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Electrical Properties of Aluminum Oxide–Ethylene Glycol (Al_2O_3–EG) Nanofluids

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Nanofluids are suspensions of nanometrical size particles in a liquid base, which is usually water, oil or ethylene glycol. The potential practical use of nanofluids caused in recent years a considerable intensification of research into their properties. The most widely studied of physical properties include the fluid rheology, thermal conductivity and electrical parameters. The paper presents electrical properties of aluminium oxide (Al_2O_3) nanofluids based on ethylene glycol (EG). Nanoparticles used to produce nanosuspensions employed in measurements have size between 100–300 nm. Electrical properties was investigated in a wide range of temperatures ($-10\,^{\circ}$C–$55\,^{\circ}$C) and frequencies (0.02–200 kHz) using a measuring LCR bridge connected to a temperature stabilization system based on liquid nitrogen and Peltier element.

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1. Introduction

In recent years nanofluids have become one of the most widely studied nanomaterials. They owe it to their properties that allow to the widespread use in industry, engineering or medicine. The largest application area for nanofluids is believed to be in the transfer of heat and stability, miniaturized systems with microchannel cooling without cogging and reduction in pumping power [1]. The main areas of research nanosuspensions focus on their mechanical properties [2, 3], thermal conductivity [4, 5], and electrical conductivity.

The study of the electrical properties of nanofluids describes only a few papers at the moment, which focused mainly on the electrical conductivity of water-based nanofluids [6–11], even fewer papers describing permittivity of nanosuspensions [10, 12]. There is a several ways to measuring electrical properties of nanofluids. The width overview on those measurement techniques was presented by Tereshchenko et al. [13] and Venkatesh et al. [14]. Further research can contribute to a better understanding of the electric charge transport processes in nanosuspensions.

2. Materials and methods

2.1. Materials and sample preparation

Nanosuspensions applied in presented measurements results were prepared using two-steps method with commercially available α–Al_2O_3 from Taimei Chemicals (Japan). The average particle size was determined by the scanning electron microscopy (SEM) Nova NanoSEM 200 (FEI, Hillsboro, USA) and Zetasizer Nano ZS (Malvern Instruments Ltd, Worcestershire, UK) and is approximately 230 nm. Figure 1 shows SEM pictures of dry Al_2O_3 nanoparticles.

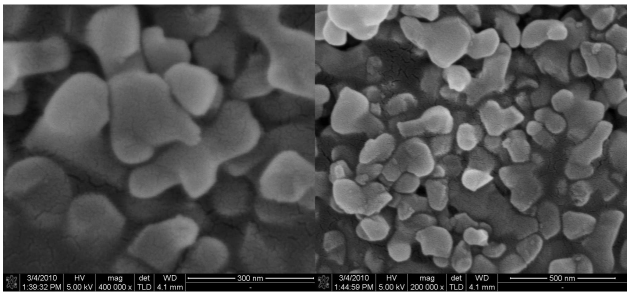

Fig. 1. SEM image of dry Al_2O_3 nanoparticles.

Samples for the measurements has been prepared as Al_2O_3 suspension in ethylene glycol (pure p.a., Chempur, Poland). Samples were prepared with mass concentration from 5% to 25% with 5% step, using an analytical balance AS 220/X (Radwag, Radom, Poland). Each sample was mechanically stirring for 30 min in a Genius 3 Vortex (IKA, Staufen, Germany). The last stage of sample preparation is to break up of the agglomerates using ultrasonic bath for 200 min Emmi-60HC (EMAG, Moerfelden-Walldorf, Germany). This sample preparation procedure is the same as previously used by us for the preparation of $MgAl_2O_4$-DEG nanofluids and is described in detail in Refs. [15–17].

2.2. Measurements methods

All measurements have been performed on a new measuring station built specifically for this purpose. This

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stand used a parallel measurement method of measuring conductivity and permittivity. Measuring system consists of LCR-Bridge Hameg HM8118 (LCR-Bridge HM 8118, HAMEG Instruments GmBH, A Rohde &Schwarz, Mainhausen, Germany) and the temperature controller Linkam TMS 94 (T94 — controllers, THM600 — stages, Linkam Scientific Instruments Ltd., Tadworth, UK) based on liquid nitrogen and a Peltier module. The stand is controlled by the software made in LabView (ver. 12.0f3). LCR-Bridge is connected to the measuring cell, which is in THM600 stage. A measuring cell is made of two metal plates with a thickness of 0.5 mm. Teflon insulator with the thickness of 1.68 mm is placed between metal plates. In the middle of the Teflon insulator is a place for a sample with diameter of 5.3 mm and 1.68 mm in thickness.

All measurements were performed in a wide range of temperatures and frequencies. The temperature was changed in the range from $-10\,^{\circ}$C to $55\,^{\circ}$C in steps of $5\,^{\circ}$C. The frequency was varied from 20 Hz to 200 kHz in 37 steps.

Electrical conductivity was calculated using a simple formula

$$\sigma = \frac{G}{l}A, \qquad (1)$$

where l — distance between metal plates, A — surface area of active plate and both are constants and are respectively 1.68 mm and 22.06 mm^2. Conductance G was measured directly by LCR-Bridge.

3. Results and discussion

Electrical properties of nanosuspensions as well as other materials depend on frequency and temperature, especially for the high value of frequency. These relationship for Al_2O_3–EG nanofluids was shown in Fig. 2.

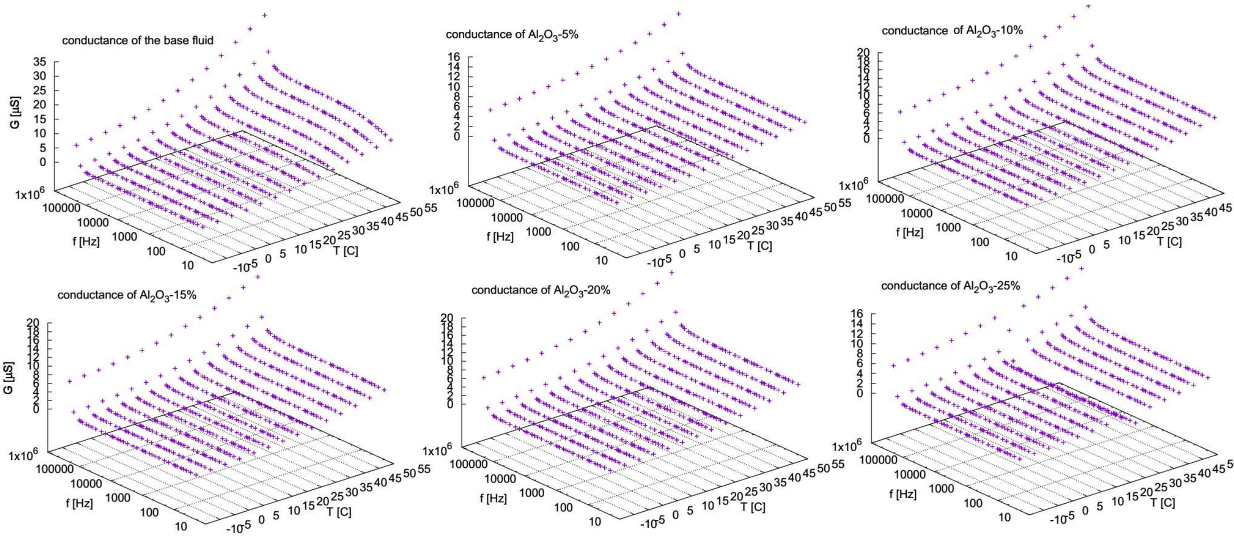

Fig. 2. Conductance, G of Al_2O_3 nanoparticles in ethylene glycol as function of frequency f [Hz] and temperature T [°C] for various mass concentration of particles in nanosuspensions.

It can be seen that changes of electrical conductivity of low frequency electric field are negligible, and conductivity can be considered as constants. The present paper investigates the influence of temperature and mass concentration of particles in the nanofluids on the electrical conductivity of Al_2O_3–EG nanofluid in electric field of low frequency. The results of the measurements are presented in Fig. 3. The study shows that increase of mass concentration of Al_2O_3 nanoparticles in based fluid causes increase in electrical conductivity.

This phenomenon becomes more visible for higher temperatures. Similar studies with Al_2O_3 nanoparticles was conducted by Ganguly et al. [6] and Sarojini et al. [7]. They studied Al_2O_3 nanoparticles in water suspensions, and also observed increase of electrical conductivity with increasing temperature and concentration of nanoparticles in based fluid.

Figure 4 shows the dependence of conductivity on the mass concentration of particles in nanosuspensions at various temperatures. It can be seen that electrical conductivity is the highest for 10% mass concentration. This is unexpected result and incompatible with Maxwell theory. According to this theory and confirmed by Barchini et al. [18] this relationship should be linear for small concentrations nanoparticles in based fluid. To explain this unexpected phenomenon it is necessary to expand a study of electrical properties of these nanosuspensions.

4. Conclusions

The paper presents results of measurements of electrical conductivity of Al_2O_3–EG nanofluids. Samples were

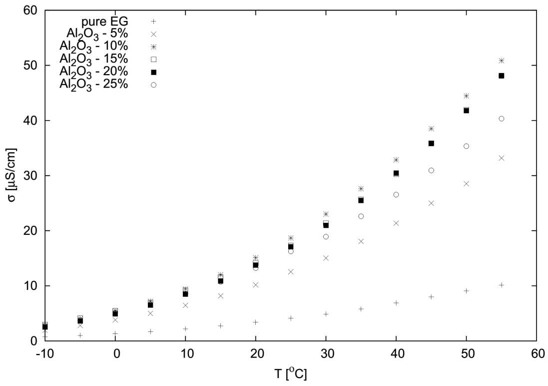

Fig. 3. Dependence of electrical conductivity of various mass concentrations of particles in Al_2O_3–EG nanofluids on temperature.

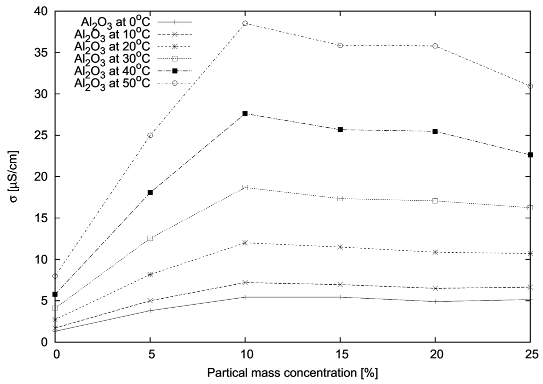

Fig. 4. Dependence of electrical conductivity for various temperatures on mass concentrations of particles in Al_2O_3–EG nanofluids.

produced with various mass concentrations and measured in wide range of temperatures.

Results shows that the increase in temperature and mass concentration causes a change in the electrical conductivity of these materials. It was observed that non-typical rise in electrical conductivity for 10% mass concentration Al_2O_3 nanoparticles in ethylene glycol, also requires a more research to explain a cause of this unusual behaviour.

Acknowledgments

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