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Natural convection in a trapezoidal enclosure filled with carbon nanotube–EG–water nanofluid

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ABSTRACT

In the present study, natural convection heat transfer inside a trapezoidal enclosure filled with carbon nanotube–EG–water nanofluid using variable properties has been numerically investigated. The bottom and top walls of trapezoidal enclosure are kept at constant temperatures T_h and T_c, respectively, while the side walls of the cavity are thermally insulated. Using the finite volume method and the SIMPLER algorithm, the governing equations have been discretized. Simulations have been carried out for different aspect ratios, Rayleigh numbers of 10^3–10^6 as well as solid volume fractions of 0.0015, 0.03, and 0.045. The results show that at low Rayleigh number ($Ra \leqslant 10^4$), the average Nusselt number Nu_{Avg} decreases with increasing the inclination angle (aspect ratio) at all solid volume fractions. While for $Ra = 10^6$, the Nu_{Avg} increases and then decreases with inclination angle (aspect ratio) with maximum Nu_{Avg} occurring at $\gamma = 30^{\circ}$. Moreover, Nu_{Avg} increases with increasing Rayleigh number at fixed inclination angle (aspect ratio) and solid volume fraction.

1. Introduction

Natural convection heat transfer in square enclosures has received considerable interest due to wide range of application in engineering. A few important applications involving this type of heat transfer are air conditioned system in building, furnace and home heating, electronic equipment cooling, drying foods, double pane windows, etc. The main advantages of natural convection cooling systems are their simplicity, low noise, and minimum cost. Increasing of heat transfer performance in this type of systems is an essential topic. Primary limitation in enhancing of heat transfer performance is low thermal conductivity of conventional fluids such as water and oils. Due to small sizes and very large specific surface areas of the nanoparticles, nanofluids have superior properties like high thermal conductivity. In addition metallic nanoparticles have larger thermal conductivity than conventional fluids (700–3000 times).

There are a large number of research works about using of nanofluid that report significant heat transfer enhancement in an enclosure, Khanafer et al. [1], Jou and Tzeng [2], Oztop and Abu-Nada [3], Ogut [4], Das and Ohal [5], Hemmat Esfe et al. [6–8], Garoosi et al. [9] and Saedodin et al. [10]. Contradictory opinion was presented by Putra et al. [11]. They reported a systematic deterioration base on their experimental investigation. In another work that conducted by Santra et al. [11], they reported same opinion as Putra et al. based on their numerical simulation. One can address the possible determining factors for the heat transfer enhancement/reduction in nanofluids includes the variations of the size, shape, and distribution of nanoparticles and uncertainties in the thermophysical properties of nanofluids.

There are complex interactions between nanofluid with the walls of the cavity. This complexity may increases with a change of the geometry or orientation of the cavity. In fact study of natural convection fluid flow and heat transfer in a trapezoidal geometry is more difficult than that of square or rectangular enclosures due to the presence of sloping walls. There are a large number of investigations on natural convection fluid flows and heat transfers in trapezoidal cavities have been published [11–25]. As an example a numerical work was performed by Basak et al. [26] for a uniformly and non-uniformly heated bottom wall. Another works on trapezoidal enclosure were done by Varol et al. [23–25]. Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure

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Nomenclature

c_p	specific heat, J/kg K
Gr	Grashof number
AR	aspect ratio
g	gravitational acceleration, m/s^2
h	heat transfer coefficient, W/m^2 K
k	thermal conductivity, W/m K
H	height of cavity, m
L	bottom length of enclosure, m
L_1	top length of enclosure, m
n	normal direction
Nu	Nusselt number
p	pressure, N/m^2
P	dimensionless pressure
Pr	Prandtl number
Ra	Rayleigh number
T	temperature, K
u, v	velocity components, m/s
U, V	dimensionless velocity components
x, y	Cartesian coordinates, m
X, Y	dimensionless Cartesian coordinates

Greek symbols

α	thermal diffusivity
β	thermal expansion coefficient
φ	solid volume fraction
ρ	density
μ	dynamic viscosity
θ	dimensionless temperature
γ	inclination angle

Subscript

Avg	average
c	cold wall
f	fluid
f,0	fluid without nano particle
h	hot wall
nf	nanofluid
p	nanoparticles

was analyzed by Saleh et al. [27]. They found that sloping wall and Cu nanoparticles with high concentration can increase the rate of heat transfer.

Buoyancy induced fluid flow and heat transfer in inclined trapezoidal cavity was analyzed by Lee [28]. He analyzes the behavior of the flow and heat transfer characteristics at different Rayleigh and Prandtl numbers in his numerical study. In this numerical study it was shown that for $Ra = 10^4$ and Pr = 0.1, the heat transfer was a strong function of the orientation angle of the cavity. Kumar and Kumar [18] conducted a numerical analysis on the natural convection heat transfer in a trapezoidal cavity filled with a porous medium. They showed that the inclination of the side wall was an important role on the fluid flow and temperature distribution in the cavity. Moukalled and Acharya [29] studied the conjugate natural convection heat transfer in a trapezoidal cavity with a divider attached onto inclined wall. Moukalled and Darwish [30] performed a numerical analysis of natural convection in a partitioned trapezoidal cavity. They showed that the presence of baffles decreased heat transfer as high as 70%. Other similar studies on natural convection in trapezoidal cavities were done by Peric [31], Van Der Eyden et al. [32], Boussaid et al. [33], Kumar [23], Papanicolaou and Belessiotis [34], Hammami et al. [35] and Natarajan et al. [36]. Recently Nasrin and Parvin [37] conducted a numerical research in order to investigate the transport mechanism of natural convection in a trapezoidal cavity filled with Cu–water nanofluid. They found that both aspect ratio and Prandtl number affect the fluid flow and heat transfer in the cavity. In addition they developed a correlation for the average Nusselt number as a function of the Prandtl number as well as the cavity aspect ratio.

Despite a number of research studies on trapezoidal cavity reported in the literature, there is a serious lack of information regarding the problem of fluid flow and heat transfer enhancement in trapezoidal enclosures filled with nanofluids. To the best of our knowledge, a little investigation of natural convection heat transfer of the nanofluids in a trapezoidal enclosure has been undertaken yet. In addition, only limited numbers of publications are available on the convective heat transfer enhancement, using CNT nanofluids, with inconsistent results. Therefore, the aim of the present paper is to analyze numerically the problem of natural convection in a trapezoidal enclosure filled with CNT–EG–water nanofluids using variable properties based on experimental study. In the following sections a complete analysis on the flow fields, temperature distributions and the rate of heat transfer are presented for different Rayleigh number and cavity aspect ratio (ratio of base length and height) graphically by presenting the streamlines, isotherms, and local and mean Nusselt numbers. The obtained results in this paper is hoped to be a useful guide for the trapezoidal enclosure filled with CNT–EG–water nanofluid to increase the rate of heat transfer.

2. Analysis

A schematic of the present study is depicted in Fig. 1. The side walls of the cavity are insulated and the bottom and top walls are kept at constant temperatures of T_h and T_c, respectively. The length of the bottom and top walls of cavity are assumed to be constant and equal to L_1 and L, respectively. The aspect ratio, AR, and the inclination angle of the side wall, γ, are defined as to be $AR = 2H/(L - L_1)$ and $\lambda = \tan^{-1}(AR)$, respectively. Five inclined angles γ of 15°, 30°, 45°, 60°, and 75° are simulated in this work.

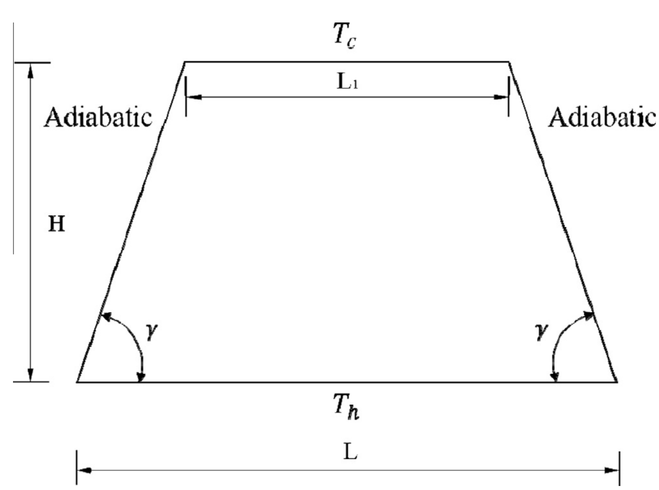

Fig. 1. Schematic of the present study.