International Journal of Thermal Sciences 84 (2014) 118–124

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Effects of surfactant on the stability and thermal conductivity of Al_2O_3/de-ionized water nanofluids

Guodong Xia*, Huanming Jiang, Ran Liu, Yuling Zhai

Key Laboratory of Enhanced Heat Transfer and Energy Conservation, Ministry of Education, College of Environmental and Energy Engineering, Beijing University of Technology, Beijing 100124, China

A R T I C L E I N F O

Article history:
Received 4 July 2013
Received in revised form
5 May 2014
Accepted 5 May 2014
Available online 12 June 2014

Keywords:
Nanofluids
Surfactant
Stability
Thermal conductivity
Concentration ratio

A B S T R A C T

Al_2O_3/de-ionized water nanofluids of different volume fractions with different surfactant mass fractions are prepared by two-step method. Thermal conductivities of the suspensions are measured by a Hot Disk thermal constant analyzer. The uncertainty of liquid thermal conductivity measurement is within 1.5% at room temperature according to the accuracy verification test of de-ionized water. Effects of two kinds of surfactants — sodium dodecyl sulphate (SDS) and polyvinylpyrrolidone (PVP) — on the stability and thermal conductivity of Al_2O_3/de-ionized water nanofluids are analyzed respectively. Results show that surfactant plays an important role in dispersing the nanoparticles into the base fluid and improving the stability of Al_2O_3/de-ionized water nanofluids. Non-ionic surfactant PVP shows better positive effects than anionic surfactant SDS on the dispersion and stability of the nanofluids. The highest thermal conductivity occurred at an optimal concentration ratio of surfactant mass fraction and particle volume fraction, where the ratio is partly associated with the particle size and decreases with the increase of particle volume fraction.

1. Introduction

As Choi [1] first introduced the concept of nanofluids in 1994, it has been proved an efficient method in improving the thermal conductivity of the working fluid to add nanoparticle materials into conventional heat transfer fluids. Since then, lots of researches have been done on the properties of fluid suspensions of nanometer-sized solid particles and fibers [2–7].

Xian et al. [8] found that the thermal conductivity had a good corresponding relation with the stability of nanofluids, the better dispersion behavior, the higher thermal conductivity was. While large specific surface area of nanoparticles and the activity of particle surface would easily result in agglomeration and form agglomerates in nanofluids. When the size of agglomerates grows to a certain extent, they will deposit due to gravity and lose the characteristics of nanofluids. Research also showed that the thermal conductivity of nanofluids is time dependence immediately after dispersed by ultrasonication, then time independence for the longer time [9]. It has been verified experimentally that surfactant is effective in dispersing nanoparticles in base fluids and weakening the agglomeration behavior in nano-suspensions [10–17].

Li et al. [10] prepared Cu–H_2O nanofluids by two-step method and found that with the addition of surfactant, the particle size distribution showed better dispersion behavior. Yu et al. [11] prepared stable ethylene glycol-based copper nanofluids with the addition of polyvinyl pyrrolidone (PVP) as surfactants. Results showed that the addition of PVP significantly improved the stability of copper nanofluids, yet had negative effects on the thermal conductivity. Yang et al. [12] reported that the presence of surfactants (PEG, PAA) could improve the stability and thermal conductivity of nanofluids, but surfactants in low concentrations had smaller influence than other influence factors such as particles and temperature on the thermal conductivity. Zhou et al. [13] experimentally investigated the thermal conductivity of several common surfactant (SDS, SDBS, CTAB, PVP) solutions, concluding that the thermal conductivities of surfactant solutions reach a stable ratio after a certain concentration, and the thermal conductivity ratios of ionic surfactant solutions are higher than those of non-ionic surfactant.

Peng et al. [14] investigated the effect of surfactants (SDS, CTAB, Span-80) on nucleate pool boiling heat transfer of refrigerant-based nanofluids, and found that adding surfactant could enhance the heat transfer of Cu-R113 nanofluids on most conditions, but

* Corresponding author. Tel.: +86 10 1067392176.
E-mail address: xgd@bjut.edu.cn (G. Xia).

http://dx.doi.org/10.1016/j.ijthermalsci.2014.05.004
1290-0729/

deteriorated it at high surfactant concentrations. Chen et al. [15] concluded that higher concentration of surfactant is a negative factor in improving the thermal conductivity of nanofluids. Wusiman et al. [16] experimentally studied the stability and thermal conductivity of MWCNT nanofluids stabilized by surfactants with SDS and SDBS. The results showed that the well-dispersed and long time stable of CNT nanofluids by adding surfactants within relative weight ratio (CNTs/surfactant) had higher thermal conductivity, and the optimal mixture weight ratio of CNT nanofluids was 0.5 wt % CNTs with 0.25 wt% SDBS (2/1). Liu et al. [17] investigated the dispersion stability of α-Al_2O_3 nanofluids with different mass fractions of surfactant (PAA, CTAB and SDBS). It was found that the dispersion of Al_2O_3 suspensions firstly increased to a maximum and then decreased with the increase of surfactant concentration.

As stated above, there were already many works studying the influence of surfactants on the stability of nanofluids. However, to the author's knowledge, researches carried on the effect of the concentration ratio of particle fraction and surfactant concentration on the thermal conductivity of nanofluids were seldom reported.

In this work, effects of surfactants on the stability and thermal conductivity were analyzed. We prepared Al_2O_3/de-ionized water nanofluids of different volume concentrations with the addition of different concentrations of surfactants. Thermal conductivities of these nanofluids were investigated experimentally. The main aim of this paper is to discuss the effects of the concentration ratio of surfactant and particles on the thermal conductivity of nanofluids on the basis of thermal conductivity measurements.

2. Preparation of nanofluids

2.1. Chemical

De-ionized water was used as base fluid of the nanofluids. α-Al_2O_3 powder with purity ≥99.9% was selected in the study. The mean grain size of the particles is about 13 nm. The transmission electron microscopy (TEM) of the α-Al_2O_3 nanoparticles is shown in Fig. 1. From Fig. 1, it is clearly seen that the particles are basically spherical and the average diameter is close to the reference value. The black ones are likely overlapped particles.

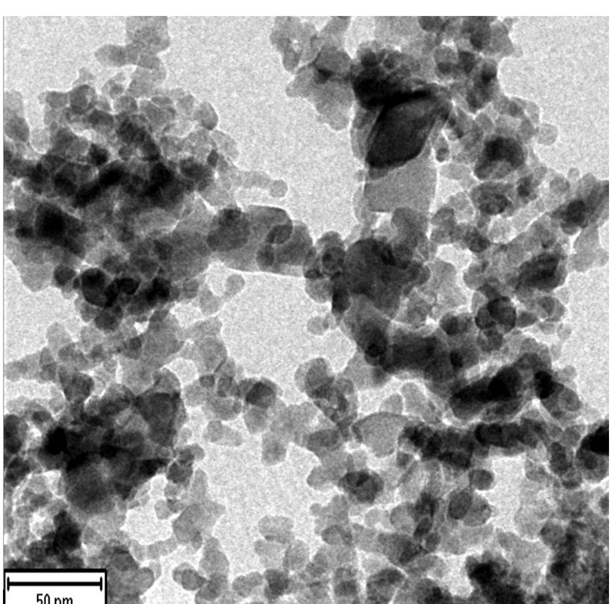

Fig. 1. TEM micrograph of α-Al_2O_3 nanoparticles dispersed in water.

Two kinds of surfactants — ionic and non-ionic — were chosen to study the effect of surfactants on the thermal conductivity of nanofluids. For the same kind of surfactant, the thermal conductivity ratio of surfactant solutions is mainly depending on the length of alkyl chain [13]. For ionic surfactants, the ratio of SDS (with shorter alkyl chains) solutions is higher than that of the others. For non-ionic surfactant, we compared the effect of two commonly used surfactants, PVP and PEG (Polyethylene glycol), and found that PVP is more effective than PEG in the dispersion of nanoparticles. Therefore, SDS and PVP were used in this work. More information of the surfactants is shown in Table 1.

2.2. Preparation process

Ultrasonic oscillation has been proved the most effective dispersion system for preparing nanofluids [18,19]. In this study, an ultrasonic oscillation (see in Table 2) was used to disperse nanoparticles into the base fluid uniformly.

Surfactant solutions were firstly prepared and transferred into an ultrasonic vibrator. Al_2O_3 powder was added to the surfactant solutions gradually in the ultrasonic vibration environment at a frequency of 40 kHz and an output power of 100 W at 18–23 °C. For comparison, suspensions without any surfactants were prepared by adding Al_2O_3 powder into de-ionized water in the same way.

2.3. Ultrasonication time

Nanofluids with 0.5 vol% particles with the addition of 0.5 wt% SDS were prepared using different times of ultrasonication. Fig. 2 shows variations of thermal conductivity ratios of Al_2O_3 nanofluids over time. The deviation of the thermal conductivity ratios of the nanofluids is negligible within 12 h. Thermal conductivity ratios of nanofluids with shorter times of ultrasonication decrease faster and lower 24 h after prepared. As all the measurements were finished within 2 h after nanofluids were prepared, which means that longer ultrasonication time would not have much influence on the measurement, the ultrasonic vibration would last 15 min after the desired powder is completely dispersed into the base fluid in the subsequent experiments.

2.4. Suspension stability

Fig. 3 shows the stability of α-Al_2O_3/de-ionized water nanofluids with different surfactants over time. And Fig. 4 shows the stability of α-Al_2O_3/de-ionized water nanofluids with 0.5 vol% particles with the addition of different concentrations of surfactants 24 h after prepared. Letter ‘a’ in the figures refers to nano-suspensions without any surfactants. Letter ‘b’ and ‘c’ refers to nano-suspensions with the addition of SDS and PVP respectively. Fig. 3(a1–c1) presents the apparent state of α-Al_2O_3/de-ionized water nanofluids 2 h after prepared. Fig. 3(a2–c2) presents the apparent state of α-Al_2O_3/de-ionized water nanofluids 48 h after prepared. Nanoparticles agglomerate and deposit quickly in de-ionized water. From Fig. 3(a1–c2), it is seen that the addition of surfactants significantly improves the stability of α-Al_2O_3/de-ionized water nanofluids. Suspension with non-ionic surfactant PVP shows better dispersion and longer time stability than that with anionic surfactant SDS.

Fig. 4(b3–b5) presents the apparent state of α-Al_2O_3 (0.5 vol%) nanofluids with the addition of different concentrations of SDS. An optimal concentration ratio of SDS mass fraction and particle volume fraction shows better stability a certain time after prepared. When the ratio increases, the stability deteriorates. When the ratio reaches 4/1, the particles almost completely deposit. Fig. 4(c3–c5) presents the apparent state of α-Al_2O_3 (0.5 vol%) naofluids with the