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Huge thermal conductivity enhancement in boron nitride – ethylene glycol nanofluids

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HIGHLIGHTS

- Huge thermal conductivity enhancement in BN-EG nanofluid was reported.
- Thermal conductivity increase very slightly with increasing of the temperature.
- Thermal conductivity increase linearly with volume concentration of particles.

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ABSTRACT

Paper presents the results of experimental studies on thermophysical properties of boron nitride (BN) plate-like shaped particles in ethylene glycol (EG). Essentially, the studies were focused on the thermal conductivity of suspensions of these particles. Nanofluids were obtained with two-step method (by dispersing BN particles in ethylene glycol) and its' thermal conductivity was analyzed at various mass concentrations, up to 20 wt. %. Thermal conductivity was measured in temperature range from 293.15 K to 338.15 K with 15 K step. The measurements of thermal conductivity of nanofluids were performed in the system based on a device using the transient line heat source method. Studies have shown that nanofluids' thermal conductivity increases with increasing fraction of nanoparticles. The results of studies also presented that the thermal conductivity of nanofluids changes very slightly with the increase of temperature.

1. Introduction

Nanofluids are suspensions of nanometer size particles in base fluids [1]. The first research study of physical properties of such complex fluids has been introduced in the late 20th century [2]. In subsequent years, there have been numerous studies of physical properties of nanofluids with a particular interest in their thermal properties. Such thermal properties of these materials can be successfully used in the industry [3–7].

Zhu et al. [8] have shown that for the Al_2O_3-H_2O nanofluids, thermal conductivity increases with increasing concentration of nanoparticles in suspension. The suspensions of Al_2O_3 nanoparticles are one of the most widely studied group of nanofluids [9–13], and all the works of researchers show that the thermal conductivity increases with increasing concentration of nanoparticles.

Not only Al_2O_3, but also other metal oxides are interesting groups of materials used in the production of nanofluids, such materials as ZnO [14–18], SnO_2 [19], CuO [20,21], CuO_2 [22] and Fe_2O_3 [23–25] should be taken into consideration and further analysis.

Among non-oxides most popular are metallic materials Fe [26], Cu [27], Ag [28,29], Au [30]. But not only, for example SiC [31–33] and AlN [34,35] nanoparticles are also commonly used for the preparation of the nanofluids.

Volume concentration of nanoparticles is not the only factor that affect thermal conductivity of nanofluids. Another factor is the temperature. Pastoriza-Gallego et al. presented papers in which they describes the thermal conductivity of nanofluids increase with increasing temperature for Al_2O_3-EG [12], and ZnO-EG [36]. The increase in thermal conductivity with temperature in ethylene glycol based nanofluids was also reported by Yu et al. [37], Timofeeva et al. [38], and Sundar et al. [39]. A similar correlation was

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presented by Abareshi et al. [40] for Fe_3O_4-H_2O, and by Colla et al. [41] for Fe_2O_3-H_2O nanofluids and in review article by Kleinstreuer and Feng [42]. On the other hand, Lee et al. [43] presented the experimental results, which show that for TiO_2-EG nanofluids, thermal conductivity enhancement does not depend on temperature. This issue seems to be insufficiently investigated at the moment and needs further experimental work in this field.

Boron nitride, due to its unique properties, is called the, “white graphene” [44,45]. The material is mostly present in the form of flakes [46,47], but may also be manufactured in the form of spheres [48], tubes [49–53], wires [54] and ribbons [55]. Zhong et al. [56] and Cumings et al. [57] presented papers describing the possibilities for the production of boron nitride on a large scale, which in the future will contribute to an even greater spread of this material in industrial applications. Dean et al. [58] reported the possibility of using boron nitride to improve high-quality graphene electronics.

Research on the interesting properties of suspensions of nanoparticles BN are conducted. Xiao et al. [59] described that compared with the PVDF/BN composites at the same BN content, the ternary PVDF/BN/CNT composites presented largely enhanced thermal conductivity. Taha-Tijerina et al. [60] described high thermal conductivity of suspension of BN nanoparticles in a mineral oil, normally used in transformers. They presented also that this material has Newtonian nature. Similar Newtonian behavior of boron nitride nanoparticles suspended in polyalpha olefin was presented by Seleiti [61]. Zhi et al. [62] carried out studies on thermal conductivity of fluids with boron nitride nanotubes and nanospheres and they revealed increase in thermal conductivity up to 2.6 times for 6 vol % nanoparticles in water. BN nanoparticles are also often used to produce high quality nanocomposites with high thermal conductivity and high insulating properties [63,64].

Some studies have already been conducted on BN-EG nanofluids thermal properties. Li et al. [65] presented a paper in which they described two unusual phenomena in the thermal conductivity of this group of materials. Li et al. showed that with low volume concentrations of nanoparticles thermal conductivity does not increase with concentration, but may decrease. This is due to the aggregation of nanoparticles BN at higher concentrations and creates a, “cloud-like compact aggregations” [65]. Guo et al. [66] investigated thermal conductivity of suspensions of BN nanoparticle in ethylene glycol with three types of dispersant. Two of them (SHMP and CTAB) caused deterioration in stability and thermal conductivity, but third - non-ionic PVP is promising. BN-EG nanofluids with PVP as dispersant shows slightly decrease in thermal conductivity enhancement but stability of nanofluids is improved.

BN-EG nanofluids present very complex rheological behavior, what has been discussed in details in Ref. [67]. This paper presents results of experimental investigation of thermal conductivity enhancement of high volume fraction BN plate-like shaped particles suspended without any dispersant and surfactants in ethylene glycol.

2. Materials

2.1. BN characterization

Nanoparticles used for producing nanofluids were manufactured by Saint-Gobain Advanced Ceramics Corporation, CAS No.: 10043-11-5, LOT: 94194, ID: AB134568. In this work a boron nitride in hexagonal crystalline form was used. Fig. 1 presents images of BN nanopowder in dry form, where the picture shows, that this material has tendency to form agglomerates. Therefore, prior to initiating measurements, it is necessary to extend the duration of ultrasound activity.

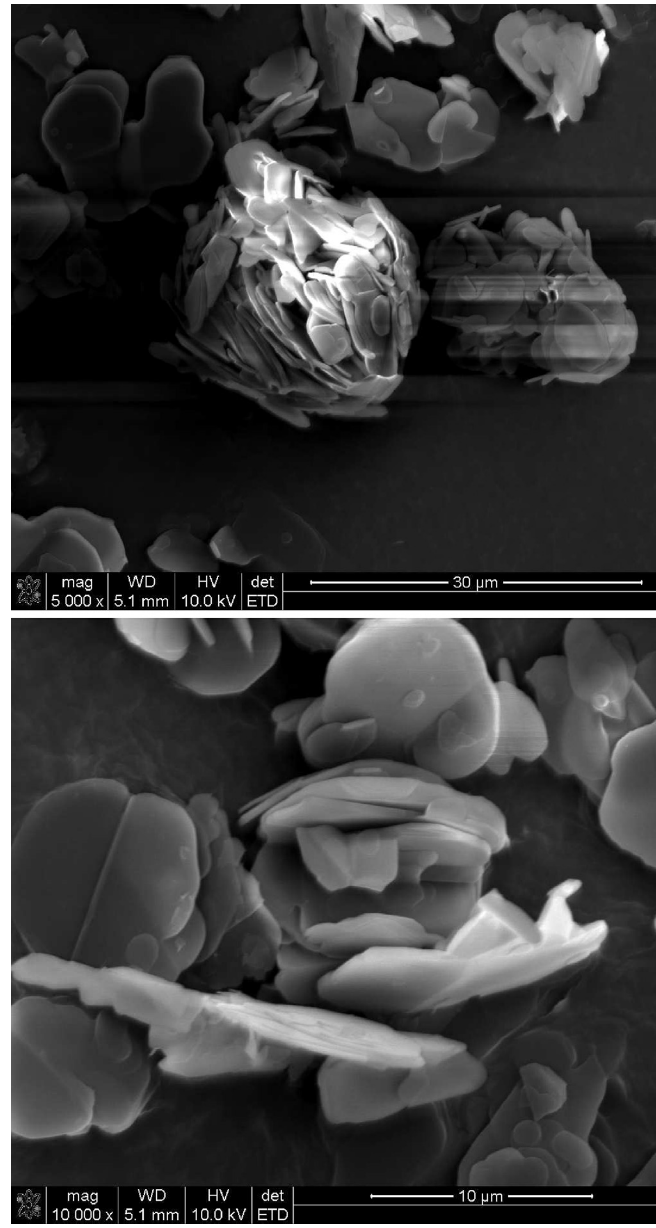

Fig. 1. Scanning Electron Microscope pictures of dry BN nanoparticles.

The characteristics of the particle size were obtained from Zetasizer nano ZS (Malvern instruments Ltd. Worcestershire, UK). DLS measurements were realized using the standard laser with a maximum continuous wave power of 4 mW at 632.8 nm. For this purpose, diluted suspensions of boron nitride were prepared in ethylene glycol (0.2 g/l), which underwent an ultrasonication prior measurement (VibraCell VCX130, Sonics & Materials, Inc., Newtown, USA). Particle size measurement revealed bimodal characteristic of size distribution with mean peak values of 192 and 2969 nm, and has been described in detail in Ref. [67], where additional SEM pictures of examined particles can be found.

In order to determine the thermal transport properties of the material, its thermal diffusivity was measured. Thermal diffusivity of the sample was measured at 20 °C by the laser flash method utilizing a Laser Flash Apparatus (LFA 427 Netzsch Gerätebau GmbH, Selb, Germany). Principles of the laser flash method were established in 1961 by Parker et al. [68]. A fully dense cylindrical