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Water based nanofluid free convection heat transfer in a three dimensional porous cavity with hot sphere obstacle in existence of Lorenz forces

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ABSTRACT

H_2O based nanofluid magnetohydrodynamic free convection in a porous cubic cavity with hot sphere obstacle is investigated by means of Lattice Boltzmann method. Influences of Darcy number (Da), Hartmann number (Ha), and Rayleigh number (Ra) on Al_2O_3-H_2O nanofluid treatment is demonstrated. Thermal conductivity is considered as function of Brownian motion. Results indicate that Lorentz forces makes temperature gradient to decrease. Thermal boundary layer becomes thicker with augment of Hartmann number but opposite treatment is observed for Darcy number.

1. Introduction

Mesoscopic approaches have been attracted attentions in recent decade. Lattice Boltzmann method is a powerful method which can be used for both compressible and incompressible fluids. Nanofluid can be offered as applicable way to improve heat transfer. Haq et al. [1] investigated water base nanofluid flow in partially heated rhombus with heated square obstacle. They solved both momentum and energy equations. Fengrui et al. [2] studied the type curves of superheated multi-component thermal fluid flow in concentric dual-tubing wells. Sheikholeslami and Sadoughi [3] investigated shape factor effect on nanofluid flow in a porous enclosure by means of mesoscopic method. Astanina et al. [4] presented the entropy generation of ferrofluid in an open trapezoidal cavity. They considered the effect of magnetic field on natural convection in a porous media. Sheikholeslami and Shehzad [5] investigated nanofluid Darcy flow in a porous medium. Ibrahim et al. [6] studied the effect of chemical reaction on MHD mixed convection Casson nanofluid flow over a plate. They considered nonlinear permeable stretching plate.

Khan et al. [7] investigated hydro magnetic dissipative alumina nanofluid flow past a moving wedge. They added the effect of thermal radiation in energy equation. Hayat et al. [8] investigated influence of radiation heat transfer in an enclosure. Sheikholeslami and Seyednezhad [9] simulated nanofluid free convection in a permeable medium under the impact of electric field. Ali et al. [10] presented a fractional model for Casson fluid in axisymmetric cylindrical tube. Sheikholeslami and Ghasemi [11] investigated application of FEM for simulating nanofluid conductive heat transfer in existence of thermal radiation. Effect of shape factor on nanofluid properties has been considered by Sheikholeslami and Bhatti [12]. Chamkha and Ahmed [13] demonstrated the transient MHD stagnation-point flow in a porous media in existence of chemical reaction. Sheikholeslami and Shehzad [14] studied the effect of magnetic source on ferrofluid flow in permeable media. They found that convective flow decreases with increase of Hartmann number. Scientists employed nanofluid various applications in their papers [15–29].

This main aim of this research is to show the roles of magnetic field on free convection of nanofluid through a porous three dimensional cubic enclosure by means of Lattice Boltzmann

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Nomenclature

f_k^{eq}	equilibrium distribution
u, v, w	velocity components
e_α	discrete lattice velocity in direction
Ha	Hartmann number
g	internal energy distribution functions
MHD	magnetohydrodynamic
g^{eq}	equilibrium internal for temperature
Nu	Nusselt number
c_s	sound velocity
Pr	Prandtl number $(= \upsilon/\alpha)$
k	thermal conductivity
T	fluid temperature

Greek symbols

σ	electrical conductivity
τ	lattice relaxation time
ϕ	volume fraction
β	thermal expansion coefficient
υ	kinematic viscosity
ρ	fluid density
ψ	stream function
α	thermal diffusivity

Subscripts

h	hot
s	solid particles
nf	nanofluid
ave	average
f	base fluid
loc	local

method. Roles of Rayleigh, Hartmann and Darcy numbers on nanofluid hydrothermal characteristics are depicted.

2. Problem definition

Free convection in a three dimensional cubic porous cavity has been investigated in this paper (see Fig. 1). The enclosure is filled with Al_2O_3- H_2O nanofluid. A sphere hot obstacle insert in cubic cavity. Constant Lorentz forces have been employed $(\theta_x = \theta_z = 90^\circ)$.

3. Governing formulation and LBM

3.1. LBM formulation

Velocity and temperature are shown by using two distribution functions. Using Boltzmann equation leads to calculate f and g. By considering BGK estimation, the governing formulas are [30]:

$$\Delta t[f_i^{eq}(x,t) - f_i(x,t)]\frac{1}{\tau_v} + f_i(x,t) + \Delta t c_i F_k = f_i(x + \Delta t\, c_i, t + \Delta t) \quad (1)$$

$$\Delta t[g_i^{eq}(x,t) - g_i(x,t)]\frac{1}{\tau_C} = g_i(x + \Delta t\, c_i, t + \Delta t) - g_i(x,t) \quad (2)$$

where $\Delta t, \tau_v, c_i, F_k$ and τ_c are lattice time step, relaxation time of flow field, discrete lattice velocity, external forces and relaxation times of temperature filed, respectively.

We employed D_3Q_{19} model (Fig. 2) with following discrete lattice velocity:

$$c_i = \begin{pmatrix} 0 & 0 & 0 & 0 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & -1 & 1 & 0 \\ -1 & -1 & 1 & 1 & 0 & -1 & -1 & 1 & 0 & -1 & 1 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \\ -1 & 1 & -1 & 1 & -1 & 0 & 0 & 0 & 1 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (3)$$

g_i^{eq} and f_i^{eq} are:

$$g_i^{eq} = w_i T\left[1 + \frac{c_i.u}{c_s^2}\right] \quad (4)$$

$$f_i^{eq} = w_i\rho\left[-\frac{1}{2}\frac{u^2}{c_s^2} + \frac{1}{2}\frac{(c_i.u)^2}{c_s^4} + 1 + \frac{c_i.u}{c_s^2}\right] \quad (5)$$

$$w_i = \begin{cases} 1/3 & i = 0 \\ 1/36 & i = 7:18 \\ 1/18 & i = 1:6 \end{cases} \quad (6)$$

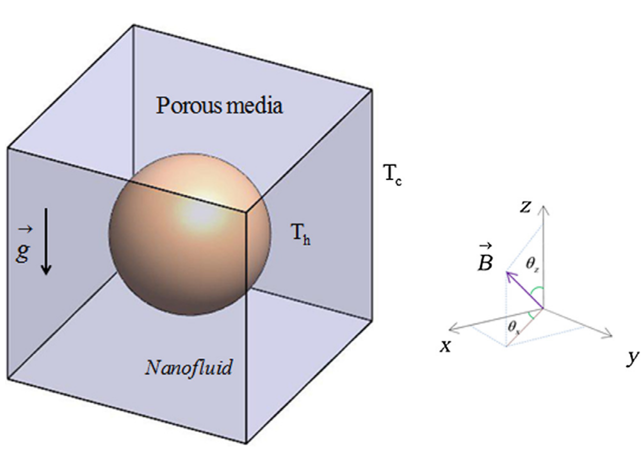

Fig. 1. Geometry of the problem.

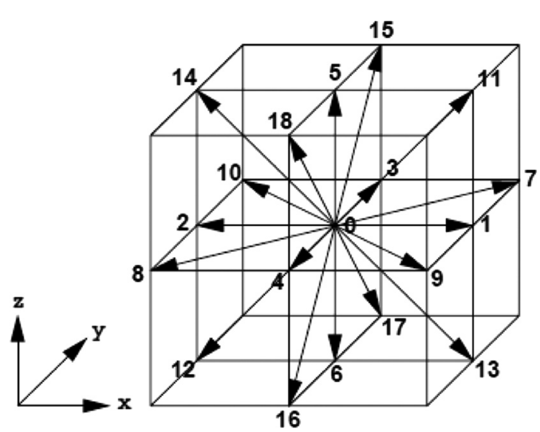

Fig. 2. Discrete velocity for the D_3Q_{19} model.