APT 2032
1 August 2018
ARTICLE IN PRESS
No. of Pages 19, Model 5G

Advanced Powder Technology xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Two-phase lattice Boltzmann simulation of natural convection in a Cu-water nanofluid-filled porous cavity: Effects of thermal boundary conditions on heat transfer and entropy generation

Dhrubajyoti Kashyap *, Anoop K. Dass

Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India

ARTICLE INFO

Article history:
Received 27 February 2018
Received in revised form 28 June 2018
Accepted 25 July 2018
Available online xxxx

Keywords:
Two-component thermal lattice Boltzmann method
Natural convection
Porous medium
Nanofluid
Thermal boundary condition

ABSTRACT

The present work investigates the effect of four different thermal boundary conditions on natural convection in a fluid-saturated square porous cavity to make a judicious choice of optimal boundary condition on the basis of entropy generation, heat transfer and degree of temperature uniformity. Four different heating conditions- uniform, sinusoidal and two different linear temperature distributions are applied on the left vertical wall of the cavity respectively while maintaining the right vertical wall uniformly cooled and the horizontal walls thermally insulated. The two-phase thermal lattice Boltzmann (TLBM) model for nanofluid is extended to simulate nanofluid flow through a porous medium by incorporating the Brinkman–Forchheimer-extended Darcy model. The close agreement between present LBM solutions with the existing published results lends validity to the present findings. The current results indicate that the uniform and bottom to top linear heating are found to be efficient heating strategies depending on Rayleigh number ($10^3 \leq Ra \leq 10^5$) and Darcy number ($10^{-1} \leq Da \leq 10^{-6}$). It is observed that the nanofluid improves the energy efficiency by reducing the total entropy generation and enhancing the heat transfer rate although its augmentation depends on the optimal volume fraction of nanoparticles.

© 2018 Published by Elsevier B.V. on behalf of The Society of Powder Technology Japan. All rights reserved.

1. Introduction

Natural convection flow phenomenon has always been a topic of intensive investigation for researchers due to its practical relevance in wide areas including ventilation in buildings, electronic equipment, energy storage tanks, nuclear reactor, different types of heat exchangers, solar energy collection, etc [1]. Natural Convection in porous media has attracted much attention in heat transfer community as it has many natural as well as practical applications such as infiltration of molten metals, gas drying and transport process, crude oil extraction, geothermal operation, separation process, thermal reservoir, insulation of building, etc. Nield and Bejan [2], Ingham and Pop [3] and Kaviany [4] are the researchers who have given comprehensive literature surveys on flow through porous medium in their books concerning the theory and review of the works done by different researchers using both experimental and numerical methodology. In the last few decades, a large body of works, mostly computational, investigated natural-convection flow through a porous medium in enclosed cavities with various configurations using analytical based numerical computations [5] and conventional numerical techniques such as finite difference [6,7], finite volume [8,9] and finite element method [10–12]. The Darcy, the Brinkman-extended Darcy, and Forchheimer-extended Darcy models [2] are the widely used models to solve fluid flow problems in a porous medium. However, these models have some limitations and to overcome that, Nithiarasu et al. [10] proposed a generalized model namely Brinkman–Forchheimer-extended Darcy model which takes into account all non-Darcy effects.

Lattice Boltzmann method (LBM) [13–15] has successfully evolved as a numerical technique for solving various fluid flow problems and has shown great potential to solve complex flow systems compared to conventional numerical methods. To model fluid flow in a porous medium using LBM two approaches based on two scales namely the pore scale and representative elementary volume (REV) scale have been adopted. LBM at the pore scale [16] uses the standard lattice Boltzmann equation (LBE) to simulate fluid flows in pores and hence retain the local information of flow at the microscopic level. Therefore, this approach requires detailed geometric information of the pores which makes it computationally inefficient for large domain size. However, LBM at the REV

* Corresponding author.
E-mail addresses: k.dhrubajyoti@iitg.ernet.in (D. Kashyap), anoop@iitg.ernet.in (A.K. Dass).

https://doi.org/10.1016/j.apt.2018.07.020
0921-8831/© 2018 Published by Elsevier B.V. on behalf of The Society of Powder Technology Japan. All rights reserved.

Please cite this article in press as: D. Kashyap, A.K. Dass, Two-phase lattice Boltzmann simulation of natural convection in a Cu-water nanofluid-filled porous cavity: Effects of thermal boundary conditions on heat transfer and entropy generation, Advanced Powder Technology (2018), https://doi.org/10.1016/j.apt.2018.07.020

Nomenclature

Be	Bejan number
C_P	specific heat capacity, J kg^{-1} K^{-1}
C_s	speed of sound in lattice scale
Cu	copper
d	diameter, m
$\mathbf{e}$	discrete lattice velocity
f	density distribution function
F	external force term
g	temperature distribution function
g_r	acceleration due to gravity, m s^{-2}
k	thermal conductivity, W m^{-1} K^{-1}
k_b	Boltzmann's constant = 1.38066×10^{23} J K^{-1}
K	permeability (m^2)
L	length of the cavity, m
Nu	Nusselt number
Pr	Prandtl number (ν/α)
$\mathbf{r}$	$[x, y]$ position vector of arbitrary lattice node
Ra	Rayleigh number $(g_r\beta\Delta TL^3/(\nu\alpha))$
Ra_m	Darcy-Rayleigh number $(Ra\times Da)$
S_θ	dimensionless entropy generation due to heat transfer
S_ψ	dimensionless entropy generation due to fluid friction
T	dimensional temperature, K
$\mathbf{u}$	$[u, v]$ Dimensional velocity vector $(=\sqrt{u^2+v^2})$, m s^{-1}
$\mathbf{U}$	$[U, V]$ Dimensionless velocity vector $(=\sqrt{U^2+V^2})$
w	weighting factor

Greek symbols

α	thermal diffusivity, m^2 s^{-1}
β	coefficient of thermal expansion, K^{-1}
Δt	lattice time step
ε	porosity of the medium
μ	dynamic viscosity, kg m^{-1} s^{-1}
ν	kinetic viscosity, m^2 s^{-1}
θ	dimensionless temperature
ρ	density of the fluid, kg m^{-3}
σ	two components of nanofluid
τ	single relaxation time
ϕ	volume fractions of nanoparticles
χ	irreversibility factor
ψ	dimensionless Stream function

Subscript and Superscript

b, t	bottom, top wall
c, h	cold, hot temperature
cup	cup-mixing
eq	equilibrium
f	base fluid
i	lattice direction $(0 \le i \le 8)$
l, r	left, right wall
nf	nanofluid
p	nanoparticles
s	porous matrix
tot	total

Abbreviations

LBM	lattice Boltzmann method
RMSD	root-mean square deviation
REV	representative elementary volume

UNCORRECTED PROOF

scale [17,18] is simple and computationally efficient in solving porous flow problem where bulk flow behavior is most desired. In this paper, we have adopted REV approach based on Guo and Zhao's [18] thermal lattice Boltzmann model (TLBM).

The thermal boundary conditions such as uniform and non-uniform heating or cooling play a vital role in the overall process of many engineering problems involving natural convection. The works related to natural convection in a cavity with non-uniform temperature variations at the walls have gained importance among the research community in recent years as it is observed in various practical applications like microwave heating of food materials, air conditioning in the room, cooling of electronic equipment, solar collector, etc. Sarris et al. [19] show that in the material melting process the materials like glass are evenly melted by using sinusoidal temperature distributions on a flat wall. Varol et al. [6] and Basak et al. [11] are the researchers who have investigated the effect of non-uniformly heated wall on natural convection in square porous cavities while maintaining different boundary conditions.

From literature, it is found that most of the studies on heat transfer and flow phenomenon in porous enclosures are made by taking into account only the first law of thermodynamics. However, it is crucial to adopt the second law-based-investigations to analyze heat transfer systems from a thermodynamics point of view, which are characterized by entropy generation. The concept of entropy generation minimization (EGM) was first introduced by Bejan [20] for various transport processes to improve the energy efficiency by analyzing the loss of available energy via entropy production. Recently, the use of EGM technique as a thermodynamic optimization tool has been significantly increased for different thermal systems. Analysis of EGM for current natural convection problem subjected to different thermal boundary conditions is carried out in order to identify the optimal configuration with high energy efficiency at which maximum heat transfer rate and minimum entropy generation prevail. Magherbi et al. [21] and Ilis et al. [22] are the researchers who have studied the effect of entropy generation on benchmark problem of natural convection which is a rectangular cavity with differentially heated vertical walls and insulated horizontal walls. Varol et al. [6], Basak et al. [11] and Siavashi et al. [9] have examined the effect of irreversibility associated with heat transfer, fluid friction in their studies for different thermal systems in a porous medium.

The high-performance cooling system is a vital need for many applications, and one way to obtain it is by adopting an efficient and effective convective heat transfer process where fluid serves the purpose of a heat carrier. Therefore, it is very important to have an energy efficient, inexpensive heat transfer fluid which eventually leads to the development of nanofluid as termed by Choi and Eastman [23], where nano-sized particles are suspended in a base fluid. Compared to the conventional fluid such as water, industrial oil, etc., the nanofluid has a higher thermal conductivity which enhances the heat transfer characteristics depending on thermo-physical properties of nanofluid as well as the particle sizes, shapes, volume fractions and stabilities [24]. Besides, use of porous media can improve conduction in presence of convection as bigger surface contact area exists between working fluid and porous structure. Therefore, simultaneous use of porous media and nanofluids has been topic of interest for their better heat transfer rates in small size systems. Mahdi et al. [25] and Kasaeian et al. [26] summarized the works in the field of nanofluid flow through

Please cite this article in press as: D. Kashyap, A.K. Dass, Two-phase lattice Boltzmann simulation of natural convection in a Cu-water nanofluid-filled porous cavity: Effects of thermal boundary conditions on heat transfer and entropy generation, Advanced Powder Technology (2018), https://doi.org/10.1016/j.apt.2018.07.020

Download English Version:

https://daneshyari.com/en/article/8965079

Download Persian Version:

https://daneshyari.com/article/8965079

Daneshyari.com