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Stability and thermal conductivity characteristics of nanofluids

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Abstract

Nanofluid is a kind of new engineering material consisting of nanometer-sized particles dispersed in base fluid. In this study, various nanoparticles, such as multi-walled carbon nanotube (MWCNT), fullerene, copper oxide, and silicon dioxide have been used to produce nanofluids for enhancing thermal conductivity and lubricity. As base fluids, DI water, ethylene glycol, and oil have been used. To investigate the thermo-physical properties of nanofluids, thermal conductivity has been measured. The experimental results of thermal conductivity of nanofluids are compared with the modeling results predicted by Jang and Choi model [14]. The stability of nanofluid has been estimated with UV–vis spectrophotometer. Thermal conductivity of nanofluid has been increased with increasing volume fraction of nanoparticle except for water-based fullerene nanofluid which has lower thermal conductivity than that of base fluid due to its lower thermal conductivity, 0.4 W/mK. Stability of nanofluid has been influenced by the characteristics between base fluid and suspended nanoparticles.

Keywords: Nanofluid; Nanoparticles; Thermal conductivity; Stability; UV–vis spectrum

1. Introduction

Nanofluid technology becomes a new challenge for the heat transfer fluid because of their higher thermal conductivity [1,2] and stability than those of the conventional heat transfer fluid or the suspensions of micro-sized particles. In recent researches, carbon nanotube (CNT) is the excellent media to enhance the thermal conductivity of a base fluid when added at a small fraction [3,4]. In these researches, thermal conductivities of the CNT nanofluids are increased up to 19.6 and 150% at a volume fraction of 0.01, respectively. Fullerene, which has a different bond structure of carbon, has great potential to the anti-wear materials [5]. These two kinds of particles have different morphologies because of the difference in the synthesis process and their unique bond structures. CNT has a fibrous morphology and fullerene has a spherical one. Thermal conductivity of the CNT is about 3000 W/mK at room temperature [6] and that of the fullerene is about 0.4 W/mK [7].

Many researches are conducted to enhance the thermal conductivity of nanofluid and also to produce more stable suspensions. In these studies, to improve the stability of the suspensions, a surface modification or changing pH values of the suspension are used [2,8]. Although the stability of nanofluid is very important for its application, there is a little study on estimating the stability of suspension. UV–vis spectrophotometric measurements have been used to quantitatively characterize colloidal stability of the dispersions [9]. It can be applied to all base fluid, while zeta potential analysis has a limitation of the viscosity of base fluid.

In this paper, the stability of nanofluid with sediment time is estimated with UV–vis spectrophotometer. To measure the thermal conductivity of nanofluid, a transient hot-wire system has been used.

2. Experimental

2.1. Materials

Table 1 shows the properties of materials for preparing nanofluids. The thermal conductivities of MWCNTs, CuO and SiO_2 nanoparticles are 3000 [11], 76.5 and 1.38 W/mK, respectively. The thermal conductivities of base fluids, such as DI water, ethylene glycol and oil, are 0.613, 0.252 and 0.107 W/mK, respectively.

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Table 1
Property of test material for preparing nanofluids

	MWCNT	Fullerene	CuO	SiO_2	H_2O	Ethylene glycol	Oil
Density (g/cm^3)	2.6	1.6	6.32	2.22	1	1.11	0.915
Thermal conductivity (W/mK)	~3000	0.4	76.5	1.38	0.613	0.252	0.107
Average size							
L	10–50 μm	~10 nm	33 nm	12 nm	–	–	–
D	10–30 nm						

Fig. 1 shows the photographs of the test particles. MWCNTs have fibrous morphologies and the average length and diameter are 10–50 μm and 10–30 nm, respectively. The average diameters of fullerene, CuO and SiO_2 nanoparticles are 10, 35.4 and 12 nm, respectively. Morphologies of these particles are spherical.

An ultrasonic disruptor is used to prepare nanofluids. After 2 h intensive sonication, the stable suspensions are obtained.

2.2. Measuring thermal conductivity of nanofluids

In this study, the transient hot-wire method for measuring electrically conducting fluid has been applied because the particles, used in this experiment, are electrically conductive [10]. It is well-known method and generally used to measure the thermal conductivity of nanofluids [10–12]. Teflon coated platinum wire, which diameter is 76 μm and the thickness of Teflon insu-

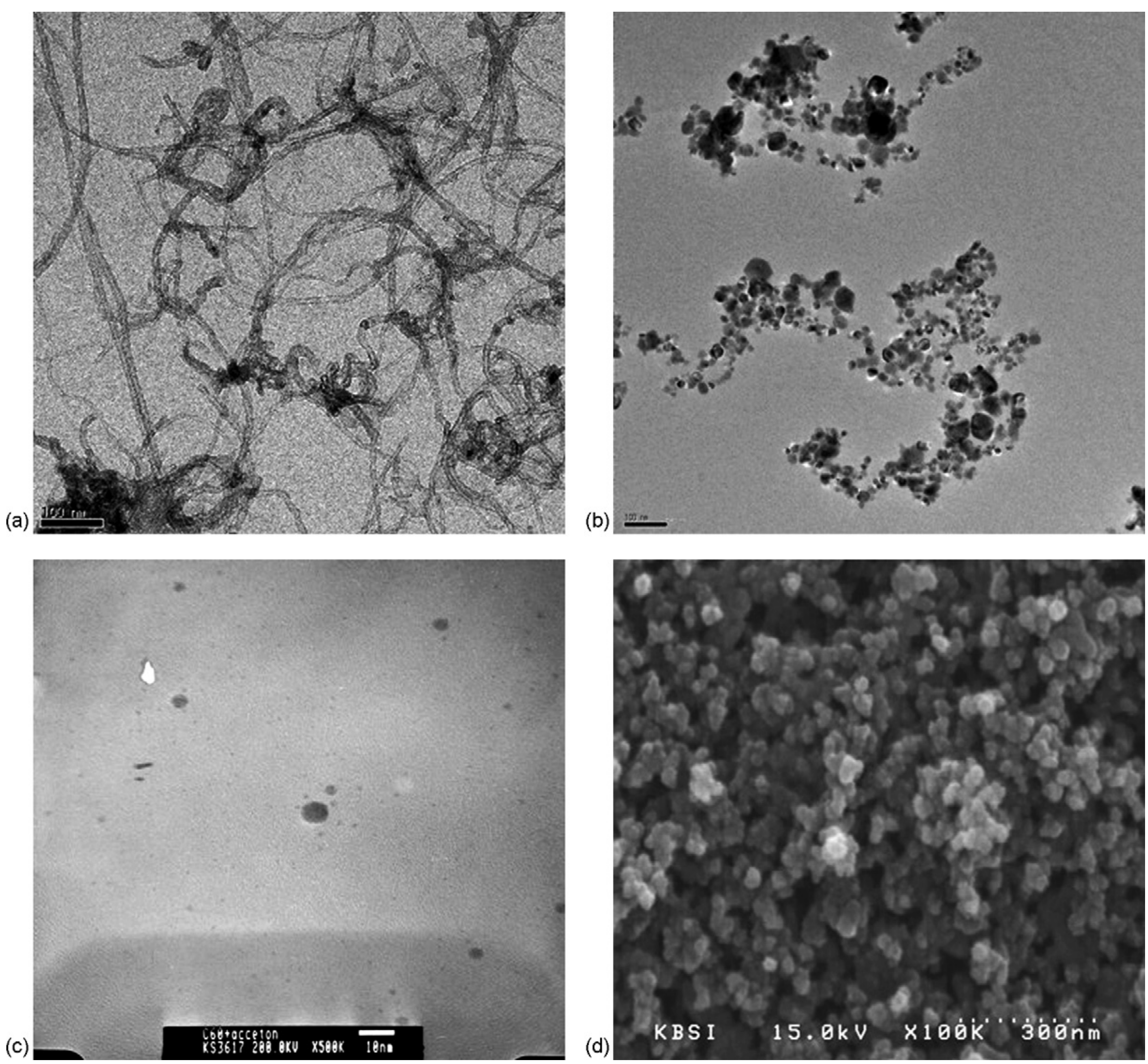

Fig. 1. Photographs of test particles. (a) MWCNT, (b) CuO, (c) fullerene, (d) SiO_2.

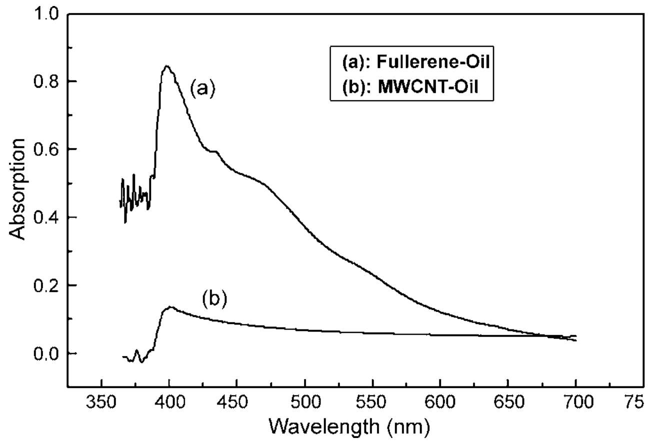

Fig. 2. (a and b) UV–vis spectrum of MWCNTs and fullerenes in oil suspension.

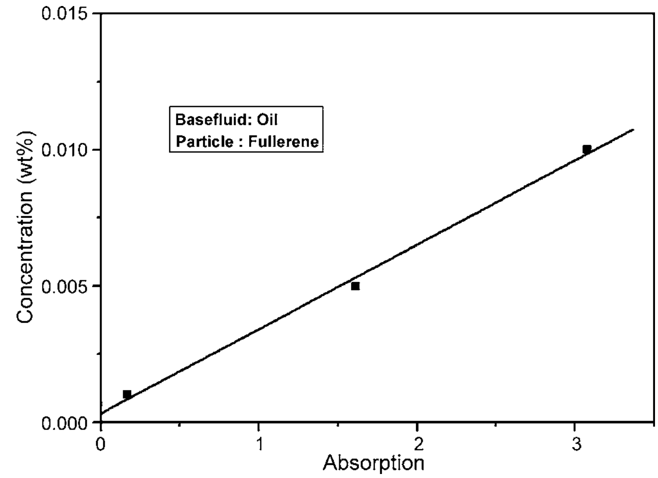

Fig. 3. Linear relationship between light absorption and concentration of fullerenes in oil suspension at wavelength of 397 nm.

lation layer is 17 μm, is used for a hot wire in the measurement system. Initially the platinum wire immersed in media is kept at equilibrium with surroundings. When a uniform voltage is supplied to the circuit, the electric resistance of the platinum wire rises with the temperature of the wire and the voltage output is measured by an A/D converting system at a sampling rate of 20 times per second. The relation between the electric resistance and the temperature of platinum wire is well-known [13]. The measured data of temperature rise is linear against logarithmic time interval. The thermal conductivity is calculated from the slope of the rise in the wire's temperature against logarithmic time interval by the following equation [10].

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

The value of k is the thermal conductivity of fluid. T is the temperature of the wire at time t.

2.3. Colloidal stability of nanofluids

Recently, a new method which can be used to estimate the suspension concentration with increasing sediment time was introduced. Fig. 2 shows that the peak absorbance of MWCNT and fullerene in oil-based suspensions appear at 397 nm. The absorbance of MWCNTs and fullerenes in oil suspensions decreases with increasing sediment time. Fig. 3 shows that a linear relation is obtained between the supernatant concentration and the absorbance of suspended particles. From these relations, the relative stability of nanofluids can be estimated with sediment time. In this paper nanofluids have been examined with UV–vis spectrophotometer (UV-3101PC, SHIMADZU, Japan).

3. Results and discussions

Fig. 4 depicts the colloidal stability of nanofluids. This graph shows the supernatant particle concentration in basefluid with sediment time. It is shown that oil-based fullerene (C_{60}) and mixed fullerene, which is the mixture of C_{60} and C_{70}, nanofluids are very stable. After 800 h, relative concentration is maintained over 80% compared with the initial concentration. Since fullerene molecule is a kind of non-polar molecule, it can be dispersed very well in non-polar fluid such as paraffin oil which is used in present study. As shown in the graph, MWCNTs nanofluids have poor stability. Since its morphology is fibrous and entangled in fluid, MWCNTs are easily agglomerated and precipitated. Especially it is more difficult to disperse MWCNTs in fluid which has high viscosity. Addition of surfactant, sodium dodecyl sulfate (SDS) in this study, can improve the stability of nanoparticles in aqueous suspensions. It is because that the hydrophobic surfaces of MWCNTs and fullerene are modified hydrophilically and that the repulsion forces between the suspended particles increase due to increase of zeta potentials which is the surface charge of the suspended particles in fluid.

Fig. 5 shows the thermal conductivity enhancement of nanofluids. MWCNT nanofluid has the highest thermal conductivity enhancement among water-based nanofluid whereas SiO_2 nanofluid has the lowest one. From this result, it is shown that the thermal conductivity enhancement of nanofluid depends on that of the suspended particles. Many previous researches show the similar results. Also, it is shown that MWCNT-in-oil nanofluid has higher thermal conductivity enhancement than that of MWCNT-in-water, and that CuO-in-ethylene glycol

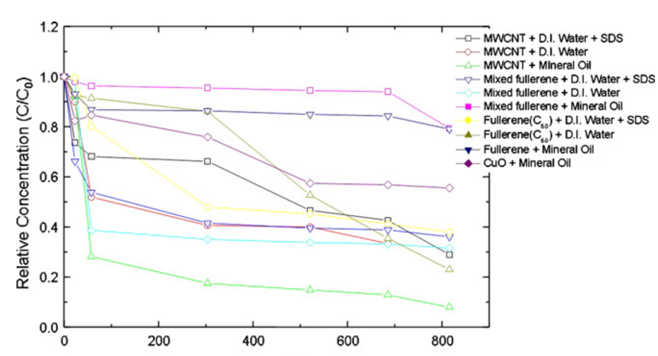

Fig. 4. Relative supernatant particle concentration of nanofluids with sediment time.

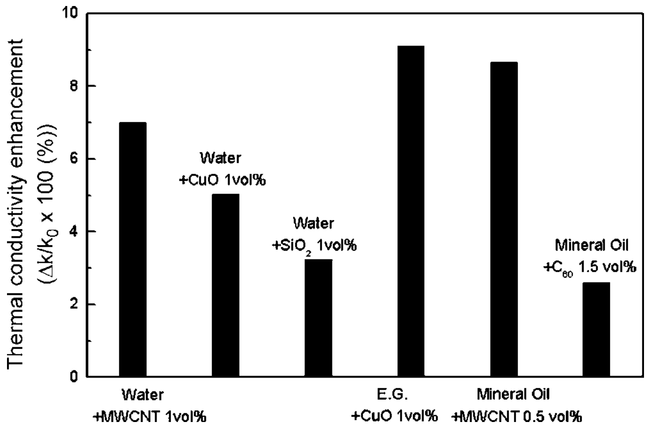

Fig. 5. Test results of thermal conductivity of nanofluids.

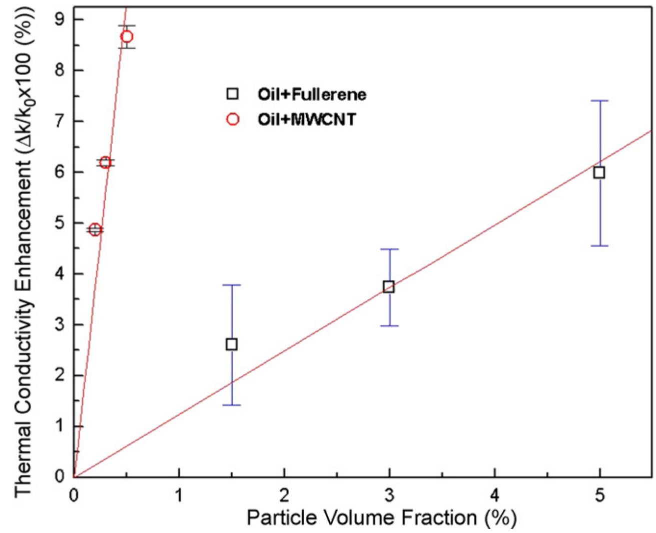

Fig. 7. Thermal conductivity enhancement of oil-based fullerene nanofluids.

nanofluid has higher thermal conductivity enhancement than that of CuO-in-water. These results imply that higher thermal conductivity enhancement can be obtained for basefluid of lower thermal conductivity.

Fig. 6 shows the thermal conductivity enhancements of water-based MWCNT and fullerene nanofluids as a function of the particle volume fraction. The value k is the thermal conductivity of basefluid or nanofluid according to the subscripts. The results show that the thermal conductivities of water-based MWCNT nanofluids increase with increasing particle volume fraction, while the thermal conductivities of water-based fullerene nanofluids are decreased with increasing particle volume fraction. It is believe that the thermal conductivity of fullerene is 0.4 W/mK which is lower than that of water. For MWCNT nanofluid, the thermal conductivity is increased by 7.0% at volume fraction of 1.0%. On the other hand, the thermal conductivity is decreased by 3.0% at a volume fraction of 1.5%.

Fig. 7 shows the thermal conductivity enhancements of oil-based MWCNT and fullerene nanofluids as function of the particle volume fraction. In case of MWCNT nanofluid, the thermal conductivity is increased up to 8.7% at 0.5 vol%. And the thermal conductivity of fullerene nanofluid is increased by 6.0% at 5 vol%. It is shown that the thermal conductivity of MWCNT nanofluid is much higher than that of fullerene nanofluid because the thermal conductivity of MWCNT is much higher than that of fullerene. It is also believed that the thermal conductivity of nanoparticles strongly affects on the thermal conductivity enhancement of nanofluids.

Fig. 8 shows validation of experimental results of the thermal conductivity of MWCNT nanofluids. In this paper, experimental results are validated with Jang and Choi model [14]. In case of water-based MWCNT nanofluids, assumed neglecting the Brownian motion of nanoparticles, we derive the following expression for the effective conductivity k_{comp}:

$$k_{\mathrm{comp}} = \langle \cos^2\theta \rangle \beta k_{\mathrm{fiber}} f_{\mathrm{fiber}} + (1 - f_{\mathrm{fiber}}) k_{\mathrm{f}} \quad (2)$$

where k_{fiber} is the thermal conductivity of MWCNT, k_{f} the thermal conductivity of basefluid, f_{fiber} a volume fraction of

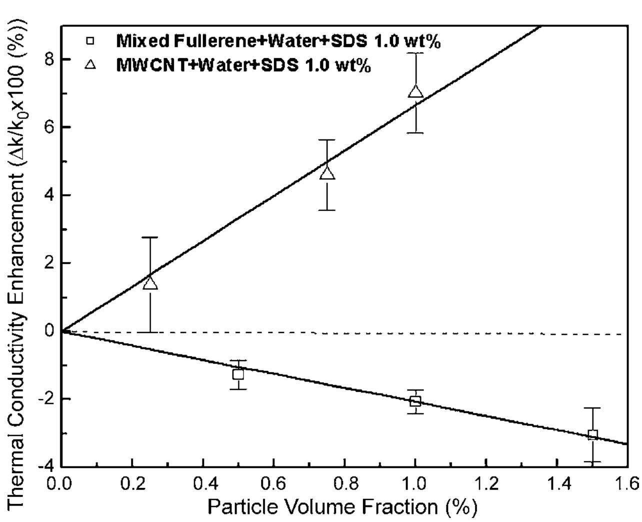

Fig. 6. Thermal conductivity enhancement of water-based MWCNT and fullerene nanofluids.

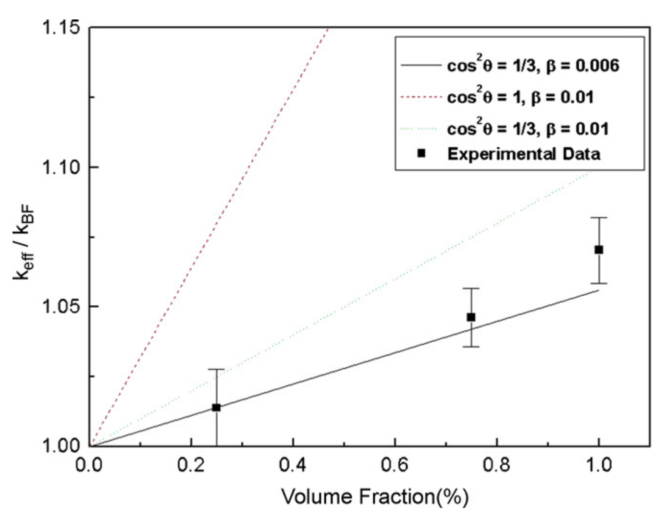

Fig. 8. Validation of the experimental results of the thermal conductivity of MWCNT nanofluids.

MWCNT, and β is the Kapitza resistance [12]. θ is the angle between a given direction and a fiber axis. For well-aligned MWCNT $\langle\cos^2\theta\rangle = 1$ and for completely random fiber orientation $\langle\cos^2\theta\rangle = 1/3$ [13].

It is assumed that MWCNTs are completely random fiber orientations, $\langle\cos^2\theta\rangle = 1/3$, since initially they have been heavily entangled. Kapitza resistance is modified due to surfactant for improving suspension stability, $\beta = 0.006$.

4. Conclusions

Various nanofluids have been prepared and their stability has been estimated by UV–vis spectrum analysis. Stability of nanofluid is strongly affected by the characteristics of the suspended particle and basefluids such as the particle morphology, the chemical structure of the particles and basefluid. Moreover, addition of surfactant, SDS in this study, can improve the stability of the suspensions.

Thermal conductivities have been measured by the transient hot-wire method. Conclusively, thermal conductivity enhancement depends on the volume fraction of the suspended particles, thermal conductivities of the particles and basefluids. Also, the experimental results of the thermal conductivity of MWCNT nanofluids have been validated with the calculated results.

Acknowledgements

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