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Study of heat transfer by natural convection of nanofluids in a partially heated cylindrical enclosure

Mabrouk Guestal[a,*], Mahfoud Kadja[a], Mai Ton Hoang[b]

[a] Laboratory of Applied Energetics and Pollution, Department of Mechanical Engineering, University of Frères Mentouri, 25000 Constantine, Algeria
[b] GRESPI EA 4694, University of Reims Champagne Ardenne, 51687 Reims, Cedex 2, France

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ABSTRACT

In this research, a numerical study was carried out on heat transfer by natural convection of two nanofluids in a partially heated horizontal cylindrical enclosure. The partial heating occurs through the lower side of the enclosure at a constant temperature. The length of the heat source is changed from 5% to 25% of the total perimeter of the enclosure. The two side parts of the enclosure are maintained at a low constant temperature, each one of them has a length of 25% of the total perimeter. The top part of the enclosure is considered as adiabatic, it has a length of 25% of the total perimeter. The two nanofluids used are Cu-water and TiO_2-water with a volume fraction of nanoparticles being varied in the range of 0–0.05. The Rayleigh number was varied in the interval 10^3 to 10^6. The results obtained were summarized in the form of correlation equations of the average Nusselt number as a function of the heated length, the Rayleigh number and volume fraction for both types of nanofluids.

1. Introduction

Heat transfer by natural convection is considered among the most important types of thermal energy transfer. It can be found in nature and in various aspects of human daily life. This importance led to the completion of many numerical and experimental studies of natural convection in recent years. Such studies focussed on the factors that affect the rate of heat transfer. These factors can be divided into two categories: The first category is the geometric form of the space within which occurs the process of heat transfer by natural convection and the second category is the physico-chemical structure of the working fluid.

The effect of the geometric form has been studied in many numerical and experimental works using various geometric forms. Martini and Churchill [1] studied natural convection inside a horizontal cylinder, they observed that the overall rate of circulation increases rapidly and then decreases slowly as the temperature difference increases. Kuehn and Goldstein [2] investigated experimentally and numerically natural convection of water and air within a horizontal annulus for Rayleigh numbers varied from 10^2 to 10^5, the Mach-Zehnder interferometer was used to determine temperature distributions and local heat transfer coefficients experimentally, they have found that the temperature distributions for both fluids were nearly the same at similar Rayleigh numbers. Xin et al. [3] investigated numerically and analytically natural convection in a differentially heated horizontal cylinder for various Prandtl numbers. They imposed a temperature distribution on the wall of the cylinder in the form of a trigonometric function. The results obtained show that the flow structure becomes rapidly independent of the Prandtl number. Calcagni et al. [4] studied experimentally and numerically free convective heat transfer in a square enclosure which contains a heater located on the lower wall. Cooling occurs through the lateral walls. Rayleigh numbers were varied in the interval 10^3 to 10^6. The holographic interferometry

* Corresponding author.
E-mail address: guestal.mabrouk@umc.edu.dz (M. Guestal).

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Nomenclature

D	Diameter of enclosure (m)
g	Acceleration due to gravity (m/s^2)
K	Thermal conductivity (W/mK)
L_c	characteristic length
Nu	Nusselt number
p	Pressure (Pa)
P	Dimensionless pressure
Pe	Perimeter of enclosure (m)
Pe_h	Heated perimeter of the enclosure (m)
Pr	Prandtl number, $\frac{\nu}{\alpha}$
R	Dimensionless radius
(r, θ)	Cylindrical coordinates
R_0	Radius of enclosure (m)
Ra	Rayleigh number, $\frac{g\,\beta\,D^3\,(T_h - T_c)}{\nu\,\alpha}$
T	Temperature (K)
(u, v)	Velocity components (m/s)
(U, V)	Dimensionless velocity components

Greek symbols

α	Thermal diffusivity (m^2/s)
β	Thermal expansion coefficient at constant pressure, (K^{-1})
ε	Dimensionless heated length, (Pe_h / Pe)
ν	Kinematic viscosity (m^2/s)
ξ	Dimensionless temperature
ρ	Density (kg/m^3)
φ_v	Nanoparticles volume fraction

Subscripts

c	Cold wall
h	Hot wall
max	Maximum value
nf	Nanofluid

technique was used in the experimental method. The variation of the local and average Nusselt numbers in the heated region were presented. Sharma et al. [5] studied numerically turbulent natural convection in an enclosure with localized heating from below and symmetrical cooling of the vertical side walls. The investigated Rayleigh numbers range from 10^8 to 10^{12} and the heat source length was varied from 20% to 80% of the total length of the bottom wall. The influence of both parameters on heat transfer was analyzed. Their effect on the flow fields and temperature distributions were also discussed.

The effect of the physico-chemical structure of the fluid has been considered in many recent studies. The change of structure was achieved by inserting solid particles of nanometer sizes within the fluid so as to increase its effective thermal conductivity. The mixture so obtained is named nanofluid. The thermal conductivity of this suspension is increased because the thermal conductivity of solids is very high compared with that of the base fluids. Abu-Nada et al. [6] investigated heat transfer enhancement in horizontal annuli between two cylinders filled with water-based nanofluids containing various volume fractions of Cu, Ag, Al_2O_3 and TiO_2 nanoparticles. They concluded that for high Rayleigh numbers and high aspect ratios ((outer cylinder diameter - inner cylinder diameter)/inner cylinder diameter), nanofluids led to significant enhancement in heat transfer. Mansour et al. [7] studied natural convection cooling of an enclosure using a Cu-water nanofluid. The heat source is localized at the bottom wall of the enclosure and a variety of thermal boundary conditions were used at the side walls. The study showed that the maximum temperature increased with increasing the heat source length, while the average Nusselt number took the opposite behavior. Basak and Chamkha [8] analyzed the thermal and dynamic fields of water and nanofluids in a square cavity with various heating conditions of walls, they observed that the nanofluids Al_2O_3-water and Cu-water exhibit larger enhancement of heat transfer. Habibi Matin and Pope [9] investigated numerically the effects of the eccentricity, the radii ratio, the volume fraction, and the Rayleigh number on heat transfer by natural convection of a nanofluid in an eccentric annulus, the results showed that the addition of Cu nanoparticles produced a remarkable enhancement of heat transfer. Hu et al. [10] investigated experimentally and numerically natural convection of a nanofluid in a

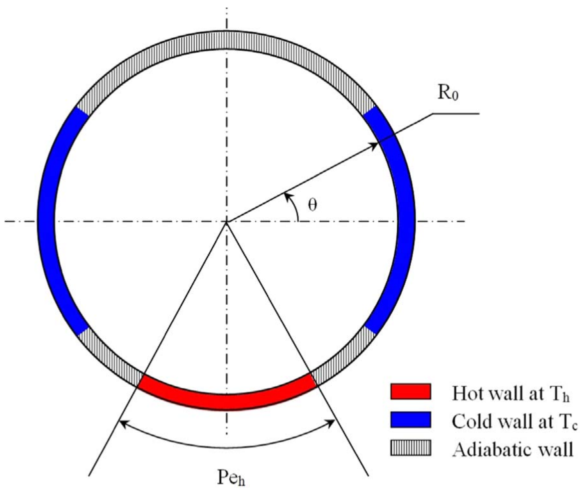

Fig. 1. Schematic of the enclosure.