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Experimental study on thermal conductivity of DWCNT-ZnO/water-EG nanofluids☆

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ABSTRACT

Experimental study on the effects of solid volume fraction and temperature on thermal conductivity of DWCNT(inner diameter of 3 nm)-ZnO(diameter of 10-30 nm)/water-ethylene glycol (60:40) nanofluids have been performed using KD2-Pro thermal analyzer in details. The experiments are carried out at solid concentration up to 1% and temperature ranging from 25 to 50 °C. Based on experimental results, using non-linear regression on results of experiments, a correlation as a function of temperature and solid volume fraction has been proposed. Measured data show that the relative thermal conductivity enhances with increasing concentration of nanoparticles. The increasing temperatures also increase the thermal conductivity of nanofluids, although its effect on the thermal conductivity compared to the effect of volume fraction is lower.

1. Introduction

Nanofluids are common base fluids that include water, ethylene glycol or oil containing nanometer particles which have innovative properties that make them potentially useful in many engineering and industrial applications. The nanoparticles used in nanofluids are usually prepared of metals, oxides or carbon nanotubes [1–10]. Information of the rheological behavior of nanofluids is found to be very important in determining their appropriateness for heat transfer applications. Hence, many researchers around the world have investigated the behaviors of nanofluids. A summary of existing experimental studies for the thermal conductivity of different oxide nanofluids is presented in Table 1. It is observed in Table 1 that the thermal conductivity of nanofluids is related to the size and the shape of nanoparticles, the solid volume fraction of nanoparticles, and the thermo-physical properties of nanoparticles and the base fluid.

Recently, carbon nanotubes (CNTs) have been frequently studied as a nano-material owing to the unique thermal properties [17–19]. Table 2 presents some studies for the thermal conductivity enhancement of CNT/nanofluids at room temperature. Since the experimental measurement of thermal conductivity of nanofluids is expensive and longtime process, many researchers tried to proposed correlations for predicting the thermal conductivity of nanofluids. Some examples of empirical correlation provided for thermal conductivity of nanofluids are shown in Table 3. All of these correlations are expressed based on experimental data and have good accuracy. In all of the correlations, k is the thermal conductivity of nanofluid, ϕ is solid concentration, T is the temperature of the nanofluid in °C and d is diameter in nm. Also, subscript of n_f, b_f and p indicates respectively nanofluid, base fluid and particle.

Recently, the computing methods are used for estimating accurately the thermal conductivity of nanofluids which are known as neural networks, genetic algorithms and fuzzy logic. In this regard, Hojjat et al. [36] measured the thermal conductivity of three different nanofluids, Al_2O_3, TiO_2, and CuO. Then, using neural network, they modeled the experimental results using temperature and volume fraction of nanoparticles as input, and thermal conductivity of nanoparticles as output of neural network. Longo et al. [37] proposed two artificial neural network models for estimating the thermal conductivity of Al_2O_3/water and TiO_2/water nanofluids by the temperature, volume fraction, diameter of nanoparticle and particle thermal conductivity as the input variables. They used thermal conductivity of nanoparticles as output of neural network. The prediction of the thermal conductivity of MgO/EG nanofluids by artificial neural network (ANN) was performed by Hemmat Esfe et al. [38] using experimental data. In their study, the solid volume fraction, diameter of nanoparticle and temperature are considered as the input data and thermal conductivity of nanofluid is the output variable. Hemmat et al. [39] also examined the thermal conductivity of the ZnO/EG nanofluid and presented a prediction model using artificial neural network. The results disclosed that the predicted results are in good agreement with the experimental data. It is clear from the above

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Table 1
A summary of existing experimental studies for the thermal conductivity of different oxide nanofluids according to the various parameters.

Authors	Base fluid	Dispersed particles	Temperature range (°C)	Nanoparticle size (nm)	Concentration range (%)
Das et al. [11]	Water	Al_2O_3	20–50	38.4	1.0–4.0
		CuO		28.6	
Li and Peterson [12]	Water	Al_2O_3	27–37	36 & 47	0.5–6.0
Chandrasekar et al. [13]	Water	Al_2O_3	NA	43	0.33–5.0
Reddy et al. [14]	EG-water	TiO_2	30–70	21	0.2–1.0
Sundar et al. [15]	Water	Fe_3O_4	20–60	13	0.0–2.0
Jeong et al. [16]	Water	ZnO	NA	20–40	0.05–5.0

Table 2
Some studies for the thermal conductivity enhancement of CNT/nanofluids at room temperature.

Authors	Base fluid	Dispersed particles	Maximum enhancement
Xie et al. [20]	Water	MWCNT	7.0%
Assael et al. [21]	Water	MWCNT	38.0%
Hwang et al. [22]	Water	MWCNT	11.3%
Amrollahi et al. [23]	EG	SWCNT	20.0%
Nanda et al. [24]	EG	SWCNT	35.0%
Glory et al. [25]	Water	MWCNT	64.0%
Jha and Ramaprabhua [26]	Water	Ag-MWCNT	37.3%
Liu et al. [27]	EG	MWCNT	12.4%
Harish et al. [28]	EG	SWCNT	14.8%

literature survey that there are little studies about thermal conductivity of DWCNT-ZnO/water-ethylene glycol (60:40) nanofluids. This motivates the present study.

2. Measurement of thermal conductivity

To examine the thermal conductivity of nanofluid, nanofluids are provided in seven solid volume fractions up to 1% using surfactant and ultrasonic vibrator. The ZnO and DWCNT are mixed with equal volume in each concentration. Size of ZnO nanoparticles is 10–30 nm while the inner diameter of DWCNTs is 3 nm.

A KD2 Pro conductimeter, Decagon Devices (USA), was employed for measurement of the thermal conductivity of all nanofluids. This commercial device uses the transient hot wire method. In this method, a tinny metal wire is inserted in the test liquid acting as both temperature sensor and heat source. The transient hot wire method acts by measurement of wire temperature/time response to a sudden electrical pulse. The thermal conductivity of the test sample can be developed by temperature variation of the hot wire over a specific time interval. The sample was presented in a sealed glass tube (20 ml) where the sensor was embedded vertically. To perform the experiment at high temperature situations the tube was plunged in a thermostatic bath where the temperature was controlled. Before any test, a period of time of 1 h was delayed for the sample to achieve the desired temperature. Then, six measurements were carried out for each nanofluid sample. During the measurement the bath was turned off to elude vibrations. It was essential to wait for about 15 min between readings to recover the

3. Results and discussion

The experimental investigation of thermal conductivity of functionalized DWCNT-ZnO/water-EG (60:40) nanofluids is performed in this work. Next, a correlation to estimate the thermal conductivity of nanofluids is proposed. Fig. 1 presents the thermal conductivity of functionalized DWCNT-ZnO/water-EG (60:40) nanofluids versus solid volume fraction for different temperatures. As expected, with increasing solid volume fraction at all temperatures, thermal conductivity increases. The thermal conductivity enhancement at low solid volume fractions (less than 0.25%) is relatively higher than that at the other volume fractions.

To make a better understanding of the effects of temperature on the thermal conductivity, the relative thermal conductivity of functionalized DWCNT-ZnO/water-EG (60:40) nanofluids versus temperature for different solid volume fractions is depicted in Fig. 2. As shown in Fig. 2, with increase in temperature, the relative thermal conductivity of nanofluids increases slightly for different solid volume fractions. The relative thermal conductivity at high solid volume fractions is higher than that at low solid volume fractions; therefore, thermal conductivity enhancement at low solid volume fractions is negligible.

The percentage of increase in thermal conductivity of nanofluids compared to the base fluid, depending on the volume fraction at different temperatures is displayed In Fig. 3. It is clear that the maximum of thermal conductivity enhancement is noted for a case with maximum values of solid volume fraction and temperature. On the other hand, the effects of temperature on the thermal conductivity at high solid volume fractions are significant, relatively to that at low solid volume fractions.

Table 3
Empirical correlation provided for thermal conductivity of nanofluids.

Authors	Nanofluids	Correlations
Chon et al. [29]	Al_2O_3/water	$\frac{k_{nf}}{k_{bf}} = 1 + 64.7\varphi^{0.7460}\left(\frac{d_{bf}}{d_p}\right)^{0.3690}\left(\frac{k_p}{k_{bf}}\right)^{0.7476}, \mathrm{Pr}^{0.9955}\mathrm{Re}^{1.2321}$
Li and Peterson [30]	Al_2O_3/water	$\frac{(k_{nf}-k_{bf})}{k_{bf}} = 0.764481464\varphi + 0.018688867T - 0.462147175$
	CuO/water	$\frac{(k_{nf}-k_{bf})}{k_{bf}} = 3.761\,088\phi + 0.017\,924T - 0.30734$
Duangthongsuk and Wongwises [31]	TiO_2/water	$\frac{k_{nf}}{k_{bf}} = \mathrm{A} + \mathrm{B}\varphi$
Teng et al. [32]	Al_2O_3/water	$\frac{k_{nf}}{k_{bf}} = 0.991 + 0.253(100\varphi) - 0.001T - 0.002d_p - 0.189(100\varphi)^2 + 0.6190 \times 10^{-5}T^2 + 1.317 \times 10^{-5}d_p^2 + 0.049(100\varphi)^3 - 7.66 \times 10^{-7}T^3$
Ghanbarpour et al. [33]	Al_2O_3/water	$\frac{k_{nf}}{k_{bf}} = 1 + 3.5\varphi + 2.5\varphi^2$
Hemmat Esfe et al. [34]	DWCNT/water	$\frac{k_{nf}}{k_{bf}} = \frac{\varphi}{0.17981 - 0.0003692(T-273)} + 1.0026$
Hemmat Esfe et al. [35]	MWCNT/water	$\frac{k_{nf}}{k_{bf}} = \frac{(360.69+T)}{(405.59-11080\varphi)}$

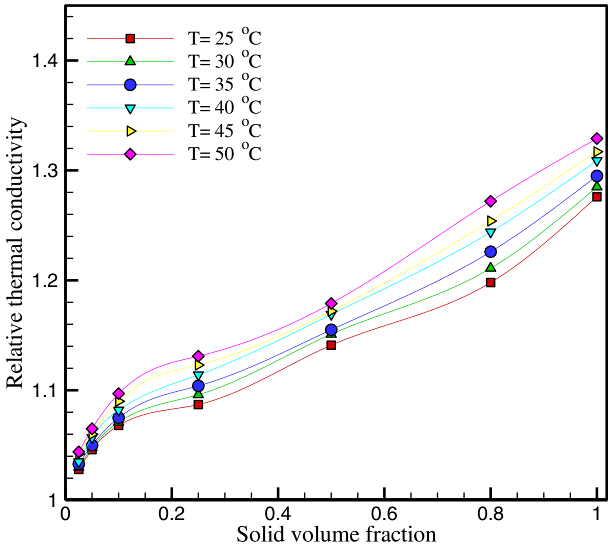

Fig. 1. Relative thermal conductivity with respect to concentration at different temperatures.

According to data from experiments conducted on the thermal conductivity of functionalized DWCNT-ZnO/water-EG (60:40) nanofluids, a correlation to estimate the thermal conductivity of the nanofluid is proposed.

$$\frac{k_{nf}}{k_{bf}} = 1.085e^{\left(0.001351T+0.13\varphi^2\right)} + 0.0288\ \ln(\varphi) \tag{1}$$

The comparison between experimental data and results obtained using the correlation is shown in Fig. 4. As can be seen, the correlation has an appropriate accuracy and is able to predict the relative thermal conductivity at various temperatures and solid volume fractions.

To understand the applicability of the experimental findings and data obtained from the correlation, the outputs of the proposed correlation versus experimental data are plotted in Fig. 5. As shown in Fig. 5, the most points have a good accuracy and locate near the bisector.

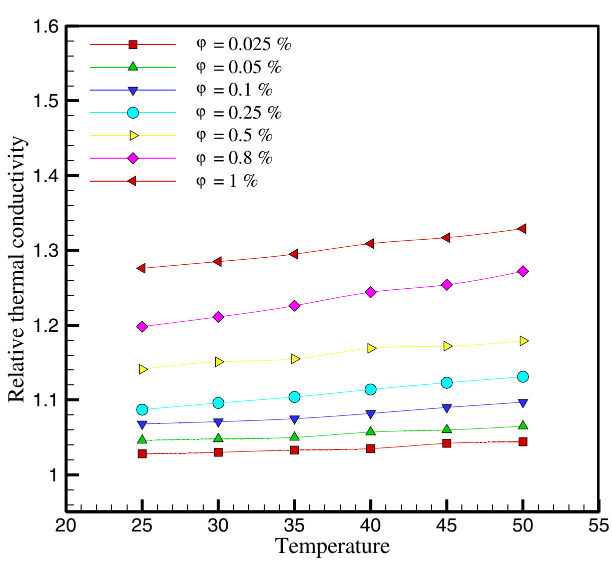

Fig. 2. Relative thermal conductivity versus temperature at different solid volume fractions.

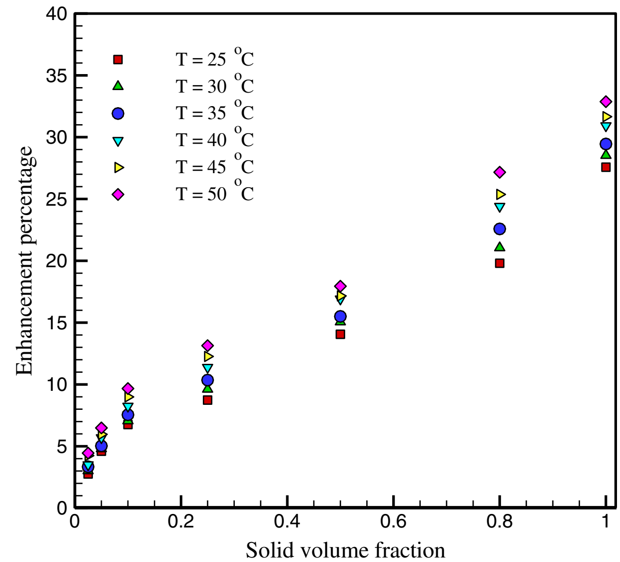

Fig. 3. Enhancement percentage at different concentrations and temperatures.

4. Conclusion

In the present study, the thermal conductivity of functionalized DWCNT(inner diameter of 3 nm)-ZnO(diameter of 10-30 nm)/water-EG (60:40) nanofluids is experimentally obtained using transient hot wire method. Experiments were carried out for solid volume fraction ranging from 0.25% to 1% and temperature ranging from 25 to 50 °C. The results showed that with increasing volume fraction of nanoparticles relative thermal conductivity enhances. The increasing temperatures also increase the thermal conductivity of nanofluids, although its effect on the thermal conductivity compared to the effect of volume fraction, was lower. Using experimental data, the correlation was proposed to estimate thermal conductivity of functionalized DWCNT-ZnO/water-EG (60:40) nanofluids. Then, the accuracy and margin of deviation were investigated using different graphs. The results of these investigations showed that the proposed correlation can accurately estimate the thermal conductivity of nanofluid at different temperatures and solid volume fractions.

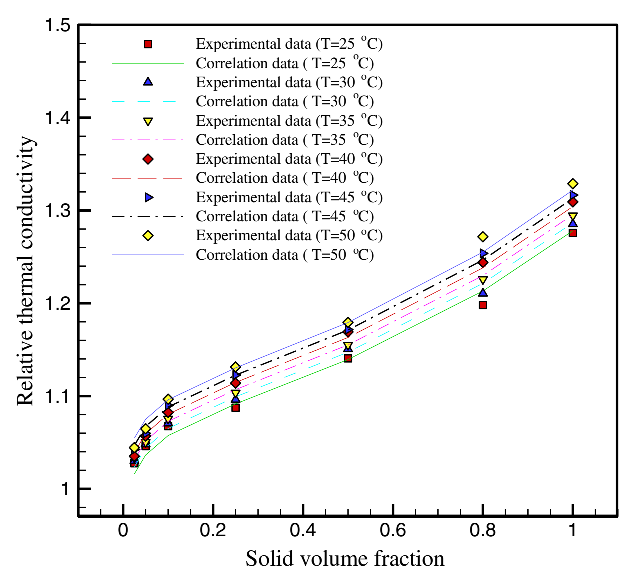

Fig. 4. Comparison between experimental data and correlation outputs at different concentrations and temperatures.

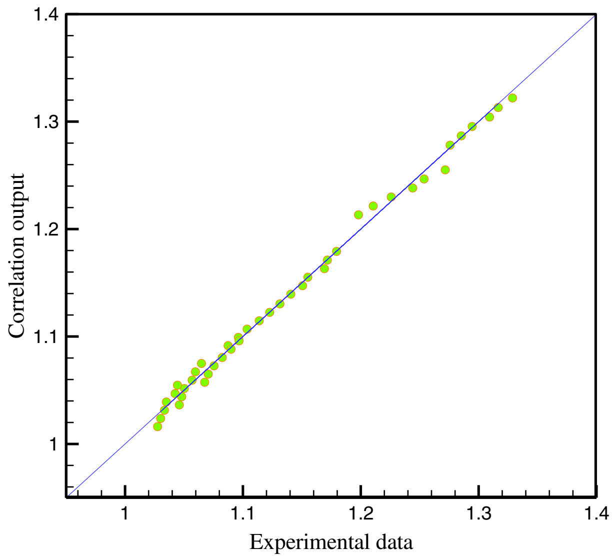

Fig. 5. Correlation output versus experimental data.

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