International Communications in Heat and Mass Transfer 87 (2017) 40–51

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Analysis of mixed convection of nanofluid in a 3D lid-driven trapezoidal cavity with flexible side surfaces and inner cylinder

Fatih Selimefendigil[a,*], Hakan F. Öztop[b], Ali J. Chamkha[c,d]

[a] Department of Mechanical Engineering, Celal Bayar University, Manisa 45140, Turkey
[b] Department of Mechanical Engineering, Technology Faculty, Fırat University, 23119 Elazığ, Turkey
[c] Mechanical Engineering Department, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia
[d] Prince Sultan Endowment for Energy and Environment, Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia

ARTICLE INFO

Keywords:
3D trapezoidal cavity
Flexible wall
Nanofluid
FEM
Mixed convection

ABSTRACT

Numerical study of mixed convection in a lid-driven 3D flexible walled trapezoidal cavity with nanofluids was performed by using Galerkin weighted residual finite element method. Effects of various pertinent parameters such as Richardson number (between 0.05 and 50), elastic modulus of the side surfaces (between 1000 and 10^5), side wall inclination angle (between 0° and 20°) and solid particle volume fraction (between 0 and 0.04) on the fluid flow and heat transfer characteristics in a 3D lid-driven-trapezoidal cavity were numerically examined. It was observed that these characteristics are influenced when the pertinent parameters change. Flexible side surface can be used as control element for heat transfer rate. Increment and reduction in the space which are provided by the flexible side walls result in heat transfer enhancement and deterioration for side wall inclination angle of 0° and 10°. Average Nusselt number enhances by about 9.80% when the value of the elastic modulus is increased from 1000 to 10^5 for side wall inclination angles of $\theta = 0°$. Adding nanoparticles to the base fluid results in linear increment of heat transfer and at the highest volume fraction, 25.30% of heat transfer enhancement is obtained. A polynomial type correlation for the average Nusselt number along the hot wall was proposed and it has a fourth order polynomial dependence upon the Richardson number and first order dependence upon the solid particle volume fraction.

1. Introduction

The interaction of natural convection effects and shear driven flow which is due to a moving surface has many important applications in practice and significant impacts on the heat transfer such as in cooling of nuclear reactors, electronic devices, some chemical processes and many others. Different geometrical shapes and various thermal boundary conditions may be encountered in practice. Studies for convection in trapezoidal shaped enclosures have received significant attention [1–10]. [11] examined the probable flow and thermal patterns in a mixed convection for a lid-driven cavity for steady configurations and for two different cases of bottom wall heating. It was observed that the flow structures in various steady configurations play an important role for higher heat transfer rates for non-isothermal heating of the bottom wall. [12] performed a simulation of lid-driven flow in a trapezoidal enclosure with Lattice Boltzmann method for Reynolds number in the range from 100 to 15,000 and the inclination angle from 50 to 90. A complex transitional of the flow in the trapezoidal cavity was observed as the value of Reynolds number is increased. [13] numerically and experimentally analyzed turbulent double diffusive natural convection in a trapezoidal cavity. The model was an idealized situation in underground coal gasification from which the numerical model can reproduce the essential features of the process. Heat loss characteristics of a trapezoidal cavity absorber were analyzed by experimental and numerical methods in [14].

The convection in enclosures can be controlled by utilizing corrugated or flexible walls [15–19]. A numerical study of mixed convection in a square cavity with flexible side walls internal heat generation was performed in [20]. It was shown that the the increment in the elastic modulus of the flexible wall results in heat transfer deterioration. Transient natural convection in a square cavity divided by an elastic membrane was performed by [21]. The change in the shape of the membrane was found to effect the heat transfer rate. [22] numerically analyzed a flexible micro-cantilever in a fluidic cell with finite element method. In the study by [23], significant enhancement in the heat transfer with flexible wall was observed for the mixed convection in a lid-driven cavity.

Recently, nanofluids which are composed of a base fluid and nano-

* Corresponding author.
E-mail addresses: fatih.selimefendigil@cbu.edu.tr (F. Selimefendigil), hfoztop1@gmail.com (H.F. Öztop), achamkha@pmu.edu.sa (A.J. Chamkha).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2017.06.015

0735-1933/ © 2017 Elsevier Ltd. All rights reserved.

Nomenclature

D	cylinder diameter
E	Young's modulus
Gr	Grashof number
h	local heat transfer coefficient
k	thermal conductivity
H	length of the enclosure
n	unit normal vector
Nu_x	local Nusselt number
Nu_m	average Nusselt number
p	pressure
Pr	Prandtl number
R	residual
Re	Reynolds number
Ri	Richardson number
T	temperature
u, v	x-y velocity components
x, y	Cartesian coordinates

Greek characters

α	thermal diffusivity
β	expansion coefficient
θ	non-dimensional temperature
θ	side wall inclination angle
ν	kinematic viscosity
ρ	density of the fluid
ϕ	solid volume fraction
Ψ	shape function

Subscripts

c	center
c	cold
h	hot
m	average
nf	nanofluid
p	solid particle
st	static

sized particles have been extensively used in various thermal engineering applications. Metallic or non-metallic fine solid particles such as Cu, CuO, Al_2O_3, TiO_2, SiO_2 with average particle size less than 100 nm are added to the heat transfer fluids such as water, ethylene glycol or oil.

Higher conductivity of the nanoparticle inclusion in the base fluid results in thermal conductivity enhancement of nanofluid even with a small amount of particle volume fraction. There are many factors that affect the thermal conductivity enhancement of nanofluids such as size, shape and type of the particles.

In heat transfer applications, a vast amount of research is dedicated to the nanofluids applications considering various geometries, thermal boundary conditions and different physical mechanisms [24–35]. [36] performed a mixed convection study of lid-driven trapezoidal cavity filled with nanofluid by using finite volume method. Different types of nanofluids were utilized and it was observed that SiO2-water has the highest heat transfer rate among various nanoparticle types. In the study by [37], numerical simulation of mixed convection in a trapezoidal cavity filled with the CuO-water nanofluid was performed by considering a new variable-property model. In the study by [38], a small amount of nanoparticle addition was found to enhance the heat transfer significantly for mixed convection in an inclined porous channel. [39] performed mixed convection in a lid-driven inclined square cavity with nanofluid. It was observed that heat transfer rate could be enhanced by the inclusion of nanoparticles and with inclination of the cavity for moderate and large values of Richardson numbers.

The main aim of the current study is to numerically examine the mixed convection in a nanofluid filled 3D trapezoidal cavity having flexible side walls with an inner stationary cylinder. This type of thermal configuration may be encountered in practice or convection in the trapezoidal cavity may be controlled by the use of some or all of the mentioned methods (flexible wall, inclusion of the nanoparticles). The mixed convection of fluid-structure interaction model with nanofluids has been performed for a three-dimensional trapezoidal cavity. The results of this present study could be utilized for the design and optimization of thermal systems in various engineering fields. A correlation for the Nusselt number along the hot wall of the trapezoidal cavity in polynomial form is also provided.

2. Mathematical formalism

Fig. 1 shows a schematic description of the physical model with boundary conditions and coordinates. A 3D trapezoidal cavity with side length H and inclination angle of θ was considered. The top and bottom surfaces are kept at constant temperatures of T_h and T_c with $T_h > T_c$ while the inclined side walls are assumed to be adiabatic. An inner stationary cylinder of diameter D was placed for the center location at (x_c, y_c, z_c). The inclined side surfaces are flexible with elastic modulus of E, density of ρ and Poisson's ratio of ν. The top surface was moving with constant speed of u_0 in negative x direction. The 3D cavity was filled with CuO-water nanofluid at various volume fractions of solid particles (ϕ). The gravitational acceleration acts in negative y direction. The buoyancy term in the momentum equation was modeled by Boussinesq approximation and effects of thermal radiation and viscous dissipation were neglected. The Arbitrary Lagrangian-Eulerian method was used to describe the fluid motion for the flexible wall of the trapezoidal cavity in the fluid-structure interaction model. The fluid is Newtonian and the flow is accepted as 3D and laminar. Navier-Stokes and energy equations

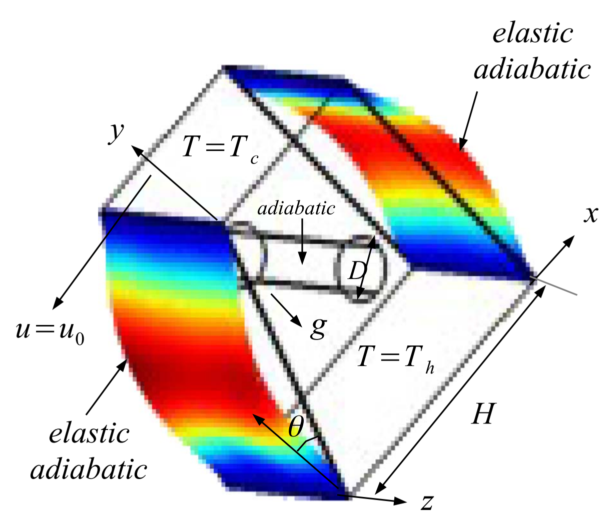

Fig. 1. Schematic representation of the physical problem with boundary conditions.

Download English Version:

https://daneshyari.com/en/article/4992808

Download Persian Version:

https://daneshyari.com/article/4992808

Daneshyari.com