



Combination of Dual-MRT lattice Boltzmann method with experimental observations during free convection in enclosure filled with MWCNT-MgO/Water hybrid nanofluid

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ABSTRACT

In the present investigation, the natural convection heat transfer is analyzed numerically and experimentally in a three-dimensional enclosure filled with MWCNT-MgO (75–25%)/Water hybrid nanofluid using an experimental setup. In addition, the thermal conductivity and dynamic viscosity of nanofluid are measured in five different solid volume fractions ($\phi = 0.25\%, 0.5\%, 1\%, 1.5\%$, and 2%) and a temperature range of 20°C – 40°C , and two correlations are developed. These correlations are utilized in the 3D numerical simulations to obtain the three-dimensional temperature field and validate the experimental results. The temperature distribution, average heat transfer coefficient based on five solid volume fractions of nanofluid plus pure water and four different temperature difference of side walls are presented comprehensively. The comparisons of experimental and numerical data reveal a close agreement with each other.

1. Introduction

The study of natural convection heat transfer is an interesting and fundamental topic for many researchers. At the last years, the investigation of natural convection in confined volume is taken into consideration. There were wide applications of natural convection in confined volume and small enclosure, such as: cooling of electronic equipment, cooling of nuclear reactors, drying foods and food industry, transportation, aeronautics, cooling of buildings and ventilation and etc. [1–9]. The heat transfer coefficient of natural convection mechanism is lower than other mechanism. Therefore, there are two methods to enhance the heat transfer coefficient and performance of a thermal system. A new design of configuration is the first way, which is not executable and effective for small systems such as Micro Electro Mechanical Systems. The other way is to add the nanoparticle to base-fluid and enhance the heat transfer capacity of fluids. There are some mechanisms of heat transport in nanofluids such as: Brownian motion, nanocluster, nanolayer, thermophoresis and ballistic nature of heat transfer which have desirable influence on thermal conductivity of nanofluids [10,11]. In this context, there are many researchers

investigated the natural convection or force convection heat transfer within enclosure filled with these smart fluids, such as: Hatami and Jing [12], Pourmehran et al. [13], Ho et al. [14], Aminossadati and Ghasemi [15], Lin and Violi [16], Song et al. [17], Hatami et al. [18], etc. Furthermore, different types of nanofluids are used in the natural convection analysis such as $\text{SiO}_2\text{-TiO}_2\text{/Water-EG}$ [19,20], DWCNTs-water [21], $\text{Al}_2\text{O}_3\text{-water}$ [22]. Abu-Nada et al. [23] studied the effect of nanofluid variable properties on natural convection within a differentially heated enclosure filled with CuO-EG - Water nanofluid. Corcione et al. [24] investigated the convective heat transfer enhancement of nanofluids in an enclosure. They showed that with increasing the average volume fraction of nanoparticle, the heat transfer enhancement increases. A numerical research of natural convection heat transfer in rectangular enclosure filled with nanofluid was carried out by Jou and Tzeng [25] which used the Khanafer's model to analyze heat transfer performance of nanofluids. Büyük Ögüt [26] examined the heat transfer enhancement of water based nanofluids in an inclined enclosure with a constant heat flux at different inclination angles (30° , 45° , 60° and 90°), various types of nanoparticles (Cu , Ag , CuO , Al_2O_3 and TiO_2), two solid volume fractions (0 and 0.2%) and Rayleigh number (10^4 and 10^6) for

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Nomenclature

g	gravitation acceleration, ms^{-2}
H	height of cavity, m
L	width of cavity, m
D	depth of cavity, m
k	thermal conductivity, $Wm^{-1}K^{-1}$
$\bar{q}$	heat generation rate in water channel, W/m^3
$\dot{m}$	mass flux in water channel, Kg/s
C_p	specific heat capacity, $J. kg^{-1}.K^{-1}$
T_h	average temperature of hot wall, K
T_c	average temperature of cold wall, K
T_{ih}	temperature of points of hot wall, K
T_{ic}	temperature of points of cold wall, K
ΔT_{En}	temperature difference of side walls, K
ΔT_{Ex}	temperature difference of water channel, K
T_{inlet}	temperature of inlet in water channel, K
T_{outlet}	temperature of outlet in water channel, K
A	area of side walls, m^2
$\bar{h}$	average heat transfer coefficient, $w/m^2. k$
$\overline{Nu}$	Averaged Nusselt number
Ra	Rayleigh number, $Ra = g\beta_{nf}(T_H - T_C)H^3/\nu\alpha$
x', y', z'	Cartesian coordinates, m
x, y, z	dimensionless coordinates ($x'/H, y'/H, z'/H$)
u, v, w	velocity components, (m/s)
U, V, W	dimensionless velocity components
p	pressure, pa

 P Dimensionless pressure*Greek symbols*

α	thermal diffusivity, $m^2s^{-1}(k/\rho C_p)$
μ	dynamic viscosity, Nsm^{-2}
ν	kinematic viscosity, $m^2s^{-1} (\mu/\rho)$
ρ	density, $kg m^{-3}$
β	thermal expansion coefficient of fluid, $1/k$
α	thermal diffusivity of fluid, m^2/s
θ	dimensionless temperature

Subscripts

h	hot
c	cold
nf	nanofluid
w	water

Abbreviations

MWCNT	multi-wall carbon nanotubes
TEM	transmission electron microscopy
THW	transient hot wire
NI	National Instrument
LBM	lattice Boltzmann method
MRT	multivariate regression tree analysis

several length of heaters. They showed that adding nanoparticles causes a substantial increasing in the heat transfer rate. Also, the maximum and minimum heat transfer takes place at the inclination angle equal 30° and 90° , respectively. The Response Surface Methodology (RSM) approach for finding the optimal profile of wavy wall of an enclosure with a heated cylinder inside the cavity filled with nanofluid was studied by Hatami [27]. Hatami [27] claimed that with increase of the heated cylinder diameter, the average Nusselt number increases and then decreases. As well as, Tang et al. [28] studied the natural convection in a cavity with double wavy walls filled with various types of nanofluids. They concluded that the Ag-water nanofluid causes a better heat transfer performance than other nanofluids.

Moreover, there were some researchers which considered three-dimensional analysis of natural convection within enclosures [29–33]. Salari et al. [34] carried out a three-dimensional investigation on natural convection and entropy generation in an cuboid enclosure filled with two immiscible fluids (air and MWCNT/water nanofluid). They reported that the increasing of nanofluid volume fraction reduces total entropy generation and increases the average Nusselt number. In another work, a numerical investigation of unsteady laminar three-dimensional natural convection and entropy generation within an inclined cubical trapezoidal enclosure was performed by Hussein et al. [35]. They showed that inclination angle is an effective parameter on flow pattern and total entropy generation which becomes insignificant for low Rayleigh number.

Although many researchers considered the nanofluid as a single phase [36–39], there are some studies that considered the relative motion of nanoparticles with the base fluid. Sheremet et al. [40] investigated the three dimensional free convection heat transfer inside a porous media enclosure filled with nanofluid using Buongiorno's mathematical model and. Also, they focused on the effect of the Rayleigh and Lewis numbers, buoyancy-ratio parameter, Brownian motion parameter and aspect ratio parameter on natural convection heat transfer characteristics and flow field. As well as, Sheremet et al. [41] studied the natural convection in a porous media within a cubical enclosure heated partially from side walls filled with nanofluid and used

the Tiwari and Das nanofluid model for the properties of nanofluids.

In an experimental analysis, the Natural convection of air in rectangular enclosure were investigated by Karatas and Derbentli [42]. They presented the heat transfer correlations for Rayleigh number in range of 2.16×10^5 to 5.06×10^7 and for different aspect ratios in range of 1–6. Salari et al. [43] numerically and experimentally studied the natural convection in a rectangular enclosure filled with two immiscible fluids (air and water) for different Rayleigh numbers and liquid height ratios. Ghodsinezhad et al. [44] experimentally investigated the buoyancy flow convection inside a rectangular enclosure filled with Al_2O_3 -water nanofluid at different solid volume fractions and Rayleigh numbers. They concluded the natural convection heat transfer coefficient enhances by adding nanoparticles, and then reduces with increasing of solid volume fraction. Hu et al. [45] studied the natural convection heat transfer of Al_2O_3 /water nanofluids inside a square enclosure. They measured the thermal conductivity coefficient and viscosity of Al_2O_3 /water nanofluid. They found that at the low nanoparticle concentration, the heat transfer of nanofluid is more sensitive to the thermal conductivity than viscosity. On the contrary, the heat transfer is more sensitive to the viscosity than the thermal conductivity at the high nanoparticle fractions. Also, Khalili et al. [46] performed an experimental analysis of nanoparticles distribution in natural convection of Al_2O_3 /water nanofluid inside a square enclosure.

An experimental and numerical investigation is carried on the natural convection heat transfer within the three-dimensional enclosure filled with MWCNT-MgO (75–25%)/Water hybrid nanofluid. The thermo-physical properties of nanofluid (thermal conductivity and dynamic viscosity) are measured experimentally, and the related temperature/concentration-based correlations are developed. The experimental and numerical data are compared which shows good agreement. It should be noted that the natural convection heat transfer is analyzed using manufactured setup, and thermo-physical are measured using modern devices.

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