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Simulation of CuO-water nanofluid heat transfer enhancement in presence of melting surface

Mohsen Sheikholeslami [a,*], M.K. Sadoughi [b]

[a] Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran
[b] Department of Mechanical Engineering, Iowa State University of Science and Technology, Ames, IA 50011, United States

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ABSTRACT

In this report, impact of melting heat transfer on nanofluid heat transfer enhancement in presence of magnetic field is simulated. Innovative numerical approach is utilized namely CVFEM. KKL model is taken into account to obtain properties of CuO- water nanofluid. Roles of melting parameter (δ), CuO-water volume fraction (ϕ), Hartmann (Ha) and Rayleigh (Ra) numbers are demonstrated in outputs. Results depict that temperature gradient augments with rise of melting parameter and Rayleigh number. Nusselt number detracts with rise of Lorentz forces. At higher concentrations, nanofluid has greater merit to be used for heat transfer enhancement.

1. Introduction

Melting process has various uses such as heat exchangers and heat engines. Various types of nanoparticles have been utilized by various researchers. Shivakumara et al. [1] investigated the thermal instability analysis on nanofluid in a porous media. Sheikholeslami and Abelman [2] utilized two phase model for nanofluid flow under the impact of axial magnetic field. Sheikholeslami and Rokni [3] reported recent development in field of nanotechnology in their review paper. Khan et al. [4] illustrated impact of melting heat transfer on transient flow over a wedge. Sheikholeslami and Shehzad [5] utilized Fe_3O_4 nanoparticles for improving the thermal behavior of water in existence of magnetic field. Sheikholeslami and Seyednezhad [6] presented an application of CVFEM for simulating nanofluid behavior in a porous cavity. Sahota et al. [7] investigated the coiled heat exchanger by means of nanofluid. Das [8] reported the radiative flow in existence of melting heat. Feng et al. [9] demonstrated melting of NEPCM in a cavity by means of LBM. Sheikholeslami and Rokni [10] illustrated melting heat transfer impact on MHD natural convection of nanofluid. Mustafa et al. [11] presented rotating flow of Maxwell fluid considering non-Fourier heat flux theory.

Sheikholeslami and Ganji [12] illustrated different uses of nanotechnology in their article. Sheikholeslami and Sadoughi [13] presented a mesoscopic simulation to find the impact of magnetic field on nanofluid flow in a permeable media. Influence of nonlinear radiative heat transfer was presented by Hayat et al. [14]. Sheikholeslami [15] investigated thermal radiation of nanofluid in complex geometry. Zabalegui et al. [16] presented the nanofluid application for thermal energy storage. Sheikholeslami [17] utilized Darcy model for porous media filled with nanofluid under the effect of magnetic field. Sheikholeslami and Chamkha [18] reported the EHD natural convection of nanofluid in a cavity with sinusoidal wall. Mesoscopic method has been utilized by Sheikholeslami and Ellahi [19] for a three dimensional problem. Sheikholeslami and Rokni [20] illustrated the induced magnetic field effect on nanofluid flow considering two phase model. Nanoparticle movement in a channel in existence of Lorentz forces was demonstrated by Akbar et al. [21]. Heat flux boundary condition has been utilized by Sheikholeslami and Shehzad [22] to investigate the ferrofluid flow in porous media. In recent decade, various researcher published papers about heat transfer [23–51].

This paper intends to report the impact of melting heat transfer on free convection of ferrofluid in presence of Lorentz forces. CVFEM is selected to find the outputs. Roles of Melting parameter, CuO-water volume fraction, Hartmann and Rayleigh numbers are presented.

* Corresponding author.
E-mail addresses: mohsen.sheikholeslami@yahoo.com, mohsen.sheikholeslami@nit.ac.ir (M. Sheikholeslami), sadoughi@iastate.edu (M.K. Sadoughi).

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Nomenclature

B	magnetic field
T	fluid temperature
Nu	Nusselt number
Ra	Rayleigh number
$\vec{g}$	gravitational acceleration vector
Ha	Hartmann number

Greek symbols

Θ	dimensionless temperature
α	thermal diffusivity
$\Omega \& \Psi$	dimensionless vorticity & stream function
δ	melting parameter
β	thermal expansion coefficient
σ	electrical conductivity
μ	dynamic viscosity

Subscripts

f	base fluid
loc	local
nf	nanofluid

2. Problem statement

Fig. 1 depicts the geometry, boundary condition and sample element. The inner wall is hot wall ($T = T_h$) and the outer one is melting surface ($T = T_m$). Other walls are adiabatic. Horizontal magnetic field has been applied. The enclosure is field with nanofluid.

3. Governing equation and simulation

3.1. Governing formulation

Nanofluid steady convective flow is considered in presence of constant magnetic field. The PDEs are:

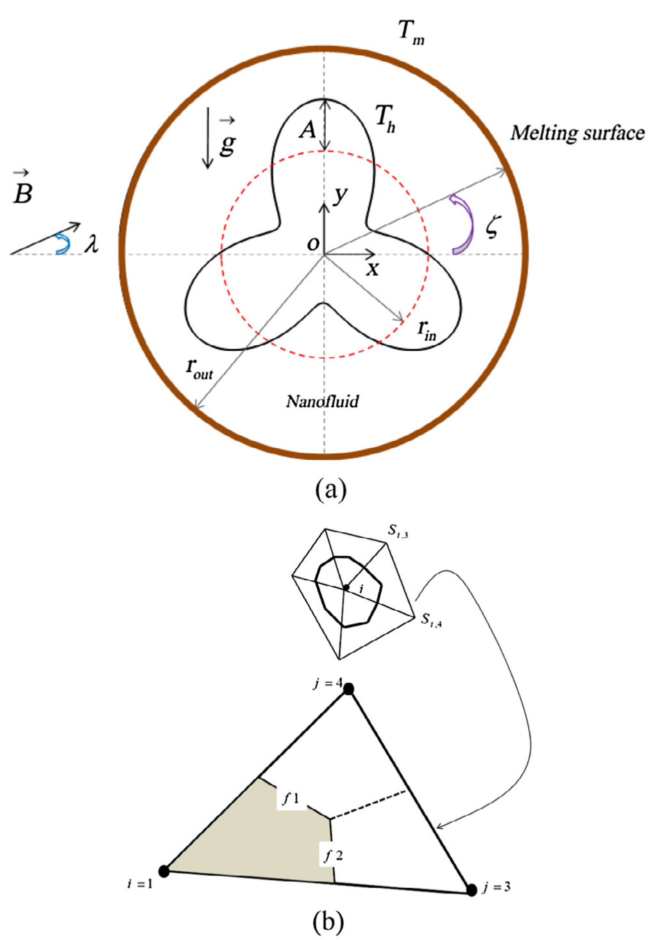

Fig. 1. (a) Geometry and the boundary conditions (b) A sample triangular element and its corresponding control volume.

$$\frac{\partial v}{\partial y}+\frac{\partial u}{\partial x}=0 \tag{1}$$

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

$$\rho_{nf}\left(\frac{\partial v}{\partial y}v+\frac{\partial v}{\partial x}u\right)=uB_y\sigma_{nf}B_x+(T-T_c)\beta_{nf}g\rho_{nf}-vB_x\sigma_{nf}B_x+\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)\mu_{nf}-\frac{\partial P}{\partial y}, \tag{3}$$

$B_x = B_o\cos\lambda,\quad B_y = B_o\sin\lambda$

$$(\rho C_p)_{nf}\left(v\frac{\partial T}{\partial y}+u\frac{\partial T}{\partial x}\right)=k_{nf}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

$(\rho C_p)_{nf}$, ρ_{nf}, $(\rho\beta)_{nf}$ and σ_{nf} are calculated as:

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

$$\rho_{nf}=\rho_f(1-\phi)+\phi\rho_s \tag{6}$$

$$\frac{(\rho\beta)_{nf}}{(\rho\beta)_f}=\phi\frac{(\rho\beta)_s}{(\rho\beta)_f}+(1-\phi) \tag{7}$$

$$\sigma_{nf}=\left[\left(\frac{(2+\sigma_s/\sigma_f)-(\sigma_s/\sigma_f-1)\phi}{3\phi(-1+\sigma_s/\sigma_f)}\right)^{-1}+1\right]\sigma_f \tag{8}$$

k_{nf}, μ_{nf} are calculated via KKL model [52]:

Table 1
The coefficient values of CuO – Water nanofluid [52].

Coefficient values	CuO – Water
a_1	−26.5933108
a_2	−0.403818333
a_3	−33.3516805
a_4	−1.915825591
a_5	6.421858E−02
a_6	48.40336955
a_7	−9.787756683
a_8	190.245610009
a_9	10.9285386565
a_{10}	−0.72009983664