IJE TRANSACTIONS B: Application Vol. 26, No. 8, (August 2013) 821-828

International Journal of Engineering

Journal Homepage: www.ije.ir

Thermal Conductivity of Cu and Al-Water Nanofluids

M.Tajik Jamal-Abadi, A. H. Zamzamian*

Department of Renewable Energy, Materials and Energy Research Center, P.O.B. 316-31787, Karaj, Iran

PAPER INFO

Paper history:
Received 28 January 2013
Received in revised form 22 February 2013
Accepted 28 February 2013

Keywords:
Thermal Conductivity
Metal Nanofluid
KD2 Pro
Theoretical Models

ABSTRACT

Nanofluids are suspensions of nanoparticles in the base fluids; a new challenge for thermal sciences provided by nanotechnology. In this paper, the tested fluids are prepared by dispersing Al and Cu into water at three different concentrations of 500, 1000 and 2000 ppm. Thermal conductivities of these fluids are measured experimentally by thermal property analyzer i.e. KD2 Pro using KS-1 sensor needle as this needle is preferred for low viscosity fluids. Experimental results show that thermal conductivity of nanofluids are higher than the base fluid and thermal conductivity of Cu/water nanofluid is more than Al/water nanofluid, because the thermal conductivity of Cu is higher in comparison to Al. In addition, a comparison is made between the experimental results of thermal conductivity and the results calculated using models presented for predicting them. Results showed that classic models failed to predict nanofluids thermal conductivity, but novel models that consider the effects of temperature provide more acceptable results, meanwhile 9% difference is found between experimental results and Xei model for Cu/water nanofluid.

doi: *10.5829/idosi.ije.2013.26.08b.03*

1. INTRODUCTION

Fluid heating and cooling are important in many industries such as power, manufacturing, transportation, and electronics. Effective cooling techniques are greatly needed for cooling any sort of high-energy device. Common heat transfer fluids such as water, ethylene glycol, and engine oil have limited heat transfer capabilities due to their low heat transfer properties. Numerous researchers are investigating better ways to enhance the thermal performance of heat transfer fluids. One of the methods used is to add nano-sized particles of high thermal conductivity materials like carbon, metal and metal oxides into the heat transfer fluid to improve the overall thermal conductivity of the fluid. But solid particles have thermal conductivity higher than that of common fluids, when they are dispersed in the fluids result in higher heat transfer characteristics. The effect is observed when nanoparticles have heat conductivity many times greater than the liquid. Usually Cu, Ag, CuO, AL_2O_3 or CNT are used. The advantages of using nanoparticles are that they are more easily suspended in the fluid, they may be used in microchannels, and the small size causes less wear to machinery. However, aggregation of particles must be minimized in order to benefit from these effects of small particle size. There are also two ways to produce nanofluids; one-step process or two-step process.

The thermal conductivity of nanofluids including metal particles or metal oxide particles have been studied by many researchers [1] such as Choi [2], Das et al. [3], Juan et al. [4], Eastman et al. [5, 6], and Lee et al. [7, 8]. Lee et al. [8] showed that thermal conductivity of SiO_2 nanofluid increases with increasing in volume concentration. Masuda et al. [9] depicted 20% increase in thermal conductivity for 3 vol.% nanofluid. Xuan and Li and Yu et al. [10] have demonstrated that the heat transfer properties of transformer oil can be improved using nanoparticle additives. Several reports for the thermal conductivity of nanofluid is shown in Table 1.

Generally, the thermal conductivity of nanofluids increases with an increase of volume fraction and some researchers have observed anomalous thermal conductivity enhancement for dilute suspensions (< 1 % by volume) of metallic nanoparticles [6, 11, 12].

* Corresponding Author Email: azamzamian@merc.ac.ir (A. H. Zamzamian)

TABLE 1. Some reports about the thermal conductivity of nanofluids

Researcher	Base fluid	Nanoparticle
Masuda et al.[9]	Distilled water	AL_2O_3, TiO_2
Xie et al. [13]	Distilled water	SiC
Das et al. [3]	Distilled water	AL_2O_3, CuO
Murshed et al. [14]	Distilled water	TiO_2
Wen and Ding [15]	Distilled water	Al_2O_3
Patel et al. [16]	Distilled water	Ag, Au
Yang and Han. [17]	oil	Bi_2Te_3

TABLE 2. Physical properties of nanosized metallic particles

Particle	Density (g/cm^3)	Mean diameters (nm)	Thermal conductivity (W/m.k)
Cu	8.954	30-40	401
Al	2.707	20-30	237

In addition to the aforementioned results of Eastman et al. [6] and Jana et al. [12], Ceylan et al. [11] reported a thermal conductivity enhancement of 33 % for 0.006 % (v/v) Ag –Cu alloy nanoparticles in pump oil.

Das et al. [3] measured the thermal conductivity of aqueous nanofluids containing Al_2O_3 and CuO at temperatures between 20 and 50 ºC. They observed that the thermal conductivity increased as the temperature increased and speculated that this behavior is typical of nanofluids over greater temperature ranges as well.

The largest thermal conductivity enhancements observed in nanofluids containing high thermal conductivity particles (copper [11], carbon nanotubes [18] and diamonds [19]). The same base fluids as nanofluids containing less conductive particles, exhibited much lower thermal conductivity enhancements [20].

Particle size is an important parameter on thermal conductivity because the opposite temperature trend was reported by Masuda et al. [9] for smaller particles. Also results suggest that the relative increase in thermal conductivity is more important at higher temperature as well as smaller diameter particles. Xie et al. [21] demonstrated the thermal conductivity decreased with an increase in pH value.

The focus of this work was on nanofluids containing metals. The specific goals were determination of the effects of temperature and nanoparticles concentration on the thermal conductivity of nanofluids and elucidation of the mechanism of conduction. Thermal conductivity measurements were performed by KD2 Pro instrument. The nanofluid samples consisted of Al and Cu particles dispersed in water. Thermal conductivity measurements were performed at wide range of temperature (35-45ºC). In addition, a comparison was made between the experimental results of thermal conductivity and the results calculated using models presented for predicting them.

2. NANOFLUID PREPARATION

There are two ways to produce nanofluids; one-step process or two-step process. The one-step process simultaneously makes and disperses the nanoparticles directly into the base fluid, while with the two-step process; the nanoparticles are made and then dispersed in the fluid. The major disadvantage of the two-step process is that the nanoparticles tend to agglomerate before the nanoparticles can be dispersed in the fluid. The one-step process is also favorable because it prevents oxidation of the nanoparticles [22]. Two series of nanofluids were prepared using two different types of nanoparticles, Al and Cu with mean diameters of 25 and 35 nm, respectively, while water used as base fluid. Nanofluids were prepared by on-step method and nanoparticles were found very stable and the stability lasted over a week. Table 2 contains the other properties of these nanoparticles.

The thermal conductivities of nanofluids were measured using a KD2 Pro thermal properties analyzer (Decagon Devices, Inc., USA). It consisted of a handheld microcontroller and sensor needles. The sensor needle used was KS- 1 which was made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and closely approximated the infinite line heat source which gave least disturbance to the sample during measurements. The sensor needle could be used for measuring thermal conductivity of fluids in the range of 0.2–2 W/m.K with an accuracy of ±5%. Each measurement cycle consisted of 60 s including heating and cooling of sensor needle for 30 s each. It should be noted that before each measurement the needle should be thermally equilibrated with the sample. At the end of the reading, the controller computed the thermal conductivity using the change in temperature (DT)–time data from:

$$k = \frac{q(\ln t_2 - \ln t_1)}{4\pi(\Delta T_2 - \Delta T_1)} \quad (1)$$

where q is constant heat rate applied to an infinitely long and small ‘‘line” source, ΔT_1 and ΔT_2 are the changes in the temperature at times t_1 and t_2, respectively. The calibration of the sensor needle was carried out first by measuring thermal conductivity of distilled water and glycerin. The measured values for distilled water and glycerin were 0.608 and 0.295 W/m.K, respectively, which are in agreement with the literature values of 0.613 and 0.285 W/m.K, respectively, within ± 5% accuracy.

Figure 1. KD2 Pro system

For accurate measurements, the needle was inserted fully into the fluid, and oriented vertically and centrally inside the vial without touching the side walls of the vial. Insertion of the sensor needle probe into the fluid in this orientation will minimize errors from free convection. Moreover, the vial was inserted in a bath at 30 °C to make sure there is no heat exchange with ambient (see Figure 1).

3. THEORETICAL MODEL

From the experimental results of many researchers, it is known that the enhancement of thermal conductivity of nanofluids depends on parameters including the thermal conductivities of the base fluid and the nanoparticles, the volume concentration, the surface area and shape of nanoparticles and the temperature. Currently, there is no theoretical equation to predict the thermal conductivity of nanofluids satisfactorily since there is no consistent theory to support such equations. In the current research three classic models and two novel methods are presented and their values compared to experimental results.

Maxwell model [23] is one of the very first mathematical models presented for predicting thermal conductivity of macro-scale suspensions with spherical particles. This equation takes into account only the particle volume concentration and the thermal conductivities of particle and liquid, and has better results in low concentrations (<1 vol. %).

Based on Maxwell's work, the effective thermal conductivity of a homogeneous suspension can be predicted as:

$$k_{eff\ ,Maxwell} = \frac{k_p + 2k_f + 2(k_p - k_f)\Phi}{k_p + 2k_f - (k_p - k_f)\Phi} k_f \tag{2}$$

where k_p is the thermal conductivity of the dispersed particles, k_f is the thermal conductivity of the dispersion liquid, and Φ is the particle volume concentration of the suspension.

Hamilton and Crosser [24] extended Maxwell model to include an experiential factor n to account for the shape of the particles:

$$k_{eff,Hamilton-Crosser} = \frac{k_p + (n-1)k_f + (n-1)(k_p - k_f)\Phi}{k_p + (n-1)k_f - (k_p - k_f)\Phi} k_f \tag{3}$$

where n is defined as $n = 3/\Psi$ and Ψ is particle sphericity and is defined as the ratio of surface area of a sphere with the same volume of particle to that of the particle.

Jeffrey [25] took pair interaction of randomly dispersed spheres into account and suggested his model as:

$$\frac{k_{eff,jeffrey}}{k_f} = 1 + 3\beta\Phi + \left[3\beta^2 + \frac{3\beta^2}{4} + \frac{9\beta^2}{16}\frac{\alpha+2}{2\alpha+3} + \dots\right]\Phi^2 \tag{4}$$

where α and β calculated as $\frac{k_p}{k_f}$ and $\frac{\alpha-1}{\alpha+2}$, respectively. High-order terms in equation above represent the pair interactions.

Bruggeman [26] by considering the interaction between randomly distributed particles, the clustering of nanoparticles and their surface adsorption proposed a new model. Based on his model, the thermal conductivity of a homogenous binary mixture with spherical particles can be calculated as:

$$\Phi\left(\frac{k_p - k_{ef}\ f}{k_p + 2k_{eff}}\right) + (1-\Phi)\left(\frac{k_f - k_{eff}}{k_f + 2k_{eff}}\right) = 0 \tag{5}$$

By rearranging the equation to be explicit for k_{eff} we have:

$$k_{eff} = \frac{f}{4}\left[(3\Phi - 1)k_p + (2 - 3\Phi)k_f\right] + \frac{k_f}{4}\sqrt{\Delta} \tag{6}$$

with

$$\Delta = \left[(3\Phi-1)^2\left(\frac{k_p}{k_f}\right)^2 + (2-3\Phi)^2 + 2\left(2+9\Phi-9\Phi^2\right)\left(\frac{k_p}{k_f}\right)\right] \tag{7}$$

The Bruggeman model results in low solid concentration which is almost the same as Maxwell results, but in high concentration this model is far superior to Maxwell model and have better agreements with experimental data.

The models presented above are developed for macro-scale solid/liquid suspensions and in many cases their results do not agree with experimental results. It is predictable as none of these models considered effect of parameters such as particle size and temperature while recent researches have showed that these parameters may have grater effects on thermal conductivity enhancement. In recent years, many researchers have tried to develop new theories or make necessary modifications to classic models to propose new and more accurate correlations, two of which are presented below.

Yu and Choi [27] suggested a modified Maxwell model with the assumption that the solid-like layer of thickness h around the particles is more ordered than that of the bulk liquid and that the thermal conductivity k_{layer} of this ordered layer is higher than that of the bulk liquid. They assumed that this nano-layer combined with particle to form an equivalent particle with radius $r+h$. They replaced the thermal conductivity of solid particles k_p in Maxwell model with the modified thermal conductivity of particles k_{pe}, which is based on the so called effective medium theory:

$$k_{pe} = \frac{\left[2(1-\gamma)+(1+\beta)^3(1+2\gamma)\gamma\right]}{-(1-\gamma)+(1+\beta)^3(1+2\gamma)} k_p \quad (8)$$

where $\beta = h/r$ is the ratio of the nano-layer thickness to the original particle radius and $\gamma = k_{layer}/k_p$ is the ratio of nano-layer thermal conductivity to particle thermal conductivity. Therefore, the Maxwell model can be modified as follows:

$$keff,Yo = k_f \left[\frac{k_p + 2k_f + 2(k_p - k_f)(1+\beta)^3 v}{k_p + 2k_f - (k_p - k_f)(1+\beta)^3 v}\right] \quad (9)$$

This model has better agreements with experimental data for particles less than 10 nm in diameter. We can use equation offered by Wang et al. [28] to calculate nano-layer thickness. This equation is as follows:

$$h = \frac{1}{\sqrt{3}}\left(\frac{4M_f}{\rho_f N_A}\right)^{\frac{1}{3}} \quad (10)$$

where M_f and ρ_f are the molar mass and the density of the base fluid, respectively and $N_A = 6.023\times10^{23}$ per mole is the Avogadro constant.

Xie et al. [29] proposed an effective thermal conductivity model by considering an ordered nano-layer with linear thermal conductivity distribution. This model take into accounts the effects of nano-layer thickness, nanoparticles size, volume concentration, and thermal conductivities of fluid, nanoparticles, and nano-layer. Their formula is:

$$k_{eff,Xie} = (1 + 3\Theta\Phi_T + \frac{3\Theta^2\Phi_T^2}{1-\Theta\Phi_T})k_f \quad (11)$$

with

$$\Theta = \frac{\beta_{lf}\left[(1+\gamma)^3 - \beta_{pl}/\beta_{fl}\right]}{(1+\gamma)^3 + 2\beta_{lf}\beta_{pl}}$$

where

$$\beta_{lf} = \frac{k_1 - k_f}{k_1 + 2k_f}$$

$$\beta_{pl} = \frac{k_p - k_1}{k_p + 2k_1}$$

$$\beta_{fl} = \frac{k_f - k_1}{k_f + 2k_1}$$

And $\gamma = \delta/r_p$ is the thickness ratio of nano-layer and nanoparticle. Φ_T is the modified total volume fraction of the original nanoparticle and nano-layer, $\Phi_T = \Phi(1+\gamma)^3$. k_1 is defined as:

$$k_1 = \frac{k_f M^2}{(M-\gamma)\ln(1+M)+\gamma M} \quad (12)$$

with $M = \varepsilon_p(1+\gamma)-1$, where $\varepsilon p = k_p/k_f$ is the reduced thermal conductivity of nanoparticle.

To gain a deeper understanding of the effective thermal conductivity of nanofluids, some key facts must be taken into account in future researches. Such facts include effect of the size and shape of the nanoparticles, the interfacial contact resistance between nanoparticles and base fluids, the temperature dependence or the effect of Brownian motion, and the effect of clustering of particles.

4. RESULT AND DISCUSSION

Each experiment was repeated three times. The overall deviation of the results was about 6%.

The trend of thermal conductivity ratio versus nanofluid concentration for Al/water nanofluid is showed in Figure 2 and there is a slight increase for increasing nanofluid concentration. The results show that nanoparticle suspensions have noticeably higher thermal conductivities than base fluid without nanoparticles and can be seen that for the Al/water suspension, the thermal conductivity can be enhanced by more than 22% at 45 ^{o}C for 2000 ppm. Similar pattern can be observed for Cu/ water nanofluid in Figure 3.

Thermal conductivity ratio rises from 1.12 at 500 ppm to more than 1.26 at 2000 ppm, once again reflecting the fact that thermal conductivity increases with nanoparticles concentration.

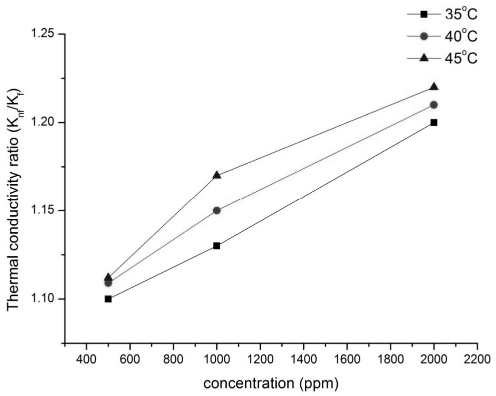

Figure 2. Thermal conductivity ratio of nanofluids containing Al in water

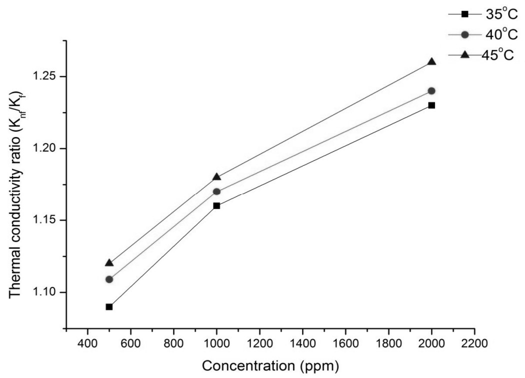

Figure 3. Thermal conductivity ratio of nanofluids containing Cu in water

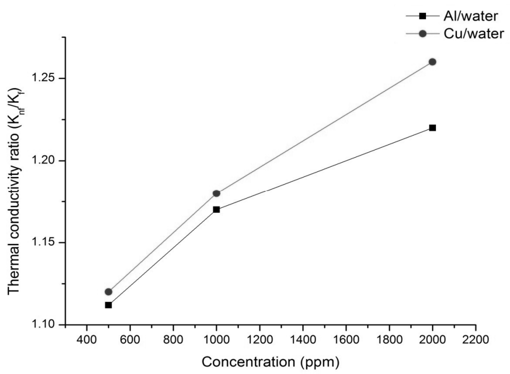

Figure 4. Thermal conductivity comparison between Al/water and Cu/water nanofluid

Throughout the range of particle concentration considered in this work (500-2000 ppm), all of the thermal conductivity models discussed exhibit a linear relationship with respect to particle concentration.

It was seen that unlike DI water, the thermal conductivity of the nanofluid samples increases non-linearly with temperature. One of the suggested reasons behind this phenomenon is the increased Brownian motion effect.

Jang and Choi [30] suggested that as the temperature is increased, the viscosity of the nanofluid decreases, which results in increase in Brownian motion of nanoparticles, which sets convection-like effects resulting in enhanced thermal conductivity. A maximum increase of 26% was obtained for Cu/water at a temperature of 45 °C for 2000 ppm. Effect of temperature on thermal conductivity enhancement is even more than water and it rises from 9 % to 22 % (for Al/ water) and 10 % to 26 % (for Cu/water). The measurement indicates that particle concentrations and temperature is an important parameter for thermal conductivity.

Figure 4 illustrates comparison between thermal conductivity ratio of Al and Cu nanofluid for different concentrations at 45 °C. Cu/water nanofluids were reported to have more significant enhancements in effective thermal conductivity than those water based nanofluids containing Al nanoparticles. For example, at 500 and 1000 ppm, the effective thermal conductivity of Cu/water nanofluid increases 12% and 26%, respectively, whereas the thermal conductivity increases of Al/water nanofluid is 11% and 22%.

Figures 5 and 6 demonstrate a comparison between experimental results and predicted values. As shown in the figures, these models do not match with experimental values well. Despite similarities, there are a number of marked differences at high concentrations. The higher-than-predicted thermal conductivity enhancement, shown in Figures 5 and 6, also implies the contribution from other mechanisms, such as the particle Brownian motion, nanofluid pH and nanoparticles clustering. The thermal conductivity enhancement should be attributed to the combined effects of the particle Brownian motion and the diffusive heat conduction. The Brownian motion would play a dominant role in thermal conductivity enhancement in nanofluids containing spherical nanoparticles. Based on these observations all of the models have underestimated the thermal conductivity value and Xei model predicts thermal conductivity better and with lower error in comparison to another model. Yu and Choi model is the second best model for predicting thermal conductivity. Meanwhile, the thermal conductivity ratio anticipated by other models is not exact. Experimental value for Cu/water at concentration of 0.02 weight fraction is 9% higher than Xei model and for Al/water at same weight fraction is 4.5%. These discrepancies are a little more for Yu and Choi model.

Furthermore, there is not appropriate model for predicting the thermal conductivity of nanofluids containing high thermal conductivity particles such as copper, silver, or diamond.

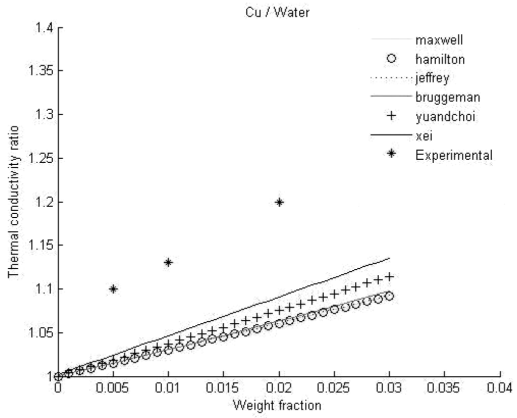

Figure 5. Comparison between experimental and predicted values of thermal conductivity for Cu/water

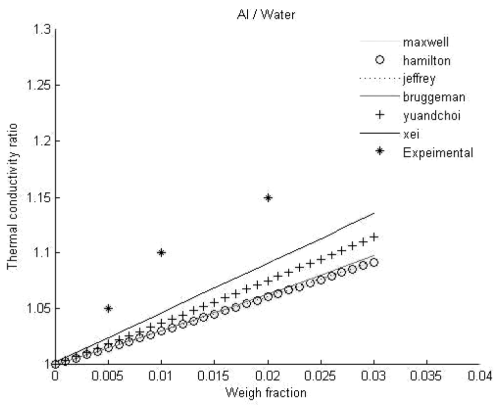

Figure 6. Comparison between experimental and predicted values of thermal conductivity for Al/water

5. CONCLUSION

In this study, thermal conductivity of nanofluids have been measured experimentally using transient hot wire method and compared with classic and novel thermal conductivity models.

The effective thermal conductivity of nanofluids can be measured by thermal property analyzer such as KD2 Pro at different ranges of temperature. The experimental results show that a dramatic increase in the enhancement of thermal conductivity of nanofluids takes place with increase in temperature. Temperature causes thermal conductivity enhancement rise from 12 % to 26 % (for Cu/water at 2000 ppm) and11 % to 22 % (for Al/water at 2000 ppm). The results indicate that particle concentration is also an important parameter for nanofluids. With increase in particle concentration, thermal conductivity of nanofluids also increased. The experimental data are compared to some models and it is found that thermal conductivities computed by theoretical models are much lower than the measured data. Although various theoretical models are proposed for predicting the effective thermal conductivity of nanofluids, there is no model that can make accurate estimations. Further research in this area is necessary.

6. REFERENCES

1. Eastman, J. A., Phillpot, S., Choi, S. and Keblinski, P., "Thermal transport in nanofluids 1", ***Annual Review of Materials Research***,, Vol. 34, , (2004), 219-246.
2. Choi, S. U. and Eastman, J., Enhancing thermal conductivity of fluids with nanoparticles., Argonne National Lab., IL (United States), (1995)
3. Putra, N., Thiesen, P. and Roetzel, W., "Temperature dependence of thermal conductivity enhancement for nanofluids", ***Journal of Heat Transfer***, Vol. 125, (2003), 567-574.
4. Xuan, Y., Li, Q. and Hu, W., "Aggregation structure and thermal conductivity of nanofluids", ***AIChE Journal***, Vol. 49, No. 4, (2003), 1038-1043.
5. Eastman, J., Choi, U., Li, S., Thompson, L. and Lee, S., "Enhanced thermal conductivity through the development of nanofluids", in Materials Research Society Symposium Proceedings, Cambridge Univ Press. Vol. 457, (1997), 3-12.
6. Eastman, J., Choi, S., Li, S., Yu, W. and Thompson, L., "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles", ***Applied Physics Letters***, Vol. 78, No. 6, (2001), 718-720.
7. Lee, S., Choi, S. U., Li, S., and and Eastman, J., "Measuring thermal conductivity of fluids containing oxide nanoparticles", ***Journal of Heat Transfer***, Vol. 121, No. 2, (1999).
8. Hwang, Y., Park, H., Lee, J. and Jung, W., "Thermal conductivity and lubrication characteristics of nanofluids", ***Current Applied Physics***, Vol. 6, (2006), 67-71.
9. Masuda, H., Ebata, A., Teramae, K. and Hishinuma, N., "Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles", ***Netsu Bussei***, Vol. 7, No. 2, (1993), 227-233.
10. Xuan, Y. and Li, Q., "Heat transfer enhancement of nanofluids", ***International Journal of Heat and Fluid Flow***, Vol. 21, No. 1, (2000), 58-64.
11. Ceylan, A., Jastrzembski, K. and Shah, S. I., "Enhanced solubility ag-cu nanoparticles and their thermal transport properties", ***Metallurgical and Materials Transactions A***, Vol. 37, No. 7, (2006), 2033-2038.
12. Jana, S., Salehi-Khojin, A. and Zhong, W.-H., "Enhancement of fluid thermal conductivity by the addition of single and hybrid nano-additives", ***Thermochimica Acta***, Vol. 462, No. 1, (2007), 45-55.
13. Xie, H.-q., Wang, J.-c., Xi, T.-g. and Liu, Y., "Thermal conductivity of suspensions containing nanosized sic particles", ***International Journal of Thermophysics***, Vol. 23, No. 2, (2002), 571-580.
14. Murshed, S., Leong, K. and Yang, C., "Enhanced thermal conductivity of TiO2 water based nanofluids", ***International Journal of Thermal Sciences***, Vol. 44, No. 4, (2005), 367-373.
15. Wen, D. and Ding, Y., "Effective thermal conductivity of aqueous suspensions of carbon nanotubes (carbon nanotube

nanofluids)", ***Journal of Thermophysics and Heat Transfer***, Vol. 18, No. 4, (2004), 481-485.

16. Patel, H. E., Das, S. K., Sundararajan, T., Sreekumaran Nair, A., George, B., and Pradeep, T., "Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: Manifestation of anomalous enhancement and chemical effects", ***Applied Physics Letters***, Vol. 83, No. 14, (2003), 2931-2933.
17. Yang, B. and Han, Z., "Temperature-dependent thermal conductivity of nanorod-based nanofluids", ***Applied Physics Letters***, Vol. 89, No. 8, (2006), 083111-083111-3.
18. Choi, S., Zhang, Z., Yu, W., Lockwood, F. and Grulke, E., "Anomalous thermal conductivity enhancement in nanotube suspensions", ***Applied Physics Letters***, Vol. 79, No. 14, (2001), 2252-2254.
19. Kang, H. U., Kim, S. H. and Oh, J. M., "Estimation of thermal conductivity of nanofluid using experimental effective particle volume", ***Experimental Heat Transfer***, Vol. 19, No. 3, (2006), 181-191.
20. Xie, H., Wang, J., Xi, T., Liu, Y. and Ai, F., "Dependence of the thermal conductivity of nanoparticle-fluid mixture on the base fluid", ***Journal of Materials Science Letters***, Vol. 21, No. 19, (2002), 1469-1471.
21. Xie, H., Wang, J., Xi, T., Liu, Y., Ai, F., and Wu, Q., "Thermal conductivity enhancement of suspensions containing nanosized alumina particles", ***Journal of Applied Physics***, Vol. 91, No. 7, (2002), 4568-4572.
22. Yu, W., France, D. M., Routbort, J. L. and Choi, S. U., "Review and comparison of nanofluid thermal conductivity and heat transfer enhancements", ***Heat Transfer Engineering***, Vol. 29, No. 5, (2008), 432-460.
23. Maxwell, J. C., "A treatise on electricity and magnetism", Clarendon press, Vol. 1, (1881).
24. Hamilton, R. and Crosser, O., "Thermal conductivity of heterogeneous two-component systems", ***Industrial & Engineering Chemistry Fundamentals***, Vol. 1, No. 3, (1962), 187-191.
25. Jeffrey, D. J., "Proc r soc london", ser. A 335, (1973).
26. Bruggeman, V. D., "Berechnung verschiedener physikalischer konstanten von heterogenen substanzen. I. Dielektrizitatskonstanten und leitfähigkeiten der mischkörper aus isotropen substanzen", ***Annalen der Physic***, Vol. 416, No. 7, (1935), 636-664.
27. Yu, W. and Choi, S., "The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated maxwell model", ***Journal of Nanoparticle Research***, Vol. 5, No. 1-2, (2003), 167-171.
28. Wang, B.-X., Zhou, L.-P. and Peng, X.-F., "A fractal model for predicting the effective thermal conductivity of liquid with suspension of nanoparticles", ***International Journal of Heat and Mass Transfer***, Vol. 46, No. 14, (2003), 2665-2672.
29. Xie, H., Fujii, M. and Zhang, X., "Effect of interfacial nanolayer on the effective thermal conductivity of nanoparticle-fluid mixture", ***International Journal of Heat and Mass Transfer***, Vol. 48, No. 14, (2005), 2926-2932.
30. Jang, S. P. and Choi, S. U., "Role of brownian motion in the enhanced thermal conductivity of nanofluids", ***Applied Physics Letters***, Vol. 84, No. 21, (2004), 4316-4318.

Thermal Conductivity of Cu and Al-Water Nanofluids

M. Tajik Jamal-Abadi, A. H. Zamzamian

Department of Renewable Energy, Materials and Energy Research Center, P.O.B. 316-31787, Karaj, Iran

P A P E R I N F O

Paper history:
Received 28 January 2013
Received in revised form 22 February 2013
Accepted 28 February 2013

Keywords:
Thermal Conductivity
Metal Nanofluid
KD2 Pro
Theoretical Models

چکیده

نانوسیال ها محلول یکنواخت نانوذرات در داخل سیال پایه است که مفهوم جدیدی را در مباحث انتقال حرارتباز کرده است. در این پژوهش نانوسیالات مس و آلومینیوم به روش یک مرحله ای در سه غلظت ppm ۵۰۰, ۱۰۰۰ و ۲۰۰۰ تهیه شده است. هدایت حرارتی نانوسیالات با استفاده از دستگاه KD2 Pro بصورت تجربی بدست آمده است. برای این منظور از سنسور KS-1 که مناسب برای سیالات با ویسکوزیته کم است استفاده شده است. نتایج نشان می دهد که, ضریب هدایت حرارتی نانو سیال آب– مس بیشتر از نانوسیال آب– آلومینیوم است. این امر تا حدودی به دلیل ضریب هدایت حرارتی بالاتر مس نسبت به آلومینیوم است. بعلاوه داده های تجربی بدست آمده با مدل های موجود برای هدایت حرارتی نانوسیالات مقایسه شده است. نتایج حاکی از آن است که, مدل های کلاسیک هدایت حرارتی نمی توانند هدایت حرارتی نانوسیالات را بخوبی پیش بینی کنند اما در مقابل مدل های جدید که تاثیر دما را نیز مد نظر دارند نتایج قابل قبولتری ارائه می دهند. برای نانوسیال مس مدل ژی ٪۹ اختلاف با داده های تجربی داشت.

doi: *10.5829/idosi.ije.2013.26.08b.03*