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Conjugate natural convection in a cavity with a conductive partition and filled with different nanofluids on different sides of the partition

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ABSTRACT

In this study, conjugate natural convection–conduction heat transfer in an inclined partitioned cavity filled with different nanofluids (Al_2O_3–water and CuO–water) on different sides of the partition is numerically investigated by using finite element method. The left and right vertical walls of the square enclosure are maintained at constant hot and cold temperatures while other wall enclosures are assumed adiabatic. Different combinations of solid nanoparticle volume fractions are imposed in the left and right half cavities. Numerical simulations are performed for different values of Grashof numbers (between 10^3 and 10^6), inclination angles of the cavity (between 0^o and 275^o), partition locations (between 0.15 and 0.75), thermal conductivity ratio (between 0.01 and 10) and solid volume fraction of the nanofluids of the two cavities (between 0 and 0.04). The averaged heat transfer enhances with Grashof number and solid particle volume fraction. It is also observed that adding nanoparticles with low thermal conductivity on the right cavity is effective for the heat transfer enhancement as compared to adding nanoparticles with high thermal conductivity. As the thermal conductivity ratio of the partition increases, the averaged heat transfer rate enhances and the highest value of the thermal conductivity ratio of 10, 14.11% of averaged heat transfer enhancement is obtained when both cavities are filled with nanofluids at the highest value of nanoparticle volume fractions.

1. Introduction

Natural convection in cavities may be encountered in various engineering applications such as heat exchangers, cooling of electronic devices, chemical reactors solar collectors and many others [1]. The cooling and heating may be partial and non-uniformities in the heating and cooling may also be of interest [2–9]. Partial or full partitions are added to control the natural convection inside the cavities. [10] presented an approach to reduce the natural convection inside the cavities of hollow bricks by inserting the cell dividers and studied the problem numerically. [11] numerically and analytically investigated the natural convection in a tilted enclosure with fluid layer separated by finite thickness solid partitions. They predicted the averaged Nusselt number in terms of Rayleigh number, thermal conductivity ratio, solid partition thickness and number of partitions. An experimental study of turbulent natural convection in a partitioned cavity with differentially heated vertical and conducting horizontal walls was performed by [12]. They showed that the heat transfer was reduced along the hot wall and the velocity and temperature field were significantly effected with the presence of the partitions. [13] numerically studied the partitioned cavities filled with air considering different thermal boundary conditions, position, length and thermal conductivity of the partition for a range of Rayleigh numbers. The influence of conductive partitions on the natural convection in a cubic enclosure was studied numerically and experimentally with glycerol as the working fluid by [14]. They used a complete vertical partition made of Plexiglas and the presence of the vertical partition reduced the convective heat transfer from 63.6% to 59.1%. [15] numerically investigated the 2D natural convection in square cavity with partitions. They showed that the presence of the partition has negligible effect if the partition does not cover the half of the total height. A numerical study of natural convection in a cavity divided by an impermeable partition was studied by [16]. The enclosure was divided into air and water regions by the partition and epoxy was chosen as the partition material. They observed that for energy saving purposes the filling of fluid into chests has important effects. Some other relevant studies can be found in references in [17–24].

In heat transfer applications, nano-sized particles of high thermal conductivity are added to the base fluid such as water or ethylene glycol to increase thermal transport and enhance the heat transfer [25–28]. The particle size varies between 10 and 100 nm and different shapes of particles can be considered. A vast amount of literature is dedicated to obtain correlations for thermophysical properties of these special type fluids called nanofluids and to investigate the performance of thermal systems using the nanofluids [29–46]. [47] investigated the steady natural convection in a cubic cavity filled with water–Au nanofluid by using the finite volume method. They observed that the onset of the convection is delayed with the addition of the nanoparticles and heat transfer rate can

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Nomenclature

c	Location of partition from left wall, (m)
d_p	Nanoparticle diameter, (m)
Gr	Grashof number, $\frac{g\beta_f(T_h-T_cH^3}{\nu_f^2}$
h	Local heat transfer coefficient, (W/m^{2}K)
k	Thermal conductivity, (W/m.K)
H	Length of the enclosure, (m)
n	Unit normal vector
Nu	Local Nusselt number
p	Pressure, (Pa)
P	Non-dimensional pressure
Pr	Prandtl number, $\frac{\nu_f}{\alpha_f}$
T	Temperature, (K)
u, v	x–y velocity components, (m/s)
x, y	Cartesian coordinates, (m)
X, Y	Dimensionless coordinates
Greek characters	
α	Thermal diffusivity, (m^2/s)
β	Expansion coefficient, (1/K)
ϕ	Nanoparticle volume fraction
θ	Non-dimensional temperature, $\frac{T-T_c}{T_h-T_c}$
ν	Kinematic viscosity, (m^2/s)
ρ	Density of the fluid, (kg/m^3)
ω	Cavity inclination angle
Subscripts	
1	Left cavity filled with nanofluid
2	Right cavity filled with nanofluid
c	Cold wall
m	Average
h	Hot wall
st	Static

be enhanced or deteriorates depending on the value of nanoparticle volume fraction and Rayleigh number. [48] studied the steady natural convection in a porous cavity filled with nanofluid and having solid walls of finite thickness by using finite difference method. The mathematical model of the nanofluid is Buongiorno' model that takes into account the Brownian diffusion and thermophoresis effects. The influence of the Rayleigh and Lewis numbers, the Brownian motion parameter, the thermal conductivity ratio, solid wall thickness on flow and thermal characteristics were investigated. [49] numerically studied the conjugate heat transfer in a thick walled cavity filled with nanofluid (Cu–water) for a range of Rayleigh number and nanoparticle volume fraction. They showed that the position of the divider and the ambient convective heat transfer coefficient have effects on the heat transfer augmentation along with the solid particle volume fraction and Rayleigh numbers. [50] numerically studied the steady natural convection–conduction in a porous cavity filled with nanofluid and heated by a triangular solid wall. Three different nanoparticles were examined dispersed in water and they observed heat transfer enhancement depends on the wall thickness and Rayleigh number.

Based on the above literature survey and to the best of authors' knowledge, conjugate natural convection–conduction in a partitioned inclined cavity filled with different nanofluids on different sides of partition has never been studied in the literature despite its importance in many engineering systems as outlined above. In nanofluid application, it is a first attempt to use two different nanofluids on different sides of a partition within a cavity. The present study aims at investigating the effects of Grashof number, inclination angle of the enclosure, thermal conductivity ratio of the partition to the fluid, location of the partition and solid volume fraction of the nanoparticles on the fluid flow and heat transfer characteristics inside the cavity.

2. Physical model and mathematical formulation

A schematic description of the problem along with the boundary conditions is demonstrated in Fig. 1. The square cavity is partitioned with a conductive wall of finite thickness (10% of the length). The partition thermal conductivity and its location from the left wall were changed. The left enclosure is filled with Al_2O_3–water nanofluid of different nanoparticle volume concentrations while the right enclosure is filled with CuO–water nanofluid. The left wall of the cavity is kept at constant temperature of T_h while the right wall is at constant temperature of T_h with $T_h > T_c$. All other walls of the cavity have no-slip boundary conditions. Thermo-physical properties of water, CuO and Al_2O_3 nanoparticles at the reference temperature are presented in Table 1. The flow is assumed to be 2D, laminar and the density in the buoyancy force is modeled according to Boussinesq approximation.

The conversation equations of mass, momentum and energy in 2D Cartesian coordinate system can be written in dimensional form for each of the sub-domains (left and right enclosures) as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{\mathrm{nf}}}\frac{\partial p}{\partial x}+\nu_{\mathrm{nf}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+g\beta_{\mathrm{nf}}(T-T_c)\sin(\omega) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{\mathrm{nf}}}\frac{\partial p}{\partial y}+\nu_{\mathrm{nf}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\beta_{\mathrm{nf}}(T-T_c)\cos(\omega) \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{\mathrm{nf}}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

where $\alpha_{\mathrm{nf}}=\frac{k_{\mathrm{nf}}}{(\rho C_p)_{\mathrm{nf}}}$ is the thermal diffusivity of the nanofluid. For the conductive solid medium,

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=0. \tag{5}$$

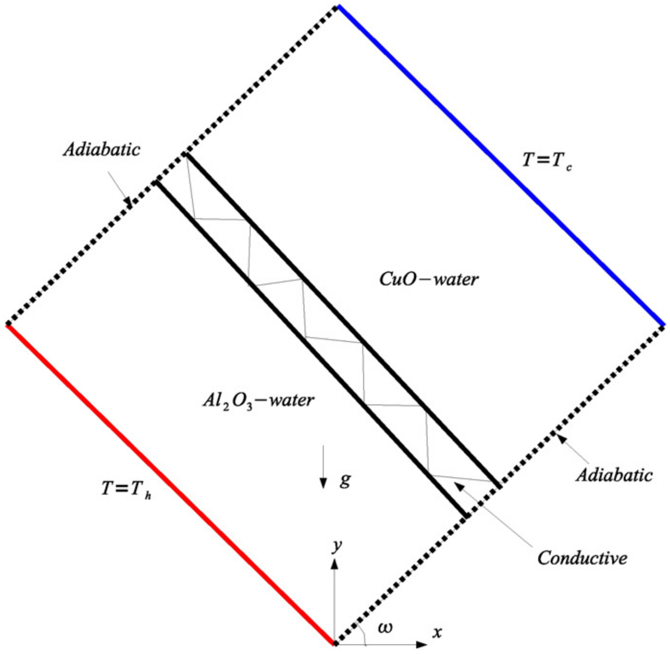

Fig. 1. Schematic description of the physical model and boundary conditions.