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Buoyancy induced convective heat transfer in particle, tubular and flake type of nanoparticle suspensions

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ABSTRACT

This paper reports the experimental study to investigate the buoyancy-induced convective heat transfer in a square cavity using different types of nanofluids. Three types of nanofluids namely, particle based (Al_2O_3/Water), tube based (MWCNT/Water) and flake based (Graphene/Water) are used. A square cavity with the dimensions $(40 \times 40 \times 200)$ mm^3 is used as the test section. Experiments are performed for 0.1%, 0.3%, and 0.5% volume fractions with varying Rayleigh number over a range of 7×10^5 to 1×10^7. For the comparison of heat transfer characteristics of different nanofluids normalized Nusselt number is estimated. It has been observed that an enhancement in natural convective heat transfer is obtained using MWCNT/Water and Graphene/Water nanofluids at 0.1% volume fraction. However for higher concentration, a deterioration in heat transfer is observed. The relative changes in thermophysical properties of nanofluids are insufficient to explain the reported results. It is proposed that the contribution of various slip mechanisms between the nanoparticle suspension and basefluid are responsible for the enhancement.

1. Introduction

The discovery of nanofluids as potentially engineered collides by Choi and Eastman [1] in 1993 has opened a very active field of research in the last two decades. Conventionally collides with macro or micro size particles have many disadvantages like sedimentation and high-pressure drop in the flow. As nanofluid consists of particles with size in range of nanometers, they are relatively stable due to less sedimentation and impart less friction which in turn minimizes pressure drop. It is concluded from the literature that there is an abnormal enhancement in the effective thermal conductivity of the nanofluids which cannot be predicted by classical Maxwell's equation. Also, there have been numerous studies investigating the thermophysical properties of nanofluids. Lee et al. [2] studied the thermal conductivity of alumina/water and copper-oxide/water nanofluids for different volume fractions. They observed that thermal conductivity of both the nanofluids is higher than the basefluids. Wang et al. [3] also studied the thermal conductivity of different oxide particles and concluded that the enhancement cannot be predicted by classical models. Patel et al. [4] studied the effect of particle size, temperature and volume fraction on different types of nanoparticles with different basefluids and concluded that thermal conductivity of the nanofluids is higher than basefluid for all the data ranges. Choi et al. [5] studied the thermal conductivity of nanotube/oil suspensions and they found that measured thermal conductivity is anomalously greater than theoretical predictions. About 50% of enhancement is observed for 0.5% of volume fraction. Shastry et al. [6] developed a model to predict thermal conductivity of MWCNT/water nanofluids. Baby and Ramaprabhu [7] have studied the effect of temperature on the thermal and electrical conductivity of graphene-based nanofluids. They observed an enhancement of about 14% and 64% compared with basefluid at 25 °C and 50 °C. Gupta et al. [8] studied the effect of volume fraction and thermal conductivity of graphene/water nanofluid and reported enhancement with respect to the basefluid. Maiga et al. [9] performed experiments for forced convection in uniformly heated tube for alumina/water nanofluid and developed the polynomial expression for dynamic viscosity and thermal conductivity variation with respect to volume fraction. Duan et al. [10] studied viscosity of alumina/water nanofluid from 1% to 5% of volume fraction and observed increase of 60% for 5% of volume fraction. Phuoc et al. [11] studied thermal conductivity and dynamic viscosity of MWCNT/water nanofluid stabilized by chitosan and concluded that the thermal conductivity increases by 2.3%

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Nomenclature

A	Area of cross section of heater, m^2
c_p	Specific heat, J/kgK
$\overline{h}$	Average convective heat transfer coefficient, W/m^2K
I	Current, A
k	Thermal conductivity, W/mK
Nu	Nusselt number
$\overline{Nu}$	Average Nusselt number
Nu_{norm}	Normalized Nusselt number. ($Nu_{norm} = Nu_{nf}/Nu_{bf}$)
$\overline{q''}$	Average heat flux, W/m^2
Ra	Rayleigh number
T	Temperature, K
V	Voltage, V
W	Characteristic length of test cell, m

Greek letters

β	Coefficient of thermal expansion,$1/K$
ε	Uncertainty in the measurement
μ	Dynamic viscosity, $Pa.s$
ϕ	Volume fraction of nanoparticles
ρ	Density, kg/m^3

Subscripts

bf	Basefluid
c	Cold
corr	Correction in heat loss
h	Hot
loss	Heat loss
nf	Nanofluid
norr	Normalized
np	Nanoparticle
t	Total heat loss

Abbreviation

GO	Graphene Oxide
H_2SO_4	Sulphuric acid
H_2O_2	Hydrogen Peroxide.
HCl	Hydrochloric acid
$K_2S_2O_8$	Potassium Per-sulphate
LBM	Lattice Boltzmann Method
$KMnO_4$	Potassium Permanganate
$NaNO_3$	Sodium Nitrate
Na_2CO_3	Sodium Carbonate
$NaBH_4$	Sodium Borohydride
$NaNO_2$	Sodium Nitrite
NH_2NH_2	Hydrazine
P_2O_5	Phosphorous Pentoxide

and 23% for 0.23% and 1.43% volume fraction respectively. They also showed that dynamic viscosity of MWCNT/water nanofluid depends on the percentage of chitosan and MWCNT nanoparticles added. Dhar et al. [12] compared the viscosity of different nanofluids and developed the model for predicting them. Meharli et al. [13] determined the thermophysical properties of graphene/water nanofluid and stated that there is 4 to 44% enhancement in dynamic viscosity compared to basefluid.

In recent times convective heat transfer has been an active field of research. It is stated from the literature that for single phase forced convection experiments there is an enhancement in heat transfer coefficient relative to basefluid [14]. Whereas in natural convection experimentation, heat transfer coefficient is observed to be lower than that of the basefluid. Putra et al. [15] performed natural convection experiments with alumina/water and copper-oxide/water nanofluids for 1% and 4% of volume fractions. The experimentation consists of horizontal cylinder heated from one side and cooled from another end as a test section. They observed deterioration in heat transfer coefficient with an increase in volume fraction compared with the basefluid. They explained the phenomenon of particle slip and sedimentation for the results obtained. Wen and Ding [16] performed experiments with titania/water nanofluid with horizontal cylinder heated from below as a test section for 0.19%, 0.36% and 0.57% of volume fractions. They also concluded that with an increase in volume fraction there is a decrease in heat transfer for all set of Rayleigh numbers. They stated that deterioration is because of increase in particle-particle interaction with an increase in volume fractions. Nnanna [17] performed natural convection experiments with the differentially heated rectangular cavity. He observed no deterioration in heat transfer for volume fraction from 0.2% to 2.0%, but beyond this volume fraction it decreases with increase in volume fraction. Li and Peterson [18] performed experiments with vertical cylinder heated from below for alumina/water nanofluid. They varied volume fractions from 0.5% to 6% for different Rayleigh numbers and observed decrease in Nusselt number with respect to the basefluid. They also did the visual study of the flow pattern and attributed the reason of Brownian motion and thermophoresis in the fluid for deterioration observed. Ho et al. [19] studied natural convection experiments with a square cavity for various range of Rayleigh number with alumina/water nanofluids. They also studied the temperature dependence of thermophysical properties and developed a correlation for various range of Rayleigh number for the obtained results. Hu et al. [20] studied natural convection heat transfer experiments with titana/water nanofluids with various volume fractions. They also did LBM(Lattice Boltzmann Method) analysis to model the experimental setup. They concluded that natural convection is more sensitive to viscosity than thermal conductivity.

The thermophysical properties of the nanofluids have been thoroughly studied so far. Also as per the literature [15,16,17,18,19,20], most of the studies involved in natural convection experiments have been done using particle based nanofluids like alumina/water, titana/water, and copper-oxide/water etc. Thus, in most of the studies pertaining to natural convection of nanofluids effect of particle sizes on the heat transfer are only considered and there are no experimental studies considering effect of particle shapes on the heat transfer as far as knowledge of authors is concerned. Moreover, all the studies performed using spherical types of nanoparticles have always showed deterioration in the heat transfer. This deterioration in natural convection studies have been attributed to the changes in thermophysical properties and effect of various slip mechanisms in the literature [21]. Magnitude of changes in thermophysical properties and slip mechanisms are greater in non-spherical particles rather than spherical particles as stated by Savithiri et al. [22]. Thus it is to be investigated that is there a possibility of any enhancement in convective heat transfer using tubular and flake based nanofluids. Therefore in present study, three different types of nanofluids namely particle based (alumina/water), tube based (MWCNT/water) and flake based