One-step Physical Method for Synthesis of Cu Nanofluid in Ethylene Glycol

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Abstract The Cu nanofluid in ethylene glycol was prepared by electrical explosion of wire, a novel one-step method. The X-ray diffraction, field emission scanning electron microscope and transmission electron microscope were used to study the properties of Cu nanoparticles. The results showed that the nanoparticles were consisted of pure face-centered cubic structure and near spherical shape with average grain size of 65 nm. Ultraviolet-visible spectroscopy (UV-Vis) confirmed Cu nanoparticles with a single absorbance peak of Cu surface plasmon resonance band at 600 nm. The nanofluid was found to be stable due to high positive zeta potential value, +51 mV. The backscattering level of nanofluid in static stationary was decreased about 2% for 5 days. The thermal conductivity measurement showed that Cu-ethylene glycol nanofluid with low concentration of nanoparticles had higher thermal conductivity than based fluid. The enhancement of thermal conductivity of nanofluid at a volume fraction of 0.1% was approximately 5.2%.

Keywords : Cu Nanofluid, Ethylene glycol, Thermal conductivity, Stability, Electrical explosion of wire

1. Introduction

Cooling is necessary for maintaining the performance and reliability of many industrial application equipment, such as transportation, electronics, automobiles, power generation, air conditioning and refrigeration. Conventional heat transfer fluids including water, ethylene glycol (EG) and mineral oils are typically used as heat transfer media in those applications. However, these heat transfer fluids have inherently poor thermal conductivity that is smaller than those of most solids. Therefore these fluids have a fundamental limit on heat transfer. Many researchers have attempted to overcome this limit by dispersing micron-sized particles in these fluids. A major drawback of these dispersions using such micron-sized particles is the fast settling in fluids due to their large mass. Decreasing the size of solid particles to the nanometer

range can be an alternative. The nanoparticles dispersion in base fluids, which are termed as nanofluids, have been first introduced by Choi [1] to describe a new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their base fluids. The nanofluids have attracted great interest recently because of their enhanced thermal properties.

Two kinds of methods have been used to preparing nanofluids: two-step method and one-step method. The former is to produce the nanoparticles and then dispersed in the base fluids. However, it presented a disadvantage that the agglomeration of the nanoparticles occurred due to strong attractive van der Waals force between nanoparticles. To avoid the aggregation, surfactants addition, pH control and/or ultrasonic agitation have been employed. Kwak and Kim [2] showed that strongly aggregated nanoparti-

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cles are still in aggregated state after dispersion in ethylene glycol after 9h of sonication.

In a one-step method, fabrication and dispersion of nanoparticles into based fluids take place simultaneously. In this process, the agglomeration of nanoparticles is minimized and the stability of nanofluids is increased. Eastman *et al.* [3] prepared Cu nanofluids in ethylene glycol using a one-step physical method, in which Cu vapor was directly condensed into the nanoparticles by contact with a flowing liquid. It has been reported that only 0.3 vol% Cu nanoparticles dispersed into ethylene glycol can increase by up to 40% over that of pure EG. Zhu *et al.* [4] presented a novel one-step method for preparing of non-agglomerated and stably suspended Cu nanofluids in EG. When the volume fraction of Cu nanoparticles in nanofluids is only 0.1%, the effective thermal conductivity increases 9%. Liu *et al.* [5] synthesized Cu water-based nanofluids using chemical reduction method. The volume fraction of Cu has been increased to 0.1 vol%, a significant increase in thermal conductivity up to 23.8% is observed at single measurement point.

In present paper, we will suggest the one-step physical method to prepare Cu nanofluid by electrical explosion of wire (EEW) in ethylene glycol, a physical and top-down approach [6-8]. The EEW has been investigated for a long time and applied for preparation of nanopowders. It is a simple method for fabricating many different types of metallic and ceramic nanosized powders in gas medium. The EEW in liquid reported in recent years was presented as a new method to prepare nanopowders with better quality and smaller size in comparison with one in gas [9].

2. Experimental Details

A schematic illustration of the equipment for preparing Cu nanofluid via electrical explosion of wire method is shown in Fig. 1. The apparatus consists of a high voltage DC power supplier, a

Fig. 1. Schematic diagram of experimental setup for the wire explosion process in ethylene glycol.

bank of capacitors, a plasma switch and an explosion beaker. The beaker contains liquid for medium of explosion process. First, a thin copper wire (99.99% purity, Nilaco Corp.) with a length of 27 mm and a diameter of 0.2 mm, which was installed between two stainless electrodes and was placed in the beaker filled with 0.5 liter of ethylene glycol. The 30 μ F capacitor was charged up to 2.5 kV, and was driven through the wire by a triggering pulse input to the spark gap switch, i.e., closing the switch. The energy stored in capacitor was released through the wire when the spark gap switch was closed. Due to a high rate of the energy injection to wire, the energy density may exceed the binding energy and the materials boils up in a burst, a plasma formation and a shockwave scatter to the ambient medium. A mixture of superheated vapor and boiling droplets of the exploding wire material were rapidly cooled down by interaction with the liquid and nanoparticles were formed in the liquid. In this method, the copper nanoparticles were formed and directly dispersed into the liquid after explosion process and therefore that can reduce the agglomeration of the nanoparticles and enhance the stability of dispersion. The experimental parameters of explosion process were summarized in Table 1.

Table 1. Summary of experimental details

Capacitance	30 μ F
Charging voltage	2.5 kV
Material	Cu
Wire diameter	0.2 mm
Length of the exploded wire	27 mm
Ambient liquid	ethylene glycol

The copper nanosized powder was taken out from the fluid by the centrifuging and then dried under vacuum for 2h and collected for the X-ray diffraction (XRD) analysis. The morphologies and the size of the prepared copper nanoparticles were carried out by field emission-scanning electron microscopy (FE-SEM) and transmission electron microscopy (TEM). The absorption spectrum was investigated by UV-Vis method in the wavelength range of 300-800 nm. The zeta potential of the samples was measured by a zeta potentiometer (ELS-Z, Otsuka Electronics, Japan). The experiment was repeated 10 times to calculate the mean value of the experimental data.

The stability of Cu dispersion was analysed by multiple light scattering using Turbiscan Lab. (Formulation Co., France). This apparatus has an optical detection head composed of a pulsed near-infrared light source ($\lambda=880$ nm) and two synchronous detectors: the transmission detector (at 180°), which receive the light going through the sample and the backscattering detector (at 45°), which receives the light scattering backward by the sample. The detection head scans the entire height of the sample, acquiring transmission and backscattering data every 40 μ m. The Turbiscan makes scans at various pre-programmed times and overlays the profiles on one graph in order to show the stabilisation of the dispersion.

The thermal conductivity of Cu nanofluid was measured by transient hot-wire (THW) method using KD2 Pro system (Decagon Devices, USA). We repeated measurement at least 10 times to get the medium with the interval of 15 min to stabilize

the thermal gradients of nanofluid. All thermal conductivity of the as-prepared nanofluid was measured at room temperature.

3. Results and Discussion

The Cu nanofluid has been prepared by employing a novel, physical, top-down approach of EEW in ethylene glycol. The color of as-synthesized nanofluid is dark brown. FE-SEM image and histogram of the diameter distribution for Cu nanoparticles synthesized by the explosion of wire in ethylene glycol are presented in Fig. 2. The FE-SEM image (Fig. 2a) shows the presence of nearly spherical particles with an average diameter of 65 nm. The histograms of diameter distribution (Fig. 2(b))

Fig. 2. FE-SEM image of (a) Cu nanoparticles and (b) the particle size distribution.

Fig. 3. TEM image of Cu nanoparticles prepared by EEW in ethylene glycol.

Fig. 4. X-ray diffraction pattern of the Cu nanopowder prepared by EEW in EG.

extracted from FE-SEM image presents Gaussian approximation of size. In the FE-SEM image, we can see continuous big aggregates which are composed of the small sized nanoparticles. This is due to handling of sample for FE-SEM observation. The detailed image of the nanoparticles produced is shown in the TEM results (Fig. 3). Besides big particles sizes, there are many small particles with size smaller than 30 nm. The particles are in well-dispersed state with only a little aggregation of nanoparticles.

Fig. 4 shows the XRD pattern of the nanopow-

Fig. 5. UV-Vis absorption spectrum of Cu nanofluid in ethylene glycol.

der collected from fluid by centrifuging of the copper nanofluid. There are peaks at 2θ (degree) = 43.38, 50.52 and 74.22 and all of these peak positions match copper in the face-centered cubic crystal structure and correspond the (hkl) planes (111), (200) (311), respectively. There were little peaks of cupric oxide phase found in the X-ray diffraction pattern.

Fig. 5 shows the UV-Vis absorption spectrum of Cu nanofluid with based fluid of ethylene glycol. There was only a peak in the whole range of measured wavelength. The optical spectrum had an absorbance peak at ~600 nm. This peak was attributed for copper surface plasmon resonance band which was reported in many previous reports in the literature on copper nanoparticle [10-12]. The exact position of this band may shift depending on the individual particle properties including size, shape, solvent, and capping agent. With larger particles size, this band shifts to higher wavelength.

A most important physical property of nanofluids is the tendency of the particles to aggregate. The aggregation between nanoparticles dispersed in fluid media occurs frequently and the stability of dispersion is determined by the interaction between the nanoparticles in the fluid. Many researchers have reported that the stability of dispersion in a fluid is closely related to its electro-kinetic proper-

ties [13-15]. The suspension can be more stable with high surface charge value due to strong repulsive forces between two similar charged particles. The surface charge properties of suspension can be evaluated via zeta potential according to Smoluchowski fomular: [15]

$$\zeta = \frac{4\pi\eta}{\varepsilon} \times U \times 300 \times 300 \times 1000$$

where ζ is zeta potential in mV, ε the dielectric constant of the medium, η the viscosity of solution, and U the electrophoretic mobility ($v/V/L$), where u the velocity of the particles under electric field in cm/s, V the applied voltage, and L the electrode distance.

In this research the zeta potential of the copper particles in ethylene glycol is 51 mV. It is high enough to keep the nanofluid stable because the threshold of stability of a colloidal nanoparticles solution in terms of the zeta potential is ± 30 mV [15].

The stability of Cu nanofluid in this work was also observed using multiple light scattering method. It was investigated at room temperature. In order to visualize the stability of nanofluid, only the backscattering variations (% , ordinate axis) on the tube height (mm, abscises axis) as a function of time was drawn. The transmission profile is not showed because no transmission light went through the nanofluid due to opaque nanofluid. Fig. 6 shows the backscattering profile and delta backscattering obtained from the Cu suspension in ethylene glycol for 5 days. On the backscattering profile (Fig. 6(a)). We could observe that the shape of the curve was flat on the whole line. The level of backscattering decreased with time over the total length of the sample. This phenomenon may be a proof of the decrease in volume fraction of the suspension in the nanofluid due to sedimentation of some big size particles or aggregation of small sizes to become big one and then sedimentation. In the middle of the measuring bottle, it can be seen that the backscattering level gradually decreased in the whole line. The decrease of backscattering level can be

Fig. 6. (a) Backscattering profile of Cu nanofluid measured in 5 days and (b) variation of backscattering level.

seen more clearly in the delta transmittance profile (Fig. 6(b)). In the first day, there was a little change in the backscattering level. The change decreases rapidly in the second day and then slowly went down. The total decrease of backscattering level for 5 days was about 2%. It can be noted that this decrease is quite small and it is difficult to observe in the sedimentation image. The sedimentation image of as-synthesized nanofluid and one after 2 months static stationary was shown in the inset of Fig. 6(b).

Thermal conductivity measurements were carried out at room temperature using a transient hot wire method. The volume fraction of Cu nanoparticles in fluid was 0.1%. The results indicated that the thermal conductivity of Cu-ethylene glycol (EG) liquids containing a small volume fraction of Cu nanoparticles was higher than that of the no Cu-EG liquids without Cu nanoparticles. The thermal conductivity of this nanofluid showed an enhancement of about 5.2%. This phenomenon resulted from due to the higher thermal conductivity of copper (386.11W/m-K at 273 K) in comparison to based fluids (0.253W/m-K at 273 K). The enhancement on thermal conductivity in our research was lower than that in some literature reports. [4, 5, 16] The size of nanoparticles can be a key of this influence. Other factors such as shape, viscosity, tem-

perature of nanofluids as well as surfactant, pH, etc. may also influence the thermal conductivity of nanofluids. Up to now, the factors influencing enhancement of thermal conductivity and mechanism influencing thermal conductivity of nanofluids are still unknown although many models have been proposed to deal with abnormal increase in thermal conductivity of nanofluids [17].

4. Conclusion

The Cu nanofluid was prepared by electrical explosion of wire in ethylene glycol, a novel one-step physical method. The pure Cu nanopowder was obtained with the average grain size around 65 nm and near spherical shape. Without addition of any surfactant and dispersant, the Cu nanofluid was found to be stable determining from the high zeta potential value and small decreasing backscattering level. The thermal conductivity of nanofluid at very low volume fraction (0.1%) showed an enhancement of 5.2%. Consequently, it is expected that electrical explosion of wire in liquid can be used to fabricate other metallic nanofluids and nanoparticles.

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