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# Forced convection in existence of Lorentz forces in a porous cavity with hot circular obstacle using nanofluid via Lattice Boltzmann method

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ABSTRACT

MHD forced convection of nanofluid inside a porous cavity with hot circular obstacle is presented. Lattice Boltzmann method is selected as simulation tool. Brownian motion impact is considered for nanofluid modeling. Roles of Reynolds number ($Re$), nanofluid volume fraction ($\phi$), Darcy number ($Da$) and Hartmann number ($Ha$) are demonstrated. Results reveal that thermal plume diminishes with augment of $Ha$. Nusselt number improves with increase of $Da$,$Re$.



## 1. Introduction

In various engineering applications, increasing heat transfer rate is a goal. One of the passive techniques for this purpose is nanotechnology. Sheikholeslami et al. [1] presented the MFD viscosity influence on natural convection of magnetic nanofluid. Kherbeet et al. [2] investigated nanofluid behavior over microscale backward and forward-facing steps. Sheikholeslami and Rashidi [3] illustrated the impact of variable magnetic field on natural convection of nanofluid. Three dimensional nanofluid flow was demonstrated by Sheikholeslami and Ellahi [4]. They illustrated that velocity detracts with augment of Lorentz forces. Sheikholeslami and Rokni [5] demonstrated various applications of magnetic nanofluid. Sheikholeslami and Shehzad [6] presented the influence of radiative mode on ferrofluid motion. They were taken in to account variable viscosity. Sheikholeslami and Sadoughi [7] simulated ferrofluid flow in a porous cavity considering MFD viscosity.

Khalili et al. [8] presented the transient pseudoplastic nanofluid flow over a plate. Garoosi et al. [9] demonstrated the application of nanofluid in a heat exchanger. Their result indicated that situation of the hot tube has sensible effect on temperature. Conjugate heat transfer of nanofluid has been reported by Selimefendigil and Oztop [10]. They considered various inclination angles. Beg et al. [11] compared single phase and two phase models for bio-nanofluid behavior. Sheikholeslami and Shehzad [12] reported numerical modeling for nanofluid flow in a permeable cavity. Sheikholeslami and Ganji [13] demonstrated shape factor effect on nanofluid flow in a porous media. Sheikholeslami [14] studied the magnetic field effect on water based nanofluid considering various shapes for nanoparticles. Heat flux boundary condition has been utilized by Sheikholeslami and Shehzad [15] to investigate the ferrofluid flow in porous media. Sheikholeslami and Rokni [16] investigated the effect of EFD viscosity on nanofluid forced convection in existence of electric field. Sheikholeslami et al. [17] examined entropy generation of nanofluid by means of LBM. Zin et al. [18] utilized Ag nanoparticles to improve convective flow over a sheet in existence of Hartmann flow. Recently, different authors published articles about nanofluid applications [19–44].

This research deals with MHD forced convection of nanofluid in a porous enclosure with hot obstacle using LBM. Roles of Hartmann number, nanofluid volume fraction, Darcy number and Reynolds number on hydrothermal behavior of nanofluid have been depicted.

## 2. Simulation and problem formulation

### 2.1. Problem formulation

Geometry and detail of current paper is depicted in Fig. 1. The porous enclosure is filled with CuO-water nanofluid and horizontal magnetic field has been applied. The upper wall is lid wall.

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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 |
| $e_\alpha$ | Discrete lattice velocity in direction |
| $B_0$ | Magnetic flux density |
| g | Internal energy distribution functions |
| T | Fluid temperature |
| $c_S$ | Speed of sound in Lattice scale |
| Pr | Prandtl number |

*Greek symbols*

| | |
|---|---|
| $\sigma$ | Electrical conductivity |
| $\rho$ | Fluid density |
| $\upsilon$ | Kinematic viscosity |
| $\phi$ | Volume fraction |
| $\alpha$ | Thermal diffusivity |
| $\psi$ | stream function |
| $\tau$ | Lattice relaxation time |

*Subscripts*

| | |
|---|---|
| $s$ | Solid particles |
| $f$ | Base fluid |
| $h$ | Hot |
| $c$ | Cold |
| $loc$ | Local |
| $nf$ | Nanofluid |
| $ave$ | Average |

### 2.2. LBM

One of the novel computational fluid dynamics (CFD) methods which is solved Boltzmann equation to simulate the flow instead of solving the Navier–Stokes equations is called Lattice Boltzmann methods (LBM). LBM has several advantages such as simple calculation procedure and efficient implementation for parallel computation, over other conventional CFD methods, because of its particulate nature and local dynamics.

$f$ 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 calculated by solving lattice Boltzmann equation. According to BGK approximation, the governing equations are [45]:

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

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

where $\tau_c, \tau_v, F_k, c_i$ and $\Delta t$ 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:

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

**Table 1**
Thermo physical properties of water and nanoparticles [24].

| | $\rho(\text{kg/m}^3)$ | $C_p$(j/kgk) | $k$(W/m.k) | $d_p$(nm) | $\sigma(\Omega\cdot\text{m})^{-1}$ |
|---|---|---|---|---|---|
| Pure water | 997.1 | 4179 | 0.613 | – | 0.05 |
| CuO | 6500 | 540 | 18 | 29 | $2.7\times10^{-8}$ |

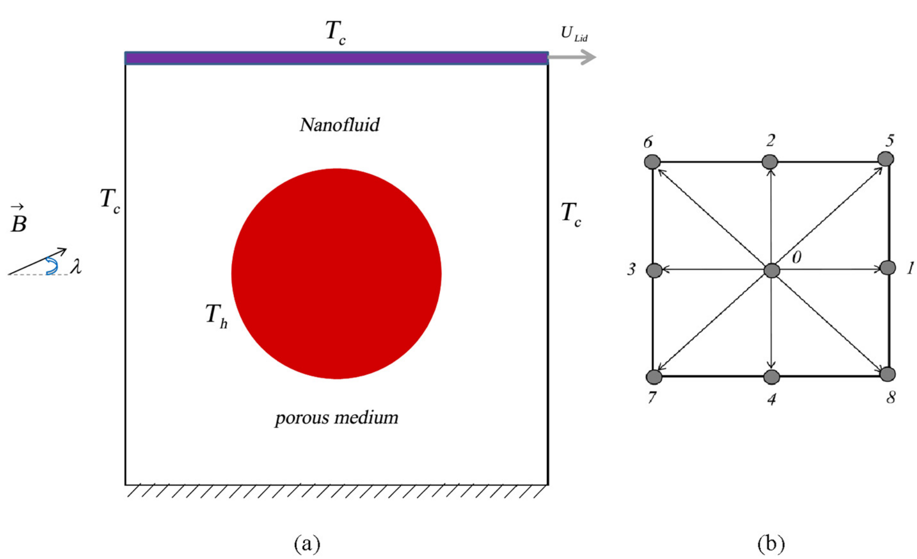


**Fig. 1.** (a) Geometry of the problem; (b) Discrete velocity set of two-dimensional nine-velocity ($D_2Q_9$) model.