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An experimental determination of thermal conductivity and electrical conductivity of bio glycol based Al_2O_3 nanofluids and development of new correlation☆

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ABSTRACT

Nanofluid, as a kind of new engineered material consisting of nanometer-sized additives and base fluids, has attracted great attention from investigators for its superior thermal properties and many potential applications. In this paper, the thermal conductivity, dispersion stability and electrical conductivity of 100% bioglycol (BG) based nanofluids containing Al_2O_3 nanoparticles were studied in a temperature range of 30 to 80 °C. Nanofluids with 0.1, 0.3, 0.5, 0.7, and 1% volume concentrations were prepared using the two-step method without using surfactant. The nanofluids demonstrated excellent stability over this temperature range after using long-term sonication. A new correlation has been developed for the thermal conductivity of nanofluids as a function of temperature and particle volume concentration. This study also revealed that the thermal conductivity enhancement of bio glycol (BG), ethylene glycol (EG) and propylene glycol (PG) of 1.0% volume concentration at 30 °C was 17%, 9% and 3.6% respectively. However, the increment in temperature reacts inversely to the thermo-electrical conductivity (TEC) ratio. The maximum value of TEC is 9.5 at 0.5% volume concentrations and temperature of 30 °C.

1. Introduction

The primary goal of nanofluid research over the past years was to develop thermo-physical properties of the fluid. Certainly the heat-transfer processes have an affective role in most of the areas of industrial engineering, which is represented in power generation, air conditioning, automotive and chemical processors [1–6]. Over the past decades, there has been a dramatic increase in using water, ethylene glycol and propylene glycol-based nanofluids due to their vast applications in the transfer of thermal energy [7–11]. The first paper on properties evaluation of nanofluids was presented by Matsuda et al. [12]. They studied the effect of Al_2O_3, SiO_2 and TiO_2 nanoparticles dispersed in water on the thermal conductivity and viscosity of the nanofluid. Since then, nanofluids have attracted wide attention as exhibited by the enormous increment in the publications on this subject. It is worth to note that the majority of these studies adopted water-based nanofluids that are often tested within the surrounding temperatures [10,13–16], followed by many other researches up until today.

Several investigations have been conducted on the role of ethylene glycol-based nanofluids in the heat transfer enhancement [17–20]. Sundar et al. [21] carried out an experimental study of thermal conductivity of ethylene glycol/water of (50:50) by weight based of Al_2O_3 and CuO nanofluids. The results demonstrated that both types of nanofluids show higher thermal conductivity compared to base fluids while CuO exhibited better enhancement than Al_2O_3. Abdul Hamid et al. [22] studied the thermal conductivity enhancement of Al_2O_3 in pure ethylene glycol with a wide range of volume concentration and working temperature ranged from 30 °C–80 °C. The result showed the maximum enhancement of 21.1% in thermal conductivity at a temperature of 70 °C and 2.0% of volume concentration. In another study, Elias et al. [23] experimentally investigated the thermal conductivity, specific heat, density, and viscosity of Al_2O_3 nanoparticles dispersed in ethylene glycol/water. The properties have been measured at different volume concentrations (0 to 1 vol.%) and a wide range of temperature (10 °C to 50 °C). The results illustrated that all thermo-physical properties increased with an increase of temperature except the specific heat. Additionally, the thermal conductivity and specific heat increase with an increase in temperature.

In spite of its versatility, the use of propylene glycol (PG) as the base liquid has been rarely investigated [24–26]. Recently, Palabiyik [27] studied propylene glycol-based nanofluid of both alumina (Al_2O_3) and titania (TiO_2) nanoparticles with a temperature range of 20–80 °C and volume concentrations of 1, 6 and 9%. The result showed that the enhancement of thermal conductivity was a nonlinear function of concentration and was temperature independent. In a different study by Suganthi and Rajan [28], they experimentally investigated the influence of ZnO dispersed in propylene glycol/water (20:80) with particle

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Nomenclature

ATC	temperature compensation
$C\mu$	viscosity enhancement
BG	bio glycol
EG	ethylene glycol
PG	propylene glycol
D	fractal index, which has an average value of 1.8 for nanofluids
TEC	thermo-electrical conductivity ratio
HS	Hashin–Shtrikman model
k_o	thermal conductivity of base fluid, W/m K
k_{BG}	thermal conductivity of bio glycol, W/m K
m	mass, gram
r	radius of primary nanoparticles, nm
r_a	radius of aggregates nanoparticles, nm
k_a	thermal conductivity of agglomerates
n	empirical shape factor

Greek symbols

ϕ	volume concentration, %
φ	volume fraction, $\varphi = (\phi/100)$
φ_a	volume fraction of aggregates
φ_i	volume fraction of agglomerates, $\varphi_i = (r_a/r)^{D-3}$
ρ	density, kg/m^3
σ	electrical conductivity
α	conductivity ratio, $\alpha = (\sigma_p/\sigma_{bf})$

Subscripts

bf	base fluid
eff	effective
nf	nanofluid
p	particle

volume concentration lower than 2% and temperature of 15–50 °C. The results revealed higher thermal conductivity enhancements at lower temperatures. A number of studies have found that the dispersion and stability of nanofluids are the essential characteristics in the enhancement of thermo-physical properties of nanofluid especially the thermal conductivity [17,29,30]. Uniform dispersion and stable suspension of nanoparticles in the liquids are the key to most applications of nanofluids since the final properties of nanofluids are determined by the quality of the dispersed state of the suspension [31–34]. Many researchers have reported the necessity of proper dispersion of nanofluids and various dispersion techniques [35]. They also measured thermal conductivity as a function of ultra-sonication (physical technique) time and showed that long hours of ultra-sonic dispersion are required to improve particle dispersion [36].

In recent years, very few experimental works have been reported on the electrical conductivity of nanofluids. The change in electrical conductivity of alumina-based fluids with particle fraction and temperature was studied by Ganguly et al. [37]. They showed a linear rise of electrical conductivity with particle fraction and almost no variation with temperature. Ganguly et al. [37] and Cruz et al. [38] both claimed that the electrical conductivity of nanofluids is related to its stability. Also, the most commonly used thermal conductivity measurement method of transient hot wire gets significantly affected by the electrical conductivity of nanofluids. Thus, this is an important parameter for the characterization of nanofluids and it needs similar attention as thermal conductivity of nanofluids. These electrically conducting fluids have a variety of applications such as field-induced pattern formation in colloidal dispersion [39,40] and electrically conducting adhesive technology [41]. Electrical conductivity of a nanofluid is inextricably linked to the ability of charged ions in the nanofluid to carry electrons, which is also termed as charges whenever an electric potential is applied [42]. This is perhaps due to the electrical double layer formation around the dispersed nanoparticles surface. Meanwhile, the whole structure movement towards oppositely charged electrode is measured as electrical conductivity of a nanofluid.

Bio glycol (BG), a new generation of glycol family, has demonstrated some pros compared to water, for instance a much lower freezing point and a much higher boiling point (−46 °C to 177 °C). Moreover, one of the BG attributes has a lower thermal conductivity than water of about one-third. Additionally, BG solution can be produced domestically, renewably sourced fluid, non-toxic, and at low temperatures provides 30% lower viscosity compared to propylene glycol, which is petroleum-derived. Moreover, it has greater thermal stability while possessing similar or even better thermo-physical properties compared to propylene and ethylene glycols. It offers better performance than propylene glycol while giving its users an environmentally safer product than ethylene glycol. The temperature-dependent material properties for the bio glycol can be found on the Dynalene manufacturer's website [43].

Literature reviews have indicated that no academic report has been found so far using bio glycol as base fluid in nanofluids. Therefore, this study aims to experimentally investigate the stability, thermal conductivity and electrical conductivity of bio glycol based Al_2O_3 nanofluid. A new correlation of thermal conductivity model for a wide range of volume concentrations (0.1, 0.3, 0.5, 0.7 and 1%) and temperature range from 30 °C to 80 °C has been proposed. The thermal conductivity data obtained in the present work are then compared to different models and correlations available in the literature as well as to pure ethylene and propylene glycol.

2. Experimental setup

2.1. Nanofluid preparation

Aluminum oxide (Al_2O_3) nanopowder with 99.8% metal basis from Sigma-Aldrich Company, USA was used in the current study. A median particle size of 13 nm and a density of 4000 kg/m^3, as shown in Fig. 1, were used. Pure bio glycol was used as a base fluid during the experimental investigation. The experiments were conducted at 0.1, 0.3, 0.5, 0.7 and 1 vol.% of Al_2O_3 nanofluids by dispersing alumina in pure bio glycol. A two-step method, which is the most applied methods based on the literature survey [35,44–46], was used to prepare the nanofluids.

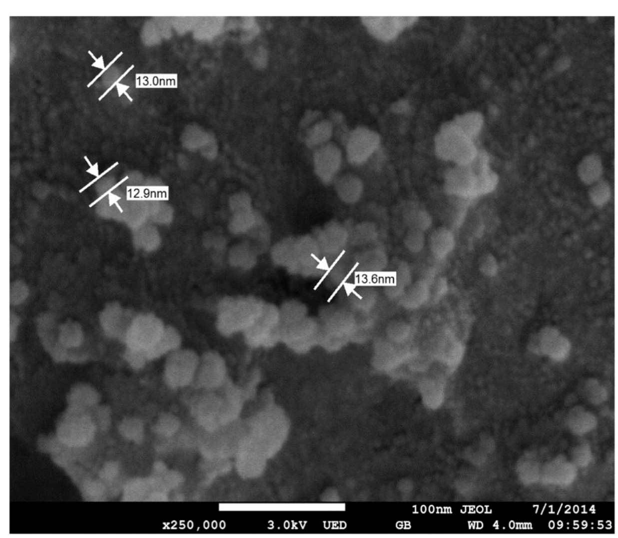

Fig. 1. FESEM image of dry Al_2O_3 nanoparticles at × 250,000 magnification.