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A review on how the researchers prepare their nanofluids

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ABSTRACT

The past decade has seen the rapid development of nanofluid science in different aspects, where the researchers focused mainly on the enhancement of heat transfer. However nanofluids preparation also deserves the same attention since the final properties of nanofluids are dependent on the stability of the dispersion. In this paper, we summarize the nanofluid preparation methods reported by different investigators in an attempt to find a suitable method for preparing stable nanofluids. In this context, nanofluids are classified according to material type as metallic and nonmetallic nanoparticles since different nanoparticles need their own stability method. Various types of nanoparticles with different base fluids are investigated. Also, the available data for the zeta potential as a function of pH is discussed.

1. Introduction

Over the last several decades, researchers have attempted to overcome the limited heat transfer capabilities of traditional heat transfer fluids such as water, engine oil, and ethylene glycol (EG), by developing a new class of fluids which offer better cooling or heating performance for a variety of thermal systems. Applying nanotechnology to thermal engineering, the novel concept of “nanofluid” which was coined by Choi in 1995 [1] has been proposed to meet these cooling challenges. Nanofluids, which are solid–liquid composite materials consisting of nanometer sized solid particles suspended in different base fluids, provide a promising technical selection for enhancing heat transfer because of its many advantages besides anomalously high thermal conductivity. Nanofluids represent improved stability compared with conventional fluids added with micrometer- or millimeter-sized solid particles because of size effect and Brownian motion of the nanoparticles in liquids. With such ultrafine nanoparticles, nanofluids can flow smoothly in a microchannel without clogging and the size of the heat transfer system can be reduced for the use of nanofluids with high heat transfer efficiency.

Preparation of stable nanofluids is the key issue of nanofluid research. The stability of nanofluids refers to several aspects: 1) Nanofluids are multi-phase dispersion system with high surface energies and are, therefore, thermodynamic unstable. 2) Nanoparticles dispersed in the nanofluids have strong Brownian motions. The mobility of the nanoparticles can offset their sedimentation caused by the gravity field. 3) Dispersion of nanoparticles in the fluids may deteriorate with time due to the aggregation of nanoparticles, which is caused by van der Waals forces. 4) No chemical reactions either between the suspended nanoparticles or between the base fluid and nanoparticles are desired at working conditions of the nanofluid. Therefore, there are two phenomena that are critical to the stability of nanofluid, *aggregation and sedimentation*.

It was found that only a few review papers have discussed on the preparation methods for nanofluids [2–4]. In the present paper, we attempt to review the preparation methods of nanofluids presented in previously published data with much more details. The purpose of this paper is to understand the lack stability of nanofluids, which is a key issue that influenced the nanofluid properties for application, and to propose suggestions that could lead to prepare stable nanofluid over a long time, with negligible agglomeration and without chemical change of the fluid properties. The review discussed different types of nanoparticles; nonmetals (Al_2O_3, ZnO, CuO, TiO_2, Fe_3O_4, CNTs, SiO_2 and AlN) and metals (Al, Ag and Cu). Also, we present the available data for the zeta potential as a function of pH values.

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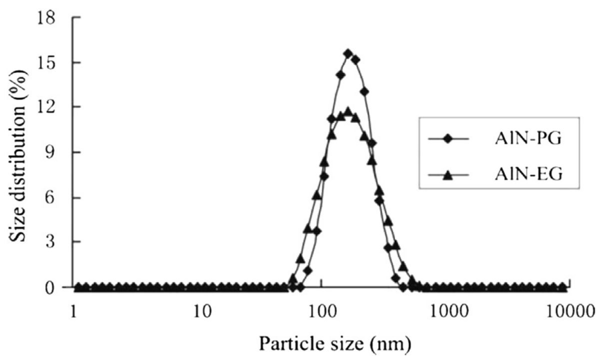

Fig. 1. Particle size distributions of AlN filtered nanofluid [7].

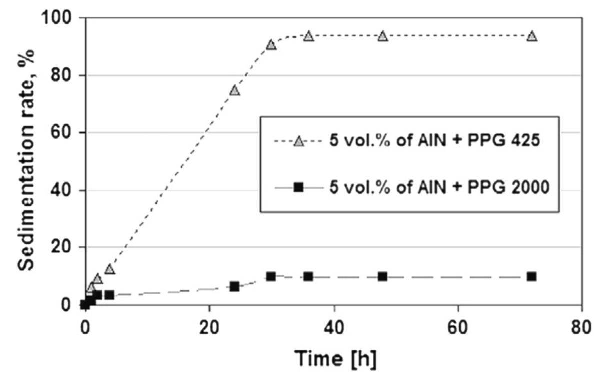

Fig. 2. Sedimentation rate of AlN–PPG 425/2000 diluted systems [8].

2. Preparation of nanofluids

Nanoparticles, the additives of nanofluids, play an important role in changing the thermal transport properties of nanofluids. At present, various types of nanoparticles, such as metallic nanoparticles and ceramic nanoparticles, have been used in the nanofluids preparation. In the following part, we will present the nanofluid preparation methods for eleven different nanoparticles reported in the literature.

2.1. Preparation of non-metallic nanofluids

2.1.1. Aluminum nitride -nanofluids

Aluminum nitride (AlN) is a nontoxic newer material in the technical ceramics family. While its discovery occurred over 100 years ago, it has been developed into a commercially viable product with controlled and reproducible properties within the last 20 years. AlN is one of the typical ceramics that have special properties such as high thermal conductivity (8–10 times that of Al_2O_3), low dielectric coefficient (about 8.15), high electrical resistance, corrosion & erosion resistance and low density. Because of these advantageous properties, it is used in various engineering applications and has attracted the intense interest of researchers. However, till date very few results concerning AlN nanofluids have been reported in the literature. In this context, Hu et al. [5] were the first to disperse AlN nanoparticle, produced by plasma arc in the gas phase into ethanol with castor oil as a dispersant to improve suspension stability. The suspension was then stirred with a high-speed magnetic stirrer. The resulting suspension was placed in an ultrasonic homogenizer for 10 min. It was observed that the prepared sample can remain stable for more than 2 weeks without settling. Choi et al. [6] mixed the agglomerated Al_2O_3 and AlN nanoparticles with *n*-hexane and a proper amount of oleic acid. The mixture was subjected to bead-milling with ZrO_2 beads in a vertical super-fine grinding mill. The powders were hydrophobic modified by esterification reaction simultaneously with bead milling by circulating the suspensions between bead mill and ultrasonic reaction bath. A surface modified solution was then filtered using ultra filtration (UF) membrane to remove excess oleic acid which did not form stable chemical bonds with the particle surface. The filtered solution was mixed with transformer oil, and then finally dried off the *n*-hexane using a rotary vacuum evaporator. They observed that for a period of one month, filtered and non-filtered Al_2O_3 nanofluids are well dispersed at the beginning, while sedimentation was very clear for non-filtered nanofluid after one month. The settling phenomenon for non-filtered suspension was interpreted as the formation of double chain of oleic acid (OA) on the particle surface, making it hydrophilic again. Yu et al. [7] prepared AlN–ethylene glycol and AlN–propylene glycol nanofluids by stirring and continuous sonication for 3 h, to ensure uniform dispersion of nanoparticles in the base fluid. As shown in Fig. 1, they found that the average particle sizes for AlN–EG and AlN–PG nanofluids are 165 and 169 nm, respectively. Wozniak et al. [8] suspended AlN nanopowder in poly propylene glycol PPG 425 and PPG 2000, and then the suspensions were homogenized by using a magnetic stirrer for 3 h. More concentrated AlN dispersions were prepared using a laboratory dissolver, which had a mechanically modulated dispersive disk. The powder was slowly and incrementally added to PPGs. Each addition was followed by homogenization step. When all the powder was added, the dispersions were stirred for 40 min at 3000 rpm. It was reported that the suspensions were of high flow-ability and noticeable homogeneity. AlN–PPG 425/2000 were of much higher sedimentation in PPG of lower average molecular mass, i.e. 425. In addition, the particles settled quite rapidly in PPG 425; after 30 h the sedimentation rate was >90% and afterward it remained at the same level. However, AlN–PPG 2000 suspension demonstrated its sedimentation behavior only slightly, which was confirmed by its low sedimentation rate (max. ~10% in 72 h), as shown in Fig. 2. The zeta potential measurements in PPG media showed that zeta potential is negative for both liquids; it averaged (−30) mV for AlN–PPG 425 dispersion and below (−10) mV in case of AlN–PPG 2000 system.

Although different surfactants and physical treatments were used for the preparation of AlN–nanofluids, only more than two weeks stable time of nanofluids was reported [5]. Thus, other preparation methods are highly desired to prepare stable AlN–nanofluids.

2.1.2. Zinc oxide-nanofluids

Zinc oxide is emerging as a material of interest for a variety of electronic applications such as semiconductor for making inexpensive transistors and thin film batteries. It can be used in a large number of areas, and unlike many of the materials with which competes, is inexpensive, relatively abundant, chemically stable, easy to prepare, antibacterial and nontoxic. One of the first investigations dealt with this type of nanofluids was presented by Yu et al. [9]. They prepared ZnO nanofluids by dispersing ZnO nanoparticles in ethylene glycol. The mixture was stirred and sonicated (40 kHz and 150 W) continuously for 3 h to ensure uniform dispersion of nanoparticles in the base fluid. Based on the influence of ultrasonification on the particle size, it was reported that the average size decreases rapidly in the first 3 h, after 3 h the average size was about 210 nm (~10–20 times the primary size). It was concluded that ultrasonification was not effective in avoiding particle aggregation and producing uniformly distributed and well-controlled size of ZnO nanoparticles. Moosavi et al. [10] first