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Mixed convection in a lid-driven square cavity filled by a nanofluid: Buongiorno's mathematical model

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ABSTRACT

Steady laminar mixed convection inside a lid-driven square cavity filled with water based nanofluid is studied numerically. The cavity is subjected to the moving upper and lower walls. The top and bottom moving walls are maintained at constant temperatures and nanoparticle volume fractions. The vertical walls of the cavity are thermally insulated. The appliance of the numerical analysis was finite difference method with upwind scheme treatments of the convective terms included in the momentum and energy equations. The governing parameters are the Reynolds, Grashof, Prandtl and Lewis numbers along with the buoyancy-ratio, the Brownian motion, the thermophoresis and the moving parameters. The effects of these parameters on the local Nusselt, local Sherwood, the mean Nusselt and Sherwood numbers, as well as on the developments of streamlines, isotherms and isoconcentrations have been analyzed. The results have shown that these parameters have substantial effects on the flow and heat transfer characteristics. The comparison with known results from the open literature shows excellent agreement.

1. Introduction

Flow in an enclosure driven by buoyancy force is a fundamental problem in fluid mechanics. It has many engineering applications such as solar collectors, thermal storage systems, and cooling of electrical and mechanical components. Therefore, it is important to understand the thermal behavior of such systems when the natural convection is the dominant mode of heat transfer. This type of flow can be also used as validation in academic researches and various applications of engineering (Davis [1] and Le Quéré [2]). Review papers and monographs published during the last several decades show that the fundamental research devoted to natural convection in enclosures has focused exclusively on flows driven by the buoyancy effect due to temperature variations alone (Ostrach [3], Catton [4], Jaluria [5], Bejan [6], etc.).

The low thermal conductivity of conventional heat transfer fluids, commonly water, has restricted designers. Fluids containing nanosized solid particles offer a possible solution to conquer this problem. The nanofluid has greater effective thermal conductivity than pure base fluid (Parvin and Chamkha [7]). A fundamental investigation of convective process effected by this class of nanofluid flows is demanded by contemporary engineering questions such as the industrial cooling applications, nuclear reactors, extraction of geothermal power, cooling of electronic equipment, solar collectors nanofluids in fuels, coolants in

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Nomenclature

C	nanoparticle volume fraction
C_c	nanoparticle volume fraction at the cold wall
C_h	nanoparticle volume fraction at the hot wall
C_p	specific heat at constant pressure
D_B	Brownian diffusion coefficient
D_T	thermophoretic diffusion coefficient
$\mathbf{g}$	gravitational acceleration vector
Gr	Grashof number
L	cavity width
Nb	Brownian motion parameter
Nt	thermophoresis parameter
Nu	local Nusselt number
$\overline{Nu}$	average Nusselt number
p	pressure
Pe	Péclet number
Pr	Prandtl number
$\mathbf{q}_C$	nanoparticle flux
Re	Reynolds number
Ri	Richardson number
Sh	local Sherwood number
$\overline{Sh}$	average Sherwood number
t	time
T	temperature
T_c	temperature of the cold wall
T_h	temperature of the heated wall
u, v	velocity components along $\bar{x}$ and $\bar{y}$ directions
$\mathbf{V}$	velocity vector
V_0	velocity of the moving walls
$\bar{x},\bar{y}$	dimensional Cartesian coordinates
x, y	dimensionless Cartesian coordinates

Greek symbols

α	thermal diffusivity
β	thermal expansion coefficient
δ	constant
φ	dimensionless nanoparticle volume fraction
λ	moving parameter
μ	dynamic viscosity
θ	dimensionless temperature
ρ	density
$\bar{\omega}$	dimensional vorticity
ω	dimensionless vorticity
$\bar{\psi}$	dimensional stream function
ψ	dimensionless stream function

Subscripts

f	fluid
p	nanoparticle

automotive, microchips cooling, nanodrug delivery, cancer therapeutics, sensing and imaging, and others (Wong and De Leon [8]). A good literature on convective flow and applications of nanofluids were done by Buongiorno [9], Das et al. [10], Kakaç and Pramuanjaroenkij [11], Saidur et al. [12], Wen et al. [13], Mahian et al. [14], Nield and Bejan [15], Haddad et al. [16], Oztop and Abu-Nada [17] and many others.

The aim of the present paper is to study the mixed convection in a lid-driven square cavity filled by a nanofluid using the mathematical nanofluid model proposed by Buongiorno [9]. He noted that the nanoparticle absolute velocity can be viewed as the sum of the base fluid velocity and a relative velocity (that he calls the slip velocity). He has also stated that in the absence of turbulent effects, it is the Brownian diffusion and the thermophoresis that are important. However, studies on heat transfer in a lid-driven cavity with both upper and lower moving walls using Buongiorno's mathematical nanofluid model have not been