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An Experimental Investigation of Electrical Conductivity of $Y_3Al_5O_{12}$-Ethylene Glycol Nanofluids

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Paper presents results of experimental studies of electrical conductivity of yttrium aluminum garnet–ethylene glycol ($Y_3Al_5O_{12}$–EG, YAG–EG) nanofluids, which were prepared by dispersing commercially available nanoparticles manufactured by Baikowski (Annecy, France, ID LOT: 18513) in ethylene glycol. The electrical conductivity was measured using conductivity meter MultiLine 3410 (WTW GmBH, Weilheim, Germany). In turn the temperature was stabilized in a water bath MLL 547 (AJL Electronic, Cracow, Poland). The electrical conductivity of YAG–EG nanofluids with various mass concentrations form 5% to 20% was investigated at different ambient temperatures. The experimental data indicate that changing volume fraction of YAG nanoparticles in ethylene glycol cause change of electrical conductivity of nanofluid. It was also presented that electrical conductivity depends on temperature of materials.

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1. Introduction

In recent years, new groups of materials with great potential application in industry appeared. One of these materials are nanofluids, which were for the first time introduced by Choi in 1995 [1]. Since this time many researchers intensively investigated their thermophysical properties such as rheological, thermal, and electrical properties. The most popular and widely studied properties of nanofluids are rheological properties such as viscosity in both experimental and theoretical field [2–4]. Equally popular among researchers are also thermal properties of nanofluids. Since 1995 there were published a lot of papers considering thermal conductivity and their enhancement. Angayarkanni et al. [5] presented a extensive review of preparation of nanofluids by various techniques, thermal conductivity of nanofluids and mechanisms of heat transport. Singh [6] and also other scientists [7–9] presented a comprehensive overview of the papers of thermal conductivity and theoretical models of nanofluids with various types of nanoparticles and base fluids. Besides rheological and thermal properties increasingly being studied are also the electrical properties of nanofluids in particular electrical conductivity. Also in this case a lot of types of nanofluids with various types of nanoparticles, different volume concentration and base fluids have been studied [10–13].

Some thermophysical properties of yttrium aluminium garnet–ethylene glycol (YAG–EG) nanofluids were investigated previously as presented in Ref. [14]. It was observed that $Y_3Al_5O_{12}$–EG exhibit Newtonian nature, and viscosity increase nonlinearly with volume concentrations of nanoparticles. Just like viscosity, the thermal conductivity of these nanosuspensions also increases nonlinearly with concentration of nanoparticles and cannot be modelled with classical theoretical static models.

2. Materials

2.1. Nanoparticles

Nanoparticles used in experiment were manufactured by Baikowski (Annecy, France), ID LOT: 18513 and are commercially available. Figure 1 presents scanning

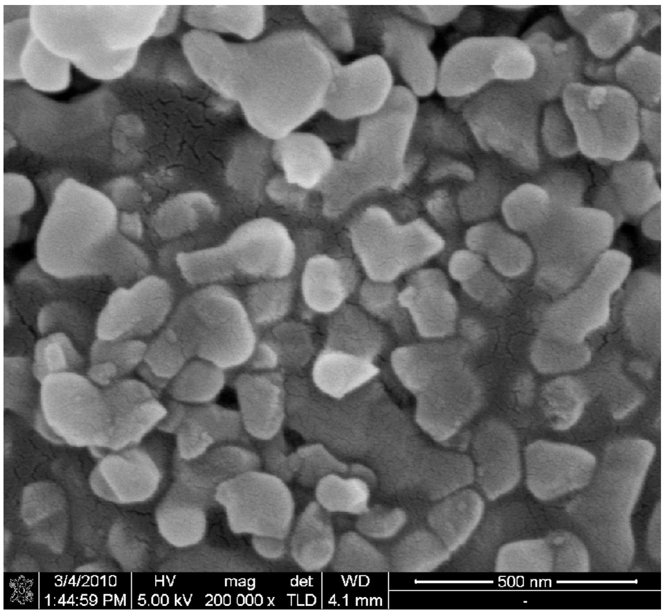

Fig. 1. Scanning electron microscope image of $Y_3Al_5O_{12}$ nanoparticles.

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electron microscope picture of dry $Y_3Al_5O_{12}$ nanoparticles taken with the Nova NanoSEM 200 (FEI, Hillsboro, USA). The average size of nanoparticles was determined using X-ray diffraction (XRD) and is 100 nm. The hydrodynamic diameter of nanoparticles was measured by Cilas Nano DS (Cilas, Oreans, France) and was 185.6 nm.

2.2. Sample preparation

Samples used in experiment were prepared as a suspensions of $Y_3Al_5O_{12}$ nanoparticles in ethylene glycol (EG) as based fluid. Four samples with different mass concentrations (5–20 wt%) were prepared using analytical balance WAS 220/X (Radwag, Radom, Poland). The next step was mechanical stirring in Genius 3 Vortex (IKA, Staufen, Germany) for 30 min. Then each sample were sonicated for 200 min using Emmi-60HC (EMAG, Moerfelden-Walldorf, Germany) to break the remaining agglomerates.

3. Methods

Electrical conductivity measurements were made using digital meter MultiLine 3410 (WTW GmbH, Weilheim, Germany) conducted with conductivity probe TetraCon 925 (WTW GmbH, Weilheim, Germany). MultiLine 3410 allows to measure electrical conductivity with accuracy 0.5% of measured value in range from 0.00 to 2000 μS/cm. Detailed description of calibration process of measuring station was presented in Ref. [13]. The resolution is 0.01 μS/cm. Temperature range starts from 268.15 K to 343.15 K with 0.1 K accuracy. The temperature sensor is inbuilt in stainless steel shaft of conductivity probe, which allow to the simultaneous measure of temperature and conductivity of sample. The electrical conductivity of each sample was measured at various ambient temperature from 283.15 K to 333.15 K with 10 K step. The temperature was stabilized for 30 min before each measurement. The electrical conductivity for each temperature were obtained as a average for measurements which were made by 5 min every 30 s. The temperature was stabilized using MLL 547 (AJL Electronic, Cracow, Poland).

4. Results and discussion

The electrical conductivity of yttrium aluminium garnet nanofluids was investigated as function of temperature and mass concentration. Figure 2 presents a dependence between electrical conductivity, mass concentration and temperature for YAG–EG nanofluids. These data were also summarized in Table I. Analysing obtained data we can conclude that electrical conductivity of YAG–EG nanofluids is dependent on mass concentration of nanoparticles in base fluid and temperature. Increase in mass concentration causes non-linear increase in electrical conductivity. The similar effect is observed for increasing temperature.

Based on these data the electrical conductivity enhancement was determined from SiO_2–EG nanofluids with various mass concentration. As we can see in Fig. 3

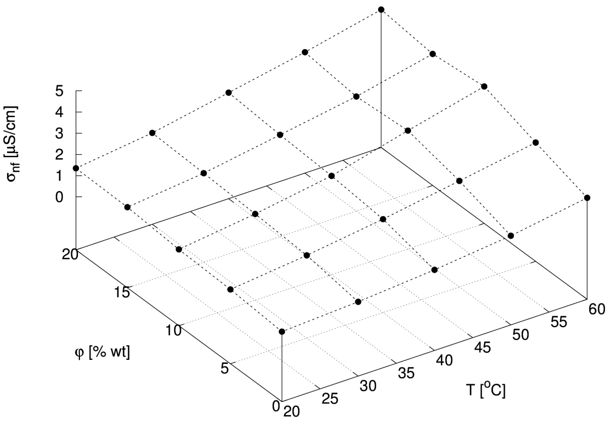

Fig. 2. Electrical conductivity as function of mass concentration and temperature for YAG–EG nanofluid.

TABLE I

Electrical conductivity of YAG–EG nanofluids for various volume concentrations at various temperatures.

φ_m	σ_{nf} [$\mu S/cm$]				
	20 °C	30 °C	40 °C	50 °C	60 °C
0.00	0.80	1.00	1.30	1.70	2.28
0.05	1.00	1.40	1.90	2.50	3.10
0.10	1.10	1.56	2.15	3.08	3.95
0.15	1.30	1.70	2.30	2.90	3.70
0.20	1.35	1.81	2.50	3.20	4.00

TABLE II

Electrical conductivity enhancement of YAG–EG nanofluids for various volume concentrations at various temperatures.

φ_m	σ_{nf}/σ_{bf}				
	20 °C	30 °C	40 °C	50 °C	60 °C
0.00	1.00	1.00	1.00	1.00	1.00
0.05	1.25	1.40	1.46	1.47	1.36
0.10	1.37	1.56	1.66	1.81	1.73
0.15	1.62	1.70	1.77	1.71	1.62
0.20	1.69	1.81	1.92	1.88	1.75

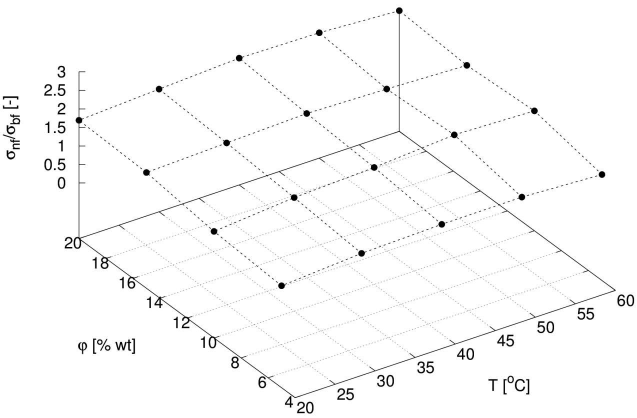

Fig. 3. Electrical conductivity enhancement as function of mass concentration and temperatures for YAG–EG nanofluid.

and Table II that the maximum enhancement in electrical conductivity was achieved for 20% mass concentration at 40 °C.

Above this temperature we can observe a decrease in electrical conductivity enhancement. Decrease in electrical conductivity above 40 °C is especially noticeable for the higher mass concentration of YAG nanoparticles in ethylene glycol. This might be caused by the increase of Brownian motion due to the increase in temperature, which leads to more frequent collisions between the particles and accelerates the sedimentation, which directly affects the decline in the enhancement of electrical conductivity. This is quite rare, because usually researchers observe an increase in enhancement of electrical conductivity with increase in concentration of nanoparticles in a liquid base [15–17].

5. Conclusion

The electrical properties of YAG–EG nanofluids were investigated for various mass concentrations and various ambient temperatures. Results indicate that increase in mass concentration of nanoparticles in base fluid cause increase in electrical conductivity of YAG–EG nanofluid. The highest enhancement was achieved for maximum mass concentration of nanoparticles (20 wt%) at 40 °C. Above this temperature can be noticed slight decrease in enhancement of electrical conductivity of YAG–EG nanofluids.

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