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Numerical study for external magnetic source influence on water based nanofluid convective heat transfer

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ABSTRACT

Influence of external magnetic source in two-dimensional Fe_3O_4–water nanomaterial is numerically addressed. Numerical solution is carried out using control based volume finite element method (CVFEM). Combined influences of Lorentz and Kelvin forces are taken into account. Vorticity–stream function forms of equations have been considered. Influences of nanofluid volume fraction, Hartmann, Rayleigh and Magnetic numbers on velocity and temperature distribution are examined. Results demonstrate that temperature gradient augments with rise of Kelvin forces while it reduces for Lorentz forces. Moreover, heat transfer augmentation enhances with augment of Lorentz forces.

1. Introduction

Nanotechnology is a novel approach for augmenting conduction mode. Nanofluid energy transportation is influenced by solid volume fraction as well as dimension of nanoparticles. Sheikholeslami and Ellahi [1] investigated LBM application for magnetic field impact in free convection flow. They indicated that temperature gradient reduces with augment of Lorentz forces. Sheikholeslami and Abelman [2] applied Buongiorno method for nanofluid hydrothermal behavior in existence of a horizontal magnetic field. Hayat et al. [3] studied MHD peristaltic flow of nanofluid in presence of Joule heating. Oztop et al. [4] examined the free convection flow of nanofluid in a cavity. They illustrated that improvement reduces with augment of Rayleigh number. Uddin et al. [5] considered slip boundary conditions for bio-convection nanofluid flow.

Elshehabey and Ahmed [6] adopted Buongiorno's model of nanofluid for the discussion of mixed convection flow. It is noticed that upper wall motion dominates the flow style. It is in view of higher buoyance ratio. They indicated that the flow style is dominated by movement of upper wall for higher value of buoyance ratio. Ellahi et al. [7] examined impacts of nanoparticle shape on entropy production. Unsteady ferrofluid convection flow in an enclosure has been addressed by Rahman et al. [8]. They concluded that augmenting Lorentz forces retards the rate of heat transfer. Selimefendigil and Oztop [9] investigated the impact of magnetic dipole on flow style of a rotating cylinder. They concluded that the effect of cylinder rotation on the temperature gradient is more marked at buoyancy forces. Magnetic convective flow in a rod core enclosure was examined by Wrobel et al. [10]. Here magnetizing force changes the Nusselt number. Further researches about nanofluid convective heat transfer can be seen in Refs. [11–16].

It is well established fact that CVFEM utilizes the profits of both finite element and finite volume techniques for modeling of complex geometries [17,18]. Impacts of radiation of nanofluid convective heat transfer in existence of magnetic source was studied by Sheikholeslami et al. [19]. Rate of heat transfer is decreasing function of Lorentz forces. Sheikholeslami et al. [20] simulated the outcome of Lorentz forces on force convection heat transfer. They illustrated that for higher Reynolds number the Magnetic number is more noticeable.

Main objective of this study is to examine a numerical simulation of hydro-thermal characteristics of a magnetic nanofluid in a half circular shape cavity. Magnetic field is considered. Various values of nanoparticle volume fraction, Hartmann, Rayleigh and Magnetic number have been investigated.

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Nomenclature

B	magnetic induction
En	heat transfer improvement
Ec	Eckert number
Gr_f	Grashof number
Ha	Hartmann number
H	the strength of magnetic field
M	magnetization
Mn_F	Magnetic number
Pr	Prandtl number
Nu	Nusselt number
T	fluid temperature
T'_c	Curie temperature
v, u	vertical and horizontal velocity
k	thermal conductivity
Ra	Rayleigh number

Greek symbols

γ	strength of magnetic field
α	thermal diffusivity
ϕ	nano particle volume fraction
μ	dynamic viscosity
ε_1	temperature number $(= T_1/\Delta T)$
σ	electrical conductivity
μ_0	magnetic permeability of vacuum
β	thermal expansion coefficient
ψ	stream function
ρ	fluid density

Subscripts

s	solid particles
c	cold
nf	nanofluid

2. Problem statement

Fig. 1 depicts the sample mesh and diagram of present study. Boundary conditions are shown in this figure. Magnetic external source has been applied to this geometry. The formula of H is [21]:

$$\overline{H_x} = \gamma \frac{(y - \bar{b})}{2\pi} \left((\bar{b} - y)^2 + (\bar{a} - x)^2 \right)^{-2} \tag{1}$$

$$\overline{H_y} = \frac{(\bar{a} - x)}{2\pi} (\gamma) \left((\bar{b} - y)^2 + (\bar{a} - x)^2 \right)^{-2} \tag{2}$$

$$\overline{H} = \sqrt{\overline{H}_y^2 + \overline{H}_x^2} = \left[(\bar{b} - y)^2 + (\bar{a} - x)^2 \right]^{-0.5} \frac{\gamma}{2\pi} \tag{3}$$

Fig. 2 illustrate the strength of magnetic field due to magnetic source.

3. Simulation procedure

3.1. Definition

Two dimensional steady incompressible flow is taken into account. Governing equations are defined as:

$$\frac{\partial u}{\partial x} = -\frac{\partial v}{\partial y} \tag{4}$$

$$\left(\frac{\partial u}{\partial y} v + \frac{\partial u}{\partial x} u \right) = (\rho_{nf})^{-1} \left[\mu_{nf} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{\partial P}{\partial x} + \mu_0 M \frac{\partial \overline{H}}{\partial x} - \sigma_{nf} B_y^2 u + \sigma_{nf} B_x B_y v \right] \tag{5}$$

$$\rho_{nf} \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial P}{\partial y} + \mu_{nf} \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + \mu_0 M \frac{\partial \overline{H}}{\partial y} + B_y \sigma_{nf} B_x u - B_x \sigma_{nf} B_x v + (T - T_c) \beta_{nf} g \rho_{nf} \tag{6}$$

$$\left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = \frac{k_{nf}}{(\rho C_p)_{nf}} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \frac{\sigma_{nf}}{(\rho C_p)_{nf}} (u B_y - v B_x)^2 - \frac{\mu_0}{(\rho C_p)_{nf}} T \frac{\partial M}{\partial T} \times \left(u \frac{\partial \overline{H}}{\partial x} + v \frac{\partial \overline{H}}{\partial y} \right) + \frac{\mu_{nf}}{(\rho C_p)_{nf}} \left\{ 2 \left(\frac{\partial u}{\partial x} \right)^2 + 2 \left(\frac{\partial v}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)^2 \right\} \tag{7}$$

The terms $\mu_0 M \frac{\partial \overline{H}}{\partial x}$ and $\mu_0 M \frac{\partial \overline{H}}{\partial y}$ are Kelvin forces and the terms $-\sigma_{nf} B_y^2 u + \sigma_{nf} B_x B_y v$ and $-\sigma_{nf} B_x^2 v + \sigma_{nf} B_x B_y u$ are Lorentz force. Joule heating and magneto Caloric effects are considered as second and third terms of energy equation, respectively. The magnetization M is defined by following equation [22,23]:

$$M = \overline{H} K' (T'_c - T) \tag{8}$$

In which T'_c is the Curie temperature and K' is a constant.

Magnetic induction definition is $\overline{B} = \mu_0 \overline{H}$. Here [24]:

$$\rho_{nf} = \rho_f (1 - \phi) + \rho_s \phi \tag{9}$$

$$(\rho C_p)_{nf} = (\rho C_p)_f (1 - \phi) + (\rho C_p)_s \phi \tag{10}$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}} \tag{11}$$

$$\beta_{nf} = \beta_f (1 - \phi) + \beta_s \phi \tag{12}$$

$$\mu_{nf} = \frac{\mu_f}{(1 - \phi)^{2.5}} \tag{13}$$

$$k_{nf} = \frac{-2\phi(k_f - k_s) + 2k_f + k_s}{\phi(k_f - k_s) + 2k_f + k_s} k_f \tag{14}$$

$$\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3(-1 + \sigma_s/\sigma_f)\phi}{(+2 + \sigma_s/\sigma_f) - (-1 + \sigma_s/\sigma_f)\phi} \tag{15}$$

In order to eliminate pressure source terms, the vorticity–stream function formulation has been utilized:

$$\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \quad u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x} \tag{16}$$

Non-dimensional parameters which are used in this study are:

$$Y = y/L, \ X = x/L, \ \Omega = \frac{\omega L^2}{\alpha_f}, \ \Psi = \frac{\psi}{\alpha_f}, \ (H, H_x, H_y) = \frac{(\overline{H}, \overline{H_x}, \overline{H_y})}{\left(\frac{\gamma}{2\pi|b|} \right)}$$
$$V = \frac{vL}{\alpha_f}, \ \Theta = \frac{T - T_c}{T_h - T_c}, \ U = \frac{uL}{\alpha_f} \tag{17}$$

The final dimensionless equations are: