Study on Influence of Dispersants on Stability, Thermal Conductivity and Viscosity of BN/EG Nanofluids

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Abstract. Boron nitride/ethylene alcohol (BN/EG) nanofluids was synthesized by two-step method. The influence of dispersant on stability, thermal conductivity and viscosity was studied. The experimental results reveal that the stability of BN/EG nanofluids deteriorates rapidly with the addition of anionic dispersants and cationic dispersants, which has no practical application value. While, non-ionic dispersant can improve the stability and fluidity obviously and maintain the enhancement of thermal conductivity at the same time.

1. Introduction
In 1995, Choi et al. [1] put forward a new concept, nanofluids. The so-called nanofluids refer to the suspension formed by adding nanoparticles or nanotubes into the liquid medium in a certain way. Nanofluids can significantly improve the thermal conductivity of base liquids and enhance the heat transfer performance of heat exchange systems, and the size of additives is nano-scale, without wear and pipeline blockage. Compared with traditional fluids with micron or millimeter solid particles, nanofluids have better suspension stability. Many studies have shown that the thermal conductivity of nanofluids has been significantly improved [2-8] compared with the base solution. However, due to the large specific surface area and high surface energy of nanoparticles, it is easy to automatically agglomerate and sink in liquid media, and it is difficult to maintain long-term stability, which limits the practical application of nanofluids. In order to make nanoparticles disperse uniformly and stably in liquid medium to form nanofluids with good dispersion, high stability and low agglomeration, the method of adding dispersant is often used [9-11]. However, the addition of dispersants can increase the stability of nanofluids and inevitably affect other thermophysical properties, such as thermal conductivity, viscosity and so on. If the addition of dispersant improves the stability of nanofluids, but greatly reduces their thermal conductivity and fluidity, the practical application value of nanofluids will be reduced. Therefore, it is of great significance to study how the kinds and amounts of dispersants affect the thermophysical properties of nanofluids, such as stability, thermal conductivity and viscosity. Ethylene glycol (EG) is a frequently-used heat transfer medium with a density of 1.11 g/cm$^3$. Boron nitride (BN) is a ceramic material with high thermal conductivity (260W/m·K), good insulation characteristics and low density (2.18 g/cm$^3$). Hexagonal boron nitride (H-BN) has a flake structure similar to graphite. Dispersing nano-sized H-BN particles in EG was expected to prepare a nano-fluid with good dielectric properties and stability on the base of improving its thermal conductivity. This fluid can be used in cooling tools of automobile engines, electronic products, chemical equipment, etc. In this paper, boron nitride/ethylene glycol (BN/EG) nanofluids were prepared by two-step method. The effect of the kinds and amount of dispersants on their stability, thermal conductivity, viscosity and other thermophysical properties was studied.

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2. Experiment

2.1. Raw Materials and Instruments
The additives used in the preparation of fluids are nano-hexagonal boron nitride powder sold by Wuxi Yulong Electronic Materials Co., Ltd. The purity of them is 99% and the average particle size of them is 140 nm. The base solution is analytical pure ethylene glycol which purchased from Tianjin Hongyan Chemical Reagent Factory. Analytical pure hydrochloric acid or sodium hydroxide was used as pH Regulator. Sodium hexametaphosphate (cationic) produced by Tianjin Bodi Chemical Co., Ltd., hexadecyltrimethylammonium bromide (anionic) produced by Tianjin Fuchen Chemical Reagent Factory and polyvinylpyrrolidone produced by Shanghai Lanji Science and Technology Development Co., Ltd. were selected as dispersant. Figure 1 is a scanning photograph of BN nanoparticles used in the experiment.

![Figure 1. SEM image of the BN nanoparticles.](image)

2.2. Preparation of Nanofluids
BN/EG nanofluids were synthesized by two-step method. The appropriate amount of nano-hexagonal boron nitride (H-BN) powder and dispersant was weighed by an analytical balance with accuracy of 0.1 mg and added directly to the appropriate amount of base liquid ethylene glycol (EG) weighed in a measuring barrel with accuracy of 1 ml. A magnetic stirrer was used to stirred for 30 minutes first, then dispersed for 30 minutes with an ultrasonic oscillator.

2.3. Analysis and Testing
Digital camera was used to take photos of fluid sedimentation. Jinan Rize-2000 laser particle size analyzer was used to observe the particle size distribution of additives and aggregates of additives in suspension. NDJ-1B-1 rotary viscometer was used to measure fluid viscosity. The thermal conductivity of the synthesized BN/EG nanofluids was measured by a homemade transient hot wire device. JSM-7000F field emission scanning electron microscopy (SEM) and JEM-2100F high resolution electron microscopy (HRTEM) were used to observe the morphological characteristics of the additives and the morphological characteristics of nanoparticle aggregates.

3. Results and Discussions

3.1. Effect of Dispersants on the Stability of BN/EG Nanofluids
In order to study the influence of dispersant types and additions on the stability of BN/EG nanofluids, 0.5% vol BN/EG nanofluids were prepared and dispersants with different mass fractions were added. The mass fractions of anionic dispersant SHMP, cationic dispersant CTAB and non-ionic dispersant PVP were 1wt%, 5 wt%, 10 wt% and 15 wt% respectively. Then the BN/EG nanofluids stay for a period of time and the stability of them was observed by photograph.
Figures 2a and 2b were settlement photographs of 0.5% vol BN/EG nanofluids added with different mass fractions of SHMP and CTAB respectively. It can be seen that when SHMP and CTAB were added into BN/EG nanofluids, the sedimentation photos of static for 3 hours showed very obvious stratification, indicating that the fluids were seriously flocculated and settled, the BN nanoparticles were deposited at the bottom of the bottle, the concentration of BN nanoparticles in the suspension was very low, and its stability was bad. Figure 2c was the settling photos of 0.5% vol BN/EG nanofluids added with different mass fractions of PVP and kept for 120 days. From the photos, there is clear liquid in the upper layer of the fluid without PVP, obvious sediment at the bottom of the bottle, light color and low concentration of the suspended fluid in the middle, which indicates that the stability of the fluid has become worse. However, after adding PVP, a small amount of clear liquid appeared in the upper layer of the fluid, and no obvious sediment appeared at the bottom of the bottle. The color of the suspension fluid was uniform and the concentration was high, which indicated that the suspension stability of nanoparticles was good. The three sedimentation pictures in figure 2 show that anionic dispersant SHMP and cationic dispersant CTAB will seriously deteriorate the stability of BN/EG nanofluids, while non-ionic dispersant PVP can increase the stability of BN/EG nanofluids obviously.

3.2. Effect of Dispersants on Viscosity of BN/EG Nanofluids

In order to study the influence of dispersant types and mass fraction on viscosity of BN/EG nanofluids, 3% vol BN/EG nanofluids added with different types dispersants were prepared. The mass fractions of anionic dispersant SHMP, cationic dispersant CTAB and non-ionic dispersant PVP relative to BN nanoparticles were 1 wt%, 5 wt%, 10 wt% and 15 wt%. The viscosity of nanofluids without dispersants and with different mass fractions of dispersants was measured by NDJ-1B-1 rotary viscometer at room temperature immediately after preparation.

Figure 3 shows the relationship between the viscosity of 3vol% BN/EG nanofluids and the dispersants. It can be seen that the type and amount of dispersant have obvious influence on viscosity of nanofluids. The viscosity of BN/EG nanofluids improve rapidly with the addition of 1wt% cationic dispersant CTAB, while the viscosity changes little with the increase of CTAB content. Anionic dispersant SHMP has little effect on the viscosity of nanofluids. When the additive amount of PVP reaches 1wt%, the viscosity of BN/EG nanofluids decreases greatly, then keep small change with the increase of PVP content. The reason for this phenomenon is that cationic dispersant CTAB and anionic dispersant SHMP makes nanoparticles flocculate, so the viscosity increases. The reason why the fluid viscosity does not change much with the addition of SHMP may be related to the slow flocculation and precipitation of nanoparticles. Non-ionic dispersant PVP effectively improved the dispersion of BN/EG nanofluids, reduced the flow resistance of nanoparticles, thus significantly decreased the viscosity of it.
3.3. Effect of Dispersants on Thermal Conductivity of BN/EG Nanofluids

Dispersants coated on the surface of nanoparticles hinder the heat conduction among nanoparticles and liquids, which will inevitably decrease the thermal conductivity of nanofluids. In order to study the effect of dispersant type and dosage on the thermal conductivity of BN/EG nanofluids, 3% vol BN/EG nanofluids were prepared and different mass fractions of dispersants were added. The mass fractions of anionic dispersant SHMP, cationic dispersant CTAB and non-ionic dispersant PVP relative to nanoparticles were 1wt%, 5wt% and 10wt%, respectively. After preparation, the thermal conductivity of these nanofluids without dispersant and with different mass fractions of dispersant were measured by a self-designed and assembled transient hot wire device at indoor temperature.

The results of thermal conductivity measurements are shown in figure 4. It can be seen that the addition of anionic dispersant SHMP decreases the thermal conductivity of the nanofluid slightly, while the cationic dispersant CTAB and non-ionic dispersant PVP decreases the thermal conductivity obviously, but the amount of it is small.

3.4. Analysis and Discussion

To analyze the mentioned above experimental results, 0.5% vol BN/EG nanofluids were prepared and PVP was added with different mass fractions. The average size of nanoparticle aggregates suspended in BN/EG nanofluids was measured by laser particle size analyzer after stewing for three days. The morphology of BN nanoparticle aggregates suspended in fluids without dispersant and with 10wt% PVP dispersant was observed by transmission electron microscopy.

Figure 5 is the average particle size of nanoparticle aggregates in 0.5% vol BN/EG nanofluids varies with the amount of PVP added. It can be seen that the particle size of nanoparticle aggregates in 0.5% vol BN/EG nanofluids decreases obviously after adding dispersant PVP. With the increase of PVP
content, the size of nanoparticle aggregates does not change much, which indicates that the non-ionic dispersant PVP inhibits the aggregation of nanoparticles effectively.

![Granularity/nm vs Addition of PVP/wt% graph]

**Figure 5.** The average size of BN nanoparticles aggregation in 0.5%vol BN/EG nanofluids.

Figure 6 is the TEM photographs of suspended BN nanoparticle aggregates in 0.5vol% BN/EG nanofluids without addition of dispersant and after adding 10wt% PVP. Observations of multiple field of view show that most BN nanoparticles in BN/EG nanofluids without dispersants are agglomerated into blocks. As shown in figure 6a, the bulk aggregates are large and easy to sink during the static process. After adding 10wt% PVP, the dispersion of most BN nanoparticles in nanofluids is shown in figure 6b. BN nanoparticles disperse more evenly and form smaller aggregation.

![TEM photographs of suspended BN nanoparticle aggregates in 0.5vol% BN/EG nanofluids](a) Without dispersant (b) 10wt% PVP

**Figure 6.** TEM photograph of suspended BN nanoparticle aggregates in 0.5vol% BN/EG nanofluids.

The experimental results of figures 5 and 6 show that the addition of dispersant PVP inhibits the agglomeration of BN nanoparticles and make them suspended in ethylene glycol as smaller aggregates. The smaller agglomeration of BN nanoparticles is the fundamental reason why BN/EG nanofluids added with PVP keep good stability and fluidity compared with them without dispersants.

4. Conclusions
The experimental results show that the stability, viscosity and thermal conductivity of BN/EG nanofluids change with the addition of dispersant. PVP reduces the increment of thermal conductivity, but the reduction is not significant, and the increase of thermal conductivity is basically maintained. At the same time, the stability and fluidity of nanofluids were improved by adding PVP. This indicates that BN/EG nanofluids added with PVP have better comprehensive thermophysical properties and have a good prospect for practical application.
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