Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H$_2$O nanofluids

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Abstract

Nanofluids have been attractive for the last few years with the enormous potential to improve the efficiency of heat transfer fluids. This work focuses on the effect of pH and sodium dodecylbenzenesulfonate (SDBS) surfactant on the thermal conductivity of nanofluids. The thermal conductivity was measured by a Hot Disk Thermal Constants Anlyser. The results showed that the thermal conductivity enhancements of Cu-H$_2$O nanofluids are highly dependent on the weight fraction of nanoparticle, pH values and SDBS surfactant concentration of nano-suspensions. The Cu-H$_2$O nanofluids with an ounce of Cu have noticeably higher thermal conductivity than the base fluid without nanoparticles, For Cu nanoparticles at a weight fraction of 0.001 (0.1 wt%), thermal conductivity was enhanced by up to 10.7%, with an optimal pH value and SDBS concentration for the highest thermal conductivity. Therefore, the combined treatment with both the pH and chemical surfactant is recommended to improve the thermal conductivity for practical applications of nanofluid.
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1. Introduction

Together with the greatly increasing thermal load in microelectronics and higher-powered automobiles, the needs for highperformance heating or cooling fluids are increasing every year. The thermal conductivity of these fluids plays a vital role in the development of energy-efficient heat transfer equipment. However, conventional heat transfer fluids have poor heat transfer properties compared to most solids. Since 1995 when U.S. Choi showed the possibility of using a new type of fluid containing nanoparticles [1], large enhancements of up to more than 100% in effective thermal conductivity (K_{eff}) of such fluids have been reported. The promising prospect for the fluid, *nanofluids*, triggered many researchers to find the best combination of particles and solvents [2–9] and to elucidate the governing mechanisms [10–15] as well. Keblinski et al. [14] suggested the potential mechanisms for thermal conductivity enhancement such as Brownian motion, liquid layering and nanoparticle clustering. Koo and Kleinstreuer [16] found that the role of Brownian motion is much more important than the thermophoretic and osmo-phoretic motions. Vadasz [17] demonstrated that the transient heat conduction process in nanofluids may provide a valid explanation for the apparent heat transfer enhancement.

Because of the aforementioned complexity and contradiction in nanofluids, the research community has not reached a solid consensus on the mechanisms. Here, we take notice of the suspension stability as a common factor in the current technological limitations. As the surface chemical treatment changes the suspension stability through surface charge states and resultant surface potential [18,19].

Therefore, in the present study we change pH of the suspension systematically to control surface potential that can be reflected by zeta potential. The effects of the pH value of the aqueous suspension, sodium dodecylbenzenesulfonate (SDBS) concentration, and the weight fraction of the dispersed Cu particles on the enhanced thermal conductivity ratio have

Fig. 1. TEM micrograph of nano-copper.

Fig. 3. Schematic diagram of TPS sensor.
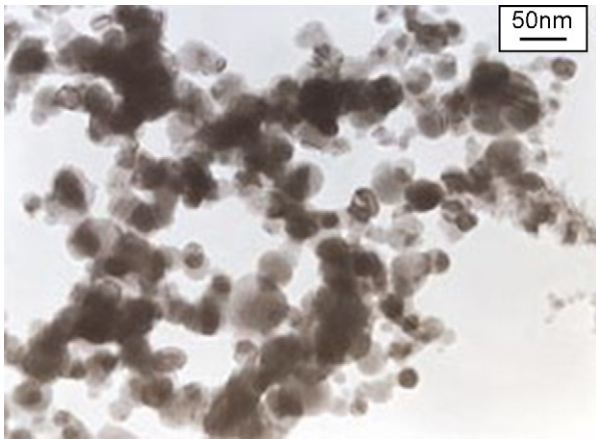
been investigated. It is expected to provide guidance to design nanofluids with excellent performance.

2. Experimental

2.1. Chemical

Cu powder (Shenzhen Junye Nano Material Ltd., China) with copper content >99.9% was used in the study. The transmission electron micrograph (TEM) of Cu powder is shown in Fig. 1. In Fig. 1, there are a few larger particles, which are likely aggregates of the smaller ones, but the whole distribution of the particles is relatively well-dispersed. The particles are basically spherical or near spherical. Particle size is relatively consistent with a unimodal distribution and an average diameter of 25 nm.

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 was controlled using hydrochloric acid (HCl) and sodium hydroxide (NaOH) in analytical grade. All chemicals were used as received without any further purification.

2.2. Measurement of zeta potential and particle size

The experiments were conducted using 0.05 wt% copper nano-suspensions. Different concentrations of the surfactant were added to the suspensions, which were stirred thoroughly and ultrasonicated (KQ2200DE Ultrasonic Cleanser, 100 W, Kunshan of Jiangsu Equipment Company, China) for at least 15 min, 2–4 ml of suspensions was transferred into a measuring cell. Then zeta potential and particle size were measured by a
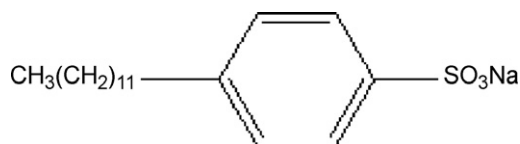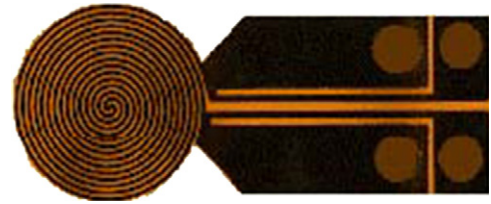

Fig. 2. Chemical structure of SDBS surfactant.

Malvern ZS Nano S analyzer (Malvern Instrument Inc., London, UK). The measurement was run at $V = 10$ V, $T = 25\,°C$ with switch time at $t = 50$ s. Each experiment was repeated at least ten times to calculate the mean value of the experimental data. The pH value of system was adjusted with HCl and NaOH solution by precise pH Meter (PHS-25, China).

3. Measurement of the thermal conductivity of nanofluids

3.1. Transient plane source (TPS) theory

Thermal conductivity of nanofluids is measured by means of the TPS method [20]. In this method, the TPS element behaves both as temperature sensor and heat source. This novel method offers some advantages such as fast and easy experiments, wide range of thermal conductivities (from 0.02 to 200 W/m K), no sample preparation and flexible sample size.

The TPS element consists of an electrical conducting pattern of thin nickel foil (10 μm) in the form of double spiral, which resembles a hot disk, embedded in an insulating layer made of kapton (70 μm) (see Fig. 3).

A Kapton insulated probe is dipped into the suspensions. A constant electric power is supplied to the sensor and the increase in temperature $\Delta T(\tau)$ is calculated from the variation in the sensor resistance with time $R(t)$ by using the equation:

$$\Delta T(\tau) = \frac{1}{\alpha}\left(\frac{R(t)}{R_0} - 1\right) \tag{1}$$

where R_0 is the hot-disk resistance in the beginning of the recording (initial resistance), α is the temperature coefficient of resistance of the nickel foil, and $\Delta T(\tau)$ is the temperature increase of the sensor expressed in terms of an only variable τ, defined as:

$$\tau = \sqrt{\frac{t}{\theta}}, \; \theta = \frac{a^2}{\kappa} \tag{2}$$

where t is the measurement time, θ is the characteristic time, which depends both of parameters of the sensor (a is the sensor radius) and the sample (k is the thermal diffusivity of the sample).

Fig. 4 shows the sensor temperature variation in a typical transient heating.

Assuming the conductive pattern to be in the Y–Z plane of a coordinate system, the temperature rise at a point (y, z) at time t due to an output of power per unit area Q is given by the