나노유체의 분산안정성 및 열물성치와 그 응용에 관한 연구

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Stability and Thermo-physical Properties of Nanofluids and Its Applications

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It has been shown that a nanofluid consisting of nanoparticles dispersed in base fluid has much higher effective thermal conductivity than pure fluid. In this study, four kinds of nanofluids such as multiwalled carbon nanotube (MWCNT) in water, CuO in water, SiO2in water, and CuO in ethylene glycol, are produced. Their thermal conductivities are measured by a transient hot-wire method. The thermal conductivity of water-based MWCNT nanofluid is shown to be increased by up to 11.3% at a volume fraction of 0.01. The measured thermal conductivities of MWCNT nanofluids are higher than those calculated with Hamilton-Crosser's model due to neglecting solid-liquid interaction at the interface. The results show that the thermal conductivity enhancement of nanofluids depends on the thermal conductivities of both particles and the base fluid. Stability of nanofluids is estimated by UV-vis spectrum analysis. Stability of nanofluid depends on the type of base fluid and the suspended particles. Also it can be improved in addition of a surfactant.

Keywords: 나노유체(Nanofluids);나노입자(Nanoparticle);열전도도(Thermal Conductivity);동점도(Viscosity); 분산안정성(Stability)

1. Introduction

Heating or cooling fluids are important to many industrial sectors, including transportation, energy supply and production and electronics. The thermal conductivity of these fluidsplays 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. In fact, an amount of studies of the effective thermal conductivity of suspensions consisting of solid particles have been conducted [Ku et al., 2000]. However, these studies have been confined to those produced with millimeter or micrometer-sized particles. The lack of stability of suspensions that involve coarse-grained particles is undoubtedly a primary reasonwhy the fluids with dispersed milli- or micro-sized particles have not been applied to any industrial sectors. In the recent researches, suspensions containing a small amount of metal, nonmetal nanoparticles orcarbon nanotubes have been reported to have substantially higher thermal conductivities than those of the base fluids [Eastman et al., 2001, Xie et al., 2003, Choi et al., 2001]. Mechanisms of the thermal conductivity enhancement in nanofluids have also been studied [Keblinski et al., 2002, Jang and Choi, 2004]. A transient hot-wire method is widely used to measure the thermal conductivity of base fluids and nanofluids. In the present study, we produce suspensions with CuO, SiO2 and multiwalled carbon nanotubes (MWCNTs) with base fluids of DI-water, ethylene glycol.

2. Materials

Table 1 shows the properties of materials for preparing nanofluids. The thermal conductivities of MWCNTs, CuO nanoparticles and SiO2nanoparticles are 3000 W/mK [Kim et al., 2001], 76.5 W/mK, and 1.38 W/mK, respectively. The thermal conductivities of DI-water and ethylene glycol are 0.613 W/mK and 0.252 W/mK, respectively.

Figure 1 shows the photographs of the test particles. MWCNTs have fibrous morphologies, and the average length and diameter are 10～50 ㎛ and 10～30 nm, respectively. The average diameters of CuO and SiO2nanoparticles are 35.4 nm and 7 nm, respectively. Morphologies of these particles are spherical.

An ultrasonic disruptor is used to produce nanofluids. The stable suspensions are obtained in case of CuO and SiO2nanofluids after 2 hours intensive sonication. Since MWCNTs are entangled and agglomerated in aqueous suspension, sodium dodecyl sulfate (SDS) is used as a surfactant when producing MWCNT nanofluids.

3 Measuring Thermal Conductivity of Nanofluids

Figure 2 shows the schematic diagram of transient hot-wire system for thermal conductivity measurement of carbon nanofluids. The transient hot-wire method for measuring thermal conductivity of a low viscosity fluid is well-known. In this study, the transient hot-wire method for measuring electrically conducting fluid due to the electrically conductive particles is usedin this experiment [Nagasaka and Nagashima, 1981]. A Teflon coated platinum wire the diameter of 76 ㎛ and the thickness of Teflon insulation layer is 17 ㎛ is used for the hot wire in the measurement system. Initially the platinum wire immersed in media is kept at equilibrium with surroundings.

Table 1. Properties of materials for producing nanofluids

Particles Properties	MWCNT	CuO	SiO2	H2O	Ethylene glycol
Specific gravity	2.6	6.32	2.22	1	1.11
Thermal conductivity (W/mK)	~ 3000*	76.5	1.38	0.613	0.252
Average size	L: 10~50 ㎛ D: 10~30 ㎚	33 nm	12 nm	-	-

*Reference: Kim et al., 2001, *Physical Review Letters*

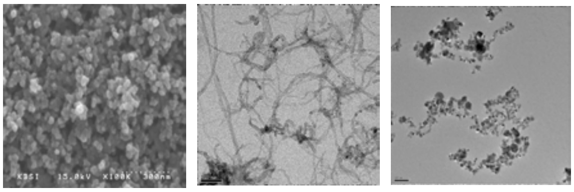


Figure 1. Photographs of test nanoparticles

When a uniform voltage is supplied to the circuit, the electric resistance of the platinumwire rises with the temperature of the wire and the voltage output is measured by an A/D converting system at a sampling rate of ten times per second. The relation between the electric resistance and the temperature of platinum wire is well-known [Bently, 1984]. 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 [Nagasaka and Nagashima, 1981].

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

q is the applied electric power and T1 and T2 are the temperature at time t1and t2.

4 Colloidal Stability of Nanofluids

Recently, a new method which can be used to estimating the suspension concentration with increasing sediment time was introduced (Jiang et al., 2003). Figure. 3 shows that the absorptions of MWCNT and fullerene in the mineral oil-based suspensions appear at 397 nm. The absorbance of MWCNTs and fullerenes in the mineraloil suspensions decreases with increasing sediment time. Figure 4 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 the mineral oil suspensions are examined with UV-vis spectrophotometer (UV-3101PC, SHIMADZU, Japan).

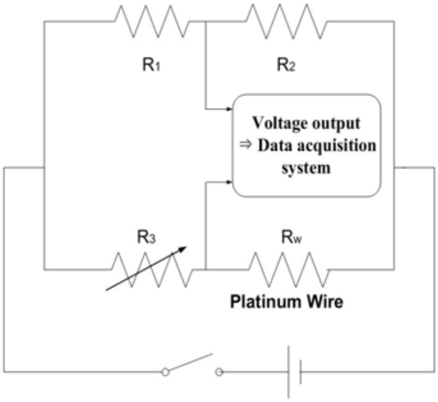


Figure 2. Schematic diagram of the transient hot-wire system for measuring the thermal conductivity of nanofluids

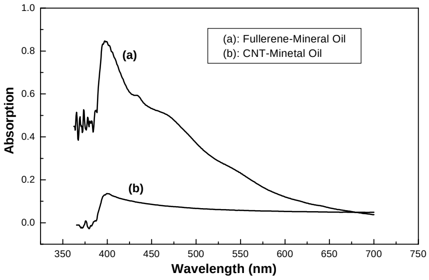


Figure 3. UV-vis spectrum of oil-based nanofluids

The estimation of the colloidal stability is conducted by measuring.

Figure5 shows that the relative absorption of the various nanofluids with the sediment time. The result shows that the stability of nanofluid is influenced by the type of base fluid and the suspended particles. Also the addition of a proper surfactant can improve the stability of nanofluids.

5 Thermal Conductivity of Nanofluids

Figure 6 depicts the thermal conductivity enhancements of DI-water based MWCNT nanofluids as a function of volume fraction of MWCNTs. In this paper, Δk is the thermal conductivity enhancement of nanofluid, and kois the thermal conductivity of base fluid. The thermal conductivity of nanofluid increases up to 11.3 % at a volume fraction of 0.01. The Uncertainties of the thermal conductivity of nanofluids increase with increasing particle volume fraction. The uncertainties of the thermal conductivity of MWCNT nanofluids are 0.51% and 2.19% at a volume fraction of 0.0025 and 0.01, respectively. It is believed that it is difficult to obtain highly stablesuspension which has good reproducible properties when the MWCNTs volume fraction increases. It is shown that the comparison between the experimental data for MWCNT in deionized water and the values calculated from Hamilton-Crosser's model [Hamilton and Crosser, 1962]. The result shows that the measured thermal conductivities are greater than those calculated from Hamilton-Crosser model. Hamilton-Crosser model is known as following equation [Hamilton and Crosser, 1962].

$$\frac{k_e}{k_o} = \frac{k_p + (n-1)k_o - (n-1)\phi(k_o - k_p)}{k_p + (n-1)k_o + \phi(k_o - k_p)} \qquad (2)$$

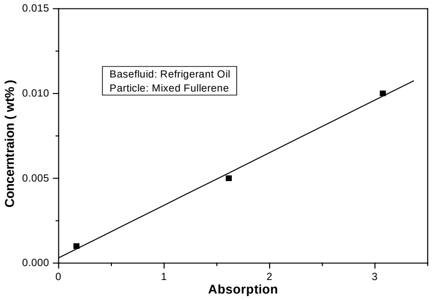


Figure 4. The linear relation of the absorption vs. particle concentration

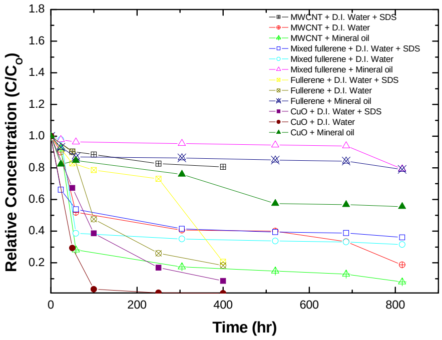
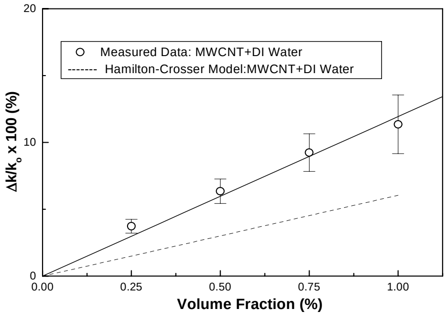


Figure 5. Relative particle concentration of nanofluids with sediment time

The subscript notations of e, p, and o represent nanofluid, article and base fluid, respectively. ϕ and k represent the volume fraction and thermal conductivity, respectively.

In suspensions, the liquid molecules close to a particle surface are known to form a solid-like layerat the interface. This solid-like structure of liquid molecules may play an important role in heat transport from solid wall to adjacent liquid. Since these interactions are not considered in conventional models for predicting the thermal conductivitiesof suspensions, they always underestimate the thermal conductivity enhancements of nanofluids. The weakness of this model has been presented elsewhere. [Eastman et al., 2001, Xie et al., 2003, Choi et al., 2001, Lee et al. 1999]

Figure 7 shows the thermal conductivities of various nanofluids. For water-based nanofluid, MWCNT nanofluid has the highest thermal conductivity whereas SiO2 nanofluid has the lowest thermal conductivity. This result shows that the



Figureure 6. Comparison between the calculated values with Hamilton-Crosser model and the experimental results for water-based MWCNT nanofluids as a function of particle volume fraction

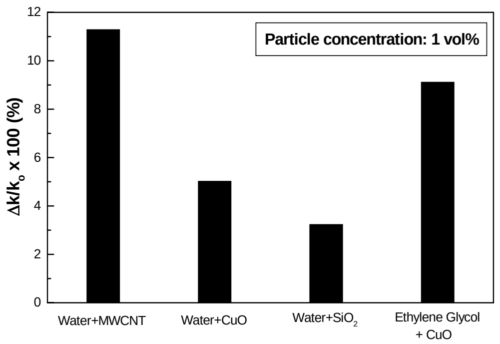


Figure 7. Thermal conductivity enhancement of four kinds of nanofluids at a particle volume fraction of 0.01

thermal conductivity enhancement of nanofluid is higher when the suspended nanoparticles have higher thermal conductivity. In case of CuO nanofluids, the thermal conductivity enhancement of ethylene glycol-based nanofluid is higher than that of water-based nanofluid. This result shows that nanofluid is more effective for a working fluid which has lower thermal conductivity.

5 Conclusions

To investigate the thermal conductivities of nanofluids, the thermal conductivities of four kinds of nanofluids such as MWCNTs in water, CuO in water, SiO2in water, and CuO in ethylene glycol, are measured by the transient hot-wire method. The thermal conductivities of MWCNT nanofluids are almost linearly increased with increasing particle volume fraction and the measured thermal conductivity of MWCNT nanofluids are higher than the calculated values with Hamilton-Crosser's model due to neglecting solid-liquid interaction at the interface. Substantial increases in thermal conductivity are shown for water-based MWCNT nanofluids, withenhancement up to 11.3% at a volume fraction of 0.01. The results show that the thermal conductivity of nanofluids depends on the thermal conductivity of the suspended particles and base fluids. The thermal conductivity enhancement of nanofluid increases with increasing the particle thermal conductivity, and with decreasing the thermal conductivity of base fluid.

The stability of nanofluids is estimated with UV-vis spectrum analysis. The type of base fluid and the suspended particles have an influence on the stability of nanofluids. Stability of nanofluids can be improved in addition of a proper surfactant.

참고문헌

Bently, J. P., 1984, "Temperature Sensor Characteristics and Measurement System Design," Journal of Physics E: Scientific Instruments, Vol. 17, pp. 430-435

Choi et al., 2001, "Anomalous Thermal Conductivity Enhancement in Nanotube Suspensions," Applied Physics Letters, Vol. 79, No. 14, pp. 2252-2254

Eastman et al., 2001, "Anomalously Increased Thermal Conductivities of Ethylene Glycol-Based Nanofluids Containing Copper Nanoparticles," Applied Physics Letters, Vol. 78, No. 6, pp. 718 -720

Hamilton, R. L. Crosser, O. K., 1962, I & EC Fundamentals 1

Jang, S., Choi., S. U. S., 2004, "Role of Brownian Motion in the Enhanced Thermal Conductivity of Nanofluids," Applied Physics Letters, Vol. 84, No.

24, pp. 4316-4318

Keblinski et al., 2002, "Mechanisms of Heat Flow in Suspensions of Nano-sized Particles (Nanofluids)," International Journal of Heat and Mass Transfer. Vol. 45, pp. 855-863

Kim et al., 2001, "Thermal Transport Measurement of Individual Multiwalled Nanotubes," Physical Review Letters, Vol. 87, No. 21, pp. 215502 -1-2215502-4

Ku et al., 2000, "Heat Transfer Characteristics of Liquid-Solid Suspension Flow in a Horizontal Pipe," KSME International Journal, Vol. 14, No. 10, pp. 1159-1167

Lee et al., 1999, "Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles," Journal of Heat Transfer, Vol.

121, pp. 280-289

Xie et al., 2003, "Nanofluids Containing Multiwalled Carbon Nanotubes and Their Enhanced Thermal Conductivities," Journal of Applied Physics, Vol. 94, No. 8, pp. 4967-4971

Y. Nagasaka and A. Nagashima, 1981, "Absolute Measurement of the Thermal Conductivity of Electrically Conducting Liquids by the Transient Hot-Wire Method," Journal of Physics E: Scientific Instruments, Vol. 14, pp. 1435-1440

Yu, W., Choi, S. U. S., 2003, "The Role of Interfacial Layers in the Enhanced Thermal Conductivity of Nanofluids: A Renovated Maxwell Model," Journal of Nanoparticles Research, Vol. 5, pp. 167-171