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Experimental Investigation on Viscosity of Cu-H_2O Nanofluids

LI Xinfang[1], ZHU Dongsheng[2], WANG Xianju[2,3]

(1. Department of Packaging & Printing, Zhongshan Torch Vocation and Technology College, Zhongshan 528436, China;
2. Key Lab of Enhanced Heat Transfer and Energy Conservation, Ministry of Education, South China University of Technology, Guangzhou 510641, China;
3. Navy Arms of Services Command Academy, Guangzhou 510431, China)

Abstract: A procedure for preparing a nanofluid that a solid-liquid composite material consists of solid nanoparticles with sizes typically of 1-100 nm suspended in liquid was proposed. By means of the procedure, Cu-H_2O nanofluids with and without dispersant were prepared, whose sediment photographs and particle size distribution were given to illustrate the stability and evenness of suspension with dispersant. The viscosity of Cu-H_2O nanofluid was measured using capillary viscometers. The mass fractions(w) of copper nanoparticles in the experiment varied between 0.04% and 0.16% with the temperature range of 30-70 ℃. The experimental results show that the temperature and SDBS concentration are the major factors affecting the viscosity of the nano-copper suspensions, while the effect of the mass fraction of Cu on the viscosity is not as obvious as that of the temperature and SDBS dispersant for the mass fraction chosen in the experiment. The apparent viscosity of the copper nano-suspensions decreases with the temperature increase, and increases slightly with the increase of the mass fraction of SDBS dispersant, and almost keeps invariability with increasing the mass fraction of Cu. The influence of SDBS concentration on the viscosity of nano-suspension was relatively large comparing with that of the nanoparticle concentration.

Key words: nano-Cu/water suspension; SDBS; kinematic viscosity; capillary viscometer

1 Introduction

With rapid development of nanomaterial technology and growing visibility of energy resource problems[1-3], researchers started to apply nanomaterial technologies to the area of heat transfer enhancement in order to develop a homogeneous, stable, new heat exchange medium of high conductivity. Nanofluids, produced by dispersing nanoparticles into conventional heat transfer fluids such as water, glycol, or oil, was coined by Choi in 1995 at Argonne National Laboratory of USA[4]. Because of their excellent characteristics, the nanofluids are found to have wide applications in enhancing heat transfer, even for microscale heat transfer[5]. It is expected that the nanofluid will become a new type of heat transfer fluid for thermal engineering.

Nanofluids have attracted great interest recently because of reports of greatly enhanced thermal properties. For example, a small amount (<1% volume fraction) of Cu nanoparticles or carbon nanotubes dispersed in ethylene glycol or oil is reported to increase the inherently poor thermal conductivity of the liquid by 40% and 150%, respectively[6,7]. Conventional particle-liquid suspensions require high concentrations (>10%) of particles to achieve such enhancement. However, problems of rheology and stability are amplified at high concentrations, precluding the widespread use of conventional slurries as heat transfer fluids. In some cases, the observed enhancement in thermal conductivity of nanofluids is orders of magnitude larger than predicted by well-established theories. Other perplexing results in this rapidly evolving field include a surprisingly strong temperature dependence of the thermal conductivity[8,9] and a three-fold higher critical heat flux compared with the base fluids[10,11]. Xuan and Roetzel[12], and Xuan and Li[13] investigated the heat transfer enhancement characteristics of nanoparticle suspensions based on their thermal conductivity and viscosity measurements. They compared their experimental results for the apparent viscosity of oil-copper nano-suspensions with that predicted by Brinkman's formula for the viscosity of suspensions, and concluded that the experimental results agree well when the nanoparticle volumetric fraction is

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LI Xinfang (李新芳): Ph D; E-mail: xtulxf@163.com

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quite small. An investigation on the viscosity and thermal conductivity of micro-suspensions[14] showed that the suspensions were Newtonian fluids at lower concentrations, but became pseudoplastic at higher concentrations. More experiments are needed to understand the non-Newtonian properties of the nanoparticle suspensions.

Research on the heat transfer enhancement with nano-suspensions is still in its infancy. Viscosity and thermal conductivity data are, of course, important fundamental information to predict the flow and convective heat transfer in nano-suspensions[15,16]. Among the very limited reports on this subject, there are even less viscosity data than thermal conductivity data. Experimentally measured viscosity data for water with Cu nanoparticles was presented in this paper. It is expected to provide guidance to design nanofluides with excellent performance.

2 Experimental

2.1 Chemical

Cu powder (Shenzhen Junye Nano Material Ltd, China) with copper content >99.9% was used in the study. The average particle size and BET surface area of the powder were found to be 25-60 nm and 30-50 m^2/g, respectively. The transmission electron micrograph (TEM) of Cu powder is shown in Fig.1. The particles are basically spherical or near spherical.

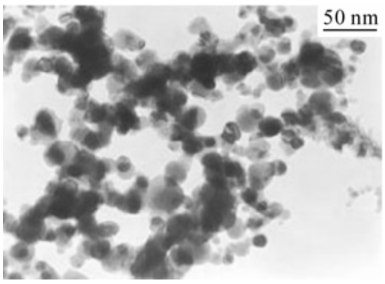

Fig.1 TEM image of Cu powder

An anionic surfactant, sodium dodecylbenzenesulfonate (referred to as SDBS) in chemical grade, from Guangzhou Chemical Reagent Factory (China), was used. The surfactant structure is shown in Fig.2. The water was purified by a Milli-Q Academic Millipore system. The pH valne was controlled by hydrochloric acid (HCl) and sodium hydroxide (NaOH) in analytical grade. All chemicals were used as received without any further purification.

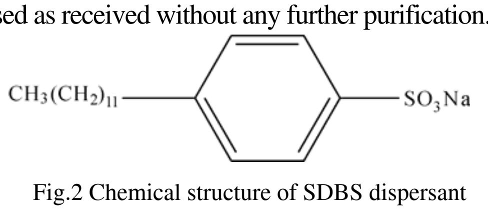

Fig.2 Chemical structure of SDBS dispersant

2.2 Measurement of the viscosity

The viscosity of the nano-fluid can be estimated with the existing relations for the two-phase mixture. Drew and Passman[17] introduced the well-known Einstein's formula for evaluating the effective viscosity μ_{eff} of a linearly viscous fluid of viscosity μ_{f} containing a dilute suspension of small rigid spherical particles. The formula yields:

$$\mu_{\text{eff}} = \mu_{\text{f}}\left(1+2.5\phi\right) \tag{1}$$

This relation is restricted for low volume concentration (ϕ <0.05). Einstein's equation was extended by Brinkman[18] as

$$\mu_{\text{eff}} = \mu_{\text{f}}\frac{1}{\left(1-\phi\right)^{2.5}} \tag{2}$$

There are other relations of the effective viscosity of the two-phase mixture in the literature[17,19]. Each relation has its own application limitation. The direct and reliable access to obtaining the apparent viscosity of the nano-fluid is by experiment. Xuan and Li[20] have experimentally measured the apparent viscosity of the transform oil-water nano-fluid and of the water-copper nano-fluid in the temperature range of 20-50 ℃. The experimental results reveal relatively good coincidence with Brinkman's theory.

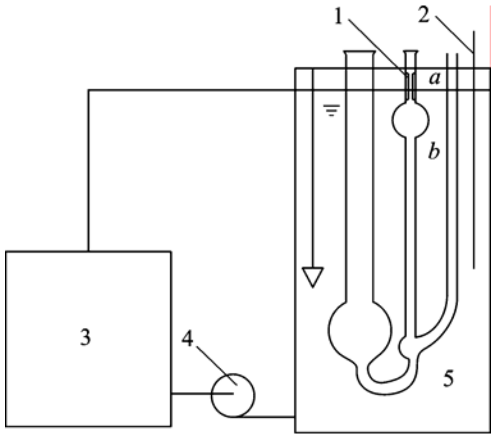

Fig.3 The experimental scheme for viscosity
1. Viscometer; 2. Thermometer; 3. Constant-temperature bath; 4. Pump; 5. Glass water tank

A capillary viscometer was used for the tests in the experimental facility shown in Fig.3. The capillary viscometer was submerged in a glass water tank. Water from a constant-temperature bath entered the bottom of the tank by a pump and returned to the bath through an overflow pipe. The water tank was maintained at a prescribed constant temperature by the water circulation. The vertical angle of the viscometer was accurately controlled with a special tripod.

The dynamic viscosity was determined from the experimental data using

$$\eta = \rho c \tau \tag{3}$$

Where ρ is the suspension density at the same temperature, c the viscometer constant calibrated with water at the same temperature, and τ the time needed for the suspension to fall from position a to b shown in Fig.2. The effect of capillary-tube diameter on the apparent viscosity was evaluated using three viscometers with diameter of 0.40 mm, 0.50 mm and 0.60 mm. The mean value obstained using three viscometers is the viscosity of each sample.

3 Preparation of nanofluids

Two-step method was selected to prepare the nanofluids, which is shown in Fig.4. Preparation of nanofluids is the first key step in applying nanophase particles to changing the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid-solid mixture. Some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles, no chemical change of the fluid. In general, these are effective methods used for preparation of suspensions: (1) to change the pH value of suspensions; (2) to use surface activators and/or dispersants; (3) to use ultrasonic vibration. All these techniques aim at changing the surface properties of suspended particles and suppressing formation of particles cluster in order to obtain stable suspensions. It depends upon the application case how these techniques are used.

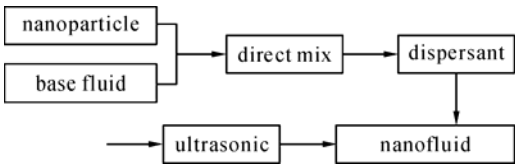

Fig.4 The preparation process of nanofluid

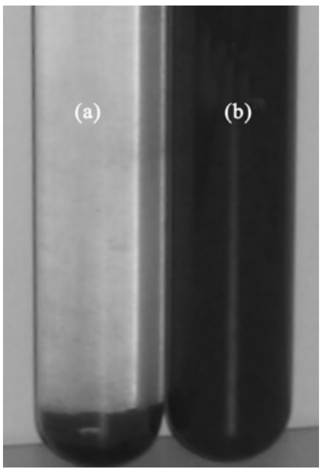

Fig.5 Photographs of Cu-H_2O suspensions in the absence (a) and in the presence (b) of dispersant depositing for a week. Concentration of Cu and the dispersant are 0.1% (mass fraction)

Ultrasonication was used for preparation of mixed aqueous nano-suspensions, which is an accepted technique for dispersing the highly entangled or aggregated nanoparticle samples[21,22], but longer time of high-energy sonication can introduce defects. In the study, copper nanoparticle (0.1 g) and a water solution (99.8 g) with dispersant (0.1 g) were directly mixed in a 150 ml beaker. The suspension was transferred into an ultrasonic vibrator and sonicated for 1 h at a frequency of 40 kHz and an output power of 100 W at 25-30 ℃. For the comparison, the suspension without dispersant was sonicated for 1 h in the same way. Their sedimentation photographs are shown in Fig.5, which shows that the stabilization of the suspension with dispersant can last about 1 week in the stationary state and no sediment is found, while the suspension without dispersant exhibits weaker dispersion and quickly occurs aggregatation.

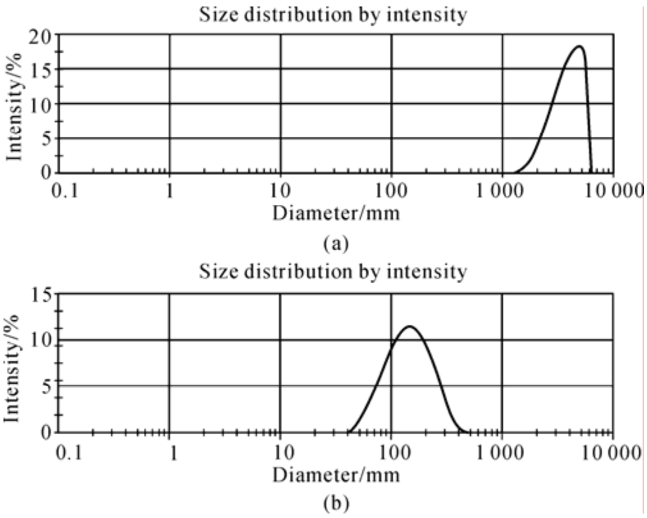

Fig.6 Particle size distributions of Cu-H_2O suspensions in the absence (a) and in the presence (b) of dispersant. Concentration of Cu and the dispersant are 0.05% (mass fraction)

Fig.6 illustrates the particle size distributions of Cu-H_2O nano-suspensions in the absence (a) and in the presence (b) of dispersant, which shows that there are obvious variations in the particle size characteristics between two samples. The average particle sizes obtained are (a) in the absence of dispersant: 5560 nm, (b) in the presence of dispersant: 130 nm. Therefore, the stabilization of Cu-H_2O suspension with dispersant is better, which exhibits considerable accordance as seen in Fig.5.

4 Measurement of Viscosity for Cu-H_2O Nanofluids

4.1 Influence of temperature and concentration on the viscosity of SDBS solution

Fig.7 shows the variation of the viscosity of different concentration SDBS solution with the temperature. The mass fractions of SDBS solution in the experiment, *w*, varied between 0.00% (pure water) and 0.16%, and the temperature range was 30 ℃ to 70 ℃. The viscosity of SDBS solution changes keenly with the temperature and decreases with increasing temperature in Fig.5. The higher the mass fraction of SDBS solution is, the bigger the apparent viscosity is.

4.2 Influence of SDBS concentration and Cu concentration on the viscosity of copper nano-suspensions

Figs 8-11 show the variation of the viscosity of copper nano-suspensions with the mass fraction of Cu, when the mass fraction of SDBS dispersant are between 0.04% and 0.16%, and temperature ranging from 30 ℃ to

70 ℃. From the Fig.8, it can be seen that the apparent viscosity of 0.04% copper nano-suspensions is very close to the viscosity of 0.04% dispersant solution. The experimental results in Figs 8-11 show that the apparent viscosity of the copper nano-suspensions decreases with the temperature increase, and increases slightly with increasing the mass fraction of SDBS dispersant, and almost keeps invariability with increasing the mass fraction of Cu. So it is obvious that the temperature and SDBS concentration are the major factors affecting the viscosity of the nanoparticle suspensions, while that of the mass fraction of Cu on the viscosity is not as obvious as the effect of the temperature and the dispersant.

4.3 Influence of SDBS concentration on stability of copper nano-suspensions

The viscosity of the copper nano-suspensions is an important basis for selecting conditions for dispersing particles. Fig.12 shows the variation of the viscosity with SDBS concentration for 0.12% copper nano-suspension at 30 ℃. The results show: as the dispersant concentration increases, the apparent viscosity of copper nano-suspension is observed to increase, resulting in a maximal value at the 0.12% SDBS, then the viscosity almost keeps invariability, which indicates the influence of SDBS concentration on the viscosity of nano-suspension exists an optimizing value. The bigger the viscosity of nanofluid is, the more the consumed energy for pump is, and the weaker the enhanced heat transfer capability is, so at the 0.12% SDBS, the system is more stable, which suggests SDBS dispersant yields well dispersed system.

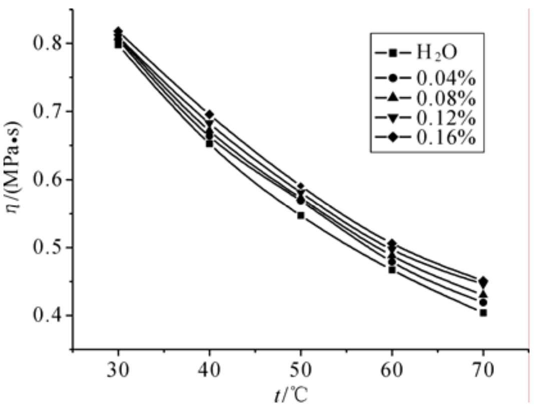

Fig.7 The variation of the viscosity of different concentration SDBS solution with the temperature

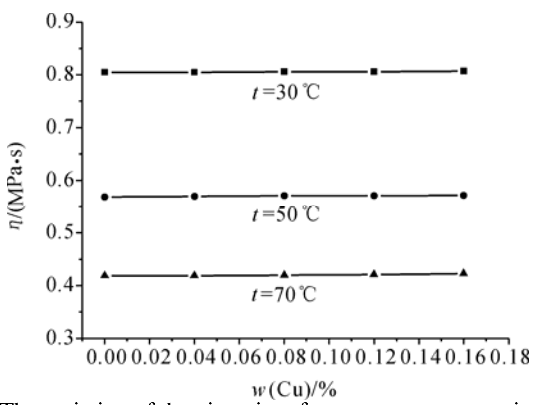

Fig.8 The variation of the viscosity of copper nano-suspensions with the mass fraction of Cu in the presence of 0.04% SDBS dispersant

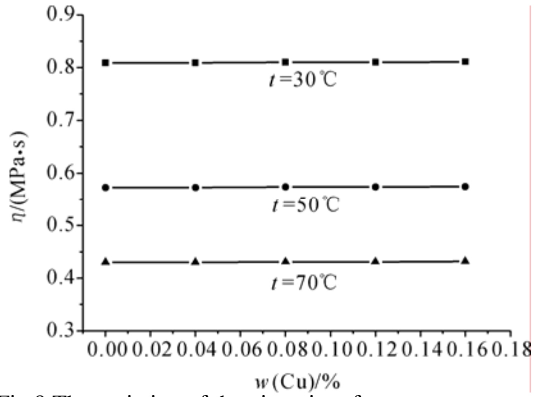

Fig.9 The variation of the viscosity of copper nano-suspensions with the mass fraction of Cu in the presence of 0.08% SDBS dispersant

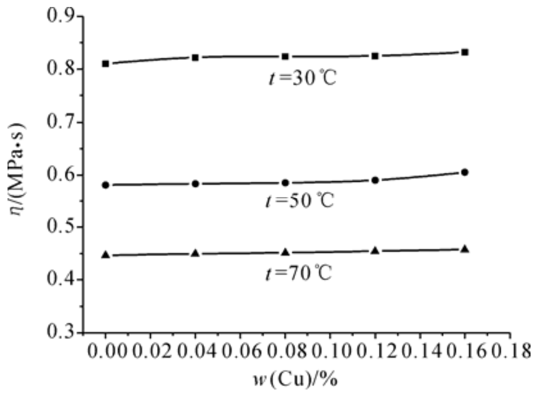

Fig.10 The variation of the viscosity of copper nano-suspensions with the mass fraction of Cu in the presence of 0.12% SDBS dispersant

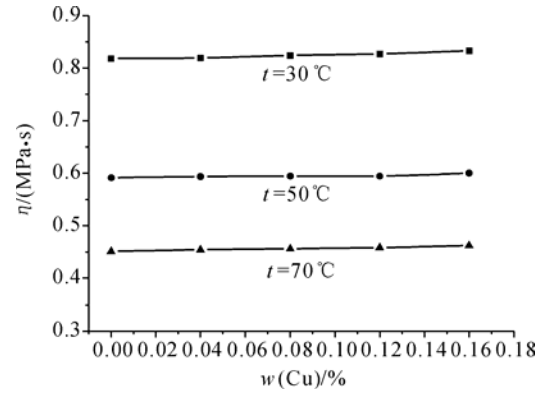

Fig.11 The variation of the viscosity of copper nano-suspensions with the mass fraction of Cu in the presence of 0.16% SDBS dispersant

4.3 Influence of SDBS concentration on stability of copper nano-suspensions

The viscosity of the copper nano-suspensions is an important basis for selecting conditions for dispersing particles. Fig.12 shows the variation of the viscosity with SDBS concentration for 0.12% copper nano-suspension at 30 ℃. The results show: as the dispersant concentration increases, the apparent viscosity of copper

nano-suspension is observed to increase, resulting in a maximal value at the 0.12% SDBS, then the viscosity almost keeps invariability, which indicates the influence of SDBS concentration on the viscosity of nano-suspension exists an optimizing value. The bigger the viscosity of nanofluid is, the more the consumed energy for pump is, and the weaker the enhanced heat transfer capability is, so at the 0.12% SDBS, the system is more stable, which suggests SDBS dispersant yields well dispersed system.

In addition, the influence of SDBS concentration on the viscosity of nano-suspension is also found to be relatively large comparing with the effect of the nanoparticle concentration.

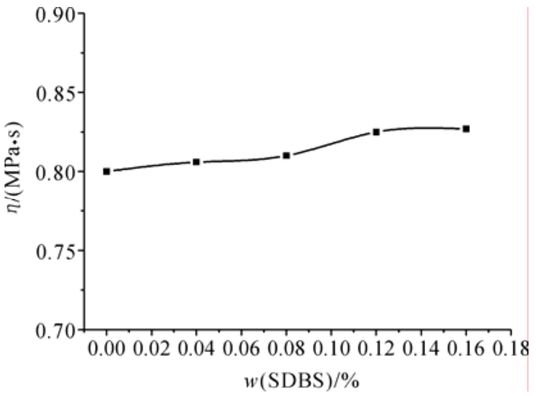

Fig.12 The variation of the viscosity with SDBS concentration for 0.12% copper nano-suspension at 30 ℃

5 Conclusions

a) $Cu\text{-}H_2O$ nanofluids by two-step method were prepared. The observed sediment photographs and particle size distribution show better dispersion behavior in the suspension with the addition of dispersant.

b) The temperature and SDBS concentration are the major factors affecting the viscosity of the nanoparticle suspensions, while that of the mass fraction of Cu on the viscosity is not as obvious as the effect of the temperature and the dispersant.

c) The apparent viscosity of the copper nano-suspensions decreases with the temperature increase, and increases slightly with increasing the mass fraction of SDBS dispersant, and almost keeps invariability with increasing the mass fraction of Cu.

d) The influence of SDBS concentration on the viscosity of nano-suspension is found to be relatively large comparing with that of the nanoparticle concentration.

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