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Effects of temperature and concentration on the viscosity of nanofluids made of single-wall carbon nanotubes in ethylene glycol☆

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ABSTRACT

This paper includes an examination of the dynamic viscosity of single-wall carbon nanotubes (SWCNTs) in ethylene glycol (EG) at temperatures ranging from 30 °C to 60 °C for various suspensions at solid volume fractions of 0.0125%, 0.025%, 0.05%, 0.075%, and 0.1%. Experimental findings revealed that SWCNTs/EG nanofluid behaves as a Newtonian fluid at solid volume fractions of 0.1% and at all considered temperatures. The measurements also indicated that dynamic viscosity increases with increasing solid volume fraction and decreases with increasing temperature. Moreover, relative viscosity results showed that that the viscosity of the nanofluid increases to 3.18 times that of the base fluid at a temperature of 30 °C and a solid volume fraction of 0.1%. Finally, using experimental data to estimate the dynamic viscosity of SWCNTs/EG nanofluid, a new correlation with acceptable accuracy was suggested.

1. Introduction

Ethylene glycol (EG) is an organic complex that is mostly used as a raw material in the manufacture of polyester fibers for the fabric industry. It is also used as an ingredient in engineering applications, such as for antifreeze and other industrial products. The most important use of EG is as a material for convective heat transfer in automobiles, chilled-water air conditioning systems, geothermal heat pumps, heat exchangers, liquid-cooled computers, and systems that must be cooled to below water's freezing temperature. However, EG has low thermal conductivity, which many researchers have tried to increase it. In this way, the researchers found that adding nanoparticles into traditional liquids (such as water, oil, and EG) can lead to an increase in thermal conductivity [1–6]. When nanoparticles are added into EG to increase its thermal conductivity, other thermo-physical properties are also affected, including viscosity [7–11]. Hence, viscosity changes due to the addition of nanoparticles to EG should be considered.

Many researchers have experimentally studied the effects of temperature and the concentration of metal or metal oxide nanoparticles on the viscosity of nanofluids containing EG. A brief review of the previous research on the viscosity of nanofluids is provided in Table 1. In these works, the authors showed the behavior of nanofluids for various temperatures, nanoparticle concentrations, and nanoparticle sizes. Moreover, they showed that these fluids behaved in a non-Newtonian fashion in some experiments.

In the many studies, the measured viscosities of nanofluids were compared with existing well-known models. One of these models was introduced by Batchelor [22], who presented a correlation to predict the viscosity of nanofluids with spherical nanoparticles:

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 + 2.5\varphi + 6.2\varphi^2\right) \tag{1}$$

Moreover, Wang et al. [23] proposed a model for predicting the viscosity of nanofluids:

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 + 7.23\varphi + 123\varphi^2\right) \tag{2}$$

In the above-mentioned studies, researchers focused on evaluating and comparing the effects of different nanoparticles on the thermophysical properties of various base fluids. Carbon nanotubes (CNTs) have been among the most-studied nanoparticles because of their unique properties. Despite CNTs' potential, their rheological behaviors have received comparatively little attention in the literature. Previous works carried out by Vakili-Nezhaad and Dorany [24,25], Chen et al. [26], Vasheghani et al. [27], Bobbo et al. [28], Ettefaghi et al. [29,30], and Hemmat Esfe et al. [31,32] deal with this issue. Although some information is currently available on the rheological behaviors of CNT,

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Table 1
A summary of experimental works for the viscosity of nanofluids containing EG.

Authors	Base fluid	Nanoparticles	Size (nm)	Temperature range (°C)	Volume fraction (%)
Namburu et al. [12]	EG:water	CuO	29	(−35)–50	0–6.12
Sahoo et al. [13]	EG:water	Al_2O_3	53	(−35)–50	1–10
Sundar et al. [14]	EG:water	Fe_3O_4	5–70	0–50	0–1
Vajiha and Das [15]	EG:water	Al_2O_3	45	20–90	10
		CuO	29		6
		SiO_2	20, 50, 100		10
Yiamsawas et al. [16]	EG:water	Al_2O_3	120	15–40	0–4
		TiO_2	21		
Said et al. [17]	EG	Al_2O_3	13	25–80	0.05–0.1
Hemmat Esfe et al. [18]	EG	ZnO	18	25–50	0.25–5
Elias et al. [19]	EG:water	Al_2O_3	13	10–50	0–1
Sundar et al. [20]	EG:water	Al_2O_3	36	20–60	0–1.5
Hemmat Esfe et al. [21]	EG:water	MgO	NA	20–50	0–3

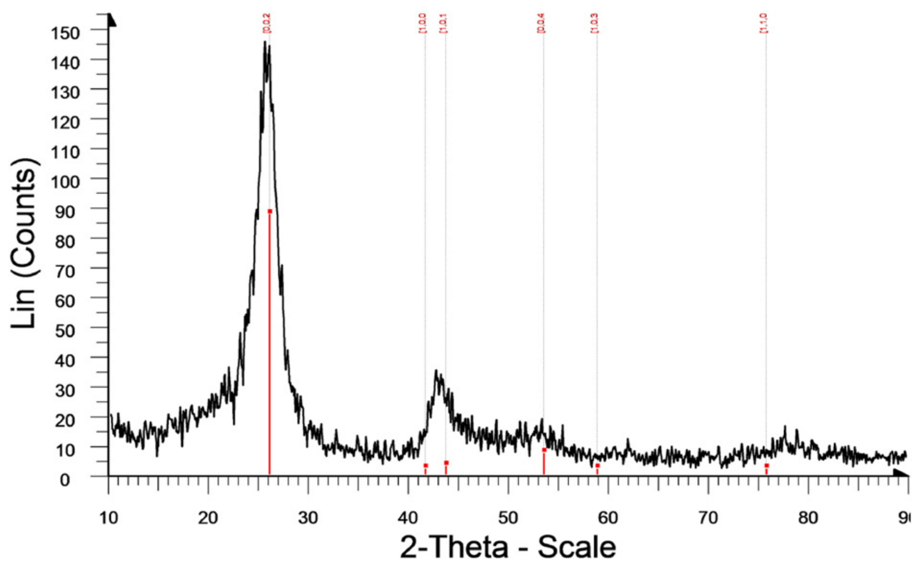

Fig. 1. XRD pattern for single-wall carbon nanotubes.

room for further research remains, especially regarding the effects that relevant parameters have on the viscosity of nanofluids made of single-wall carbon nanotubes (SWCNTs) in EG.

In this work, SWCNTs/EG nanofluid was prepared at various solid volume fractions. The effects of nanoparticle concentration and temperature on the dynamic viscosity of the nanofluids were examined by a viscometer. Moreover, the measured viscosities of the nanofluids were compared with those obtained from the existing models [22,23]. Finally, using experimental data, a new correlation was suggested to predict the dynamic viscosity of SWCNTs/EG nanofluid in engineering applications.

2. Experiments

2.1. Samples preparation

In the present work, SWCNTs were dispersed into an EG base fluid. SWCNTs/EG nanofluids with solid volume fractions of 0.0125%, 0.025%, 0.05%, 0.075%, and 0.1% were prepared using a two-step method. In order to create stable SWCNTs/EG nanofluids, after magnetic stirring for 2 h, the suspensions were exposed to an ultrasonic processor (Hielscher Company, Germany) for 6 h. In order to obtain a characterization of the sample, the structural properties of the dry SWCNTs were measured by X-ray diffraction, as presented in Fig. 1.

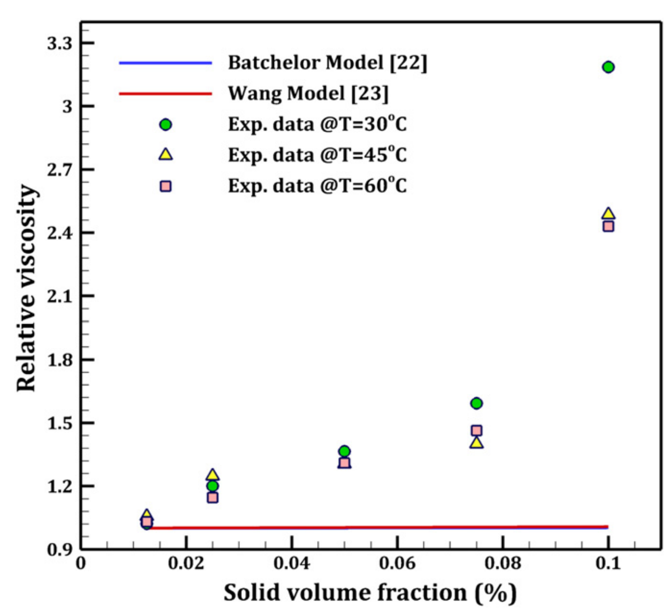

Fig. 2. Comparison between theoretical models and experimental findings.