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Thermochimica Acta 455 (2007) 66–69
thermochimica acta
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Study of thermal conductivity of nanofluids for the application of heat transfer fluids

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Available online 9 December 2006

Abstract

TiO_2, Al_2O_3, Fe, and WO_3 nanofluids are prepared in a two-step procedure by dispersing nanoparticles in a basefluid. Since nanoparticles form clusters in fluids, a cell disrupter generating high power pulses is used for improving the dispersion of nanoparticles. The transient hot wire method is used for the measurement of thermal conductivity. The thermal conductivities of TiO_2, Al_2O_3, Fe, and WO_3 nanofluids are studied and compared with each other. Nanofluids show a large enhancement of thermal conductivity compared with their basefluids, which exceeds the theoretical expectation of two-component mixture system. We compare thermal conductivities of various nanofluids and discuss the important factors in determining thermal conductivity in this study.

Keywords: Nanofluids; Thermal conductivity; Hot wire method; Ceramic nanoparticles; Metallic nanoparticles

1. Introduction

It has been recognized that the suspension of solids in fluids enhances the effective thermal conductivity of the material [1]. Enhancement of thermal conductivity of fluids contributes to improving the efficiency of heat transfer fluids. Furthermore, it is possible to reduce the size of the heat exchange system, which has been limited due to the poor thermal transport property of fluids. In earlier days, micron-sized or larger particles were suspended in fluids and they led to causing the problems, such as the settlement of particles, clogging, abrasion of devices, etc. [2].

It was proposed that fluids containing nanometer-sized particles can be a new class of engineered fluids with high thermal conductivity [2]. The nanoparticle suspended fluids, named nanofluids, have been produced as the nanotechnology producing nanoparticles developed rapidly. There have been many researches in the enhancement of thermal conductivity of nanofluids [3–8]. It was reported that the nanofluid containing 10-nm-sized Cu nanoparticles showed a large enhancement of thermal conductivity compared with Al_2O_3 nanofluid containing 35 nm nanoparticles [6]. We also reported that 18% enhancement of thermal conductivity was achieved by using 10 nm Fe nanoparticles [7]. Large enhancement of thermal conductivity of nanofluids could not be predicted by conventional theories on the effective thermal conductivity of two-component materials [9–11]. The exact mechanism of thermal transport in nanofluids is not known at this moment, even if several potential mechanisms were suggested to describe experimental results of thermal conductivity of nanofluids. Many factors, such as particle size, effect of surfactant, dispersion of particles, and thermal property of dispersed particles have been expected to influence the thermal property of nanofluids. Moreover, the surface-to-volume ratio of particles increases dramatically as the particle size reduces, which can lead to potentiality of the significant enhancement of thermal conductivity of fluids [7]. The successful commercialization of nanofluids will bring the industrial advantages by reducing the energy consumption and the exhaust gas [12].

The results of Cu and Al_2O_3 nanofluids suggested the effect of intrinsic thermal conductivity and particle size of dispersed nanoparticles on thermal conductivity of nanofluids, but more nanofluids are needed for understanding of the effect. This work uses the oxide nanoparticles, such as TiO_2, Al_2O_3, and WO_3 and metal nanoparticles of Fe for nanofluids for the study of thermal conductivity of nanofluids. As comparing those results with

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0040-6031/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.tca.2006.12.006

Al_2O_3, and Cu nanofluids, we would like to understand important factors in determining thermal conductivity of nanofluids. We also compare the experimental results with the calculated results with the conventional model for two-component materials.

2. Experimental

TiO_2, Al_2O_3, Fe, and WO_3 nanoparticles were synthesized by a chemical vapor deposition process for the preparation of nanofluids. The mean sizes of TiO_2, Al_2O_3, Fe, and WO_3 nanoparticles determined with transmission electron microscope (TEM) images are 25 nm, 48 nm, 10 nm, and 38 nm, respectively. The crystal structures of nanoparticles were determined with X-ray diffraction (XRD) patterns. We prepared TiO_2, Al_2O_3, Fe, and WO_3 nanofluids in a two-step procedure by dispersing nanoparticles in basefluids. Deionized water was used as a basefluid for TiO_2 and Al_2O_3 nanofluids, and ethylene glycol was used for Fe and WO_3 nanofluids. Table 1 shows the size and volume fraction of nanoparticles and basefluids of the nanofluids prepared in this study. Since no stabilizing agents were added in the preparation of nanofluids, nanoparticles must have been forming clusters in nanofluids. In order to improve the dispersion of particles in fluid, we used an ultrasonic cell disrupter (Jeiotech, ULH-700S) generating ultrasonic pulses of 700 W at 20 kHz. Even though the sonication cannot break nanoparticles individually, the cluster of nanoparticles breaks into smaller clusters resulting in the decrease of clusters [7,8].

Thermal conductivity of nanofluids was measured with a transient hot wire (THW) method, which is one of the most accurate methods for determining thermal conductivity of fluids [13,14]. A Teflon™-coated pure (99.9%) platinum wire was used in the measurement. The wire is used as both heater and thermometer. THW method measures the temperature and time response of the wire to an abrupt electrical pulse. Thermal conductivity, k, is calculated from a derivation of Fourier's law:

$$k = \left[\frac{q}{4\pi(T_2 - T_1)}\right] \ln\left(\frac{t_2}{t_1}\right), \quad (1)$$

where q is the applied electric power and T_1 and T_2 are the temperatures at times t_1 and t_2, respectively. From the temperature coefficient of the electrical resistance of a wire, the temperature rise of the wire can be determined by the change in its electrical resistance with time [12]. We measured thermal conductivity of nanofluids right after the sonication for 50 min. The thermal conductivity of nanofluids was obtained as a function of volume fraction of nanoparticles suspending in the nanofluids.

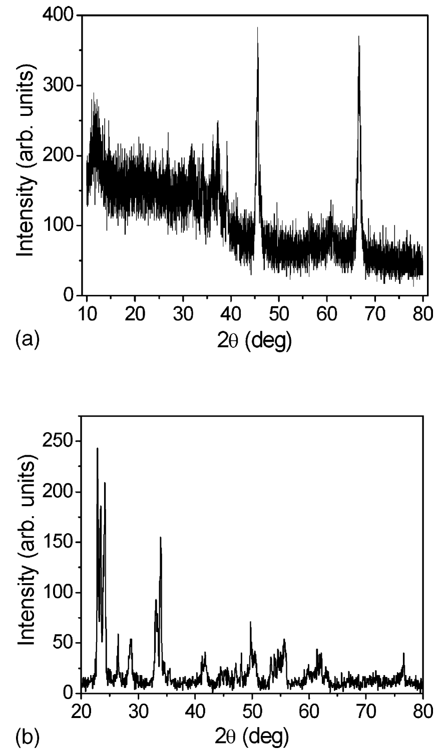

Fig. 1. XRD patterns of: (a) Al_2O_3 and (b) WO_3 nanoparticles.

3. Results and discussion

XRD patterns of Al_2O_3 and WO_3 nanoparticles are given in Fig. 1(a and b), respectively. Al_2O_3 nanoparticles form in γ-Al_2O_3 phase having the peaks of (4 0 0) and (4 4 0) and WO_3 nanoparticles form in monoclinic phase. The main XRD peaks at 23° and 24° correspond to the (0 0 2) and (1 1 0) reflections in bulk WO_3 crystal.

Fig. 2 shows the thermal conductivities of TiO_2 and Al_2O_3 nanofluids as a function of volume fraction of nanoparticles. Deionized water was used as a basefluid for both nanofluids. k and k_0 in the figure represent thermal conductivity of nanofluid and basefluid, respectively. As reported by other groups [6], Al_2O_3 shows very slow increase with the volume fraction of nanoparticles. It has been known that nanofluids containing ceramic nanoparticles exhibit smaller enhancement compared with nanofluids containing metallic nanoparticles. While there is only 4% enhancement of thermal conductivity with 1.0% volume fraction of Al_2O_3 nanoparticles, TiO_2 containing 1.0% volume fraction of nanoparticles exhibits the 14.4% enhancement of thermal conductivity. TiO_2 nanofluid shows higher

Table 1
Characterization of nanoparticles and basefluids used in the preparation of nanofluids

	Nanoparticle			
	TiO_2	Al_2O_3	Fe	WO_3
Average size of particles (nm)	25	48	10	38
Volume fraction	0.1, 0.5, 1.0	0.3, 0.5, 0.7, 1.0	0.2, 0.3, 0.4, 0.55	0.05, 0.1, 0.2, 0.3
Basefluid	Water		Ethylene glycol	