ASIAN JOURNAL OF CHEMISTRY

Investigation of Thermal Conductivity of NaHCO₃ Modified Activated Carbon Nanofluids

Won-Chun Oh[1,*], Yong-Le Wang[2], Shi-Choon Lee[3], Dae-Seung Hong[3], Doo-Hwan Kim[1] and Ming-Liang Chen[1]

[1]Department of Advanced Materials Science & Engineering, Hanseo University, Seosan-si, Chungnam 356 706, South Korea
[2]Department of Management, Hefei University, Hefei 230022, Anhui Province, P.R. China
[3]N-Barotech Co. Ltd., Ulsan 681-802, South Korea

*Corresponding author: Tel:/Fax: +82 41 6883352; E-mail: wc_oh@hanseo.ac.kr

Recent research has focused on enhancing the effectiveness of activated carbon by modifying their specific properties in order to enable the carbon to develop stable nanofluid. Commercial carbons were modified by wetness modification with aqueous solutions of NaHCO₃, followed by sonications at low temperature. The materials were characterized using XRD, SEM, EDX, size distribution, UV dispersion and thermal conductivity test. Their performance for thermal conductivity was evaluated at room temperature. the thermal conductivity of nanofluid is enhanced up to 12 % at 5 wt. % of activated carbon. The results indicate that activated carbons modified with NaHCO₃ solution and sonication treatment can be used for the nanofluid.

Key Words: Activated carbon, NaHCO₃, Thermal conductivity, Nanofluid.

INTRODUCTION

Heating or cooling is one of the most important technical challenges facing many diverse industries, including microelectronics, transportation, solid-state lighting and manufacturing. With the rapid development of technology, more and more electronic devices become smaller, light-weight, compact structure and running highly efficient[1], leading to produce and accumulate large amounts of heat during running process. Therefore, light weight, high thermal conductivity materials are needed urgently. Recently, a new generation of heat transfer fluid systems was introduced through the pioneering research work on nanofluids at the Argonne National Laboratory by Choi[2,3]. Nanofluids are solid-liquid composite materials consisting of solid nanoparticles or nanofibers with sizes typically of 1-100 nm suspended in liquid[4]. Nanofluids have attracted great interest recently because of reports of greatly enhanced thermal properties. A comprehensive review by Wang *et al.*[5] summarizes the work done on nanofluids. Different levels of thermal conductivity enhancement are reported, indicating a direct dependence on variables such as the type and dimensions of the nano-filler, filler concentration and the inherent properties of the coolant.

Carbon materials with high thermal conductivity, low density and low thermal expansion coefficient properties become a promising thermal management material in recent

years[6-8]. Mesophase carbon material has excellent thermal and electrical conductivity due to its high degree of preferred orientation and less lattice defects[9-12]. The thermal conductivity of these systems can be much higher than those of commercial coolants. Hwang *et al.*[13] compared the thermal conductivity of four kinds of nanofluids such as MWCNTs in water, CuO in water, SiO₂ in water and CuO in ethylene glycol. They found that the thermal conductivity of MWCNT nanofluid was increased up to 11.3 % at 1 vol %, which is relatively higher than that of the other groups of nanofluids.

While morphologically different than CNTs, activated carbon-based nanofluid suspensions have shown similarly high potential for boosting thermal conductivity. The activated carbon structured nanofluids in this study hold potential to further increase energy efficiency while reducing life cycle costs. In this paper, NaCHO₃ modified activated carbon based nanofluids for high thermal conductivity materials were studied.

EXPERIMENTAL

Preparations of activated carbon nanofluids: The present steps involved in the preparation of activated carbon nanofluids include: (1) mill the activated carbon to optimal size by ball milling and mono-planetary high energy mill; and (2) disperse the cut and treated activated carbon into water base fluids. Wood based activated carbon (average size 300 μm) was selected as the starting material. In a typical

treatment, 10 g of activated carbon powder was ball milled for 24 h at room temperature in a laboratory tumbling ball mill and then the mechano-chemically activated carbon was obtained using a laboratory Pulverisette 6 mono-planetary high energy mill (Frisch, Idar-Oberstein, Germany) for 4 h in N_2 atmosphere; the cut and treated activated carbon were ultrasonicated in 0.01 mol/L $NaCHO_3$ solution, using a VCX750 Ultrasonic Probe CV33 at a setting of 1.3×10^5 J power. After 1 h intensive sonication, the stable activated carbon nanofluids are obtained.

Characterizations: XRD techinque was used for crystal phase identification of the carbon and $NaCHO_3$. XRD patterns were obtained at room temperature with a diffractometer Shimata XD-D1 (Japan) using Cu K_α radiation. SEM was used to observe the surface state and porous structure of the activated carbon composites using a scanning electron microscope (Jeol, JSM-5200, Japan). EDX spectroscopy was used to measure the elemental analysis of the activated carbon composites. The dispersion effect of activated carbon nanofluids were investigated using UV/VIS spectroscopy (Optizen POP, Korea) with the absorbance change of the nanofluids, which was measured as function of time. The size distribution of the samples prepared was tested with laser particle size analyzer (model: analysette 22 Nano Tec).

Thermal conductivity measurements: Thermal conductivity was measured by using a transient hot-wire method (THW) at 22 ℃. Every sample was tested by 5 times and obtained their mean value. For comparison, the base fluid (water) was used and their thermal conductivity was 0.604 W/m K (THW). The hot wire method is a standard transient dynamic technique based on the measurement of the temperature rise in a defined distance from a linear heat source (hot wire) embedded in the test material. If the heat source is assumed to have a constant and uniform output along the length of test sample, the thermal conductivity can be derived directly from the resulting change in the temperature over a known time interval[14]. The hot wire probe method utilizes the principle of the transient hot wire method. Here the heating wire as well as the temperature sensor (thermocouple) is encapsulated in a probe that electrically insulates the hot wire and the temperature sensor from the test material[15].

The ideal mathematical model of the method is based on the assumption that the hot wire is an ideal, infinite thin and long line heat source, which is in an infinite surrounding from homogeneous and isotropic material with constant initial temperature. If q is the constant quantity of heat production per unit time and per unit length of the heating wire (W m^{-1}), initiated at the time t = 0, the radial heat flow around the wire occurs. Then the temperature rise $\Delta T(r, t)$ at radial position r from the heat source conforms to the simplified formula:

$$k = \left(\frac{q}{4\pi\Delta T(r, t)} \right) \ln\left(\frac{4at}{r^2c} \right) \tag{1}$$

where k is the thermal conductivity (W m^{-1} K^{-1}), a thermal diffusivity (m^2 s^{-1}) (a = k/ρc_p, with ρ is the density (kg m^{-3}) and c_p the heat capacity (J kg^{-1} K^{-1}) of the test material and C = exp (γ), γ = 0.5772157 is the Euler's constant.

RESULTS AND DISCUSSION

Taking into consideration all the process parameters and their possible influences on the particle properties, we chose the sample before sonication as a process-testing example. As seen in Fig. 1, an average diameter of 1 µm was obtained by laser particle size analyzer (model: analysette 22 Nano Tec). The particle size primarily ranged from 0.1-10 µm.
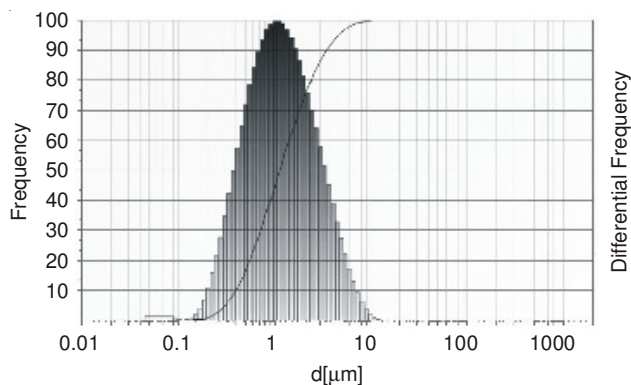

Fig. 1. Partical size distribution of activated carbon before sonication

The XRD results for the sample is shown in Fig. 2. The structure of the composite showed an nahcolite crystal ((PDF #15-0700) and the amorphous activated carbon. It is well known that the crystal structure of $NaHCO_3$ is introduced during the treatment of activated carbon. And the sonication did not change the phase. Sharp intense peaks from nahcolite crystal still appeared in the samples.
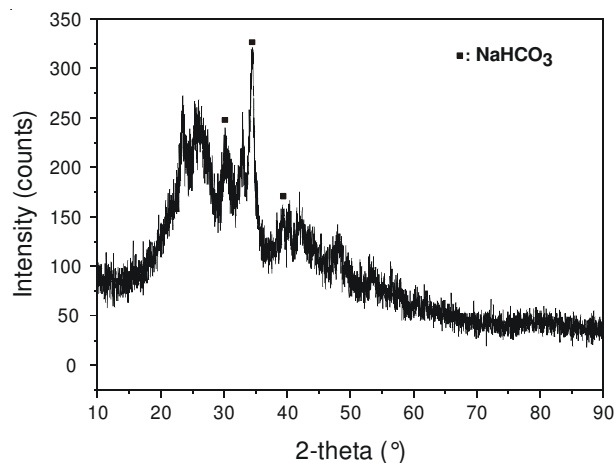

Fig. 2. XRD pattern of powdered $NaCHO_3$ treated activated carbon composites

The micro-surface structure and morphology of the $NaCHO_3$ treated activated carbon composites were characterized by SEM (Fig. 3). As shown in Fig. 3, the activated carbon particles were well mixed with to the $NaCHO_3$ particles and the distribution was uniform. It was observed that these suspension included micrometer and nanometer particles and even size of about 100 nm was obtained. It was beneficial for the enhancement of the dispersion effect of these composites. EDX is conducted on several zones of the composite. The main elements and wt. % found in a representative analysis are shown in Fig. 4. As observed in Fig. 4, three kinds of main
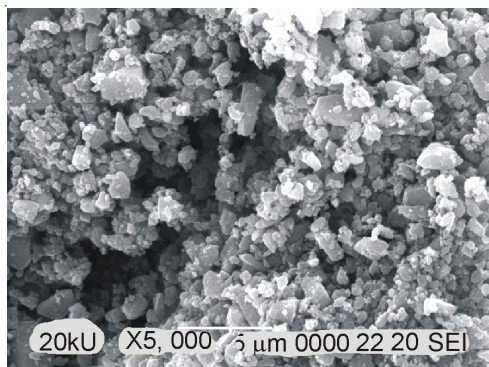
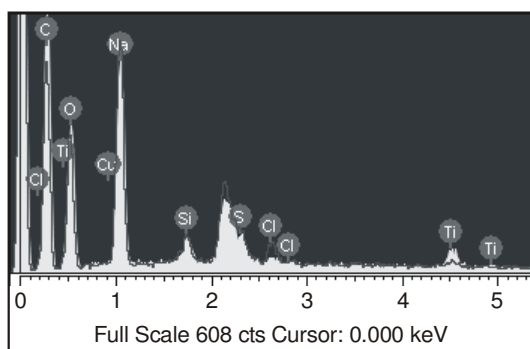Fig. 3. SEM image of powdered NaCHO₃ treated activated carbon composites

Fig. 4. EDX elemental microanalysis of powdered NaCHO₃ treated activated carbon composites.

elements, which is C, O and Na, are existed with some other impure elements.

Fig. 5 shows absorbance of activated carbon nanofluids with a function of time for different particle concentration with or without NaCHO₃ treatment. As expected, the absorbances of activated carbon nanofluids decrease with a decrease of particle concentration. After 72 h, all of samples were reached relative equilibrium, however the decreases of absorbance for all samples are little Fig. 5(a-b). For the non NaCHO₃ treated samples, the decrease amount of absorbance is more than that of NaCHO₃ treated samples. And the results of adsorbance are consistent with the photography of activated carbon nanofluids after 72 h (Fig. 4c). We could not find any deposit in the bottom of these nanofluids.
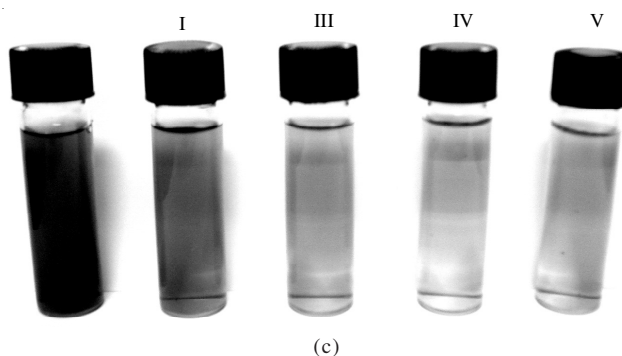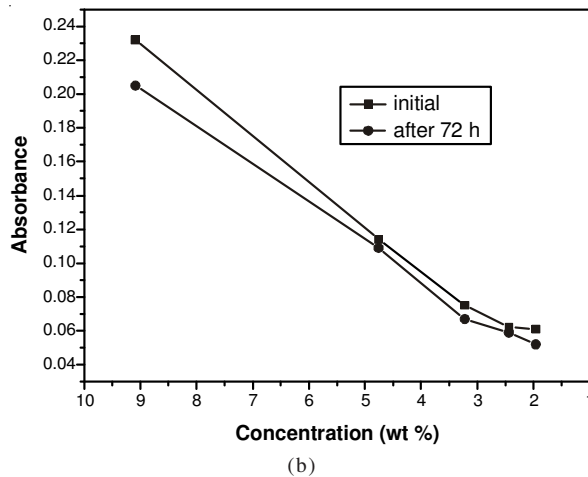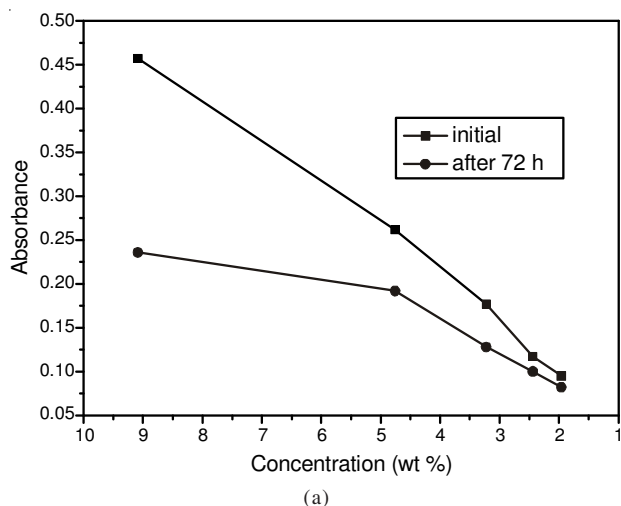

(a)

(b)

(c)

Fig. 5. (a) Absorbance of pristine activated carbon nanofluids with a function of time; (b) absorbance of activated carbon nanofluids with a function of time; (c) photography of activated carbon nanofluids after 72 h for different particle concentration. I: 9 wt. %, II: 5 wt. %, III: 3.5 wt. %, IV: 2.5 wt. % and V: 2 wt %

Fig. 6 depicts the thermal conductivity enhancements of water based activated carbon nanofluids as a function of activated carbon concentration (wt. %). In this paper, the thermal conductivity of nanofluid is enhanced up to 12 % at 5 wt %. Uncertainty of the thermal conductivity of nanofluid is increased with increasing activated carbon concentration. The uncertainties of the thermal conductivity of activated carbon nanofluid are 2 and 8 % at a activated carbon concentration of 2 and 9 wt. %, respectively. It is believed that it is difficult to obtain highly stable suspension which has good reproducible proper properties when the activated carbon concentration increases. In suspensions, the liquid molecules close to a particle surface are known to form a solid-like layer at the interface. This solid-like structure of liquid molecules may play an important role in heat transport from solid wall to adjacent liquid[16]. Since these interactions are not considered in conventional models for predicting thermal conductivity of suspension, they always underestimate the thermal conductivity enhancement of nanofluid.

Conclusion

To investigate the thermal conductivity of activated carbon nanofluid, the thermal conductivity of five kinds of concentration in water are measured by a transient hot-wire method. The thermal conductivity of activated carbon nanofluids are almost linearly increased with increasing activated carbon concentration before 5 wt. % and the thermal
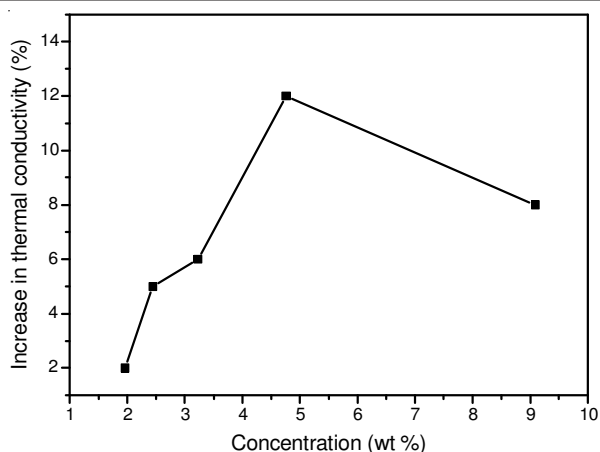
Fig. 6. Relative increase in the thermal conductivity as a function of the weight fraction of nanoparticles

conductivity enhancement of water-based activated carbon concentration nanofluid is increased up to 12 % at concentration of 5 wt. %. The results show that the thermal conductivity of nanofluids depends on the thermal conductivity of the suspended particles and base fluids.

ACKNOWLEDGEMENTS

REFERENCES

1. R.T. Lu, Z.H. Huang and F.Y. Kang, *Mater. Rev.*, **19**, 69 (2005).
2. S.U.S. Choi, In eds.: D.A. Singer and H.P. Wang, Enhancing Thermal Conductivity of Fluids with Nanoparticles, In: Developments and Applications of Non-Newtonian Flows, American Society of Mechanical Engineers, New York, FED-Vol. 231/MD, Vol. 66, pp. 99-105 (1995).
3. S.K. Das, S.U.S. Choi and H.E. Patel, *Heat Trans. Eng.*, **27**, 3 (2006).
4. P. Keblinski, J.A. Eastman and D.G. Cahill, *Mater. Today*, **8**, 36 (2005).
5. X.Q. Wang and A.S. Mujumdar, *Int. J. Thermal Sci.*, **46**, 1 (2007).
6. H.P. Qiu, Y.Z. Song and Q.G. Guo, *Fuctinla Mater.*, **33**, 473 (2002).
7. W.C. Morgan, *Carbon*, **10**, 73 (1972).
8. Z.K. Ma, J.L. Shi, L. Liu and J.R. Song, *New Carbon Mater.*, **20**, 223 (2005).
9. C.X. Li, B.X. Ma, X.X. Huo and Z.B. Hao, *Mater. Eng.*, **12**, 3 (1998).
10. Z.M. Shen, W.D. Chi, X.J. Zhan and W.P. Chang, *New Carbon Mater.*, **12**, 1 (2005).
11. Z.K. Ma, J.L. Shi, Q.G. Guo, G.T. Zhai and L. Liu, *Carbon*, **44**, 1298 (2006).
12. P.M. Adams, H.A. Katzman, G.S. Rellick and G.W. Stupian, *Carbon*, **36**, 233 (1998).
13. Y.J. Hwang, Y.C. Ahn, H.S. Shin, C.G. Lee, G.T. Kim, H.S. Park and J.K. Lee, *Curr. Appl. Phys.*, **6**, 1068 (2006).
14. W.R. Davis, In eds.: K.D. Magliae, A. Cezairliyan and V.E. Peletsky, Hot-Wire Method for the Measurement of the Thermal Conductivity of Refractory Materials, Compendium of Thermophysical Property Measurement Methods, Survey of Measurement Techniques, New York, London, Plenum Press, Vol. 1, p. 161 (1984).
15. A.E. Wechsler, In eds.: K.D. Magliae, A. Cezairliyan and V.E. Peletsky, The Probe Method for Measurement of Thermal Conductivity, Compendium of Thermophysical Property Measurement Methods, Recommended Measurement Techniques and Practices, New York, London, Plenum Press, Vol. 2, p. 281 (1992).
16. W. Yu and S.U.S. Choi, *J. Nanoparticle Res.*, **5**, 167 (2003).

25TH INTERNATIONAL APPLIED GEOCHEMISTRY SYMPOSIUM 2011

22 — 26 AUGUST, 2011

ROVANIEMI, FINLAND

Contact:

Pertti Sarala
Senior Scientist (PhD)
Geological Survey of Finland
PO Box 77
96101 Rovaniemi, Finland
Tel. +358 205 50 4222

Juhani Ojala
Senior Geologist (PhD)
Store Norske Gull AS
Ounasvaarantie 1
96400 Rovaniemi, Finland
Mob. +358 40 8480 285

Website: http://www.iags2011.fi/index.html