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Numerical study of the natural convection of nanofluids based on mineral oil with properties evaluated experimentally

Douglas Hector Fontes, Elie Luis Martínez Padilla, Daniel Dall'Onder dos Santos, Enio Pedone Bandarra Filho*

Faculty of Mechanical Engineering, Federal University of Uberlândia, Av. João Naves de Ávila 2121, Uberlândia, MG 38400-902, Brazil

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ABSTRACT

This paper deals with the numerical simulation of natural convection inside a closed cavity of multi-walled carbon nanotubes and diamond nanoparticles dispersed in pure mineral oil. The data of the thermal conductivity and viscosity of the nanofluids were obtained experimentally, while specific heat and density were evaluated by the first law of thermodynamic and mass conservation principle, respectively. The physical model considered is a 2D cavity with adiabatic horizontal walls, where the left vertical wall with high temperature and the right vertical wall with low temperature and all walls with no-slip boundary conditions. The simulations were performed in a numerical code based on the Finite Volume Method-FVM, where second order temporal and spatial schemes were used. The results showed that only the Nusselt number for MWCNT based nanofluids increased in comparison to the mineral oil for the same Grashof number. However, the comparison between the convective coefficient for nanofluids and mineral oil showed that nanofluids presented better convection characteristics, for the same Grashof number. Furthermore, the diamond nanofluid with higher volumetric concentration presented the maximum increase of the convection coefficient, about 23%, though this nanofluid did not presentthe higher Nusselt number in comparison to the other nanofluids analyzed.

1. Introduction

Natural convection is an important heat transfer mechanism which has many industrial applications: solar energy, electronic devices, nuclear plants, electrical transformers, among others. Therefore, the research on heat transfer mechanism has led to an efficiency improvement of equipments. This research is mainly focused on changing the physical properties of the common fluids used in natural convection, instead in the heat transfer geometry which presents limited possibility of improvement.

The innovative use of nanotechnology on changing liquid properties has been known as nanofluids, proposed by [1]. Nanofluids are dispersions of solid particles (with an order of magnitude lower than 100 nm) in liquids. Due to the fact that solid particles present better properties (directly related to the heat transfer, such as thermal conductivities) than liquids, nanofluids have showed higher capacity of transporting thermal energy than their base liquids [2–7].

The researches involving nanofluids in natural convection have not showed consistent and similar results for different nanofluids. [8] experimentally evaluated the natural convection of Al_2O_3 and CuO based on water in closed cavity with high and low temperature at the vertical walls and horizontal adiabatic walls. They found, for the same Rayleigh numbers, that the nanofluids presented Nusselt numbers smaller than that of the base fluid. [9] studied numerically the natural convection of Cu nanofluids based on water in a two-dimensional closed cavity, using a thermal conductivity model for the nanofluids. This model is dependent of the thermal dispersion and related with nanoparticle dimension, volumetric concentration and velocity field. The authors found an increase over the mean Nusselt number with the volumetric concentration for the same Grashof numbers. This enhancement of the Nusselt number was related with thermal dispersion considered in the thermal conductivity model. A different configuration was used to study the natural convection of nanofluids based on water by [10]. The natural convection was evaluated in a cavity with a heat source located at the bottom surface, considering different Rayleigh number, volumetric concentrations, nanoparticles and positions of the heat source at the bottom surface. Thermal conductivity and viscosity were evaluated using, respectively, the [11] and [12] models.The results for the nanoparticles used (Cu, Al_2O_3, TiO_2 and Ag) showed that the maximum temperature of the heat source was reduced with the volumetric concentration, with pronounced reduction at smaller Rayleigh numbers, which means, prevalence of diffusion over convection

* Corresponding author.
E-mail addresses: douglas.fontes@ufu.br (D.H. Fontes), epadilla@ufu.br (E.L.M. Padilla), dallonder@ufu.br (D.D. dos Santos), bandarra@ufu.br (E.P. Bandarra Filho).

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Nomenclature

A	surface area $[m^2]$
c_p	specific heat $[J \cdot kg^{-1} \cdot K^{-1}]$
CS	control surface $[m^2]$
CV	control volume $[m^3]$
dA	infinitesimal surface area $[m^2]$
dS	infinitesimal surface $[m^2]$
dV	infinitesimal volume $[m^3]$
g	gravity $[m \cdot s^{-2}]$
Gr	Grashof number [–]
h	convection coefficient $[W \cdot m^{-2} \cdot K^{-1}]$
L	characteristic length $[m]$
n	normal vector
Nu	Nusselt number [–]
P	adimensionalized pressure [–]
p	pressure $[Pa]$
Pr	Prandtl number [–]
q''	heat flux $[W \cdot m^{-2}]$
T	temperature $[K]$
t	time $[s]$
U	adimensionalized velocity [–]
u	velocity $[m \cdot s^{-1}]$
V	volume
x	spatial dimension $[m]$

Greek letters

α	thermal diffusivity $[m^2 \cdot s^{-1}]$
β	volumetric expansion coefficient $[K^{-1}]$
δ_{ij}	Kronecker delta function
κ	thermal conductivity $[W \cdot m^{-1} \cdot K^{-1}]$
μ	dynamic viscosity $[Pa \cdot s]$
ν	kinematic viscosity $[m^2 \cdot s^{-1}]$
ϕ	volumetric concentration [–]
ρ	density $[kg \cdot m^{-3}]$
τ	adimensionalized time [–]
θ	adimensionalized temperature [–]

Subscripts

bf	base fluid
H	high
i	components of a vector
j	components of a vector
L	low
nf	nanofluid
np	nanoparticle
w	wall

transport. The authors found higher mean Nusselt number in the heat source for nanoparticles with higher thermal conductivity (*Ag* and *Cu*). A closed cavity with a solid heat source, located inside the cavity, was used by [13] to evaluate the natural convection of *Cu*, TiO_2 and Al_2O_3 nanofluids based on water. The authors also evaluated the thermal conductivity and viscosity respectively, by the classical models of [11] and [12]. The authors obtained an enhancement of 0.76% to 4.86% on the Nusselt number for the volumetric concentration utilized. [14] evaluated the natural convection of *Cu*-water nanofluid, using classical correlations for nanofluid viscosity and thermal conductivity, in some inclined cavities with low aspect ratios. The authors obtained an enhancement on Nusselt number about 25% for an aspect ratio of 0.1 without inclination and 2% volumetric concentration. Recently, [15] evaluated the effect of inclination on the natural convection of Al_2O_3-water nanofluids with maximum volumetric concentration of 3%, using the empirical correlation of [16] to estimate viscosity and thermal conductivity of the nanofluid. The authors employed two-phase mixture model with two slip velocity mechanism (Brownian motion and thermophoresis). In contrast to the results of [14], [15] obtained a reduction of the water Nusselt number using nanofluids, while using single-phase modeling significant differences were not found. The present paper reports results from numerical study of nanofluids based on mineral oil inside a closed cavity in a simple arrangement to simulate an electrical transformer. The transport properties such as thermal conductivity and viscosity of MWCNT and diamond of nanofluids were measured experimentally. To the authors knowledge, no other work with similar data coverage has been found in the literature.

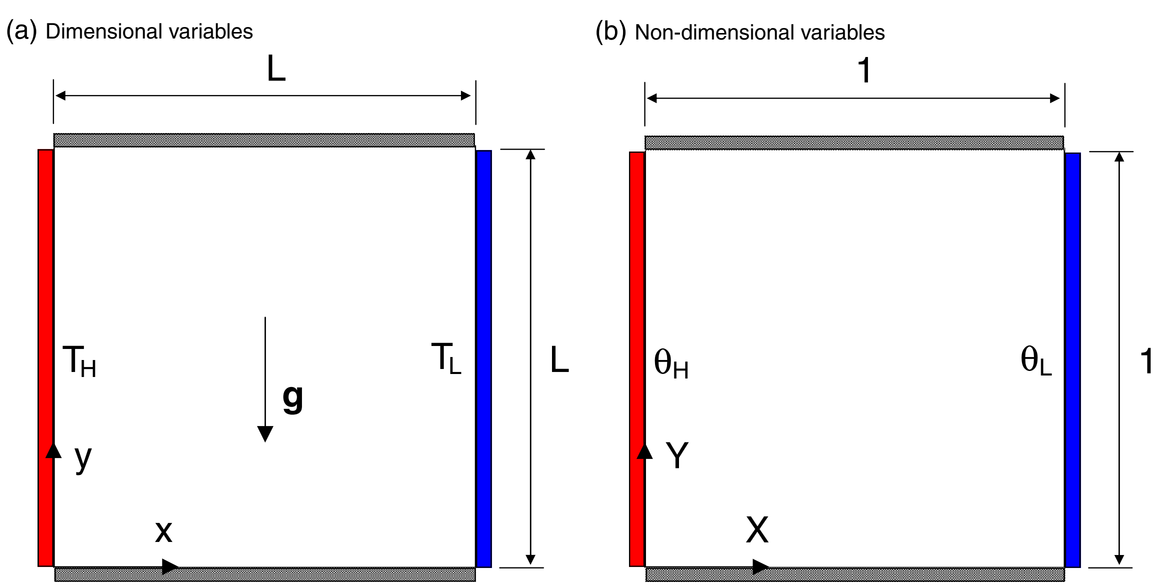

Fig. 1. Physical model of the square cavity for natural convection.