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An experimental study on thermal conductivity of F-MWCNTs–Fe_3O_4/EG hybrid nanofluid: Effects of temperature and concentration☆

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ABSTRACT

In this paper, an experimental study on the effects of temperature and concentration on the thermal conductivity of f-MWCNTs–Fe_3O_4/EG hybrid nanofluid is presented. The experiments were carried out for solid volume fraction range of 0 to 2.3% in temperatures ranging from 25 °C to 50 °C. The results revealed that the thermal conductivity ratio enhances with increasing the solid volume fraction and temperature. Results also showed that, at higher temperatures, the variation of thermal conductivity ratio with solid volume fraction was more than that at lower temperatures. Moreover, the effect of temperature on the thermal conductivity ratio was more noticeable at higher solid volume fractions. The thermal conductivity measurements also showed that the maximum thermal conductivity ratio was 30%, which occurred at temperature of 50 °C for solid volume fraction of 2.3%. Finally, for engineering applications, based on experimental results, a precise correlation was suggested to predict the thermal conductivity of f-MWCNTs–Fe_3O_4/EG hybrid nanofluids.

1. Introduction

Nanofluids, which were first introduced by Choi [1], are practical colloids composed of a base fluid and the solid nanoparticles. Nanoparticles are usually made of metals, oxides or carbon nanotubes (CNTs). Nanofluids have advanced properties that make them conceivably useful in numerous heat transfer applications such as electronics, heat exchangers, heat pipes, solar collectors and so on [2–6]. Since the thermal conductivity of nanoparticles is higher than that of the base fluids, they enhance the thermal conductivity and heat transfer performance of the base fluids significantly. Accordingly, several researchers reported the thermal conductivity enhancement of nanofluids in many studies [7–16]. All these studies showed that nanofluids improved the thermal conductivity of the base fluids. They also described that the thermal conductivity of nanofluids is dependent on temperature, size and concentration of nanoparticles.

In recent years, there has been concentration on new nanofluids, called hybrid nanofluids, to improve the performance of heat transfer fluids. The hybrid nanofluids can be prepared by suspending various types of nanoparticles in the base fluids. Many studies on the thermal conductivity of hybrid nanofluids can be found in the literature. In this regard, Suresh et al. [17] synthesized Al_2O_3–Cu hybrid particles by hydrogen reduction technique. They prepared Al_2O_3–Cu/water hybrid nanofluids with volume concentrations from 0.1% to 2%. Their results revealed that the thermal conductivity of the hybrid nanofluid increases with the solid volume fraction. The experimental data showed a maximum thermal conductivity enhancement of 12.11% for a solid volume fraction of 2%. Nine et al. [18] investigated the water based Al_2O_3–MWCNTs hybrid nanofluids over 1% to 6% weight concentration. They compared the thermal conductivity of hybrid nanofluids with Al_2O_3/water monotype nanofluids. Their results showed that hybrid nanofluids with spherical particles exhibited a smaller increase in thermal conductivity comparing cylindrical shape particles. Baghbanzadeh et al. [19] synthesized a hybrid of SiO_2/MWCNTs by wet chemical method at room temperature. They investigated the effect of MWCNTs, SiO_2 nanospheres and hybrid nanostructures on the thermal conductivity of distilled water. Their results showed that the maximum and minimum enhancements in the effective thermal conductivity of the fluids were related to MWCNTs and silica nanospheres. They also reported that the enhancement for the hybrid nanomaterial was a value between the monotype nanofluids. Madhesh et al. [20] investigated the thermal conductivity of copper–titania/water hybrid nanofluids in volume concentrations ranging from 0.1% to 2.0% and temperatures ranging from 30 °C to 60 °C. Their results showed that the thermal conductivity of the hybrid nanofluid increases to 60%. Munkhbayar et al. [21] reported significant enhancement in the thermal conductivity of Ag–MWCNTs/water. They showed that the maximum

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thermal conductivity enhancement was achieved by a fluid containing '0.05 wt.% MWCNTs–3 wt.% Ag' composite. Chen et al. [22] examined the effect of combining MWCNTs and Fe_2O_3 nanoparticles on thermal conductivity of water based nanofluids. Their results revealed that the thermal conductivity enhancement of the nanofluid containing 0.05 wt.% MWCNTs and 0.02 wt.% Fe_2O_3 nanoparticles was 27.75%. They reported that this amount was higher than the thermal conductivity enhancement of nanofluid containing 0.2 wt.% single MWCNTs or Fe_2O_3 nanoparticles. Sundar et al. [23] investigated the thermal conductivity of MWCNT–Fe_3O_4/water hybrid nanofluids in temperatures ranging from 30 °C to 60 °C for solid volume fractions of 0.1% and 0.3%. Their experimental data showed a maximum thermal conductivity enhancement of 40%. Hemmat Esfe et al. [24] measured the thermal conductivity of Ag–MgO/water hybrid nanofluid with solid volume fraction range between 0% and 3%. They showed a maximum thermal conductivity enhancement of 20%. Hemmat Esfe et al. [25] investigated the effects of temperature and solid volume fraction on thermal conductivity of CNTs–Al_2O_3/water nanofluids. They conducted the experiments with various solid volume fractions in ranging from 0.02% to 1.0% and various fluid temperatures of 303, 314, 323 and 332 K. their measurements revealed that the maximum enhancement of thermal conductivity was 17.5%.

Previous research study shows that research on the composition of MWCNTs and Fe_3O_4 nanoparticles only has been performed by Sundar et al. [23]. They dispersed the hybrid solid additives in water. Fe_3O_4 nanoparticles are magnetite; thus, fluid flow and heat transfer of this nanofluid can be changed by a magnetic field. In many previous studies, the effects of the magnetic field on fluid flow and heat transfer rate have been reported [26–32]. In this study, for the first time, the composition of functionalized multi-walled carbon nanotubes (f-MWCNTs) and iron oxide (Fe_3O_4) nanoparticles is dispersed in ethylene glycol (EG) as a base fluid. The thermal conductivity of the hybrid nanofluid is examined at different temperatures for various solid volume fractions. Moreover, a comparison between the thermal conductivity enhancement of f-MWCNTs–Fe_3O_4/EG hybrid nanofluid and other monotypes of nanofluids, reported in previous works, is presented. Finally, efforts will be made to provide a precise correlation, as a function of temperature and solid volume fraction, for predicting the thermal conductivity of the hybrid nanofluid.

2. Experimental

2.1. Preparation of samples

In the present study, a two-step method has been employed to prepare the samples. In this way, dry f-MWCNTs and Fe_3O_4 nanoparticles were mixed with an equal volume. This combination was dispersed in ethylene glycol with solid volume fractions of 0.1%, 0.25%, 0.45%, 0.8%, 1.25%, 1.8% and 2.3%. The properties of f-MWCNTs, Fe_3O_4 nanoparticles and ethylene glycol are presented in Tables 1, 2 and 3, respectively. In order to attain a characterization of the sample, the structural properties of dry MWCNTs and Fe_3O_4 nanoparticles were measured using X-ray diffraction and are displayed in Fig. 1.

Table 2
Properties of Iron oxide (Fe_3O_4) nanoparticles.

Parameter	Value
Purity	>98%
Color	Dark brown
Diameter	20–30 (nm)
SSA	40–60 (m^2/g)
Shape	Spherical
True density	4.8–5.1 (g/cm^3)

To attain a suitable dispersion, after magnetic stirring for 2 h, each sample was exposed to an ultrasonic processor (Hielscher Company, Germany) with the power of 400 W and frequency of 24 kHz for optimal duration of 5.5 h. All samples have a good stability and no sedimentation was observed in the long time before the experiments. The photograph of solid particles and nanofluid samples is shown in Fig. 2.

2.2. Thermal conductivity measurement

In the present work, a KD2 Pro (Decagon Devices, Inc., USA) thermal property analyzer, with the KS-1 probe made of stainless steel, is used for measuring the thermal conductivity of the nanofluid samples. This probe is vertically inserted into the nanofluid located in a stable temperature bath. The maximum error of this device is about 5%. Before the experiments, the device was calibrated with glycerin suggested by the company. All the measurements of the thermal conductivity were repeated three times in the temperatures ranging from 25 °C to 50 °C. Based on the experiments, the "thermal conductivity ratio" and "thermal conductivity enhancement" are defined as,

$$\text{Thermal conductivity ratio} = \frac{k_{nf}}{k_{bf}}. \tag{1}$$

$$\text{Thermal conductivity enhancement } (\%) = \frac{k_{nf} - k_{bf}}{k_{bf}} \times 100 \tag{2}$$

where, k_{nf} and k_{bf} are respectively the thermal conductivity of nanofluid and base fluid.

3. Results and discussion

In this study, the examination of the thermal conductivity of f-MWCNTs–Fe_3O_4/EG hybrid nanofluids was performed in the temperature ranging from 25 °C to 50 °C for samples with solid volume fraction of 0.1%, 0.25%, 0.45%, 0.8%, 1.25%, 1.8% and 2.3%. Results were divided into three subsections that are mentioned below.

Table 1
Properties of functionalized MWCNTs.

Parameter	Value
Purity	>97%
Content of –COOH	2.56 (wt.%)
Color	Black
Outer diameter	5–15 (nm)
Inner diameter	3–5 (nm)
Length	~50 (μm)
Thermal conductivity	1500–3000 (W/m·K)
True density	~2100 (kg/m^3)

Table 3
Properties of ethylene glycol (EG).

Parameter	Value
Ignition temperature	410 (°C)
Melting point	−13 (°C)
Molar mass	62.07 (g/mol)
Density	1.11 (g/cm^3)
pH value	6–7.5
Boiling point	197.6 (°C)
Thermal conductivity	0.249 (W/m·K)