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# Experimental investigation of thermal and electrical conductivity of silicon oxide nanofluids in ethylene glycol/water mixture

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ABSTRACT

In this paper, the thermal conductivity and electrical conductivity of $SiO_2$ nanofluids using mixture of ethylene glycol (EG) and water ($H_2O$) as the base fluid are investigated. The two-step method was used to prepare $SiO_2$-EG/$H_2O$ nanofluids with a mass concentration of 0.3%. The variations in thermal conductivity and electrical conductivity as functions of EG concentration (0–100%, v/v) and temperature (25–45 °C) are present. Experimental results showed that the thermal conductivity and electrical conductivity of $SiO_2$-EG/$H_2O$ nanofluids both decreased as the EG content percentage increases in the EG/$H_2O$ mixture. At a specific EG content percentage, thermal conductivity and electrical conductivity both increased with the increase in temperature. To better evaluate the enhancement performance of $SiO_2$-EG/$H_2O$ nanofluids, the relative electrical conductivity was introduced and studied explicitly. The mechanism of electrical conductivity enhancement in $SiO_2$-EG/$H_2O$ nanofluids was analyzed in detail. Meanwhile, the ratio of thermal conductivity and electrical conductivity was also discussed.



## 1. Introduction

The generation of heat energy has a negative effect on lots of machines and instruments. Thus, heat transmission is very important to majority of the fields of industrials engineering such as electric generation, solar collector, air-condition, and automobile [1–4]. The common and traditional fluids used in heat exchanger are water, ethylene glycol (EG), etc. In the past decades, more and more research has been performed to improve the heat transfer performance of these traditional fluids. Among these, preparing nanofluids based traditional fluids is an attractive study direction. The nanofluids are low-concentration suspensions of metallic or nonmetallic nanoparticles with sizes typically of 1–100 nm in a base fluid, e.g. water, oil and alcohol [5].

Murshed et al. [6] investigated the thermal conductivity of titanium dioxide ($TiO_2$) nanofluids and aluminum (Al) nanofluids. They found that the thermal conductivity of $TiO_2$/EG nanofluids (particle volumetric loading 5%) exhibited 18% enhancement compared with that of base fluid. And the enhancement is 45% for Al/EG nanofluids with the same concentration. Hong and co-workers [7] made a study about thermal conductivity of Fe/EG nanofluids. Research results showed that the thermal conductivity of Fe nanofluids (0.55 vol%) was increased to 118% compared with that of base fluid. Sundar et al. [8] conducted an experiment to research the thermal conductivity and viscosity of $Al_2O_3$ nanofluids. They employed EG/$H_2O$ (20:80%. v/v) as a base fluid, and they discovered that at a particles concentration of 0.3 vol%, the thermal conductivity enhancement reached to 11% at a temperature of 20 °C. The work of Li and co-workers [9] also achieved a noticeable thermal conductivity enhancement by applying 50-nm ZnO nanoparticles and EG as the base fluid. To further employed this nanoparticle for natural heat transfer study, the thermal conductivity of ZnO-EG/$H_2O$ nanofluid was also studied under different EG and $H_2O$ ratios (v/v) [10]. In addition, there are still lots of articles about thermal conductivity of various nanofluids, such as CuO [11], Cu [12], and $ZrO_2$ [13]. These articles commonly declared that nanofluids could effectively increase thermal conductivity of based fluids. As is well-known, the key technology to improve the heat transfer properties of traditional fluids is increasing the thermal conductivity [14]. Nanofluid has a more superior heat transfer performance when compared with pure liquids and promises to be a new heat transfer medium [15–18]. More investigations and research need to be performed before commercialization and industrialization for nanofluids.

Recent few decades, nanofluids have attracted increasing attention and the reported properties about various nanofluids mainly involve thermophysical properties, natural convection capability, boiling heat transfer performance, etc. A major goal of our research is to assess the effect of temperature and the proportion of EG on thermal conductivity of $SiO_2$ nanofluids. $SiO_2$ nanofluid was chosen because it is of a lot of excellent performances, such as stable

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chemical properties, insulation, easy to synthesis, and economy. There are a lot of literatures about the variety of properties of $SiO_2$ nanofluids including the thermal conductivity. In the study of Pang et al. [19], the $SiO_2$ nanofluids using methanol as the base fluid were prepared and the thermal conductivity increased in an increase of the nanoparticle volume concentration. According to the experimental results of Zhu et al. [20], the thermal conductivities of $SiO_2$ nanofluids were higher than those of base fluids, and increased with the increase of volume fraction and temperature. Other research about the thermal conductivity of $SiO_2$ nanofluids all drew basically the same conclusion. Although there are some literatures reporting the influence factors of thermal conductivity of $SiO_2$ nanofluids, e.g., nanoparticle concentration, temperature, diameter of nanoparticle, there are few literatures concerning to the effect of composition of the base fluid.

In addition to the thermal conductivity of $SiO_2$ nanofluids, electrical conductivity is another important property of nanofluids. The electrical conductivity of nanofluids is related to the ability of charged particles in the nanofluids to carry the charges toward respective electrodes when an electric potential is applied [21]. The ratio of thermal conductivity and electrical conductivity is considered as an essential index to evaluate the feasibility of a certain nanofluid to be implemented in an electrically active heat transfer application [22]. The stability of a suspension depends on its electrostatic characteristics such as isoelectric point (IEP) and zeta potential which play a critical role in the electrical conduction process [23]. Thus, the electrical conductivity of nanofluids is well worth studying because it is related to the stability of nanofluids and might provide valuable information about the stability of nanofluids. However, few literatures about the electrical conductivity of nanofluids were published. The experimental work concerning to the electrical conductivity of $SiO_2$ nanofluids is rare.

To the best of our knowledge, although the thermal conductivities of $SiO_2$ nanofluids are widely investigated, the effect of the composition of base fluid on thermal conductivity of $SiO_2$-EG/$H_2O$ nanofluids is few or not comprehensively mentioned in the literatures. And almost no research concerns the electrical conductivity of $SiO_2$-EG/H2O nanofluids. In this work, $SiO_2$-EG/$H_2O$ nanofluids were prepared by the two-step method with the help of magnetic stirring and ultrasonic oscillation. The morphology and structure of the $SiO_2$-EG/$H_2O$ nanofluids were characterized by X-ray diffraction (XRD) and transmission electron microscopy (TEM). The objective of this work was to experimentally investigate the effect of temperature and the mix ratio of $H_2O$ and EG on the thermal and electrical conductivity of $SiO_2$-EG/$H_2O$ nanofluids. What's more, the electrical conduction mechanism of $SiO_2$-EG/$H_2O$ nanofluids was discussed.

## 2. Experiment

### 2.1. Preparation of nanofluid

$SiO_2$ nanoparticles (Beijing Dk Nano technology Co. LTD, China) with an average diameter of 30 nm and purity of 99.9% were used in this work. Base fluids were prepared by mixing both distilled water (Robust Co. Ltd, China) and EG (Aladdin Industrial Co. Ltd, China) to yield a 40 -mL base fluid. The purity of EG is 99.9% and it was used without any purification. The $SiO_2$-EG/$H_2O$ nanofluids were prepared by the two-step method without using any surfactant. The mass fraction of nanofluids was calculated from the weight of dry $SiO_2$ powder and the total weight of the suspension using the Eq. (1).

$$\varphi = m_p \Big/ \left( V_{EG} \cdot \rho_{EG} + V_{H_2O} \cdot \rho_{H_2O} + m_p \right) \tag{1}$$

where $m_p$ means the mass of the $SiO_2$ nanoparticles, the $V_{EG}$ and $V_{H_2O}$ represent the volume of EG and $H_2O$ respectively, and the $\rho_{EG}$ and $\rho_{H_2O}$ represent the density of EG and $H_2O$ respectively. By using a sensitive electronic balance (BSA423S, Sartorius Scientific Instruments Co. LTD, Germany) with an accuracy of 1 mg, nanoparticle sample preparation was carried out. Then nanoparticles were dispersed into the base fluid with a mass concentration of 0.3%. The electrical conductivities of the $H_2O$ and EG at 25 °C are 5.44 μS/cm and 0.33 μS/cm by measurement. With a magnetic stirring (HJ-6, Jintan JIERUIER electric appliance Co. LTD, China) for 6 h and an continuous ultrasonic oscillation (40 kHz, PS-100A, Jie kang ultrasonic cleaning machine Co. LTD, China) for 2 h, the nanofluid mixture was well blended.

### 2.2. Characterization

The structural property of the dry $SiO_2$ nanoparticles was evaluated by using X-ray diffraction (XRD, D8 ADVANCE, BRUKER AXS GMBH, Germany). The TEM analysis of the $SiO_2$ nonoparticles sample was used to illustrate the descriptive details about $SiO_2$ nonoparticles. An UV–visible spectrum (TU-1810, Beijing Purkinje General Instrument Co. LTD, China) was performed to show the stability of $SiO_2$- EG/$H_2O$ nanofluids.

The thermal conductivities of the nanofluids were measured using a transient hot-wire apparatus (TC 3020L, Xi'an Xiatech Electronic Technology Co. LTD, China). The accuracy of this transient hot-wire apparatus is ±2–3% and its measuring range is 0.001–20 W/m K. The operating temperature range of this instrument is between −160 and 150 °C. For the measurement of the electrical conductivity of nanofluids, an electric conductometer (3175–307, Jenco Instruments Inc., America) with a pair of electrodes (Model No. 109 L, Serial No. JC03345) was applied. The accuracy and measuring range of the device are ±0.5% and 0.0–199.9 μS/cm, respectively. It has two conductivity resolutions: 0.01 μS/cm for conductivity range from 0.00 to 19.99 μS/cm and 0.1 μS/cm for conductivity range from 2.00 to 199.9 μS/cm. To ensure that the stability of the sample did not impact the measurements and results, each sample needs a continuous ultrasonic oscillation before any measurements. During the measuring process of thermal and electrical conductivity, a T-type thermocouple (SMCL-1, Zenith International Trade CO. LTD, China) with an accuracy of ±0.5% and a data acquisition instrument (Agilent 34972A, USA) were used to detect the temperature of nanofluids. In addition, a temperature-controlled bath was used to keep constant temperature of every nanofluids sample during measurements. To ensure the uniformity of temperatures between the thermal conductivity and electrical conductivity, all measurements were started at a temperature of 25.0 °C and increasing to 45 °C in a 5 °C interval.

### 2.3. Calibration of devices

To ensure the accuracy of the devices to measure the thermal conductivity, pure drinking water (Cestbon Co. Ltd, China) was measured as standard sample. Calibration result of the thermal conductivity measuring instrument is available in Ref. [9]. To further ensure the precision and repeatability of the electrical conductometer, electrical conductivity of standard sample [0.1 mM potassium chloride (KCl) solution] was measured 10 times. The standard electrical conductivity of the solution at 25 °C should be 14.94 μS/cm [24,25]. Results of the measurement are within the limits of 14.9–15.0 μS/cm. Table 1 shows the measuring values of electrical conductivity of the standard KCl solution at 25 °C. The maximum error is ±0.40%, which proved the reliability of the conductometer.