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Natural convection of nanofluids in enclosures with low aspect ratios

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ABSTRACT

This paper analyzes heat transfer and fluid flow of natural convection in inclined cavity filled with CuO-water nanofluid heated from one side and cooled from the ceiling. The transport equations for the flow are solved numerically by the finite volume element method using the SIMPLER algorithm Based on numerical predictions. The effects of Rayleigh number and aspect ratio on flow pattern and energy transport are investigated for Rayleigh numbers ranging from 10^4 to 10^7 volume fraction of solid varied to 0%–4% and for five different aspect ratios of 0.08, 0.1, 0.125, 0.25 and 0.5. It is found that the effect of Rayleigh number on heat transfer is less significant when the enclosure is shallow ($AR = 0.5$) and the influence of aspect ratio is stronger when the enclosure is tall and the Rayleigh number is high.

The subject of this paper is to study the effect of Rayleigh number on the nanofluid flow inside the enclosure and the effect of nanoparticles on heat transfer.

Introduction

Over the last few years, the analysis of natural convection in enclosures filled with nanofluids has been studied extensively using different geometries, equation models, and numerical techniques and can be used in numerous applications of engineering. Most of the previous natural convection in enclosures is related to either side heating or bottom heating [1–4]. Today nanoparticles used for detection and removal of chemical and biological substances include metals (e.g cadmium, copper, lead, mercury, nickel, zinc and copper oxide). Still, several researches are performed by many authors for a better understanding of nanoparticles effects [5–8]. Furthermore, nanofluids have been widely used in industry because of the growing use of these smart fluids. Many studies [9–12] explained that nanofluids clearly exhibit enhanced thermal conductivity which goes up with increasing volumetric fraction of nanoparticles. Nanofluid concept is utilized to describe a fluid in which nanometer-sized particles are suspended in conventional heat transfer basic fluids. There are mainly two techniques used to produce nanofluids which are the single-step and the two-step method (see Akoh et al. [13] and Eastman et al. [14]). Both of these methods have advantages and disadvantages as discussed by Wang and Mujumdar [15]. The materials with sizes of nanometers possess unique physical and chemical properties (Das et al. [16]). They can flow smoothly through microchannels without clogging them because it is small enough to behave similar to liquid molecules (Kanafer et al. [17]). This fact has attracted many

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Nomenclature

AR	aspect ratio of the cavity, L/H
Cp	specific heat at constant pressure, J kg^{-1} K^{-1}
d_s	nanoparticle diameter, m
g	gravitational acceleration, m s^{-2}
H	height of the cavity, (m)
k	thermal conductivity, W m^{-1} K^{-1}
L	length of the cavity, m
Nu(x)	local Nusselt number, $(-k_{eff}/k_f(\partial\theta/\partial y)_{y=0})$
Nu	space averaged Nusselt number
Pr	Prandtl number, (ν_f/α_f)
Ra	Rayleigh number, $(g\beta_f H^3(T_h-T_c)/\nu_f\alpha_f)$
u,v	dimensionless velocity components, (normalized by α_f/H)
x,y	dimensionless coordinates, (normalized by H)

Greek symbols

α	thermal diffusivity, $(k/\rho C_p)$, m^2 s^{-1}
β	thermal expansion coefficient, K^{-1}
φ	solid volume fraction
θ	dimensionless temperature, $(T-T_c)/(T_h-T_c)$
μ	dynamic viscosity of the fluid, kg m^{-1} s^{-1}
ν	kinematic viscosity of the fluid, (μ/ρ), m^2 s^{-1}
ρ	density of the fluid, kg m^{-3}
ω	inclination angle of the cavity

Subscripts

c	cold
eff	effective
h	hot
f	fluid
nf	Cuo-water nanofluid
s	solid

researchers such as Abu-Nada [18], Tiwari and Das [19], Maïga et al. [20], Polidari et al. [21], Oztop and Abu-Nada [22], Nield and Kuznetsov [23], Kuznetsov and Nield [24] and Muthtamilselvan et al. [25]. Choi et al. [26] showed that the addition of small amount (less than 1% by volume) of nanoparticles to conventional heat transfer liquids increased the thermal conductivity of fluid up to approximately two times. Oztop and Abu-Nada [22] investigated heat transfer and fluid flow due to buoyancy forces in a partially heated enclosure using nanofluids with various types of nanoparticles. It was found that the heat transfer enhancement due to using a nanofluid is more pronounced at a low aspect ratio than at a high aspect ratio. Putra et al. [27] conducted experiments to investigate natural convective heat transfer of aqueous CuO and Al_2O_3 nanofluids inside a cylinder. They observed a systematic and significant deterioration in natural convective heat transfer at Rayleigh numbers from 10^6 to 10^9.

In the present study, natural convection in a rectangular enclosure heated from one side and cooled from the ceiling is analyzed numerically. Both the hot wall and cold ceiling temperatures are assumed to be uniform. This type of boundary conditions has a practical importance especially in cooled ceiling applications. The main objective of this study is to determine the effect of aspect ratio and Rayleigh number on flow pattern and heat transfer in the enclosure.

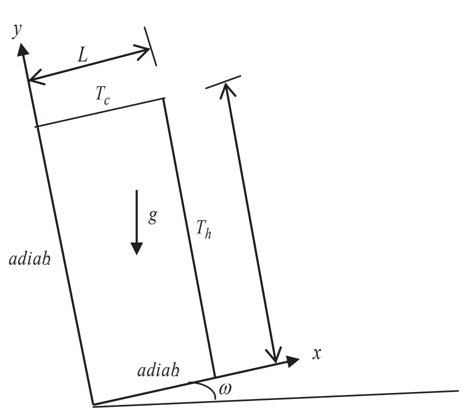

Fig. 1 – Studied problem with boundary conditions and coordinate system.

Statement of the problem and mathematical formulation

We consider a rectangular cavity of length L and height H as shown in Fig. 1. The cavity is filled with CuO-water nanofluid.

Table 1 – Physical properties of pure water and CuO solid particle.

	ρ (kg m^{-3})	C_p (J kg^{-1} K^{-1})	k (Wm^{-1} K^{-1})	β (k^{-1})
Pure water	997.1	4179	0.613	2.1×10^{-4}
CuO	6320	531.8	76.5	1.8×10^{-5}

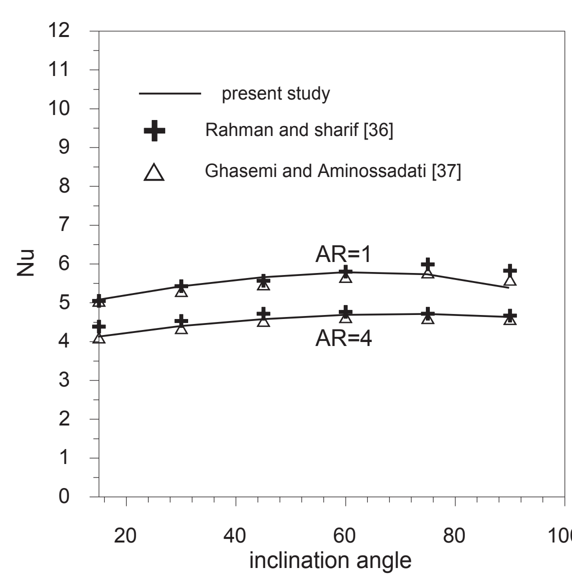

Fig. 2 – Validation of the present code against numerical results of Rahman and sharif [35] and Ghasemi and Aminossadati [36].

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