cold
h	hot
ave	average
loc	local
nf	nanofluid
f	base fluid
s	solid particles
in	inner
out	outer

free convection in a heat exchanger. Magnetic and Radiation source terms were considered by Sheikholeslami et al. [12] in final formulae. They reported that Lorentz forces can reduce the temperature gradient. Sheremet and Pop [13] presented the Buongiorno model for nanofluid convection in an enclosure with moving wall. The effect of non-uniform Lorentz force on nanofluid flow has been studied by Sheikholeslami Kandelousi [14]. Lorentz forces impact on flow in an enclosure with oscillating wall was investigated by Selimefendigil and Öztop [15]. They concluded that maximum performance occurs at tilted angle of 90°. Noreen et al. [16] presented nanofluid motion in a curved channel. They showed that the curvature can enhance the longitudinal velocity. Sheikholeslami and Chamkha [17] studied flow and heat transfer of a ferro-nanofluid. Sheikholeslami et al. [18] examined the influence of a magnetic field on forced convection. Farooq et al. [19] investigated two layer nanofluid flow and mass transfer. They illustrated the dissipation effects on the nanofluid motion. In recent decade, several researchers examined nanofluid heat transfer in existence of magnetic field [20-29].

In this paper, the impacts of variable magnetic field on the hydrothermal nanofluid flow in a cavity heated from below are examined. The control volume based finite element method (CVFEM) is chosen to simulate the pertinent results. Effects of the Hartmann number, the volume fraction of Fe_3O_4 and the Rayleigh number on hydrothermal characteristics are