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Effect of geometrical parameters on natural convection in a porous undulant-wall enclosure saturated by a nanofluid using Buongiorno's model

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ABSTRACT

The paper refers to investigate the effect of geometrical parameters on natural convection of nanofluid over a cylindrical heater located inside of a porous undulant-wall cavity using local thermal non-equilibrium (LTNE) condition. Two phase-Buongiorno's model was applied to consider the thermal and flow indexes under geometrical variations. The validity of the numerical procedure was examined by contrasting the present and the previous works. The effect of governing parameters of the cavity, including horizontal and vertical displacement of cylindrical heat source (x and y respectively), the amplitude of the lateral wave walls (λ) on streamlines, isotherms of two porous medium phases and also concentration of nanoparticles has been inquired. Overall, the results show that temperature distribution is different for the two phases in the porous medium, making it inevitable to utilize the non-equilibrium model for porous media. It is obvious that the flow is weakened as the heat source is elevated, while by the horizontal deviation of the flow toward a certain direction, it becomes stronger in the region opposite to the deviation and weakened at the deviated side. When the cylindrical heat source is located at the bottom of the cavity, the nanofluid becomes more homogeneous as a result of the agitation by strong vortices. As the corrugation amplitude of the lateral walls is increased, the nanofluid flow becomes stronger, leading to a more uniform distribution of nanoparticles around the cavity. At lower corrugation amplitudes, the average Nusselt number of the fluid is reduced as the heater is elevated. On the other hand, at higher amplitudes, the variations of the average Nusselt number of the fluid shows an increasing-decreasing trend as the cylinder is elevated.

1. Introduction

In recent years, due to the superior thermal properties of the nanofluids in comparison with the commonly used fluids in heat transfer, they are an interest matter to many researchers. Nanofluids are known as common fluids in which nanoparticles are distributed and become stable. The presence of nanoparticle in common fluids meaningfully enhances the effective thermal conductivity and consequently the convection heat transfer of the flow [1–14]. The natural convection of two-dimensional cavity filled by nanofluid has been studied by Khanafer et al. [15]. They compared different models together with regard to the physical properties of nanofluid. Kaviany [16] has numerically considered the effect of a protuberance on thermal convection of a square enclosure. The results indicate that the attendance of the protuberance results in a reduction in heat transfer rates in the lower part of the enclosure. A numerical simulation on a square cavity with a pair of hot horizontal cylinders positioned at different locations was fulfilled by Park et al. [17]. The dependency of local Nusselt numbers on the gap distance between the walls of the cavity and the two hot cylinders was obtained. Using nonhomogeneous equilibrium model, Buongiorno [18] considered the effect of the Brownian motion and thermophoresis on the heat transfer process of nanofluids. This model could be predicted distribution of nanoparticles all over the nanofluid by solving an extra equation for nanoparticles. Selimefendigil and Oztop [19] numerically analyzed Natural convection of CuO-water nanofluid inside a horizontal annulus under the influence of an inclined magnetic field. They reported that there is a relatively linearly relation between the average Nusselt number and solid volume fraction of nanoparticle.

On the other hand, one well-known way for meliorating convective heat transfer is applying porous medium. Natural convection in porous media has a wide range of usage such as high-performance building insulation, multishield structures used in the insulation of nuclear reactors, catalytic reactors, geothermal energy, etc. this practical field of

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Nomenclature

g	gravitational acceleration, $m \cdot s^{-2}$
p	Pressure, Pa
Pr	Prandtl number
Ra	Rayleigh number
T	Temperature, K
x, y	Cartesian coordinates, m
X, Y	dimensionless Cartesian coordinates
u, v	velocity in x and y directions, $m \cdot s^{-1}$
U, V	dimensionless velocity in x and y directions
W	Length of horizontal wall, m
H	height of the cavity, m
D	Diameter of heater, m
Da	Darcy number
K	Permeability, m^2
k	Thermal conductivity, $W \cdot m^{-1} \cdot K^{-1}$
D_B	Brownian diffusion coefficient, $m^{-2}\ s^{-1}$
D_T	thermophoresis diffusion coefficient, $m^{-2}\ s^{-1}$
C	nanoparticle volume fraction
C_0	nanoparticle volume fraction at uniform value
h_{nsf}	Convection heat transfer coefficient at nanofluid-solid matrix interface, $W \cdot m^{-2} \cdot K^{-1}$
Nu	Nusselt number

Greek symbols

α	thermal diffusivity, $m^{-2}\ s^{-1}$
β	thermal expansion coefficient
θ	Non-dimensional temperature
λ	Amplitude, m, ε
μ	Dynamic viscosity, $kg \cdot m^{-1} \cdot s^{-1}$
ϕ	normalized nanoparticle volume fraction
ρ	Density, $kg \cdot m^{-3}$

Subscripts

a	average
f	Base fluid
c	Cold
h	Hot
nf	nanofluid
s	Solid matrix
p	Nanoparticles
l	local

heat transfer has been attended by many researchers due to diversity of applications.

The convection heat transfer inside concentric and eccentric annulus have many applications in science and engineering, such as electrical motor and generator, completion of an oil source, heating and cooling of underground electric cables. Recently, investigation of the effect of eccentricity on heat transfer has become a subject of interest to most of researchers and they have studied the problem of convection heat transfer with various boundary conditions.

Recently, nanofluids and porous metal foams with high thermal conductivity have been proposed as a potential medium for enhancing heat transfer in energy harvesting systems. Many studies have addressed the natural convection heat transfer of nanofluids in enclosed cavities that were saturated with a porous medium [20–29]. For instance, Sun and Pop [30] studied the natural convection heat transfer of a nanofluid in a triangular cavity considering thermal non-equilibrium between the nanoparticles, and the solid and liquid phases of the porous medium. Mehmood et al. [31] investigated mixed convection of a nanofluid inside a porous enclosure under the non-linear thermal radiation and inclined magnetic field. They reported that Darcy number, radiation and porosity parameter enhances heat transfer. Natural convection of a nanofluid through a porous cavity of two trapezoidal enclosures was numerically investigated by Javed et al. [32]. Briefly, it is concluded that the porosity parameter enhances average Nusselt numbers.

In the recent few decades, extensive numerical, experimental, and analytical studies have been conducted on natural convection heat transfer in cavities of various shapes. Hence, the investigation of the physics of cavities is historically, and scientifically important. Researchers have investigated the natural convection in enclosures of various geometries, such as rectangular or square [24,33–45], trapezoidal [22,46–48], triangular [25,49–51], C-shaped [52], L-shaped [53,54], T-shaped [55], H-shaped [56] cavities. Shermet et al. [20] studied the natural convection of nanofluids in a square cavity filled with a porous medium using the Tiwari-Das model for nanofluids.

Generally speaking, almost all of the previous studies addressed the convection heat transfer in porous cavities with simple square or similar geometries and not the flow and heat transfer in complex geometries. The studied geometry can be used to control heat transfer with a passive technique. Therefore, this study investigates the influence of geometrical properties on the flow and heat transfer characteristics of a nanofluid in a complex geometry using the thermal non-equilibrium model for the porous medium and the Buongiorno model for nanofluids.

2. Description and formulation of the model

The problem concerns modeling of the flow of nanofluids and natural heat transfer in a porous cavity with wave-like walls using Buongiorno's model. A simple schematic of two-dimensional view with geometric characteristics of present study is pictured in Fig. 1. The sinusoidal amplitude is equal to λ, and the governing equation adapted to the waveform wall is written as follows:

$$x=\mp\left(\frac{W}{2}+\lambda\left[1-\sin\left(\frac{\pi}{2}+\frac{2\pi y}{A}\right)\right]\right), 0\le y\le A \tag{1}$$

In the above relation, the negative and positive sign is, respectively, for the left and right side wave wall. The upper and lower horizontal walls are insulated, while the vertical-wavy walls are kept at cold

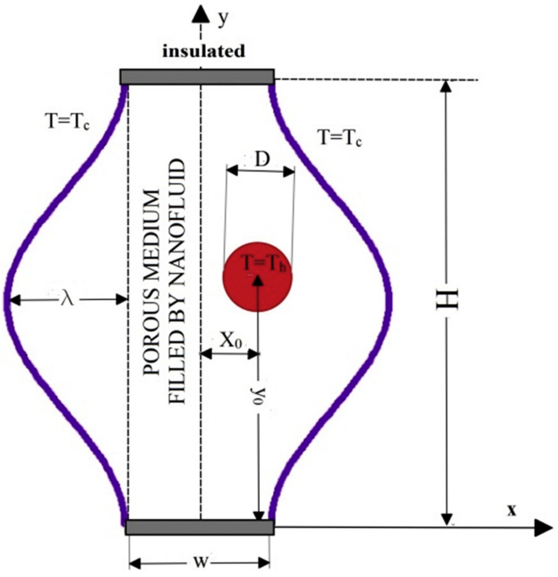

Fig. 1. A simple schematic view of the problem.