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Study of natural convection cooling of a nanofluid subjected to a magnetic field

Ahmed Mahmoudi *, Imen Mejri, Ahmed Omri

Unité de Recherche Matériaux, Energie et Energies Renouvelables (MEER), Faculté des Sciences de Gafsa, B.P.19, Zarroug, Gafsa, 2112, Tunisie

HIGHLIGHTS

- Lattice Boltzmann method is applied to the problem.
- Heat sinks effect is studied.
- The effects of Hartmann number, Rayleigh number and solid volume fraction are examined.

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ABSTRACT

This paper presents a numerical study of natural convection cooling of water-Al_2O_3 nanofluid by two heat sinks vertically attached to the horizontal walls of a cavity subjected to a magnetic field. The left wall is hot, the right wall is cold, while the horizontal walls are insulated. Lattice Boltzmann method (LBM) is applied to solve the coupled equations of flow and temperature fields. This study has been carried out for the pertinent parameters in the following ranges: Rayleigh number of the base fluid, $Ra = 10^3$ to 10^5, Hartmann number varied from $Ha = 0$ to 60 and the solid volume fraction of nanoparticles between $\phi = 0$ and 6%. In order to investigate the effect of heat sinks location, three different configurations of heat sinks are considered. The effects of Rayleigh numbers, Hartmann number and heat sinks location on the streamlines, isotherms, Nusselt number are investigated. Results show that the heat transfer rate decreases with the increase of Hartmann number and increases with the rise of Rayleigh number. In addition it is observed that the average Nusselt number increases linearly with the increase of the nanoparticles solid volume fraction. Also, results show that the heat sinks positions greatly influence the heat transfer rate depending on the Hartmann number, Rayleigh number and nanoparticle solid volume fraction.

1. Introduction

Laminar natural convection on cavities has attracted many researchers, due to its practical engineering applications, such as heat removal from electrical and electronic equipments, solar collectors and nuclear reactor design. Because traditional fluids used for heat transfer applications such as water, mineral oils and ethylene glycol have a rather low thermal conductivity, nanofluids (homogeneous suspensions of nanoparticles in a base fluid) with relatively higher thermal conductivities due to the high thermal conductivity of the nanoparticles, have attracted enormous interest from researchers due to their potential in enhancement of heat transfer. Khanafer et al. [1] studied numerically natural convection in a

* Corresponding author.
E-mail address: ahmed.mahmoudi@yahoo.fr (A. Mahmoudi).

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Nomenclature

B_0	Magnetic field
c	Lattice speed
c_s	Speed of sound
$\mathbf{c_i}$	Discrete particle speeds
c_p	Specific heat at constant pressure
F	External forces
f	Density distribution functions
f^{eq}	Equilibrium density distribution functions
g	Internal energy distribution functions
g^{eq}	Equilibrium internal energy distribution functions
$\vec{g}$	Gravity vector
Ha	Hartmann number
k	Thermal conductivity
Ma	Mach number
Nu	Local Nusselt number
Ra	Rayleigh number
T	Temperature
$\mathbf{u}(u, v)$	Velocities
$\mathbf{x}(x, y)$	Lattice coordinates

Greek symbols

Δx	Lattice spacing
Δt	Time increment
τ_α	Relaxation time for temperature
τ_ν	Relaxation time for flow
ν	Kinematic viscosity
α	Thermal diffusivity
ρ	Fluid density
σ	Electrical conductivity
ψ	Non-dimensional stream function
ϕ	Solid volume fraction
μ	Dynamic viscosity

Subscript

bf	Base fluid
c	Cold
f	Fluid
h	Hot
nf	Nanofluid
p	Particle

nanofluid filled enclosure. The found results show that the heat transfer rate increases with the increase of the solid volume fraction. Jahanshahi et al. [2] studied nanofluid natural convection using two different models, in the first model a set of experimental data for thermal conductivity of nanofluid is employed and in the second model the thermal conductivity using the theoretical formulations is calculated. The results show an enhancement in thermal conductivity due to the adding of nanoparticles at both models. Ghasemi et al. [3] examined natural convection in an enclosure that is filled with a water–Al_2O_3 nanofluid and is influenced by a magnetic field. The results show that the heat transfer rate increases with an increase of the Rayleigh number but it decreases with an increase of the Hartmann number. Sheikholeslami et al. [4] studied the influence of non-uniform electric field on nanofluid filled enclosure with sinusoidal upper and moving lower walls. Results show that supplied voltage can change the flow shape. Also, the effect of electric field on heat transfer is more pronounced at low Reynolds number. Sheikholeslami et al. [5] investigated the influence of a spatially varying magnetic field on nanofluid flow. The lattice Boltzmann method is applied to solve the governing equations. Results indicate that the presence of the magnetic field affects considerably the flow field. Sheikholeslami et al. [6] applied Lattice Boltzmann Method to investigate the natural convection flows utilizing water–Al_2O_3 nanofluids in a cubic cavity. Results indicate that enhancement in heat transfer has direct relationship with Hartmann number while it has inverse relationship with Rayleigh number. Nusselt number increases with increase of nanoparticle volume fraction and Rayleigh number while it