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Simulation of water based nanofluid convective flow inside a porous enclosure via non-equilibrium model

M. Sheikholeslami [a],*, S.A. Shehzad [b],*

[a] Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran
[b] Department of Mathematics, COMSATS Institute of Information Technology, Sahiwal 57000, Pakistan

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ABSTRACT

In this article, nanofluid convective flow inside a porous enclosure is simulated by means of two-temperature model. Control volume based finite element method is employed for this purpose. Nanofluid properties are estimated by means of KKL model. Darcy- Boussinesq approximation is utilized for nanofluid flow field. Lorentz forces effects are taken into consideration. Roles of solid-nanofluid interface heat transfer parameter (*Nhs*), Rayleigh number (*Ra*), porosity (ε), and Hartmann number (*Ha*) are examined. Outputs demonstrate that $|\psi|_{\max}$ enhance with rise of *Nhs* but it augments with rise of *Ra*. Porosity has opposite relationship with temperature gradient.

1. Introduction

Fluid flow in a porous cavity has wide applications, such as drying technologies, solar power collectors and geothermal systems, etc. Various applications of porous medium such as energy storage should be analyzed by non-equilibrium model. Hayat et al. [1] investigated three dimensional nanofluid convective heat transfer in existence of magnetic field over a stretching plate. Sheikholeslami and Rokni [2] simulated thermal radiation effect of nanofluid convective flow in existence of electric field. Ahmed et al. [3] studied the transient radiative flow over a stretching surface in existence of chemical reaction. Sheikholeslami and Shehzad [4] demonstrated nanofluid flow in a porous media in presence of Lorentz forces. Sheikholeslami and Bhatti [5] reported nanofluid forced convection in presence of Lorentz forces. They utilized various shapes of nanoparticles. Sheikholeslami and Shehzad [6] presented the role of radiative mode on nanofluid behavior. Basak et al. [7] simulated the convective flow in a permeable cavity considering different boundary conditions.

Khan et al. [8] studied the nanofluid squeezing flow in a rotating duct with stretching wall. Sheikholeslami and Sadoughi [9] investigated melting surface effect on nanofluid convective flow. Hayat et al. [10] investigated nanofluid flow over a rotating porous disk. They utilized carbon nanotubes. Sheikholeslami and Seyednezhad [11] utilized nanofluid for heat transfer improvement in a porous cavity in existence of non-uniform magnetic field. Sheremet et al. [12] presented the application of Buongiorno model for nanofluid free convection in a porous media. Sheremet et al. [13] depicted the convective motion of ferrofluid inside a rotating cavity. Sheremet et al. [14] used Boussinesq-Darcy approximation for porous cavity. Sheikholeslami and Shehzad [15] employed non-Darcy model for nanofluid motion in a permeable medium under the impact of variable Lorentz forces. Sheikholeslami and Rokni [16] demonstrated nanofluid MHD free convection in existence of melting surface. Sheikholeslami and Sadoughi [17] investigated the effect of nanoparticles' shape on thermal behavior of nanofluid inside a porous enclosure in existence of magnetic field. Different publications have been published about nanofluid flow in various applications [18–43].

This paper intends to investigate nanofluid treatment in a porous enclosure considering thermal non-equilibrium model under the impact of Lorentz forces. CVFEM is employed to show the impact of magnetic field. Roles of Rayleigh number, porosity, the solid-matrix/nanofluid interface heat transfer parameter and Hartmann number are depicted in results.

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* Corresponding authors.
E-mail addresses: mohsen.sheikholeslami@nit.ac.ir, mohsen.sheikholeslami@yahoo.com (M. Sheikholeslami), sabirali@ciitsahiwal.edu.pk, ali_qau70@yahoo.com (S.A. Shehzad).

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Nomenclature

h_{nfs}	interface heat transfer coefficient
B	Magnetic field [Tesla]
Nhs	solid-matrix/nanofluid interface heat transfer parameter
Nu	Nusselt number
Ha	Hartmann number
Ra	Rayleigh number
K	permeability [m^2]
X, Y	Horizontal and vertical space coordinates
T	Fluid temperature [K]

Greek symbols

ε	porosity of the porous medium
β	Thermal expansion coefficient [K^{-1}]
μ	Dynamic viscosity [Pa s]
ρ	Fluid density
θ	dimensionless temperature
ψ	stream function
σ	Electrical conductivity
δ_s	modified thermal conductivity ratio

Subscripts

s	solid matrix
p	particle
nf	Nanofluid
f	Base fluid

2. Definition of the problem

Fig. 1 shows the boundary condition and geometry. The hot wall formulation is:

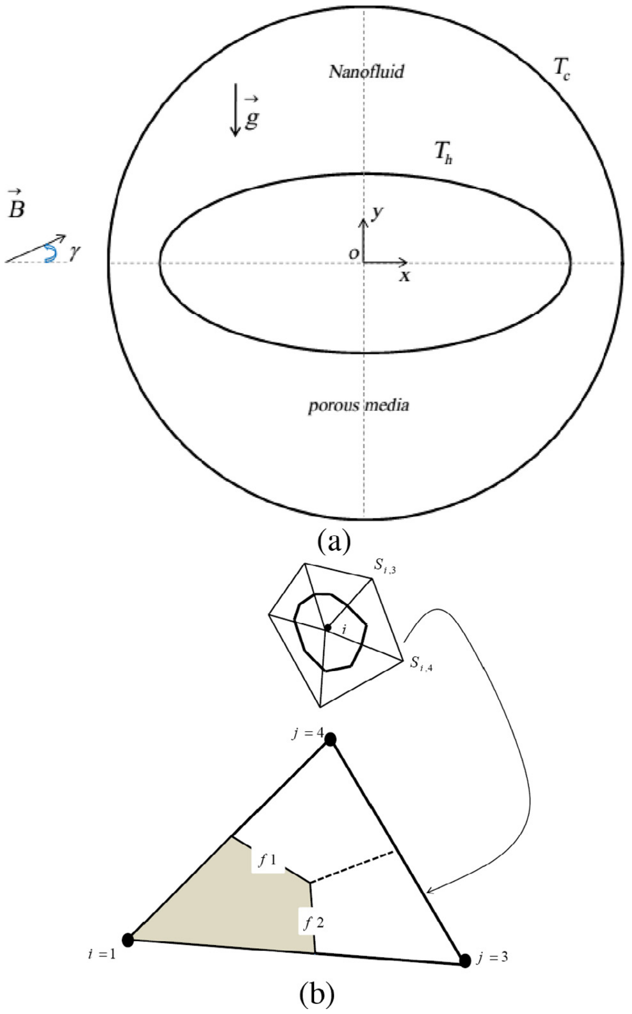

Fig. 1. (a) Geometry and the boundary conditions with (b) A sample triangular element and its corresponding control volume.

$$b = \sqrt{1-\varepsilon_1^2}\cdot a \tag{1}$$

where a, b, ε_1 are the major, minor axis of elliptic cylinder and eccentricity for the inner cylinder. Horizontal magnetic field is employed. The porous enclosure is filled with CuO-water nanofluid.

3. Formulation and simulation

3.1. Governing equation

The thermal non-equilibrium model and Boussinesq-Darcy law for flow are employed. So, the 2-temperature model is utilized. Considering these conditions, the governing PDEs are:

$$\nabla\cdot\vec{V} = 0 \tag{2}$$

$$-\frac{\mu_{nf}}{K} - (\rho\beta)_{nf}(T_{nf}-T_c)\,\vec{g} - \sigma_{nf}(\vec{V}\times\vec{B}) - \nabla p = 0 \tag{3}$$

$$\frac{k_s}{(\rho C_p)_s}\nabla^2 T_s + \frac{h_{nfs}}{(1-\varepsilon)(\rho C_p)_s}(T_{nf}-T_s) = 0 \tag{4}$$

$(\rho C_p)_{nf}$, $(\rho\beta)_{nf}$, ρ_{nf} and σ_{nf} can be defined as:

$$(\rho C_p)_{nf} = \phi(\rho C_p)_p + (1-\phi)(\rho C_p)_f \tag{5}$$

$$(\rho\beta)_{nf} = (1-\phi)(\rho\beta)_f + \phi(\rho\beta)_p \tag{6}$$

$$\rho_{nf} = \rho_f(1-\phi) + \rho_p\phi \tag{7}$$

$$\frac{\sigma_{nf}}{\sigma_f} = 3\frac{(MM-1)\phi}{\phi(1-MM)+(MM+2)} + 1,\; MM = \frac{\sigma_p}{\sigma_f} \tag{8}$$

Table 1
The coefficient values of CuO–Water nanofluid.

Coefficient values	CuO–Water
a_1	−26.593310846
a_2	−0.403818333
a_3	−33.3516805
a_4	−1.915825591
a_5	6.42185846658E−02
a_6	48.40336955
a_7	−9.787756683
a_8	190.245610009
a_9	10.9285386565
a_{10}	−0.72009983664