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Natural convection of Al_2O_3/H_2O nanofluid in an open inclined cavity with a heat-generating element

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ABSTRACT

Free convection of alumina-water nanofluid in a tilted open cavity with a heat-generating solid element has been studied. The considered topic allows understanding an opportunity of nanofluids for cooling of the heat-generating elements in open cavities. Upper border is supposed to be open where nanofluid penetrates into the cavity. Simulation has been performed using the Oberbeck–Boussinesq equations formulated in non-dimensional stream function, vorticity and temperature. Finite difference method of the second order accuracy has been applied. The effects of cavity inclination angle ($0 \le \gamma \le \pi/2$), heater location ($0.1 \le \delta \le 0.7$, where δ is the dimensionless distance between the heater and left wall) and nanoparticles volume fraction ($0 \le \phi \le 0.04$) have been analyzed. It has been found that the considered parameters allow minimizing average heater temperature. The cavity inclination angle of $\pi/3$ characterizes the heat transfer enhancement (average Nusselt number has the maximum value), while the heater average temperature has the minimum value. At the same time, a proximity of the heater to the cavity wall characterizes non-essential cooling of the heat-generating element. The most effective cooling of the heat-generating element occurs for central heater location with cavity inclination angle of $\pi/3$. The considered alumina-water nanoparticles do not allow to intensify the cooling process for the heater element.

1. Introduction

Natural convection heat transfer is occurred in the presence of heat generation in electronic equipments and power batteries as shown by Xie et al. [1]. Ashorynejad and Shahriari [2] studied the MHD natural convection of Al_2O_3-Cu/water hybrid nanofluid in open wavy closed space by adopting the lattice Boltzmann method. They found that the Nusselt number decreases with the increasing of the Hartmann number. Open cavities can be seen in many engineering problems especially for electronics cooling as given by Bilgen and Oztop [3]. Bairi [4] investigated the natural convection heat transfer in a hemispherical cavity. In his work, the external cupola is kept isothermal and the active internal hemisphere is an electronic assembly generating significant power. Bondareva et al. [5] performed a computational work on free convection in an inclined wavy open porous cavity with a nanofluid. They also studied the influence of the uniform magnetic field in the presence of right bottom corner heater and found that an inclination angle can be used as a control parameter for heat and fluid flow. Kolsi et al. [6] have studied three-dimensional magnetohydrodynamic natural convection in an open cubical closed space filled with CNT-water nanofluid. The closed space is heated from left vertical wall and an inclined plate is attached in the closed space with finite length. They found that Nusselt number is changed according to nanoparticle volume fraction. Kalidasan and Kanna [7] solved the two-dimensional laminar natural convection in the open square space containing nanofluid of water with multi-walled carbon nanotube (MWCNT). They used the stream function–vorticity approach. The effect of amplitude on the rate of heat transfer is remarkable on the hot wall but it is subtle on the opposite cold wall. Karami et al. [8] experimentally investigated the natural convection of three finned-tube exchangers with an array of square fins at different fin width. They showed that the average heat transfer coefficient increases for some values and then it decreases

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Nomenclature

Roman letters

C	specific heat
d	dimensional distance between the left wall and heater
g	gravitational acceleration
$H_1(\phi), H_2(\phi), H_3(\phi), H_4(\phi)$	special functions
k	thermal conductivity
L	length and height of the cavity
l	perimeter of the heater
$\overline{Nu}$	average Nusselt number
p	dimensional pressure
Pr	Prandtl number
Q	internal volumetric heat flux
Ra	Rayleigh number
T	dimensional temperature
t	dimensional time
T_c	ambient nanofluid temperature
u, v	dimensionless velocity components
$\bar{u}$, $\bar{v}$	dimensional velocity components
x, y	dimensionless Cartesian coordinates
$\bar{x}$, $\bar{y}$	dimensional Cartesian coordinates

Greek symbols

α	thermal diffusivity
β	thermal expansion coefficient
ΔT	reference temperature difference
δ	dimensionless distance between the left wall and the heater
θ	dimensionless temperature
μ	dynamic viscosity
ρ	density
ρc	heat capacitance
$\rho\beta$	buoyancy coefficient
τ	dimensionless time
γ	cavity inclination angle
ϕ	nanoparticles volume fraction
$\bar{\psi}$	dimensional stream function
ψ	dimensionless stream function
$\bar{\omega}$	dimensional vorticity
ω	dimensionless vorticity

Subscripts

avg	average
c	cold
f	fluid
hs	heat source
max	maximum value
nf	nanofluid
p	(nano) particle

with fin space increasing. Mansour and Ahmed [9] made a computational work on natural convection in an inclined triangular closed space filled with Cu-water nanofluid saturated porous medium in the presence of heat generation effect. They applied two heat sources which are located onto bottom and left walls of the closed space. They observed that average Nusselt number is increased in the nanoparticle volume fraction. Job and Gunakala [10] considered the MHD mixed convection flows of copper (Cu)-water and silver (Ag)-water nanofluids in an L-shaped channel. Four heat-generating components are located on the channel wall and their affect is analyzed on heat and fluid flow. Mahmoudi et al. [11] examined the natural convection in an open cavity with non-uniform temperature boundary condition by using Lattice Boltzmann method (LBM). They found that nanoparticles addition effect is more important for higher Rayleigh numbers. Mliki et al. [12] solved a problem on MHD natural convection of nanofluid and pure water in a closed space with the left wall being linearly heated. They used the Lattice Boltzmann Method (LBM). Their results showed that the heat generation or absorption coefficient has a significant effect on heat and fluid flow. Shahi et al. [13] investigated the conjugate natural convection and conduction in a vertical annulus formed in heat generating solid circular cylinder and an outer isothermal cylindrical boundary. It is shown that the driven flow in the annular tube is strongly influenced by orientation of tube and this study has been carried out for different inclination angles. Seetharamu et al. [14] worked on forced convective heat transfer with internal heat generation in a micro-channel by using the finite element method for varying wall heat flux and temperature. They found that velocity slip coefficient can have negligible effect on the Nusselt numbers for all the three cases. Raisi [15] investigated conjugate natural convection heat transfer within a square enclosure with a copper–water nanofluid under the effect of centered heat-generating solid square block. It was revealed that augmentation of Rayleigh number and the solid volume fraction enhance the thermal performance of the enclosure.

The main aim of this research is to analyze free convection in an open inclined square cavity filled with an alumina-water nanofluid under the effect of heat-generating and heat-conducting element. It should be noted that the present work deals with analysis of passive cooling system for heat-generating source on the basis of a nanofluid under the effect of cavity inclination.

2. Basic equations

The physical model of natural convection in a cavity with a heater and the coordinate system are schematically shown in Fig. 1a. All rigid walls are adiabatic except for the upper open boundary where cold nanofluid penetrates into the cavity. A heat-conducting source with length of $0.2L$ (where L is the size of the square cavity) is located on the bottom wall and has a constant internal volumetric heat flux Q and the distance between the left vertical wall and the heater is d. The nanofluid contains solid spherical aluminum oxide nanoparticles and their physical properties can be found in [16]. Thermal equilibrium between the fluid phase and nanoparticles is supposed. It is worth noting that the considered geometry is important for understanding the fluid flow structures and heat transfer performance in the case of open electronic cabinet with the heat-generating and heat-conducting element under the effects of the analyzed parameters. At the same time, results of the present analyses of the heat transfer behavior for a discrete element can be used for optimization of passive cooling system in the case of local heat-generating element.

It is assumed in the analysis that the nanofluid is heat-conducting, Newtonian, and the Boussinesq approximation is valid. The single-phase nanofluid model is used taking into account that the base fluid (water) and nanoparticles are in thermal equilibrium and no slip between them occurs. For the considered problem it is supposed that the heat-generating element is elongated along the z-coordinate that is directed perpendicularly to the domain of interest presented in Fig. 1a. It has been shown earlier in the paper