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Experimental and theoretical investigation of thermal conductivity of ethylene glycol containing functionalized single walled carbon nanotubes

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ABSTRACT

In this paper, functionalized single walled carbon nanotubes (FSWCNTs) were suspended in Ethylene Glycol (EG) at different volume fractions. A KD2 pro thermal conductivity meter was used to measure the thermal conductivity in the temperature range from 30 to 50 °C. Nanofluids were prepared in solid volume fraction of 0.02, 0.05, 0.075, 0.1, 0.25, 0.5 and, 0.75%. Experimental results revealed that the thermal conductivity of the nanofluid is a non-linear function of temperature and SWCNTs volume fraction in the range of this investigation. Thermal conductivity increases with temperature and nanoparticles volume fraction as usual for this type of nanofluid. Maximum increment in thermal conductivity of the nanofluids was found to be about 45% at 0.75 vol fractions loading at 50 °C. Finally, a new correlation based on artificial neural network (ANN) approach has been proposed for SWCNT-EG thermal conductivity in terms of nanoparticles volume fraction and temperature using the experimental data. Used ANN approach has estimated the experimental values of thermal conductivity with the absolute average relative deviation lower than 0.9%, mean square error of 3.67×10^{-5} and regression coefficient of 0.9989. Comparison between the suggested techniques with various used correlation in the literatures established that the ANN approach is better to other presented methods and therefore can be proposed as a useful means for predicting of the nanofluids thermal conductivity.

1. Introduction

Today it is obviated that in the fields of thermal and fluid science, better understanding of processes involved in microscale fluid flow and heat transfer has become a major concern [1]. In the convection heat transfer, it is approved that working fluid thermal conductivity has a significant role in the heat transfer efficiency. Concerning to this, a new class of fluids, instead of conventional fluid, named as nanofluids was presented. Nanofluids consisting of nano-sized particles dispersed in fluid [2], having this possibility due to their thermal conductivity that are significantly higher than the conventional fluids. Nanofluids thermal conductivity of suspension containing suspended metallic nanoparticles has been reported to be higher than the average values of the conventional heat transfer fluids [3–16]. Higher thermal conductivity directly affects the heat transfer coefficient in heat exchangers and other thermal systems [17–28].

Physical and chemical characteristics of base fluid and solid nanoparticles will influence the thermal conductivity of suspension. For this reason, using appropriate type of solid nanoparticles has vital role for obtaining a suspension with a high efficiency. Some types of nanoparticles are metallic, metallic oxide and carbon nanotubes that are commonly used in the published research works. Among the most used nanoparticles, single, double, or multi-walled carbon nanotubes (CNTs) have gained particular attention due to their thermophysical properties. Published research work showed that carbon nanotubes (CNTs) were the best nanomaterials to prepare nanofluids. In the present investigation, Single Wall Carbone Nanotubes (SWCNTs) has been used as solid nanoparticles. The thermal conductivity of very low volume fractions of this new type of nanoparticles dispersed in ethylene glycol is measured. Here, a brief review on the experimental investigation for measuring and estimating of thermal conductivity is performed.

Hemmat Esfe et al. [29] examined the thermal conductivity of MWCNTs-water nanofluid. Their investigations were done for various temperatures and MWCNTs volume fractions. They reported that the thermal conductivity of MWCNTs-water nanofluid increased with temperature. In addition they observed that temperature has a considerable effect on thermal conductivity at low concentration while opposite behavior was observed at high concentration. In another work by Indhuja et al. [30] experimentally studied the effect of temperature

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and nanoparticles volume fraction on the thermal conductivity of MWCNTs–water nanofluids. They reported that there is an inextricable connection between temperature and thermal conductivity especially for temperatures above 45 °C. Nasiri et al. [31] conducted an experimental investigation on the effect of dispersion method for thermal conductivity and stability of nanofluid. Utilized nanofluids were five different types of carbon nanotubes (CNTs) including: single-wall CNTs (SWNTs); double-wall CNTs (DWNTs); two multiwall nanotubes (MWNTs); and few-wall CNTs (FWNTs). These differences were created to organize nanofluids with three different dispersion methods. Their results showed that the highest thermal conductivity and best stability of nanofluids are associated with functionalized nanofluids.

It is worth to note that in experimental investigation, analytical and numerical techniques have been employed for estimation of nanofluids thermophysical properties [32–42]. Several models have been suggested to predict the dynamic viscosity and thermal conductivity of nanofluids. One of the methods that recently used to predict nanofluids properties is artificial neural network (ANN) [43–55]. In this regard, Hojjat et al. [56] firstly examined thermal conductivity of water-based nanofluids of Al_2O_3, TiO_2, and CuO. After that, they correlated their findings emloying the neural network. They considered three parameters including temperature, volume fraction, and thermal conductivity of nanoparticles. Hemmat Esfe et al. [57] measured thermal conductivity of MgO-EG nanofluids and correlated their measurements by ANN. The used variables in their experimental investigation were nanoparticles volume fraction, temperature, and nanoparticles diameter. They reported that the obtained model was very accurate.

In the present work, for the first time, the thermal conductivity of single wall carbon nanotubes (SWCNTs)–water is experimentally investigated. In this way, nanofluid with different nanoparticles volume fractions and temperatures has been prepared and tested. In addition to measuring the thermal conductivity, a new correlation for estimating the thermal conductivity of nanofluid based on artificial neural network (ANN) has been proposed.

2. Experiment

2.1. Nanofluids preparation

The first step in each experimental study is preparation of nanofluids. Nanofluids are not simply liquid–solid mixtures. Stable suspension, negligible agglomeration of particles, durable suspension and no chemical change in the fluid are some essential and special requirements for this type of suspension named nanofluids. As it is well known, there are two ways to create sustainable nanofluids containing CNTs: 1- using surfactant, and 2- the functionalization of the CNTs. The use of surfactant may lead to the insertion of undesirable effects on the thermal conductivity of the nanofluids. functionalized carbon nanotubes were used to reach sustainable nanofluid (because of it's important effect on nanofluids' stability [58]). Functionalizing SWCNTs by COOH functional groups makes the carbon nanotubes hydrophilic; subsequently, the stability of the prepared nanofluids is better. The properties of COOH functionalized SWCNT's have been described in Table 1.

Table 1
Physicochemical specification of SWCNTTs.

Parameter	Value
Color	black
Purity	Carbon nanotubes > 96 wt%
SSA	> 580 m^2/g
Outer diameter	1–2 nm
Inner diameter	0.8–1.6 nm
Length	15–50 µm
True density	~2.1 g/cm^3

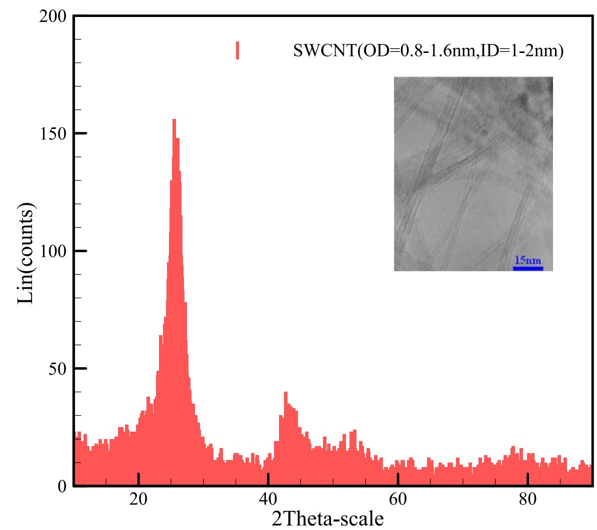

Fig. 1. XRD and TEM image of the SWCNTs.

In this work, nanofluids were prepared by dispersing COOH functionalized SWCNTTs in the ethylene glycol with volume fractions of 0.02, 0.05, 0.075, 0.1, 0.25, 0.5 and, 0.75%. Magnetic stirring was performed for 2 h to mix SWCNTs with water. Next, an ultrasonic processor (power= 400 W, frequency=24 kHz) is used for 6 h for breaking down the cluster of the nanotubes. After 16 h, no sedimentation was observed (with the naked eye) in the samples. A TEM and XRD image of SWCNTs are shown in Fig. 1 to display an approximation of the size and shape of the particles and results.

It should be noted that by functionalizing the carbon nanotubes with COOH, the dispersion of nanotubes will be better in the base fluid. Therefore; there is no need to use a surfactant to have a stable suspension. In this way, the negative effects of surfactant on the thermophysical properties will not be observed.

2.2. Thermal conductivity measurement

Experimental thermal conductivities were done by a KD2 Pro thermal properties analyzer probe instrument manufactured by Decagon Devices, USA. Thermal conductivity measuring principle is based on the transient hot-wire method. In this method, a KS-1 sensor made from stainless steel having 60 mm long and 1.27 mm in diameter is used for measuring the thermal conductivity. It is worth noting that a hot water bath was used in order to stabilize the temperature. The used thermometer has an accuracy of 0.1 °C. Before using this apparatus and starting the experimental procedure, KD2 was previously checked and calibrated with distilled water. Thermal conductivity has been measured within the range of temperature from 30 °C to 50 °C and at nanoparticles volume fraction up to 0.75. In addition, every test at any temperature and nanoparticles volume fraction is repeated three times. For better measuring and evaluating the enhancement of nanofluids, it is important to measure both the nanofluid and base fluid with a unique technique and the same temperature range. For this reason, thermal conductivity of Ethylene Glycol was also measured in the whole range of temperature. It must be noted that the uncertainty related to thermal conductivity measurement is inferior to 3%.

2.3. Thermal conductivity of nanofluids

Thermal conductivity of the FSWCNTs-EG nanofluid has been measured. The thermal conductivity values have been measured by the KD2 pro instrument at various nanofluid concentrations over the temperatures ranging from 30 °C to 50 °C. Fig. 2 shows the thermal conductivity ratio (TCR) with respect to a solid volume fraction and temperature. According to the figure, in each temperature adding

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