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Proposing a new experimental correlation for thermal conductivity of nanofluids containing of functionalized multiwalled carbon nanotubes suspended in a binary base fluid

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ABSTRACT

In this study, thermal conductivity of the nanofluid obtained by suspension of functionalized multi-walled carbon nanotubes (FMWCNTs) was experimentally assessed in the base fluid of water (80%) and ethylene glycol (20%). The nanofluid was tested at solid volume fractions from 0.025% to 0.8% and temperatures from 25 °C to 50 °C. The results showed that thermal conductivity has a direct relationship with solid volume fraction and temperature of the nanofluid. In the best case, it enhanced by 27.3% compared to the base fluid. Experimental results showed a sharp increase in thermal conductivity of nanofluid at lower solid volume fractions compared to the base fluid. Also, results were compared with the results of mathematical models. Accordingly, based on the experimental data, a correlation is presented as a function of temperature and solid volume fraction of nanofluids. The results of this study were compared with other studies in which carbon nanotubes were used as nanoparticles and water, ethylene glycol or a mixture of water and ethylene glycol was used as the base fluid. Comparison results showed that the quality of the nanofluid, solid volume fractions and percent of water and ethylene glycol as the base fluid, noticeably affect the thermal conductivity of nanofluid.

1. Introduction

In most thermal applications, ethylene glycol (EG) is an improver which added to water to reduce the freezing point of water. Antifreeze is a mixture of water and EG which decreased freezing-point for cold environments. It can also be used to achieve boiling-point elevation to allow higher coolant temperature. Because of appropriate properties of this mixture, it is used in internal combustion engines and other heat transfer applications such as HVAC devices and solar collectors. The importance and necessity of enhanced thermal conductivity in heat exchange devices motivated engineers and researchers to use different methods to enhance thermal conductivity including adding the metallic, non-metallic and polymeric particles in the base fluids. Use of micrometer or millimeter particle size in liquids is one of the newest methods for enhancing the heat transfer. However, this method has several disadvantages such as friction, clogging and pressure drop in the channels. Choi and Eastman [1] showed for the first time that use of nanoparticles can minimize the disadvantages of using micrometer-size nanoparticles. They claimed that nanofluids can be better fabricated, are more stable and can be better transferred than conventional solid-liquid suspensions and microfluids. However, from different perspectives, research on nanofluids and its various structures is ongoing. Many studies have shown that use of nanoparticles can present higher thermal properties than traditional cooling methods [2–9].

Solid volume fraction and temperature of nanofluid are the most important factors in variations in thermal conductivity. Masuda et al. studied thermal conductivity of the nanofluids for the first time [10]. They used a two-stage method to prepare nanoparticles. They added 13 nm aluminum oxide, 12 nm silicon dioxide and 27 nm titanium dioxide nanoparticles diameter in water. The results showed 32.4% increase in thermal conductivity of water-aluminum oxide nanofluid at a solid volume fraction of 4.3% at 31.8 °C. There was a linear relationship between thermal conductivity and solid volume fraction. Eastman et al. [11] showed that ethylene glycol containing < 10 nm copper nanoparticles increases thermal conductivity by 40% in a solid volume fraction of 0.3% compared to pure ethylene glycol or ethylene glycol containing other oxide nanoparticles with a similar solid volume fraction. Harish et al. [12] investigated thermal conductivity of nanofluid containing single-walled carbon nanotubes and ethylene glycol. They tested the nanofluid at solid volume fractions > 0.2%. They used the

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THW method to measure thermal conductivity. The results showed a nonlinear enhancement in thermal conductivity by increasing the solid volume fraction and 14.8% increasement was detected in the thermal conductivity at a solid volume fraction of 0.2%.

Temperature is one of the most important parameters in variations in thermal conductivity which considered in many studies. Variations in thermal conductivity are more noticeable in nanofluids with larger particles. Duangthongsuk and Wongwises [13] studied thermal conductivity of titanium dioxide/water nanofluid at different temperatures and solid volume fractions. The results showed that thermal conductivity varies from 0.60 to 0.61 at temperatures from 15 °C to 35 °C at a solid volume fraction of 0.2% and varies from 0.63 to 0.645 by increasing the solid volume fraction to 2%.

In this paper, thermal conductivity of the nanofluid obtained by suspension of functionalized multi-walled carbon nanotubes was assessed in a mixture of water (80%) and ethylene glycol (20%) at temperatures from 25 to 50 °C and solid volume fractions from 0.20 to 0.8%. The relationship of thermal conductivity with temperature and solid volume fraction was also predicted.

2. Experimentation

2.1. Nanofluid preparation

The nanoparticle which used in this study is functionalized multi-walled carbon nanotubes purchased from US Research Nanomaterials Inc. It was prepared in two stage method. The properties and specifications of the nanotubes used in the studied nanofluid are given below in Table 1.

The X-ray diffraction (XRD) pattern was used to determine phases and crystal structure of the nanotubes and was shown in Fig. 1.

In this study, a mixture of water (80%) and ethylene glycol (20%) was used as the base fluid. Ethylene glycol (EG) more properly used for cooling than other fluids. It is mostly used in antifreezes. Chemical and physical properties of water and ethylene glycol are shown in Table 2.

A magnetic stirrer was used for 2.5 h to prepare a stable nanofluid. An ultrasonic device was used for 6 h to ensure stability and dispersion of the nanotubes in the nanofluid. This method was used to obtain a stable nanofluid and breakdown agglomeration of particles. Fig. 2 shows the nanofluid obtained by suspension of functionalized multi-walled carbon nanotubes in a mixture of water and ethylene glycol.

In this study, 0.25, 0.05, 0.1, 0.2, 0.4 and 0.8% solid volume fractions of nanoparticles in the nanofluid were used in 25, 30, 35, 40, 45 and 50 °C.

2.2. Measurement of thermal conductivity

The thermal conductivity of FMWCNTs/Water-EG nanofluid was measured using a KD2 Pro instrument (Decagon Devices, Inc., USA). The accuracy of the instrument is ± 5%. This device measures the thermal conductivity of the fluid using a transient hot wire with KS-1 sensor. Length and diameter of the sensor were 60 mm and 1.27 mm respectively. The sensor was vertically placed in the fluid in a constant temperature bath.

Table 1
Specifications of used multi-walled carbon nanotube.

Parameter	Value
Purity	< 97%
COOH	2.56 (wt%)
Color	Black
Outer diameter	5–15 nm
Inner diameter	3-5 nm
Length	~50 μm
Actual density	~2100 kg/m^3

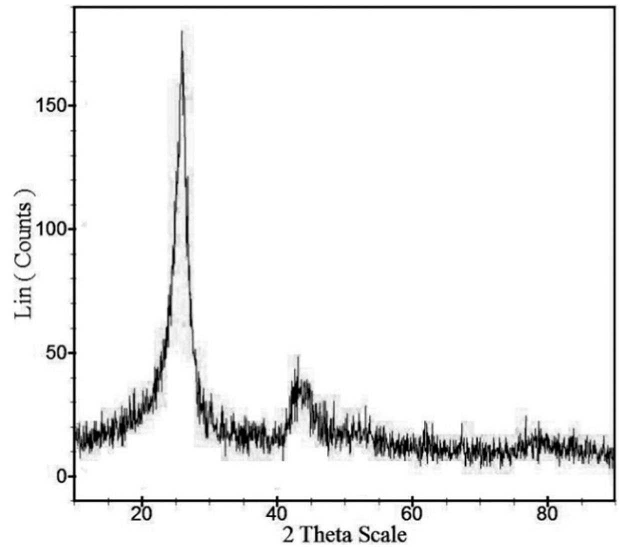

Fig. 1. XRD pattern for multi-walled carbon nanotubes.

Table 2
Chemical and physical properties of water and ethylene glycol.

Parameter	Value	
	Water	Ethylene glycol
Chemical formula	H_2O	$C_2H_6O_2$
Molar mass (g/mol)	18.01528	62.07
Appearance	Transparent, colorless	Light, colorless
Odor	Odorless	Odorless
Density (kg/m^3)	998.21	1113.2
Melting point (°C)	0	−12.9
Boiling point (°C)	100	197.3
Thermal conductivity (at 20 °C) (W/m.K)	0.6	0.244
Viscosity (at 20 °C) (cP)	1	16.1

Fig. 2. Nanofluid obtained by suspension of functionalized multi-walled carbon nanotubes in a mixture of water and ethylene glycol.

The controller recorded the data and calculated the thermal conductivity using temperature variations (∇T). The following equation shows measurement of thermal conductivity by the controller:

$$k = \frac{q(\ln t_2 - \ln t_1)}{4(\nabla T_2 - \nabla T_1)} \quad (1)$$

where ∇T_1 and ∇T_2 show temperature variations at t_1, t_2 times and q shows thermal heat flux.