PAPER • OPEN ACCESS

An Experimental Study on Buoyancy Induced Convective Heat Transfer in a Square Cavity using Multi-Walled Carbon Nanotube (MWCNT)/Water Nanofluid

To cite this article: Pranit Joshi and Arvind Pattamatta 2016 *J. Phys.: Conf. Ser.* **745** 032033
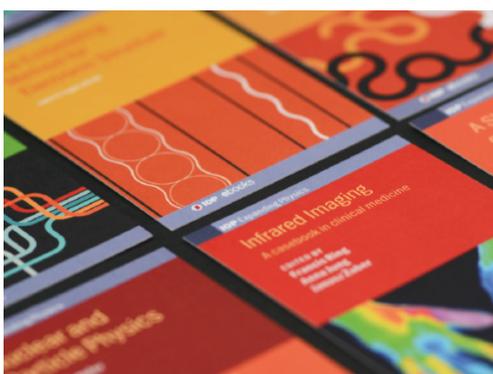
View the article online for updates and enhancements.

Related content

- Synthesis and characterization carboxyl functionalized Multi-Walled Carbon Nanotubes (MWCNT-COOH) and NH2 functionalized Multi-Walled Carbon Nanotubes (MWCNTNH2)
  S. A. Wulandari, Arifin, Hendri Widiyandari et al.

- Preparation and Analysis of the Thermal properties of Engine oil Reinforced with Multi-walled Carbon Nanotubes
  S D Sathishkumar and T Rajmohan

- Influence of Temperature on the Conductivity of Multi-walled Carbon Nanotube Interconnects
  Lu Qi-Jun, Zhu Zhang-Ming, Yang Yin-Tang et al.

Recent citations

- Free convection with MWCNT/water nanofluid having varying aspect ratio of MWCNT nanoparticle in thermally undulated enclosures
  Dwesh K. Singh

- 3D investigation of natural convection of nanofluids in a curved boundary enclosure applying lattice Boltzmann method
  Mehdi Hosseini Abadshapoori and Mohammad Hassan Saidi

- Heat and mass transfer characteristics of carbon nanotube nanofluids: A review
  Muhammad Noor Afiq Witri Muhammad Yazid *et al*

An Experimental Study on Buoyancy Induced Convective Heat Transfer in a Square Cavity using Multi-Walled Carbon Nanotube (MWCNT)/Water Nanofluid.

Pranit Joshi[1], **Arvind Pattamatta**[2*]

[1]Research Scholar,Heat Transfer and Thermal Power Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai - 600 036, Tamil Nadu, India
[2]Associate Professor,Heat Transfer and Thermal Power Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai - 600 036, Tamil Nadu, India

E-mail: arvindp@iitm.ac.in[*]

Abstract.   In recent times, convective heat transfer using nanofluid has been a active field of study. However experimental studies pertaining to buoyancy induced convective heat transfer using various nanofluid is relatively scarce. In present study, a square enclosure of dimensions $(40 \times 40 \times 200)$ mm is used as test section. Initially, Al_2O_3/Water nanofluid with volume fractions 0.3%, 1% and 2% and Rayleigh numbers ranging from 7×10^5 to 1×10^7 are studied . These results are then compared with Ho's[1] experimental data. Nusselt number is calculated based on the thermo-physical properties that are measured in-house for the given conditions. Further, MWCNT/Water nanofluid with volume fractions 0.1%, 0.3% and 0.5% is formulated and are studied for various Rayleigh numbers. Comparison of Al_2O_3/Water and MWCNT/Water nanofluid have been made for different volume fractions and for various range of Rayleigh numbers. It is observed that MWCNT/Water nanofluid when compared with Al_2O_3/Water nanofluid yields higher values of the Nusselt number for a given volume fractions. All the existing experimental studies using particle based nanofluid concluded a deterioration in natural convective heat transfer. This study for the first time demonstrates an enhancement in natural convection using MWCNT/Water nanofluid. Such enhancement cannot be simply explained based only on the relative changes in the thermophysical properties. Other factors such as percolation network in MWCNT/Water nanofluid which increases the heat transfer pathway between two walls and the role of slip mechanisms might be the possible reasons for the enhancement.

1. Introduction
The conclusions drawn from the study of Choi and Eastman[2] that nanofluids are potentially engineered colloids for the heat transfer enhancement and thermal management has paved impetus to very active area of research in heat transfer studies. Hitherto, considerable studies have been performed for enhancement in thermal conductivity for various nanofluid. But, there are very few studies on natural convection of the nanofluids. Putra et al.[3] performed natural convection experiments for Al_2O_3/Water and CuO/Water nanofluid inside the horizontal cylinder heated from one end and cooled from other . They showed deterioration in heat transfer with increase in volume fraction of nanoparticles Nnanna[4] studied Al_2O_3/Water nanofluid for

various range of volume fractions in differentially heated rectangular cavity and concluded that heat transfer increases for $\phi < 2\%$ but decreases for $\phi > 2\%$ due to reduction in Rayleigh number. Ho et al.[1] did experimental studies on Al_2O_3/Water nanofluid in a square cavity for various volume fraction and Rayleigh numbers. They also concluded that heat transfer decreases with increase in ϕ. Hu et al.[5] performed experiments for TiO_2/Water nanofluid in vertical square enclosure for various value of ϕ and simultaneously conducted a numerical study and concluded that natural convection in nanofluids is more sensitive to viscosity than thermal conductivity. The conclusions drawn from the experimental studies alone is that adding nanoparticle results in deterioration of buoyancy induced convective heat transfer in nanofluids. However there is no experimental study till date on enhancement of natural convection in square cavity using MWCNT/Water nanofluid. Kim et al.[6], S.U.S Choi et al.[7], Shastry et al.[8],Soujit et al.[9] and many have shown that MWCNT/Water nanofluid have very high thermal conductivity enhancement. Whereas Phuoc et al.[10], Dhar et al.[11] have studied the effect of volume fraction and temperature on the viscosity of CNT/Water nanofluid.

In the present study, experiments have been performed by using MWCNT/Water nanofluid for potential heat transfer enhancement in an enclosure of square cross section as a test section. Nanofluid in test section is heated using plate heater from one side and the other side is maintained at constant temperature. All other walls are maintained adiabatic. Initially, Al_2O_3/Water nanofluid with volume fractions 0.3%, 1% and 2% and Rayleigh number ranging from 7×10^5 to 1×10^7 is studied. The results are validated with Ho's experiment. Further, MWCNT/Water nanofluid with 0.1% ,0.3% and 0.5% are formulated. They are studied for different Rayleigh numbers varying from 7×10^5 to 1×10^7. Comparison of MWCNT/Water with Al_2O_3/Water nanofluid has been made for the 0.3% volume fraction and various Rayleigh numbers.

2. Description of Experimental Setup
Figure 1 shows photographic representation of experimental setup used in the present study. Experimental set-up consists of the constant temperature bath, heat source, test section, Al_2O_3/Water nanofluid, MWCNT/Water nanofluid and Data acquisition system. The test section with cross-section (40×40)mm dimensions and the other dimension around 5 times the side is used for the study in order to remove the three-dimensionality effect. Two vertical walls of the enclosure are maintained at constant temperature while other walls are insulated. The hot plate is made of copper in which nichrome wire heater is placed. Cold plate is also made from copper with grooves inside it for the passage of the cold fluid through the plate thereby maintaining uniform temperature. As shown in Figure 2, five thermocouples are placed inside the cold and hot plate at different locations to measure the temperature across the plate. Remaining walls of the test cell are made up of acrylic which acts as an insulator. In addition, external surfaces of the test cell are covered with glass-wool(k=0.40 W/mk) insulation with 45mm thickness and then 25mm thick Styrofoam(k=0.45 W/mk). To estimate the heat losses from the heater, two-thermocouple are placed between the heater and glass-wool insulation and the other two are placed on the outside of the glass-wool insulation. The temperature at these thermocouple are measured at steady-state and losses are calculated based on Fourier's law. Thermocouples are calibrated using a constant temperature bath and relative error in temperature measurement is measured to be 0.77%. Temperatures are recorded by using Hioki Data logger. Leakage test is done for the test section by filling water and monitoring it for several days before the actual experiments. Efforts are taken to prevent any bubble formation while filing the cavity at the time of experiments. DC power source used is of TDK-Lamda(GEN model) make with voltage range of 0 to 240V and current range of 0 to 19A. Constant temperature bath(Julabo 300F) is used to circulate temperature controlled fluid across the cold wall. System is turned on and temperatures are continuously monitored for about three hours which is

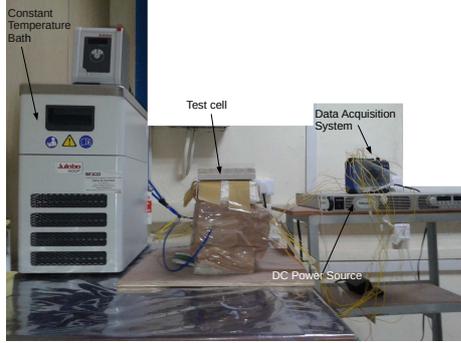sufficient to attain steady state.
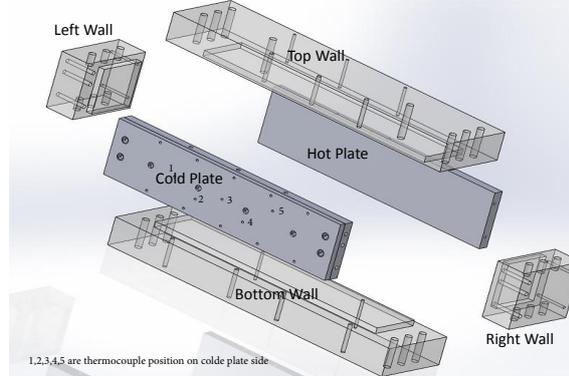

Figure 1. Experimental Setup

Figure 2. Testcell

3. Preparation and Characterization of nanofluid

For validation study, Al_2O_3 nanoparticles (Nanoshel,γ,high purity 99.5%,80nm) with density 3950 kg/m^3 are used to synthesize nanofluid using distilled water as basefluid. For the heat transfer enhancement study, MWCNT nanoparticles (Nanoshel, OD 10-20nm, length 3-8μm) with density 2000 kg/m^3 are used. TEM images of the Alumina and MWCNT nanoparticles are shown in figure 3 and 4. For the preparation of nanofluids, required quantity of the alumina and MWCNT nanoparticles are weighed and dispersed in the distilled water samples respectively. Ultrasonication with a probe type sonicator(QSonica) is done for 15 min for obtaining stable nanofluids. SDS(Sodium Do-decyl sulfate) is added to 2% of Al_2O_3/Water and to each volume fraction of MWCNT/Water so as to have stable suspension. A stability of about two days is obtained for both nanofluids.

For the characterization of prepared nanofluids, the thermophysical properties such as effective dynamic viscosity and effective thermal conductivity are measured as a function of volume fraction. Fluid viscosity is measured with the automated micro-viscometer(Anton Paar GmbH, Austria), which is rolling ball viscometer with deviation of less than 1%. Thermal conductivity is measured by transient hot wire method(KD2 Pro) in temperature controlled bath with operating limits between 25°C to 60°C. The deviation of the thermal conductivity is found to be 1.2%. These properties are compared with Maiga and Nyugen[12] correlation.

$$\mu_{nf}/\mu_{bf} \quad = \quad 1 + 7.3\phi + 123\phi^2 \tag{1}$$
$$k_{nf}/k_{bf} \quad = \quad 1 + 2.72\phi + 4.97\phi^2 \tag{2}$$

The plot of effective viscosity and thermal conductivity of nanofluid as a function of volume fraction are shown in Figure 5 and 6. The other properties of the nanofluid such as density, specific heat and volumetric thermal expansion co-efficient are calculated as below:

$$\rho_{nf} \quad = \quad \phi.\rho_{np} + (1-\phi).\rho_{bf} \tag{3}$$
$$\rho_{nf}c_{p,nf} \quad = \quad \phi.\rho_{np}.c_{p,np} + (1-\phi).\rho_{bf}.c_{p,bf} \tag{4}$$
$$\beta_{nf} \quad = \quad \phi.\beta_{np} + (1-\phi).\beta_{bf} \tag{5}$$

Properties for MWCNT nanoparticles namely specific heat and volumetric thermal expansion co-efficient are determined from the literature [13] [14] which are ($c_{p,np}$=410$J/kg.K$, β_{np} = $2.1 \times 10^{-5}/K$). Also the effective density of the nanofluids as a function of volume fraction is shown in Figure 7.
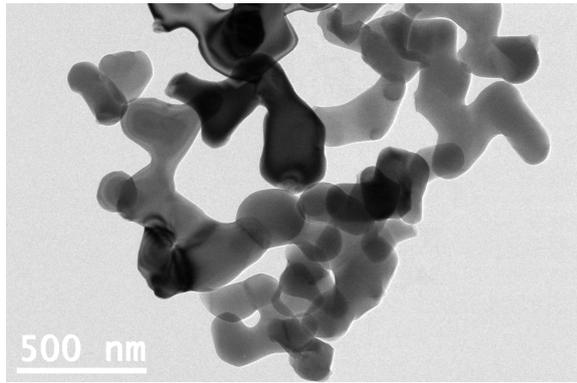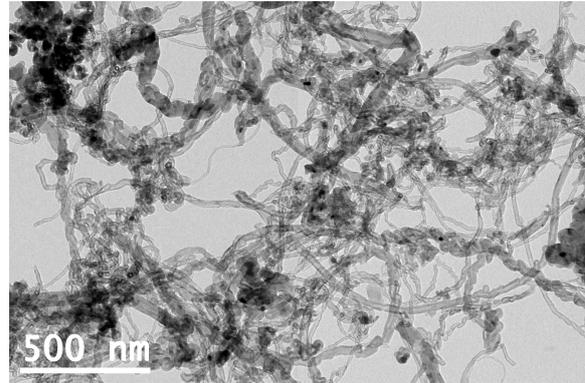
Figure 3. TEM image of Alumina nanoparticle.

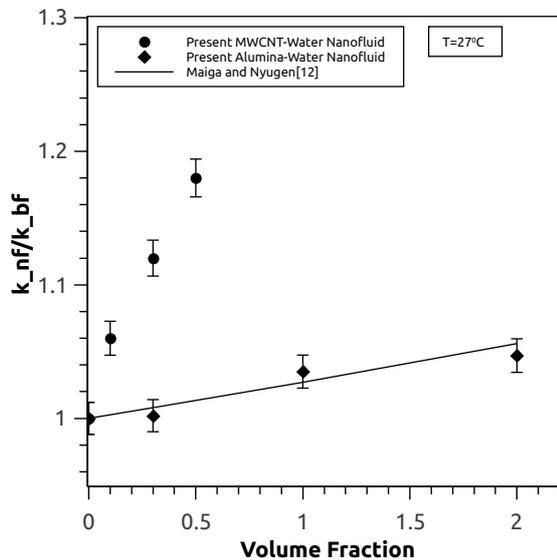
Figure 4. TEM image of MWCNT nanoparticle.

Figure 5. Variation of Thermal Conductivity with Volume Fraction.
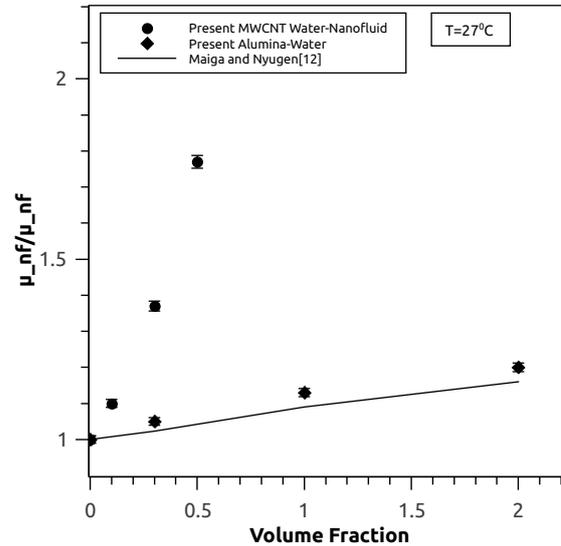

Figure 6. Variation of Dynamic Viscosity with Volume Fraction.

4. Calculation of Nusselt number and Error analysis

The experimental data are then reduced to the heat transfer coefficient and dimensionless parameters are obtained as follows. The input power to the heater plate is adjusted by DC power source. Average heat flux at steady state is calculated as:

$$\overline{q_t^{''}} = \frac{V \cdot I}{A} \tag{6}$$

The corrected heat flux is calculated by subtracting the heat flux loss from the heater. So, the corrected heat flux is given as:

$$\overline{q_{corr}^{''}} = \overline{q_t^{''}} - \overline{q_{loss}^{''}} \tag{7}$$
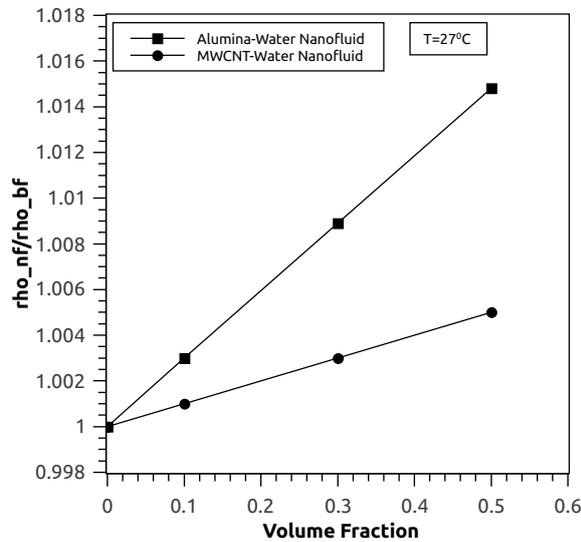
Figure 7. Variation of Effective Density of Nanofluid with Volume Fraction.

After calculating the corrected heat flux, h_{nf} which is based on the temperature difference between the hot and cold plate $(T_h - T_c)$ is calculated as:

$$\overline{h_{nf}} = \frac{\overline{q''_{corr}}}{T_h - T_c} \tag{8}$$

Finally, the average Nusselt number is calculated as:

$$\overline{Nu_{nf}} = \frac{\overline{h_{nf}} \cdot W}{k_{nf}} \tag{9}$$

The Rayleigh number is based on the temperature difference between the hot plate and cold plate given by:

$$Ra_{nf} = \frac{g \cdot \rho_{nf}^2 \cdot c_{p,nf} \cdot \beta_{nf} \cdot (T_h - T_c) \cdot W^3}{k_{nf} \cdot \mu_{nf}} \tag{10}$$

All the thermophysical properties are calculated based on the mean temperature between the hot and cold plate.

Uncertainty of the experiments is estimated based on Kline-McClintock method. The parameters considered for the experimental uncertainties are temperature, power supplied, thermal conductivity, viscosity. In the present study temperature is measured by using K-type thermocouple with an uncertainty of $\pm 0.77\%$, and that of thermal conductivity, viscosity measurement and input power are $\pm 1.2\%$, $\pm 1\%$ and $\pm 0.8\%$ respectively.

So the experimental uncertainity is calcualted as:

$$\Delta Nu = \pm \sqrt{\left\{ \left(\frac{\partial Nu}{\partial q} \right)^2 (\epsilon_q)^2 + \left(\frac{\partial Nu}{\partial T_h} \right)^2 (\epsilon_{T_h})^2 + \left(\frac{\partial Nu}{\partial T_c} \right)^2 (\epsilon_{T_c})^2 + \left(\frac{\partial Nu}{\partial k} \right)^2 (\epsilon_k)^2 \right\}} \tag{11}$$

Average experimental uncertainty is found to be about $\pm 9.4\%$.

5. Results and Discussion

All the results shown in this section are obtained after attaining the steady-state. Higher Rayleigh numbers are achieved by maintaining larger temperature difference between the two plates which is obtained by adjusting the power supplied from the DC power source. Initially, the validation of the experimental data is done with the Ho et al.[1] results for Al_2O_3/Water nanofluid and then MWCNT/Water nanofluid results are presented.

5.1. Validation of the Al_2O_3/Water nanofluid.

For the validation, firstly the test section is filled with basefluid and Rayleigh numbers are varied by setting different input power and the corresponding Nusselt number are calculated. It is found that there is a increase in Nusselt number with increase in Rayleigh number as expected. Figure 8 shows the comparison of Nusselt number for the basefluid with the experimental data of Ho et al. [1] and Bejan's correlations[15] along with the error bars for different Rayleigh number. Results shows very good agreement with previous data as difference of less than 10% is observed. Further, the experiments with Al_2O_3/Water nanofluid are performed and the results are compared with [1] for 0.3%, 1% and 2% of volume fraction. The deterioration in Nu number for the nanofluids are examined on the basis of increased density of nanofluids as shown Figure 7. The increase in effective density reduces the buoyancy and hence lowers heat transfer. It can be seen from the Figure 9. that the Nusselt number are in good agreement with [1] and predicts deterioration with increase in volume fraction. Slight variation in the results may be attributed to the fact that the average particle size of the Al_2O_3 nanoparticle are different for present study and previous work[1]. The variation in the Nusselt number with Rayleigh number for different volume fraction are shown in Figure 9. It can be interpreted from the graph that with increase in volume fraction, Nusselt number decreases for given Rayleigh number. The Nusselt number value for higher Rayleigh numbers with $\phi = 0.3\%$ of Al_2O_3/Water nanofluids is slightly greater than the basefluid. But for $\phi = 2\%$ it is lower than the basefluid by 21% for the same Rayleigh number. Decrease in Nusselt number may be due to relative changes in the thermophysical properties of nanofluid and the role of slip-mechanisms such as Drag force, Brownian motion and Thermophoresis as stated in the literature [16].

5.2. Experiments with MWCNT/Water nanofluid.

MWCNT/Water nanofluid with volume fraction 0.1%, 0.3% and 0.5% are prepared and experiments are performed for different Rayleigh numbers. Figure 10. shows the variation of the Nusselt number with Rayleigh number for different volume fraction. It is evident from the plot that for the volume fraction 0.1% and 0.3% of MWCNT/Water nanofluid, the enhancement in Nusselt number (compared to basefluid) is 35% and 11% respectively for the Rayleigh number of 1×10^6. The normalized Nusselt number Nu_{nf}/Nu_{bf} is plotted as the function of Rayleigh number as shown in Figure 11 . The 0.3% volume fraction results of MWCNT/Water nanofluid is compared with the Al_2O_3/Water nanofluid as shown in Figure 11. It is observed that there is an increase of about 15% in Nusselt number for MWCNT/Water nanofluid compared with Al_2O_3/Water nanofluid with 0.3% volume fraction for given Rayleigh number.

As stated in the literature the average heat transfer coefficient depends on the relative changes in the thermophysical properties of nanofluid with respect to basefluid. But the relative changes in thermophysical properties are not alone enough to predict the deterioration as stated by Savithiri et al [16]. The role of slip mechanisms such as Drag force, Brownian, Thermophoresis, etc. are also of prime importance in natural convection studies. Moreover, the role of percolation in the anomalous enhancement in thermal conductivity of CNT/Water nanofluid has been discussed in Dhar et al.[17] So, the relative enhancement in buoyancy induced convective heat transfer using MWCNT/Water nanofluid can be attributed to the percolation network which aids an increase in the heat transfer pathway from hot to cold wall. The effective density of
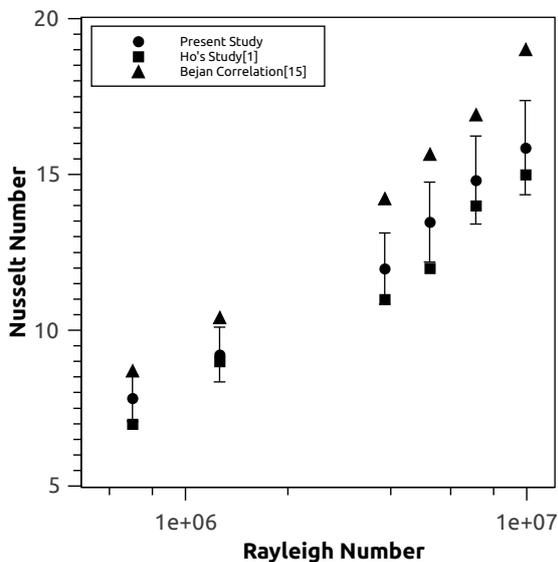
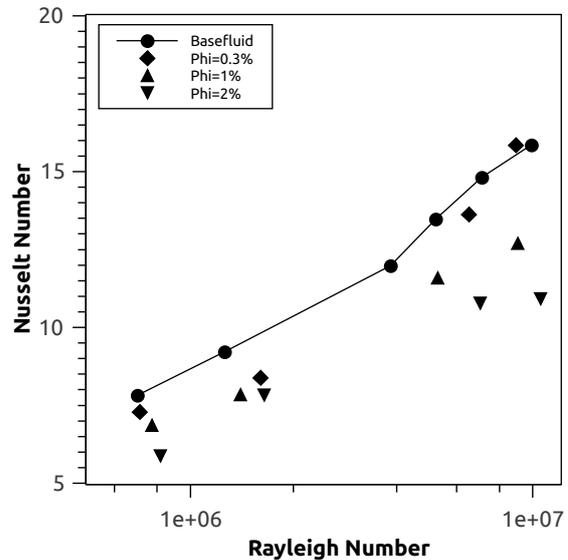**Figure 8.** Nu vs Ra number comparison for basefluid.

Figure 9. Nu vs Ra for Al_2O_3/Water nanofluid for different ϕ.

MWCNT/Water nanofluid is lower than Al_2O_3/Water nanofluid as seen in Figure 7. hence the buoyancy effect are more pronounced in MWCNT/Water nanofluid. Thus for the first time an enhancement in the Nusselt number with nanofluid in natural convection has been observed. However, with the increase in volume fraction of MWCNT/Water nanofluid the resistance to natural convection increases which, results in reduction of Nusselt number.
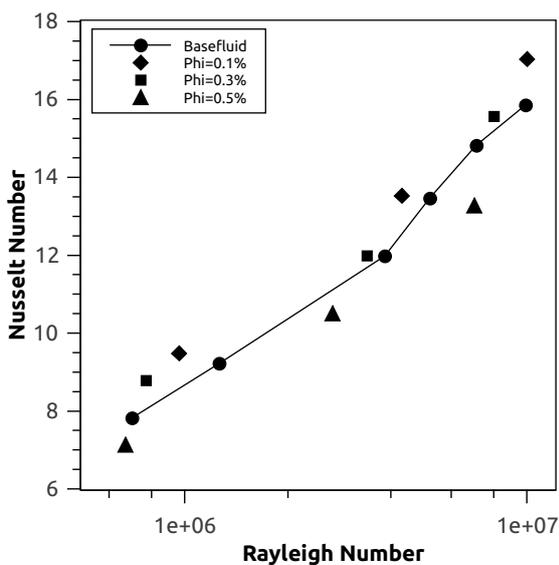

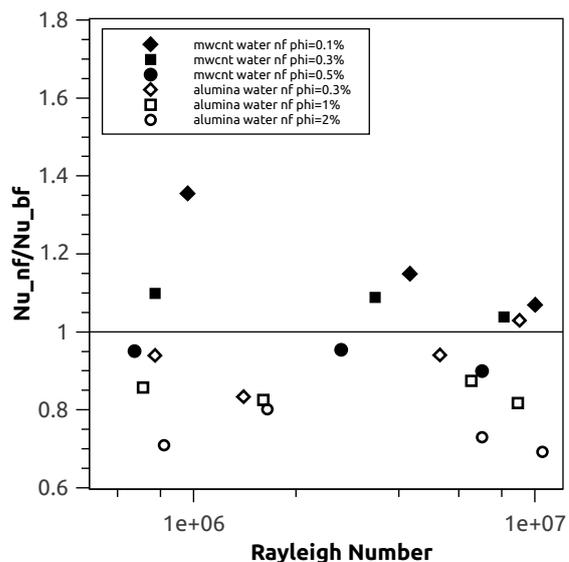**Figure 10.** Nu vs Ra for MWCNT/Water nanofluid for different ϕ.

Figure 11. Nu_{nf}/Nu_{bf} vs Ra for different nanofluid

6. Conclusion

The experimental study on buoyancy induced convective heat transfer has been performed using Al_2O_3/Water and MWCNT/Water nanofluids in the square cavity. The conclusions from the experiments are as follows:

- The Nusselt number increases with increase in Rayleigh number for the basefluid as well as for nanofluids.

- The increase in Nusselt number of about 35% is observed with MWCNT/Water nanofluid for $\phi = 0.1\%$ when compared with the basefluid for the Rayleigh number 1×10^6.

- Nusselt number value for the MWCNT/Water nanofluid are higher for $\phi = 0.3\%$ compared to that with Al_2O_3/Water and basefluid for the corresponding Rayleigh number. Increase of about 11% and 17% was found for the Nusselt number value of the MWCNT/Water nanofluid for 0.3% of volume fraction when compared with basefluid and Al_2O_3/Water nanofluids respectively for 9×10^5 Rayleigh numbers.

In MWCNT/Water nanofluid the percolation network might aid the heat transfer by increasing the heat transfer pathway form hot to cold plate. The role of slip mechanism in the heat transfer of MWCNT/Water nanofluid needs to be investigated in the future study so as to get complete picture of the enhancement in heat transfer.

Acknowledgments

References

[1] Ho C, Liu W, Chang Y and Lin C 2010 *International Journal of Thermal Sciences* **49** 1345–1353
[2] Choi S 1995 *ASME-Publications-Fed* **231** 99–106
[3] Putra N, Roetzel W and Das S K 2003 *Heat and Mass Transfer* **39** 775–784
[4] Nnanna A 2007 *Journal of Heat Transfer* **129** 697–704
[5] Hu Y, He Y, Wang S, Wang Q and Schlaberg H I 2014 *Journal of Heat Transfer* **136** 022502
[6] Kim P, Shi L, Majumdar A and McEuen P 2001 *Physical review letters* **87** 215502
[7] Choi S, Zhang Z, Yu W, Lockwood F and Grulke E 2001 *Applied physics letters* **79** 2252–2254
[8] Sastry N V, Bhunia A, Sundararajan T and Das S K 2008 *Nanotechnology* **19** 055704
[9] Gupta S S, Siva V M, Krishnan S, Sreeprasad T, Singh P K, Pradeep T and Das S K 2011 *Journal of Applied Physics* **110** 084302
[10] Phuoc T X, Massoudi M and Chen R H 2011 *International Journal of Thermal Sciences* **50** 12–18
[11] Dhar P, Ansari M H D, Gupta S S, Siva V M, Pradeep T, Pattamatta A and Das S K 2013 *Journal of nanoparticle research* **15** 1–12
[12] Maiga S E B, Nguyen C T, Galanis N and Roy G 2004 *Superlattices and Microstructures* **35** 543–557
[13] Zahari F, Salim M N, Mohamad I, Abdullah N and Thiru S 2015 *Proceedings of Mechanical Engineering Research Day 2015: MERD'15* **2015** 11–12
[14] Deng L, Young R J, Kinloch I A, Sun R, Zhang G, Noé L and Monthioux M 2014 *Applied Physics Letters* **104** 051907
[15] Bejan A 1993 *Convection heat transfer* (John wiley & sons)
[16] Savithiri S, Pattamatta A and Das S K 2011 *Nanoscale research letters* **6** 1–15
[17] Dhar P, Gupta S S, Chakraborty S, Pattamatta A and Das S K 2013 *Applied Physics Letters* **102** 163114

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.
$\overline{q''}$ Average heat flux, W/m^2.
Nu   Nusselt number.
$\overline{Nu}$ Average Nusselt number.
T   Temperature, K .
Ra   Rayleigh number.
V   Voltage, V.
W   Characteristic length of test cell, m.
k   Thermal conductivity, W/mK.

Greek symbols

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

Subscripts

bf Basefluid.
c Cold.
$corr$ correction in heat loss.
$loss$ Heat loss.
nf Nanofluid.
np Nano particle.
t Total Heat loss.
h Hot.