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Mesoscopic method for MHD nanofluid flow inside a porous cavity considering various shapes of nanoparticles

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ABSTRACT

Lattice Boltzmann method has been utilized to investigate magnetic field impact on nanofluid natural convection inside a porous enclosure with four square heat sources. Brownian motion impact on nanofluid properties is considered. Impacts of shapes of nanoparticle, Rayleigh number (Ra), Darcy number (Da), nanofluid volume fraction (ϕ), Hartmann number (Ha) on heat transfer treatment are demonstrated. Outputs indicate that convective heat transfer decreases with increase of Ha but it augments with increase of Da, Ra.

1. Introduction

One of the great kinetic based theory approaches is LBM. In this mesoscopic method, pressure can be obtained by using equation of state. Mustafa et al. [1] investigated rotating flow with non-uniform conductivity. They utilized non-Fourier heat flux theory. Sultana and Hyder [2] reported the natural convection in a sinusoidal porous cavity. Sheikholeslami et al. [3] illustrated nanofluid forced convection in existence of non-uniform Lorentz forces. Nanofluid convection in 3D enclosure has been reported by Sheikholeslami and Ellahi [4]. Sheikholeslami [5] applied LBM for simulation of nanofluid flow in a permeable media in existence of magnetic field. Sheikholeslami and Shehzad [6] reported the impact of thermal radiation on ferrofluid motion. They were taken into account variable viscosity. Nithyadevi et al. [7] presented the impact of tilted angle on nanofluid mixed convection in a permeable media.

Sheikholeslami and Bhatti [8] illustrated the impact of shape factor on ferrofluid forced convection. Sheikholeslami and Zeeshan [9] simulated nanofluid movement in a permeable medium with constant heat flux. Conjugate heat transfer of nanofluid was reported by Selimefendigil and Oztop [10]. They considered various inclination angles. Uddin et al. [11] investigated the blowing impact on nanofluid flow. Sheikholeslami [12] demonstrated the three dimensional nanofluid forced convection in a cubic cavity. Hayat et al. [13] examined the MHD nanofluid flow over a plate. Impact of variable Kelvin forces on ferrofluid motion was reported by Sheikholeslami Kandelousi [14]. Heat flux boundary condition has been utilized by Sheikholeslami and Shehzad [15] to investigate the ferrofluid flow in a porous media. Nanoparticle movement in a channel in existence of Lorentz forces was demonstrated by Akbar et al. [16]. Sheikholeslami and Bhatti [17] utilized active methods for augmentation in heat transfer. Sheremet et al. [18] demonstrated transient nanofluid flow in a permeable cavity. In recent years, different researchers reported about nanofluid heat transfer [19,6,20–42].

In this paper, influence of Hartmann number on MHD convective flow in a permeable medium is modeled. Mesoscopic method is employed as numerical approach. KKL model is selected to estimate μ_{nf}. Influences of shape of nanoparticle, nanofluid volume fraction, Darcy number, Hartmann and Rayleigh numbers on hydrothermal behavior are demonstrated.

2. Simulation and problem formulation

2.1. Problem formulation

Porous cavity is filled with CuO-H_2O nanofluid and horizontal magnetic field has been applied. Geometry and detail of current paper is depicted (see Fig. 1).

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Nomenclature

Ha	Hartmann number
f_k^{eq}	equilibrium distribution
u, v	x and y-directions velocities
Nu	Nusselt number
g^{eq}	equilibrium internal for temperature
k	thermal conductivity
e_α	discrete lattice velocity in direction
B_0	magnetic flux density
c_s	speed of sound in lattice scale
T	fluid temperature
Pr	Prandtl number
g	internal energy distribution functions
Greek symbols	
τ	lattice relaxation time
ρ	fluid density
υ	kinematic viscosity
ϕ	volume fraction
α	thermal diffusivity
ψ	stream function
σ	electrical conductivity
Subscripts	
s	solid particles
f	base fluid
h	hot
loc	local
nf	nanofluid
ave	average

2.2. LBM

f and g are two distribution functions which are used for velocity and temperature, respectively. Cartesian coordinate is used. Fig. 1(b) shows the D_2Q_9 model. f and g can be obtained by solving lattice Boltzmann equation. According to BGK approximation, the governing equations are [4]:

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

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

where τ_c, τ_v, F_k, c_i and Δt represent relaxation times of temperature and flow fields, external forces, discrete lattice velocity and lattice time step, respectively.

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

$$f_i^{eq} = \left[\frac{c_i.u}{c_s^2} + 1 - \frac{1}{2}\frac{u^2}{c_s^2} + \frac{1}{2}\frac{(c_i.u)^2}{c_s^4}\right] w_i \rho \quad (3)$$

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

F in Eq. (1) can be defined as:

$$\begin{aligned} &F = F_x + F_y \\ &F_x = 3w_i\rho[-(u\sin^2(\lambda))A + (v\cos(\lambda)\sin(\lambda))] - 3w_i\rho BBu, \\ &F_y = 3w_i\rho[-(v\cos^2(\lambda))A + g_y\beta(T - T_m) + (u\cos(\lambda)\sin(\lambda))A] - 3w_i\rho BBv \\ &Ha = LB_0\sqrt{\tfrac{\sigma}{\mu}},\quad A = Ha^2\upsilon L^{-2},\quad Da = \tfrac{K}{L^2},\quad BB = \tfrac{\upsilon}{DaL^2} \end{aligned} \quad (5)$$

At last, ρ, u, T can be calculated as follows:

$$\rho = \sum_i f_i, \quad \rho u = \sum_i c_i f_i, \quad T = \sum_i g_i. \quad (6)$$

2.3. The LBM for nanofluid

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

$$(\rho C_p)_{nf} = (\rho C_p)_f(1 - \phi) + (\rho C_p)_s\phi \quad (7)$$

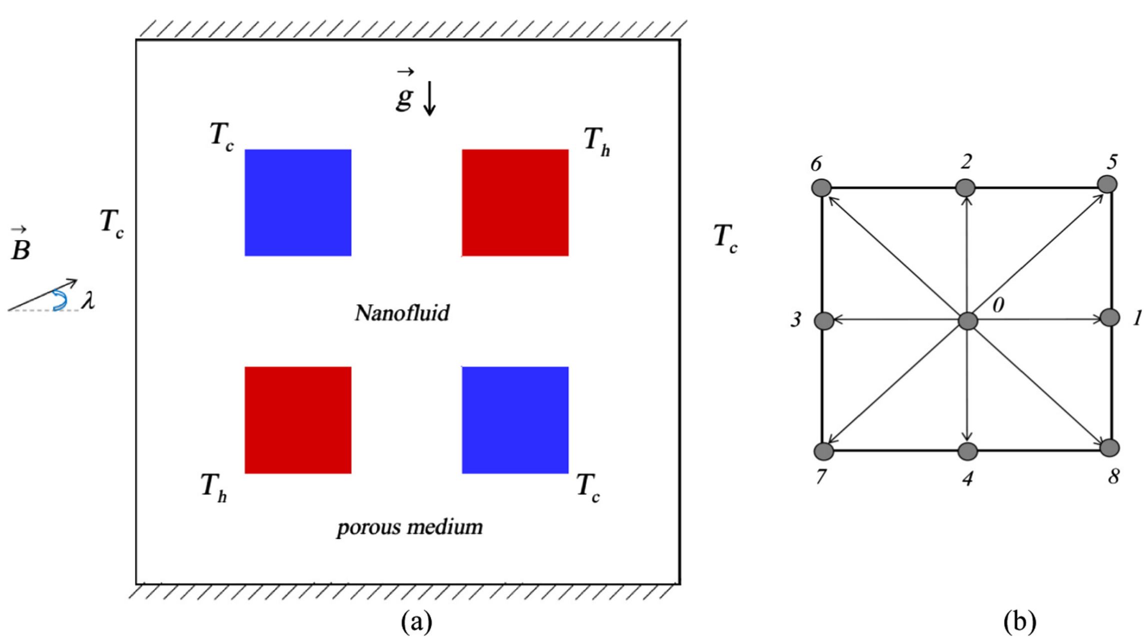

Fig. 1. (a) Geometry of the problem; (b) discrete velocity set of two-dimensional nine-velocity (D_2Q_9) model.