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Fe_3O_4–H_2O nanofluid natural convection in presence of thermal radiation

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ABSTRACT

Impacts of magnetic field and thermal radiation on Fe_3O_4–H_2O nanofluid hydrothermal behavior are investigated. Constant heat flux condition is taken into account for inner wall. Innovative numerical method is chosen namely Control volume based finite element method. Influences of radiation parameter (Rd), Rayleigh (Ra), Hartmann (Ha) numbers and volume fraction of Fe_3O_4–H_2O (ϕ) on hydrothermal treatment are shown graphically. Results reveal that impact of thermal radiation on convection heat transfer is more sensible for higher buoyancy forces. Thermal boundary layer thickness augments with rise of Rd, Ha while it reduces with rise of Ra, ϕ. Nanofluid velocity reduces with augment of Hartmann number but it enhances with augment of radiation parameter.

Introduction

Novel kinds of fluid required to obtain more efficient performance in these days. Nanofluid was offered as novel way to augment heat transfer. CuO-water nanofluid heat transfer in inclined cavity was examined by Bouhalleb and Abbassi [1]. Their outputs revealed that influence of aspect ratio is more sensible for higher buoyancy forces. The influence of the inclined angle on the hydrothermal behavior was investigated by Bouhalleb and Abbassi [2]. Sheikholeslami and Ganji [3] presented various application of nanofluid in their paper. Sheikholeslami et al. [4] studied CuO-water nanofluid hydrothermal analysis in a complex shaped cavity. Several kinds of nanoparticles have been utilized by several researchers [4–10].

Kataria and Mittal [11] studied nanofluid forced convective flow past an oscillating vertical sheet. Kataria et al. [12] investigated the influence of Lorentz forces on transient free convection of micropolar fluid. Influence of thermal radiation on nanofluid concentration has been studied by Hayat et al. [13]. They indicated that temperature gradient reduces with rise of thermal radiation. Influence of thermo-diffusion on MHD flow with ramped wall temperature was presented by Kataria and Patel [14]. Kataria and Patel [15] examined the effect of thermal radiation on MHD flow past an oscillating vertical plate. Impact of electric field on Fe_3O_4–H_2O nanofluid thermal augmentation was examined by Sheikholeslami [16]. Sheikholeslami and Ellahi [17] utilized LBM to simulate Lorentz forces influence on nanofluid heat transfer behavior. They depicted that the temperature gradient decreases with rise of Hartmann number. Mohyud-Din et al. [18] reported the effect of Lorentz forces on nanofluid flow in convergent channels. MHD nanofluid free convective hydrothermal analysis in a tilted wavy enclosure was presented by Sheremet et al. [19]. Their outputs illustrated that change of inclined

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Nomenclature

B	Magnetic induction
Ec	Eckert number
H	The magnetic field strength
$\vec{g}$	Gravitational acceleration vector
Nu	Nusselt number
Ha	Hartmann number
T	Fluid temperature
Ra	Rayleigh number
V, U	Vertical and horizontal dimensionless velocity
Y, X	Vertical and horizontal space coordinates
Greek symbols	
β	Thermal expansion coefficient
μ_0	Magnetic permeability of vacuum
α	Thermal diffusivity
Ω & Ψ	dimensionless vorticity & stream function
Θ	dimensionless temperature
ρ	Fluid density
μ	Dynamic viscosity
σ	Electrical conductivity
Subscripts	
nf	Nanofluid
f	Base fluid
loc	Local
c	Cold

angle causes convective heat transfer to augments. Influence of non-uniform Lorentz forces on nanofluid flow style was simulated by Sheikholeslami Kandelousi [20]. He concluded that augmentation in heat transfer reduces with augment of Kelvin forces. Nanofluid over a permeable stretching plate was investigated by Khan et al. [21]. Nanofluid over a stretching wedge has been examined by Khan et al. [22]. Mohyud-Din et al. [23] studied the nanofluid flow between two rotating parallel plates. Sheikholeslami et al. [24] reported the impact of inconstant Lorentz force on forced convection. They illustrated that Kelvin forces impact becomes more sensible in high Reynolds number. Application of nanofluid for heat transfer improvement has been reported by several authors [25–39].

The goal of this paper is to study effect of thermal radiation on nanofluid hydrothermal treatment in a curved cavity under the influence of external magnetic source. CVFEM is chosen to simulate this article. Impacts of Radiation parameter, Rayleigh and Hartmann numbers and volume fraction of Fe_3O_4 are presented.

Problem statement

A curved cavity with hot left wall is considered. Boundary conditions are shown in Fig. 1. A magnetic source exists near the middle of hot wall. Magnetic source is considered as depicted in Fig. 2. $\overline{H}_x, \overline{H}_y, \overline{H}$ can be calculated as follow [24]:

$$\overline{H}_y = \left[\left(\overline{b}-y\right)^2 + (\overline{a}-x)^2\right]^{-1} \frac{\gamma}{2\pi}(\overline{a}-x), \tag{1}$$

$$\overline{H}_x = \left[\left(\overline{b}-y\right)^2 + (\overline{a}-x)^2\right]^{-1} \frac{\gamma}{2\pi}\left(y-\overline{b}\right), \tag{2}$$

$$\overline{H} = \sqrt{\overline{H}_x^2 + \overline{H}_y^2} \tag{3}$$

Numerical method

Governing formulation

2D laminar nanofluid flow and forced convective heat transfer is taken into account. The governing PDEs are:

$$\frac{\partial v}{\partial y} + \frac{\partial u}{\partial x} = 0, \tag{4}$$

$$\left(\rho_{nf}\right)\left(u\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y}v\right) = \left[\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial x^2}\right)\mu_{nf} - \frac{\partial P}{\partial x} - \mu_0^2\sigma_{nf}H_y^2 u + \sigma_{nf}\mu_0^2 H_x H_y v\right] \tag{5}$$

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

$$\left(\rho C_p\right)_{nf}\left(v\frac{\partial T}{\partial y} + u\frac{\partial T}{\partial x}\right) = \sigma_{nf}\mu_0^2\left(H_x v - H_y u\right)^2 + k_{nf}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \mu_{nf}\left\{2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right\} - \frac{\partial q_r}{\partial y}, \left[q_r = -\frac{4\sigma_e}{3\beta_R}\frac{\partial T^4}{\partial y}, T^4 \cong 4T_c^3 T - 3T_c^4\right] \tag{7}$$

$\rho_{nf}, (\rho C_p)_{nf}, \alpha_{nf}, \beta_{nf}, k_{nf}$ and σ_{nf} are calculated as

$$\rho_{nf} = \rho_f(1-\phi) + \rho_s\phi, \tag{8}$$

$$\left(\rho C_p\right)_{nf} = \left(\rho C_p\right)_f(1-\phi) + \left(\rho C_p\right)_s\phi, \tag{9}$$

$$\alpha_{nf} = \frac{k_{nf}}{\left(\rho C_p\right)_{nf}}, \tag{10}$$

$$\beta_{nf} = \beta_f(1-\phi) + \beta_s\phi. \tag{11}$$

$$k_{nf} = k_f\left(\frac{k_s - 2\phi(k_f - k_s) + 2k_f}{k_s + \phi(k_f - k_s) + 2k_f}\right), \tag{12}$$

$$\sigma_{nf} = \sigma_f\left[\frac{3(\sigma 1 - 1)\phi}{(\sigma 1 + 2) - (\sigma 1 - 1)\phi} + 1\right], \quad \sigma 1 = \sigma_s/\sigma_f \tag{13}$$

Magnetic field dependent (MFD) viscosity has been considered as follows [27]: