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Effect of Temperature and Mass Concentration of SiO_2 Nanoparticles on Electrical Conductivity of Ethylene Glycol

J. Fal and G. Żyła*

Department of Physics and Medical Engineering, Rzeszów University of Technology, Rzeszów, Poland

Electrical conductivity of nanofluids is one of the physical properties which are intensively investigated by researchers. This paper brings contributions in this research area. Electrical conductivity of nanofluids containing various mass concentration of silicon dioxide (SiO_2) nanoparticles suspended in ethylene glycol (EG) were investigated at various ambient temperatures. Temperature was changed from 20 °C to 60 °C with 10 °C step. Measurements were performed with digital conductivity meter (MultiLine 3410, WTW GmbH, Weilheim, Germany) and it was observed that increase in mass concentration of SiO_2 nanoparticles cause increase in electrical conductivity. The same dependence was observed between temperature and electrical conductivity.

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1. Introduction

The increase in energy consumption in industry and the related need to exchange large amounts of heat leads to finding new materials which will be able to improve heat exchange process. Nanofluids as a new kind of fluids can have huge contribution in this field. This type of fluids were introduced in 1995 by Choi [1]. He classified nanofluids as suspension of particles with nanometric size in base fluid. Since this time nanofluids are object of interests of many researchers, especially in rheological, thermal, and electrical properties. The rheological properties of ethylene glycol based nanofluids with various types of nanoparticles were investigated both in experimental and theoretical fields [2–5]. Also thermal conductivity of various types of nanofluids based on ethylene glycol was widely studied [6–8]. Another property of nanofluids but less popular among researchers is electrical conductivity [9, 10].

Rheological properties of silicon dioxide nanofluids were investigated. Namburu et al. [14] carried out study on viscosity of silicon dioxide ethylene glycol/water (SiO_2–EG/W) nanofluids with various diameters of nanoparticles. They found non-Newtonian behaviour of SiO_2-EG/W nanofluids at sub-zero temperatures, and observed correlation between viscosity, volume concentration and temperature. Sharifpur et al. [11] also studied viscosity of SiO_2-EG nanofluids with various volume fractions and temperatures, prepared using two different energy density. They also revealed that all these factors have influence on the viscosity of SiO_2–EG nanofluids. In like manner Talib et al. [12] conducted studied on thermophysical properties of SiO_2 nanoparticles suspended in base fluid (SiO_2-EG/W). Beyond viscosity they studied also thermal and electrical conductivity of SiO_2–EG/W and reported that thermal conductivity as well as electrical conductivity increase with increasing volume concentration of SiO_2 nanoparticles. The electrical conductivity of silicon oxide–ethylene glycol was also investigated by Sharifpur et al. [11]. Like the others they observed increase in electrical conductivity with increase of both volume concentration of nanoparticles in base fluid and temperature of sample.

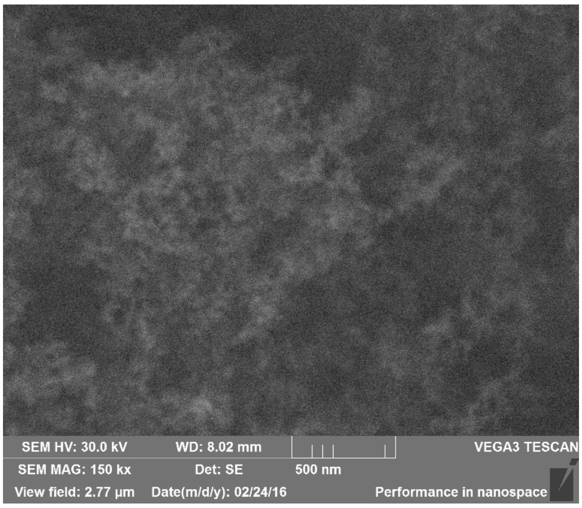

Fig. 1. SEM image of SiO_2 nanoparticles.

This paper presents results of experimental investigation on electrical conductivity of SiO_2–EG nanofluids and its enhancement with increasing of mass concentration for suspensions of nanoparticles with smaller specific surface area than were used by Sharifpur et al. in Ref. [11].

2. Materials

2.1. Nanoparticles

Commercially available SiO_2 nanoparticles produced by PlasmaChem GmbH (Berlin, Germany, CAS: 112945-

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*corresponding author; e-mail: gzyla@prz.edu.pl

52-5) were used in this study. The primary particle average size declared by manufacturer is 7–14 nm, with purity more than 99.8% and specific surface area 200 m^2/g. The electrical conductivity of SiO_2 is 10^{-21} μS/cm as reported in Ref. [12]. Figure 1 presents scanning electron microscope image of dry SiO_2 nanoparticles (VEGA3 microscope, TESCAN Brno, s.r.o., Brno, Czech Republic).

2.2. Sample preparation

Five samples of silicon dioxide–ethylene glycol nanofluids with various mass concentration from 1 wt% to 5 wt% were prepared using two-step method. To weigh the appropriate amount of SiO_2 nanoparticles analytical balance WAS 220/X (Radwag, Radom, Poland) with the accuracy of 0.1 mg was used. The mixture of base fluid and SiO_2 nanoparticles were mechanically mixed for 30 min in Genius 3 Vortex (IKA, Staufen, Germany), then each sample was sonicated for 300 min in Emmi 60 HC (EMAG, Moerfelden-Walldorf, Germany). After preparation samples electrical conductivity of nanofluids were immediately investigated.

3. Method

Electrical conductivity of SiO_2–EG nanofluids was measured with digital conductivity meter MultiLine 3410 (WTW GmBH, Weilheim, Germany) and conductivity probe TetraCon 925. Temperature was changed between 20 °C and 60 °C with 10 °C step, and stabilized at least 30 minutes before each measurement. To stabilize temperature water bath was used. Values of electrical conductivity were calculated as average from 10 measurements during 5 minutes.

The measurements of electrical conductivity were conducted with 1.0% uncertainty of measurement. Full procedure of calibration of measuring stand was described in detail in Ref. [13].

4. Results and discussion

The electrical conductivity of ethylene glycol based silicon dioxide nanofluids with five different mass concentration of SiO_2 nanoparticles from 1% to 5% were studied. Results of these investigation were presented in Table I and plotted in Fig. 2. Based on the experimental data it is obvious that there is correlation between electrical conductivity and mass concentration of nanoparticles and temperatures. Increase in mass concentration of SiO_2 nanoparticles in base fluids cause increase in electrical conductivity.

The same effect was observed for impact of temperature on electrical conductivity, but it is much smaller than effect of the mass concentration. The increase in electrical conductivity of SiO_2–EG nanofluid was also observed by Sharifpur et al. [11]. They noticed increase in electrical conductivity at level of 250 times for 5 vol.% at 70 °C. Such huge increase is probably caused by using SiO_2 nanoparticles with much higher specific surface area (640 m^2/g).

TABLE I

Electrical conductivity of SiO_2–EG nanofluids for given concentration of $0 \div 5$ [wt.%] and temperature.

T [°C]	σ_{nf} [μS/cm]					
	0	1	2	3	4	5
20	0.8	0.8	0.9	0.9	1.0	1.1
25	0.9	0.9	1.0	1.1	1.2	1.3
30	1.0	1.1	1.2	1.3	1.4	1.6
40	1.3	1.5	1.7	1.7	2.0	2.2
50	1.7	1.9	2.2	2.3	2.6	2.8
60	2.3	2.5	2.8	3.0	3.4	3.7

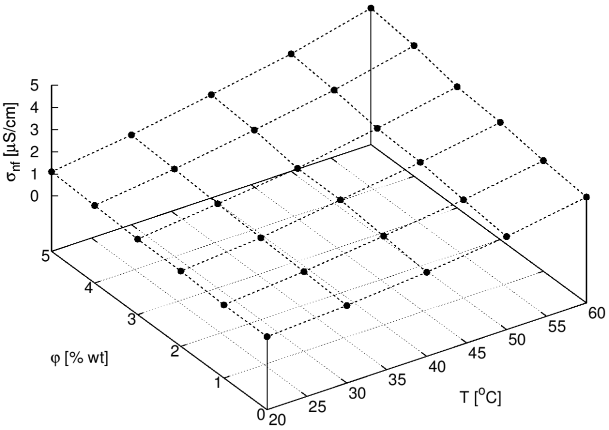

Fig. 2. Variation of electrical conductivity of SiO_2–EG nanofluid with various mass concentration and temperature.

Based on the obtained data, the enhancement of electrical conductivity was calculated as ratio between electrical conductivity of nanofluid (σ_{nf}) and electrical conductivity of base fluid (σ_{bf}). The values of electrical conductivity enhancement of SiO_2–EG nanofluids ware summarized in Table II and presented in Fig. 3. It might be noticed that increase in mass concentration results in increase in enhancement of electrical conductivity of SiO_2–EG nanofluids. Increase in temperature also causes increase in enhancement of electrical conductivity but above 40 °C it can be observed decrease in electrical conductivity enhancement.

TABLE II

Relative enhancement of electrical conductivity of SiO_2–EG nanofluids for given concentration $0 \div 5$ [wt.%] and temperature.

T [°C]	σ_{nf}/σ_{bf}					
	0	1	2	3	4	5
20	1.00	1.00	1.13	1.14	1.25	1.38
25	1.00	1.05	1.22	1.29	1.40	1.55
30	1.00	1.10	1.20	1.30	1.45	1.55
40	1.00	1.15	1.31	1.31	1.54	1.66
50	1.00	1.13	1.29	1.35	1.53	1.65
60	1.00	1.10	1.23	1.30	1.49	1.61

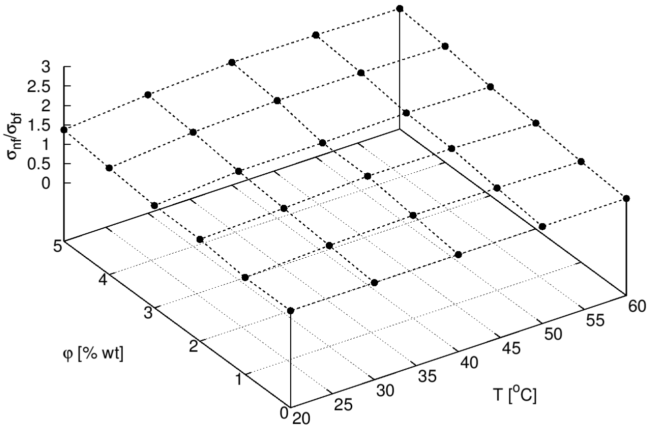

Fig. 3. Enhancement of electrical conductivity of SiO_2–EG nanofluids for various mass concentration and temperature.

5. Conclusion

The experimental data of electrical conductivity and enhancement of electrical conductivity for silicon dioxide–ethylene glycol nanofluids with various mass concentrations were presented and discussed.

The results clearly indicate that there is a relation between the increase in the electrical conductivity and the mass concentration of the nanoparticles in a base fluid and the temperature of nanofluid. Increase in both mass concentration and temperature give rise to increase in electrical conductivity. Mass concentration effect is linear, but temperature effect is nonlinear.

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