Research Article

Preparation and Enhancement of Thermal Conductivity of Heat Transfer Oil-Based MoS$_2$ Nanofluids

Yuan-Xian Zeng, 1 Xiu-Wen Zhong, 1 Zhao-Qing Liu, 1 Shuang Chen, 2 and Nan Li 1

1 School of Chemistry and Chemical Engineering, Guangzhou Key Laboratory for Environmentally Functional Materials and Technology, Guangzhou University, Guangzhou 510006, China
2 Guangzhou Institute of Railway Technology, Guangzhou 510430, China

Correspondence should be addressed to Nan Li; nanli518@126.com

Received 13 November 2013; Accepted 8 December 2013

Academic Editor: Wenjie Mai

Copyright © 2013 Yuan-Xian Zeng et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The lipophilic MoS$_2$ nanoparticles are synthesized by surface modification with stearic acid (SA). The heat transfer oil-based nanofluids, with the mass fraction of lipophilic nanoparticles varying from 0.25% up to 1.0%, are prepared and their thermal conductivity is determined at temperatures ranging from 40 to 200 $^\circ$C using an apparatus based on the laser flash method. It has been found that the nanofluids have higher thermal conductivity and the thermal conductivity enhancement increased not only with increasing mass fraction of nanoparticles, but also with increasing temperature in the range 40–180 $^\circ$C. The results show a 38.7% enhancement of the thermal conductivity of MoS$_2$ nanofluid with only 1.0% mass fraction at 180 $^\circ$C.

1. Introduction

Heat transfer fluids, such as water, ethylene glycol, and mineral oil, play important roles in many thermal transport applications. Their low thermal conductivity is one of the limits of the traditional heat transfer fluids. In order to improve the low thermal characteristics of the conventional heat transfer fluids, solid nanoparticles are added to form nanofluids, which were first introduced by Choi [1]. Enhanced thermophysical properties are the main favorable characteristics of nanofluids based on the fact that most solids have much higher thermal conductivities than common fluids. In the past decade, enhanced thermal conductivities of the water or ethylene glycol-based nanofluids containing a small amount of metals, metal oxides, nonmetallic materials, and polymers have been reported [2–8]. Currently many efforts have been focused on the oil-based nanofluids because of the needs in many industry fields to develop heat transfer fluids with preferred heat transfer properties in high temperature. Various oil-based nanofluids with silicon oil, diathermic oil, engine oil, and heat transfer oil used as the based fluid have been prepared [9–12].

However, the nanoparticles are easily sedimented after being added to the oil because of the poor compatibility between the nanoparticles and the base oil. The dispersion of nanoparticles in oils is still a principal problem for the application of nanofluids. In order to obtain better dispersion, an appropriate lipophilic modification process can be employed to improve the compatibility between the nanoparticles and the oil-based fluid. The organic ligands with long hydrocarbon chains were linked to the surface of the nanoparticles, and the surface-modified nanoparticles possess good dispersion behavior in oils. So far, most of these oil-soluble nanoparticles are investigated as lubricating oil additives [13–16], and only a few of them are used to prepare nanofluids for thermal conductivity enhancement [17, 18].

Molybdenum disulfide (MoS$_2$) has a layered structure and has been known and used as a lubricant and catalyst for several years because of its unique properties such as anisotropy, chemically inertness, and photocorrosion resistance [19]. The MoS$_2$ nanoparticles, which are capped by dialkyldithiophosphate, have been synthesized and exhibit good lubrication properties [20, 21]. The sodium oleate and cetylamine also have been used together as the surface
modified reagents, and the oil-soluble MoS$_2$ nanoparticles product can be directly used as hydrogenation nanocatalysts [22]. Nevertheless, to the best of our knowledge, no studies have been reported on the increased thermal conductivity of MoS$_2$ nanofluids. Furthermore, the heat transfer oil is the preferred heat transfer medium in high temperature. So it is worthwhile to prepare and investigate heat transfer oil-based nanofluids containing MoS$_2$ nanoparticles.

In the present work, MoS$_2$ nanoparticles capped by stearic acid (SA-MoS$_2$) are synthesized via a simple solution method. And the heat transfer oil-based nanofluids are prepared by dispersing these modified MoS$_2$ nanoparticles with dibenzyl toluene as base fluid. The as-prepared nanofluids exhibit higher thermal conductivity compared to the base oil.

2. Experimental

2.1. Chemicals and Materials. Hydrazine hydrate (80%) was purchased from Shanghai Aladdin Chemical Regent Co., Ltd (China). Heat transfer oil B350, which is one of the trade names of dibenzyl toluene, was obtained from Shanghai Ethylene Chemical Co. Ltd (China). All other reagents were of research grade or better and were obtained from commercial sources.

2.2. Synthesis of MoS$_2$ Nanoparticles. The surface-modified MoS$_2$ nanoparticles were prepared as follows: Na$_2$MoO$_4$·2H$_2$O (5.0 mmol) and 3.0 mmol stearic acid were dissolved in 25.0 mL distilled water and 25.0 mL absolute alcohol at 80°C in a 250 mL three-necked flask. Then 0.6 mL N$_2$H$_4$·H$_2$O was added into the reaction flask and kept at that temperature for 1 h. After that the hydrochloric acid (1.0 mol/L) was added slowly into the reaction solution to adjust the pH value below 1.0 and stirred for 6 h. Then the temperature fell to 60°C, and 75.0 mL sodium sulfide solution (0.20 mol/L) was dropped slowly into the reaction solution and reacted for 8 h. The products were filtered, washed with hot ethanol, and then dried overnight in a vacuum at 60°C.

The nonmodified MoS$_2$ nanoparticles were prepared by the same method only without stearic acid added.

2.3. Preparation of Nanofluids. The MoS$_2$ nanofluids were prepared by dispersing the surface-modified MoS$_2$ nanoparticles in heat transfer oil B350 as base liquid. The samples were homogenized for about 5 min by ultrasonic vibration to ensure proper dispersion of the nanoparticles.

2.4. Characterization and Measurements. The phase analysis of surface-modified MoS$_2$ was conducted by powder X-ray diffraction (XRD, Bruker, D8 ADVANCE) with Cu-Kα radiation. The morphology of MoS$_2$ was analyzed by using a JEOL JSM-7001F field emission scanning electron microscope (FESEM). A Nicolet 6700 ESP Fourier transform infrared spectrometer was used for FT-IR spectrum recording of the samples.

The long-term stability of MoS$_2$ nanoparticles in organic solvents was characterized by the sediment test. The MoS$_2$ nanoparticles which were introduced to cyclohexane and heat transfer oil B350, respectively, underwent ultrasonic vibration for about 10 min and were allowed to stand for more than 20 days. The thermal conductivity of MoS$_2$ nanofluids was measured based on the laser flash method using the LFA447 Thermal Conductivity Properties Analyzer (NETZSCH, Germany).

3. Results and Discussion

3.1. Characterization of MoS$_2$ Nanoparticles. The results of sedimentation test of two types of MoS$_2$ nanoparticles suspended in cyclohexane are shown in Figure 1. Solution containing bare MoS$_2$ nanoparticles has high settling rate and
3.2. Thermal Conductivities of Nanofluids. Figure 5 shows the effect of temperature on the enhancement of thermal

Figure 2: XRD patterns of (a) MoS$_2$ nanoparticles without being annealed, (b) the samples annealed at 600°C for 1h, and (c) the samples annealed at 800°C for 1h.

Figure 3: FT-IR spectrum of the stearic acid (a) and stearic acid modified MoS$_2$ nanoparticles (b).
Figure 4: SEM images of nonmodified MoS$_2$ nanoparticles (a) and SA-MoS$_2$ nanoparticles (b).

The thermal conductivity enhancement of heat transfer oil B350-based nanofluids significantly increases with increasing temperature when the temperature is lower than 180°C. This tendency is consistent with the previously reported results which are all measured at the temperature below 80°C [9, 27, 28]. Actually, to the best of our knowledge, the thermal conductivity measurement of oil-based nanofluid at high temperature (more than 100°C) has rarely been reported yet. The most probable explanation for this sensitivity to temperature is that the Brownian motion of nanoparticles is more intense at higher temperature [27]. However, the thermal conductivity enhancement decreases when the temperature is higher than 180°C. This observation is probably attributed to vaporization of the organic oil because the flash point of dibenzyl toluene is 200°C. So it can be suggested that the vaporization is aggravated when the temperature is close to the flash point. And the considerable vapor generated in the sample holder leads to the reducing of the measuring data, since the gas has lower thermal conductivity than that of liquid. This suggestion also is suitable for why the thermal conductivity enhancement increases sharply at low temperature (below 80°C) but slowly at high temperature (above 80°C). Anyway, the heat transfer oil-based MoS$_2$ nanofluids exhibit fantastic enhancement of the thermal conductivity compared with base oil at high temperature.

4. Conclusions

The heat transfer oil-based MoS$_2$ nanofluids have been prepared by dispersing stearic acid-modified MoS$_2$ in heat transfer oil B350. The modified ligand is effective to improve the lipophilic property of MoS$_2$ nanoparticles. Thermal conductivity measurements reveal that the thermal conductivity enhancement reaches up to 38.7% at a mass fraction of only 1.0% at 180°C. And the thermal conductivities have been determined experimentally as a function of mass fraction and temperature. It has been found that the thermal conductivity increases with the mass fraction of nanoparticles. And the temperature variation has obvious effects on the thermal conductivity enhancement. Interestingly, the measured thermal conductivity enhancement decreases when the temperature...
is close to the flash point of the base oil. Anyway, the long-
term stability and high thermal conductivity clearly identify
the lipophilic MoS$_2$ nanoparticles as a favorable additive in
thermal energy engineering.

**Acknowledgments**

The authors acknowledge the financial support of this
work by Natural Science Foundations of China (Grant no.
21306030), the Natural Science Foundations of Guangdong
Province (Grant nos. S2012010009719 and S2013040015229),
the Innovative Talents Cultivation Project of Guangdong
Province (Grant no. LYM11096), the Science and Technology
Project of Guangzhou (Grant no. I2C5201621), Scientific Re-
search Project of Guangzhou Municipal Colleges and Uni-
versities (Grant no. 2012A064), and the National Undergrad-
uate’s Innovation and Entrepreneurship Training Program
(Grant no. 20131078001).

**References**

nanoparticles,” in *Developments and Applications of Non—
Newtonian Flows*, D. A. Siginer and H. P. Wang, Eds., vol. 231,

B. George, and T. Pradeep, “Thermal conductivities of naked
and monolayer protected metal nanoparticle based nanoflu-
ids: manifestation of anomalous enhancement and chemical
2003.

Li, “Thermal conductivity enhancement dependent pH and
chemical surfactant for Cu-H$_2$O nanofluids,” *Thermochimica

and ethylene glycol + water mixtures,” *Journal of Nanoparticle

TiO$_2$-water nanofluids,” *Experimental Thermal and Fluid Sci-

nanofluid characterization: thermal conductivity and viscosity measurements and correlation,” *Advances in Mechanical

*International Journal of Heat and Mass Transfer*, vol. 49, no. 1–2,

L. D. Jim, “Nanodiamond nanofluids for enhanced thermal

nanotubes nanofluid with optimized thermal conductivity enhancement,” *Colloids and Surfaces A*, vol. 352, no. 1–3, pp. 136–
140, 2009.

[10] G. Colangelo, E. Favale, A. de Risi, and D. Laforgia, “Results of experimental investigations on the heat conductivity of
nanofluids based on diathermic oil for high temperature appli-

ductivity, thermal diffusivity, and specific heat of nanofluids,”

[12] D. Ashtiani, M. A. Akhavan-Behabadi, and M. Fakoor Pak-
daman, “An experimental investigation on heat transfer char-
acteristics of multi-walled CNT-heat transfer oil nanofluid flow
inside flattened tubes under uniform wall temperature condition,” *International Communications in Heat and Mass Transfer*,

12, no. 4, pp. 1124–1127, 2002.

modification of amorphous ZrO$_2$ nanoparticles as a lubricant additive,” *Surface Review and Letters*, vol. 14, no. 6, pp. 1047–

modified Sb$_2$S$_3$ nanoparticles and their tribological behaviors
in liquid paraffin,” *Journal of Dispersion Science and Technology*,

[16] X. Xiong, Y. Kang, G. Yang, S. Zhang, L. Yu, and P. Zhang,
“Preparation and evaluation of tribological properties of cu
nanoparticles surface modified by tetradecyl hydroxamic acid,”

[17] D. Li, W. Xie, and W. Fang, “Preparation and properties of
copper-oil-based nanofluids,” *Nanoscale Research Letters*, vol.
6, article 373, 2011.

synthesis and size-dependent thermal conductivity of Fe$_3$O$_4$

nanoparticles by a modified hydrothermal method and the photo-


[21] L. Yu, P. Zhang, and Z. Du, “Tribological behavior and struc-
tural change of the LB film of MoS$_2$ nanoparticles coated with
dialkylithiophosphates,” *Surface and Coatings Technology*, vol.

[22] S. Wang, C. An, J. He, and Z. Wang, “Facile preparation of

and characterization of molybdenum disulfide nanotubes and

*Journal of Alloys and Compounds*, vol. 501, no. 2, pp. 275–281,
2010.

[25] X.-L. Li and Y.-D. Li, “MoS$_2$ nanostructures: synthesis and

