Applied Mathematical Modelling 39 (2015) 4164–4179

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

Accurate finite volume investigation of nanofluid mixed convection in two-sided lid driven cavity including discrete heat sources

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ARTICLE INFO

Article history:
Received 2 March 2014
Received in revised form 26 November 2014
Accepted 12 December 2014
Available online 24 December 2014

Keywords:
Mixed convection
Nanofluid
Lid-driven cavity
Flow and heat transfer
Finite volume method
Numerical simulation

ABSTRACT

In the present work, two-dimensional mixed convection fluid flow and heat transfer of water–(Cu, Ag, Al_2O_3 and TiO_2) nanofluids in a two-sided facing lid-driven cavity partially heated from below have been investigated numerically. Two discrete heat sources are located on the bottom wall of the enclosure; however, the vertical moving walls and the ceiling are cooled at constant temperature. The remaining boundary parts of the bottom wall are kept insulated. The flow is driven by the moving two facing vertical walls in the same direction and the buoyancy force. The governing equations are solved using a second order accurate finite volume approach. The effects of the monitoring parameters in given ranges such as Reynolds ($1 \leqslant Re \leqslant 100$) and Richardson numbers ($1 \leqslant Ri \leqslant 20$), solid volume fraction ($0 \leqslant \varphi \leqslant 0.2$), the nanoparticles materials as well as the two heat sources positions are investigated. The conducted benchmark study leads to excellent accordance with previous findings. The present study analyzes and discusses the flow patterns (streamlines structures and isotherms distributions) set up by the competition between the forced flow driven by the moving walls and the buoyancy force effects, and the heat transfer rate quantified by the averaged Nusselt number along the heat source. It was found that significant heat transfer enhancement can be obtained: (i) increasing Ri at high Reynolds number ($Re = 100$) results in up-to 20% augmentation of heat transfer rate for all Cu volume fractions; (ii) increasing the volume fraction φ, a maximum heat transfer rate increase of 47.010% is reached with Cu suspensions for $\varphi = 0.2$ and $Ri = 1$, while a minimum increase of 7.059% is observed for TiO_2-water nanofluid at $Ri = 10$ and $\varphi = 0.05$; (iii) a highest heat transfer enhancement occurs when heat sources move toward the two vertical moving walls, while a lower heat transfer is obtained for heat sources located at bottom wall center.

1. Introduction

Study of mixed convection and heat transfer problem in lid driven cavities was met with great interest by researchers and industrials due to its increasing applications in practical situations such as nuclear reactors, lubrication technologies, food storage processing, cooling of microprocessors and electronic components. Besides, to enhance the thermal conductivity

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http://dx.doi.org/10.1016/j.apm.2014.12.035

Nomenclature

C_p	specific heat (J $kg^{-1}K^{-1}$)
d_1	distance of heat source from the left wall (m)
d_2	distance of heat source from the right wall (m)
D_1	dimensionless distance of heat source from the left wall d_1/L
D_2	dimensionless distance of heat source from the right wall d_2/L
e	length of the heat source (m)
g	gravitational acceleration
Gr	grashof number $g\beta\Delta TL^3/\vartheta_f^2$
k	thermal conductivity ($Wm^{-1}K^{-1}$)
L	enclosure width (m)
Nu	local Nusselt number along the heat source
$\overline{Nu}$	average Nusselt number along the heat source
p	pressure (N m^{-2})
P	dimensionless pressure
Pr	Prandtl number ϑ_f/α_f
q	heat flux (W m^{-2})
Re	reynolds number V_wL/ϑ_f
Ri	Richardson number Gr/Re^2
t	times (s)
T	temperature (K)
u, v	velocity components in x and y direction (m s^{-1})
U, V	dimensionless velocity components in X and Y direction
V_w	Lid velocity
x, y	cartesian coordinates (m)
X, Y	dimensionless coordinates

Greek symbols

α	thermal diffusivity (m^2 s)
β	thermal expansion coefficient (K^{-1})
ΔT	temperature gradient $T_h–T_c$
τ	dimensionless time
θ	dimensionless temperature $T–T_c/\Delta T$
μ	dynamic viscosity (kg m^{-1} s^{-1})
ρ	density (kg m^{-3})
υ	kinematic viscosity (m^2 s^{-1})
φ	volume fraction of the nanoparticles
ε_1	dimensionless length of left heater e_{S1}/L
ε_2	dimensionless length of left heater e_{S2}/L

Subscripts

c	cold
f	fluid
h	hot
nf	nanofluid
s	solid particles
S1	the left heater
S2	the right heater

of conventional fluids such as water, oil and ethylene glycol, new technique emerges; that consists of adding minor volume fraction of high thermal conducting nano-scale particles (<100 nm) in the base fluid. The product is called by Choi [1] nanofluids. It is expected that the presence of the nanoparticles in the fluid really increases the effective thermal conductivity of the fluid and consequently enhances the heat transfer characteristics [1–12].

In the last several years, different researches concerning the problem of convection heat transfer in cavities filled with nanofluids have been carried out analytically, numerically and experimentally. For instance, Tiwari and Das [13] investigated numerically the problem of mixed convection in two-sided lid-driven differentially heated square cavity filled with Copper–water nanofluid. They found that for the Richardson number equal to unity, the average Nusselt number increased substantially with increase in the volume fraction of the nanoparticles. Sebdani et al. [14] used the finite volume method to investigate flow and heat transfer in a square cavity with a heat source on the bottom wall using Al_2O_3-water nanofluid. The