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Numerical analysis of nanofluid transportation in porous media under the influence of external magnetic source

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ABSTRACT

This article is made to examine the impact of external magnetic source on Fe_3O_4-water ferrofluid convective heat transfer in a porous cavity. The solutions of final equations are obtained by Control volume based finite element method (CVFEM). Graphs are shown for various values of Darcy number (Da), Fe_3O_4-water volume fraction (ϕ), Rayleigh (Ra) and Hartmann (Ha) numbers. Results indicate that augmenting in Hartmann number results in reduce in velocity of nanofluid and augment the thermal boundary layer thickness. Adding nanoparticles in the based fluid is more effective for higher values of Hartmann number and lower values of Darcy number.

1. Introduction

New types of fluid are needed to obtain more efficient performance in new days. Nanofluid was proposed as innovative way to enhance heat transfer. Beg et al. [1] examined the bio-nanofluid transport phenomena by means of both single and two phase models. Wavy duct in existence of Brownian forces has been examined by Shehzad et al. [2]. They selected Nelder-Mead method to find the solution. Impact of Lorentz force on boundary layer flow has been analyzed by Beg et al. [3]. Sheikholeslami [4] investigated nanofluid forced convection in a three dimensional porous cavity. He selected LBM for this problem. Rashidi et al. [5] investigated the nanofluid free convection flow over a plate. Garoosi et al. [6] examined the simulation of nanofluid by means of Buongiorno model.

Sheikholeslami and Ganji [7] presented various application of nanofluid in their review article. Influence of nonlinear radiative heat transfer has been examined by Hayat et al. [8]. Influence of Coulomb forces on ferrofluid convection was analyzed by Sheikholeslami and Chamkha [9]. They concluded that augmenting Coulomb force has more profit in low Reynolds number. Sheikholeslami and Bhatti [10] presented an active method for heat transfer augmentation by means of electric field. Chamkha and Rashad [11] reported the nanoparticle migration on porous cone. Ellahi et al. [12] analyzed free convection of carbon nanotubes over a cone. They considered the Lorentz forces impact in governing equations. Raju et al. [13] studied the transient ferrofluid flow over a cone. Makinde et al. [14] presented the radiative heat transfer of nanofluid with variable viscosity. Mezrhab et al. [15] reported the radiation impact in a cavity. Sheikholeslami and Shehzad [16] examined the influence of thermal radiation on ferrofluid flow in existence of uniform magnetic field. Influence of asymmetric heating on the Nusselt number in a microchannel has been reported by Malvandi et al. [17]. Their outputs illustrated that Ha augments the Nu about 42%. Sheikholeslami et al. [18] investigated the impact of magnetic field on transportation of nanofluid in a porous media. Sheikholeslami and Rokni [19] reported the influence of variable Lorentz force on nanofluid free convection heat transfer.

Chen et al. [20] studied the performance of solar collectors by using silver nanoparticle. Sheikholeslami and Ellahi [21] selected LBM to simulate Lorentz forces influence on nanofluid convective heat transfer. They depicted that temperature gradient reduces with augment of magnetic strength. Kefayati [22] studied the Soret and Dufour influences on MHD natural convection of power-law fluid. He proved that Nu augments with augment of Dufour parameter. Effect of Marangoni convection on nanofluid flow in existence of magnetic field has been investigated by Sheikholeslami and Chamkha [23]. Sheikholeslami et al. [24] reported the impact of inconstant Lorentz force on forced convection. They illustrated that higher lid velocity has more sensible Kelvin forces effect. Several papers have been published in recent decade about nanofluid hydrothermal analysis [25–40].

This paper deals with influence of external magnetic source on nanofluid flow in a porous enclosure. CVFEM is selected to simulate

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Nomenclature

B	Magnetic induction [Tesla]
K	Permiabilty
Da	Darcy number
Ra	Rayleigh number
T	Fluid temperature [K]
Nu	Nusselt number
Ha	Hartmann number
$\vec{g}$	Gravitational acceleration vector
V,U	Vertical and horizontal dimensionless velocity [m/s]
Y,X	Vertical and horizontal space coordinates

Greek symbols

Θ	dimensionless temperature
ζ	Rotation angle
Ω&Ψ	dimensionless vorticity & stream function
β	Thermal expansion coefficient [1/K]
ρ	Fluid density [kg/m^3]
σ	Electrical conductivity
μ	Dynamic viscosity [Pa.s]

Subscripts

nf	Nanofluid
f	Base fluid
loc	Local

this problem. Roles of Darcy number, Fe_3O_4-water volume fraction, Hartmann and Rayleigh numbers are examined.

2. Problem statement

Boundary conditions are depicted in Fig. 1. The inner elliptic wall has constant temperature considered as hot wall. Outer circular wall is cold wall, the others are adiabatic. Magnetic source has been considered as shown in Fig. 2. $\overline{H_x}, \overline{H_y}, \overline{H}$can be calculated as follow:

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

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

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

3. Simulation method

3.1. Governing formulation

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

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

$$\begin{aligned}&\left(\rho_{nf}\right)\left(u\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y}v\right) = \left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial x^2}\right)\mu_{nf} - \frac{\partial P}{\partial x}\\ &-\mu_0^2\sigma_{nf}H_y^2 u + \sigma_{nf}\mu_0^2 H_x H_y v - \frac{\mu_{nf}}{K}u,\end{aligned} \tag{5}$$

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

$$\begin{aligned}&(\rho C_p)_{nf}\left(v\frac{\partial T}{\partial y} + u\frac{\partial T}{\partial x}\right) = \sigma_{nf}\mu_0^2(H_x v - H_y u)^2 + k_{nf}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right)\\ &+\mu_{nf}\left\{2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right\},\end{aligned} \tag{7}$$

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

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

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

$$\beta_{nf} = \beta_f(1-\phi) + \beta_s\phi, \tag{10}$$

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

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

μ_{nf} is obtained as follows [41]:

$$\mu_{nf} = \left(0.035\mu_0^2 H^2 + 3.1\mu_0 H - 27886.4807\phi^2 + 4263.02\phi + 316.0629\right)e^{-0.01T} \tag{14}$$

Dimensionless parameters are defined as:

$$\begin{aligned}&(b,a) = \frac{\left(\overline{b},\overline{a}\right)}{L}, (H_y, H_x, H) = \frac{\left(\overline{H_y},\overline{H_x},\overline{H}\right)}{H_0}, P = \frac{p}{\rho_f(\alpha_f/L)^2}\\ &U = \frac{uL}{\alpha_f}, V = \frac{vL}{\alpha_f}, \Theta = \frac{T-T_c}{(T_h - T_c)}, (X,Y) = \frac{(x,y)}{L}.\end{aligned} \tag{15}$$

So equations change to:

$$\frac{\partial V}{\partial Y} + \frac{\partial U}{\partial X} = 0, \tag{16}$$

$$\begin{aligned}&U\frac{\partial U}{\partial X} + \frac{\partial U}{\partial Y}V = \Pr\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right]\left(\frac{\partial^2 U}{\partial Y^2} + \frac{\partial^2 U}{\partial X^2}\right)\\ &-Ha^2\Pr\left[\frac{\sigma_{nf}/\sigma_f}{\rho_{nf}/\rho_f}\right]\left(H_y^2 U - H_x H_y V\right) - \frac{\partial P}{\partial X} - \frac{\Pr}{Da}\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right]U,\end{aligned} \tag{17}$$

$$\begin{aligned}&V\frac{\partial V}{\partial Y} + U\frac{\partial V}{\partial X} = \Pr\left(\frac{\partial^2 V}{\partial Y^2} + \frac{\partial^2 V}{\partial X^2}\right)\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right]\\ &-Ha^2\Pr\left[\frac{\sigma_{nf}/\sigma_f}{\rho_{nf}/\rho_f}\right]\left(H_x^2 V - H_x H_y U\right)\\ &-\frac{\partial P}{\partial Y} + Ra\Pr\left[\frac{\beta_{nf}}{\beta_f}\right]\Theta - \frac{\Pr}{Da}\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right]V,\end{aligned} \tag{18}$$