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A New Model for the Thermal Conductivity Prediction of Al_2O_3 and CuO Nanofluids in Water

Mostafa Keshavarz Moraveji, Hadi Hezaveh and Reza Davarnejad

Department of Chemical Engineering, Arak University, Arak, Iran

Abstract: In this study, a new model for the thermal conductivity prediction of Al_2O_3+ H_2O and CuO+ H_2O nanofluid mixtures was developed using a method which was regarding the volume fraction and shape factor of nanoparticles. According to this research, it was investigated that Al_2O_3 and CuO nanoparticles are not as complete spherical molecules. By applying the Brailsford and Major equation, a new correlation was obtained for water and nanoparticles as continuous and dispersed phases, respectively. Further, more realistic shape factor values for these nanoparticles were obtained. Theoretical data were compared with the experimental data obtained from the literature. According to this research, thermal conductivities ($K=k_{eff}/k_m$) for Al_2O_3 were obtained around 0.998, 1.067, 1.128 and 1.202 at volume fractions of 0, 0.0175, 0.0325 and 0.050 while according to the literature, they were obtained about 1.000, 1.053, 1.130 and 1.215 at the same as volume fractions. Furthermore, in order to this research thermal conductivities for CuO were obtained around 1.038, 1.058, 1.079, 1.099, 1.121 and 1.63 at volume fractions of 0.01, 0.015, 0.02, 0.025, 0.03 and 0.04 while in order to the literature they were obtained about 1.040, 1.059, 1.087, 1.090, 1.138 and 1.210 at the same as volume fractions. Therefore the theoretical results were in good agreement with the experimental ones while the previous researches did not show an excellent convergence the same as the current research.

Key words: Correlation · Modeling · Nanofluid · Shape factor · Thermal conductivity

INTRODUCTION

The thermal conductivity of fluids has a significant effect on the energy efficient in the heat transfer equipments [1]. Traditional heat transfer fluids including oil, water and ethylene glycol (EG) are poor heat transfer fluids [2].

Nanofluids are stable colloidal suspensions of nanoparticles, nano fibers and nano composites in common base fluids such as water, oil, ethylene-glycol mixtures (antifreeze) and polymer solutions [3]. Since thermal conductivity of nanofluids plays an important role in the development of energy efficient of heat transfer equipments so, several methods have been considered to improve the thermal conductivity. Not only nanoparticles are stable and have small sizes and low masses to block flow passages but also their low kinetic energy in collisions prevents a serious damage [4].

According to the literature, the thermal conductivity of water can be enhanced by a factor (which is usually assumed around 1.5) at the nanoparticle fluids low volume fractions (around 5 %) [4]. This finding theoretically demonstrates that feasibility of nanofluids such as metallic nanoparticles significantly increase the thermal conductivity of conventional heat transfer fluids.

Various researches based on the conventional models on the thermal conductivity of solid/liquid suspensions have been carried out by Maxwell [5], Hamilton and Crosser [6], Jeffery [7], Davis [8], Lu and Lin [9], Bonnecaze and Brady [10, 11].

According to the Hamilton and Crosser's research, copper nanoparticles effect on water thermal conductivity was considered and compared with the copper+water mixture estimated by Choi [12]. Copper, aluminum and their oxide nanoparticles dispersed in a fluid have been widely investigated by a lot of researchers [13].

The thermal conductivity of metallic liquids is more than that for nonmetallic liquids. Therefore, the thermal conductivities of fluids which contain suspended solid metallic particles are higher than those of conventional fluids.

Corresponding Author: Mostafa Keshavarz Moraveji, Department of Chemical Engineering, Arak University, Arak, Iran
Email: m-moraveji@araku.ac.ir

Table 1: Effective thermal conductivities based on various models

Model	Mathematical Expression	Comments
Maxwell [5]	$\frac{k_{eff}}{k_m} = 1 + \frac{3(\alpha - 1)v}{(\alpha + 2) - (\alpha - 1)v}$	Developed for spherical nano- particles
Hamilton-Crosser [6]	$\frac{k_{\mathrm{eff}}}{\mathrm{k_m}} = \frac{\alpha + (\mathrm{n} - 1) - (\mathrm{n} - 1)(1 - \alpha)v}{\alpha + (\mathrm{n} - 1) - (1 - \alpha)v}$	For cylindrical particles with n=6 and spherical particles with n=3
Jeffery [7]	$\frac{k_{eff}}{k_m} = 1 + 3\beta + \left(3\beta^2 + \frac{3\beta^2}{4} + \frac{9\beta^2(\alpha + 2)}{16(2\alpha + 3)} + \cdots\right)v^2$	Including interaction between a pair of spherical particles
Xue[2]	$\frac{k_{eff}}{k_m} = \frac{\frac{1 - f + 2f\frac{k_c}{k_c - k_m}\mathrm{In}(k_c + k_m)}{2k_m}}{\frac{1 - f + 2f\frac{k_c}{k_c - k_m}\mathrm{In}(k_c + k_m)}{2k_m}}$	CNTs-based composites based on Maxwell theory

In this article, an excellent correlation for effective thermal conductivity of nanofluids such as Al_2O_3+ H_2O and CuO+ H_2O based on a new analysis for shape factor was investigated. The new data obtained from the current model were compared with the experimental and theoretical data obtained from the literature.

Nanofluids Thermal Conductivity Modeling: The conventional and previous models for thermal conductivity of suspensions have been listed in Table 1.

k_{eff} is the effective thermal conductivity of the suspension, k_m and k_c are the thermal conductivities of the suspending medium and solid particle, respectively, n is particle shape factor and ν is the particle volume fraction.

α and β are empirical fitting parameters and are calculated using the following equations:

$$\alpha = (k_c/k_m) \tag{1}$$

$$\beta = (\alpha - 1) / (\alpha + 2) \tag{2}$$

As shown in Table 1, the shape of nanoparticles is one of the most important factors in modeling. Furthermore, the continuous phase has a direct effect on the expression. In this article, the liquid and nanoparticles phases were assumed as continuous and dispersed phases, respectively.

Brailsford and Major [14] presented a general equation for thermal conductivity of a multi-component system as following:

$$K = \frac{\sum_{i=1}^{m} k_i v_i \frac{d_i \bar{k}}{(d_i - 1)\bar{k} + k_i}}{\sum_{i=1}^{m} v_i (d_i - 1)\bar{k} + k_i} \tag{3}$$

Where, d_i is shape factor and $\tilde{k}$ indicates which phase is considered as a continuous phase. By selecting some suitable data for d_i and $\tilde{k}$, a novel correlation for nanofluids of Al_2O_3+ H_2O and CuO+ H_2O was investigated.

According to TEM images provided by Premkumar and Geckeler [15] and Lee *et al.* [16], CuO and Al_2O_3 nanoparticles are not complete spherical particles. In fact, its shape is a little far from sphere. Therefore, shape factors between 3 (spherical) and 4.5 (middle of spherical and cylindrical assumption of particle) was considered. Then by fitting the empirical data, 4.1 was selected.

This value theoretically confirms non-spherical matter of nanoparticles which is in contrast with the value obtained by the other researchers [2, 17 & 18]. Since water was as a continuous phase in this research so, d_i and $\tilde{k} = k_2$ were defined for water. So, equation (3) was specialized for the applicable current systems as following:

$$K = \frac{\frac{4.1k1k2v}{3.1k2 + k1} + k2(1 - v)}{v(\frac{4.1k2}{3.1k2 + k1} - 1) + 1} \tag{4}$$

Where, v, k_1 and k_2 are volume fraction of nanoparticles, thermal conductivity of nano- particles and water, respectively.

The data obtained from equation (4) were compared with the experimental data reported by Xie [19]. In order to the experimental work, the transient hot wire (THW) method is employed to measure the thermal conductivity of nanofluids. The principle measurement of the transient hot wire technique is based on the transient heat field around a thin wire (hot wire) which can be treated as a linear source. The obtained constant in the current research is supplied for a wire to consider temperature increment. The wire is surrounded by nanofluid which its thermal conductivity and thermal diffusivity can be measured. The wire is served as both the heat source and the temperature sensor. Heat is distributed inside the wire to increase the temperature of the wire and also the nanofluid sample. The temperature increment inside the wire depends on the thermal conductivity of nanofluid sample which the wire has been inserted in it [19].

RESULTS AND DISCUSSION

Al_2O_3+H_2O Nanofluid: As shown in Figure 1, the model shows a linear and increment trend versus Al_2O_3 volume fractions. The modeled data show very good agreement with the experimental data. Table 2 shows the Relative Deviation [RD = (Experimental data-Theoretical data)/ Experimental data] of data for each model from the experiment.

CuO+H_2O Nanofluid: Figure 2 shows the prediction and comparison of five models including the current model with the experimental data. As illustrated, the current model has good very agreement with the experimental data especially in lower concentrations of CuO nanoparticles. As expected, an enormous enhancement in the thermal conductivity of the nanofluid in low concentrations of nano CuO is observed. Table 3 shows the Relative Deviation of data for each model from the experiment.

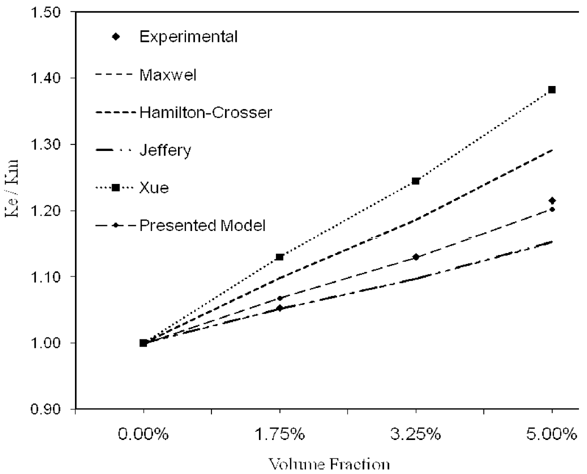

Fig. 1: Various models comparison with the experimental data for Al_2O_3+ H_2O system

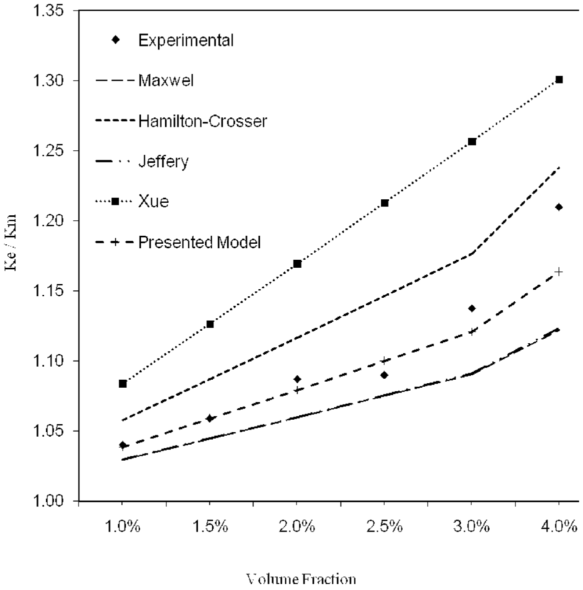

Fig. 2: Various models comparison with the experimental data for CuO+H_2O system

Table 2: Models deviation for nano Al_2O_3 from the experimental data

Model	RD %
Present Model	0.6830
Maxwell [5]	2.0860
Hamilton-Crosser [6]	3.8917
Jeffrey [7]	2.0290
Xue [2]	7.8085

Table 3: Models deviation for nano CuO from the experimental data

Model	RD %
Present Model	1.1901
Maxwell [5]	2.9406
Hamilton-Crosser [6]	3.0098
Jeffrey [7]	2.8920
Xue [2]	8.0767

A slight decrease in effective thermal conductivity based on the current model at CuO volume fraction of 3 % is observed. It is believed that this decrease is because of agglomeration of particles and also temperature distribution.

In both investigations, it was observed that the deviation of modeled data from the experimental data increased with increasing the nanoparticles concentrations. This result was supported by the experimental data reported by Xie [19] and the other previous models [5-11]. Since there is more molecular dispersion in high concentrations of nanoparticles, temperature distribution profile which affects on some parameters of the current correlation can legitimize this enhancement of the thermal conductivity.

CONCLUSIONS

In this research, the effective thermal conductivities of Al_2O_3+ H_2O and CuO+ H_2O nanofluids were considered using volume fraction and shape factor of nanoparticles. The basic applied equation in this research was Brailsford and Major general equation for multi-components and then it was developed for the current systems which were containing nanoparticles and water as dispersed and continuous phases, respectively. An empirical value which was around 4.1 for the shape factor was obtained. In fact, this data was an adjustable parameter which could make modeled data very close to the experimental data. Further, this data legitimized non-spherical matter of Al_2O_3 and CuO, properly.

The modeled data obtained from the current research were compared with the experimental and the other modeled data obtained from the literature. According to the current research, thermal conductivities for Al_2O_3 were obtained around 0.998, 1.067, 1.128 and 1.202 at volume fractions of 0, 0.0175, 0.0325 and 0.050 while according to the experimental work achieved by Xie *et al.* [19], they were obtained about 1.000, 1.053, 1.130 and 1.215 at the same as volume fractions. In order to this research thermal conductivities for CuO were obtained around 1.038, 1.058, 1.079, 1.099, 1.121 and 1.63 at volume fractions of 0.01, 0.015, 0.02, 0.025, 0.03 and 0.04 while in order to the experimental data reported by Xie *et al.* [19], they were obtained about 1.040, 1.059, 1.087, 1.090, 1.138 and 1.210 at the same as volume fractions. It was concluded that the data obtained from the presented correlation were in very agreement with the experimental data especially in lower concentrations of nanoparticles.

REFERENCES

1. Eastman, J.A., S. Choi, S. Li, W. Yu and L.J. Thompson, 2001. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, Appl. Physics Letters, 78(6): 718-720.
2. Xue, Q. and W.M. Xu, 2005. A model of thermal conductivity of nanofluids with interfacial shells. Mater Chem Phys., 90: 298-301.
3. SUS, C., Z.G. Zhang and P. Keblinski, 2004. Encyclopedia of nanoscience and nanotechnology, Vol. 6. New York: American Scientific Publishers, pp: 757.
4. Lee, S., S.U.S. Choi, S. Li and J.A. Eastman, 1999. Measuring thermal conductivity of fluids containing oxide nanoparticles. J. Heat Transfer, 121: 280-289.
5. Maxwell, J.C., 1904. A Treatise on Electricity and Magnetism, 2nd Ed., Oxford Univ. Press, Cambridge.
6. Hamilton, R.L. and O.K. Crosser, 1962. Thermal conductivity of heterogeneous two component systems, I & EC Fundam, 1: 182-191.
7. Jeffrey, D.J., 1973. Conduction through a random suspension of spheres, Math. Phys. Sci J., pp: 355.
8. Davis, R.H., 1986. The Effective Thermal Conductivity of a Composite Material with Spherical Inclusions, Int. J. Thermophysics, 7: 609-620.
9. Lu, S. and H. Lin, 1996. Effective conductivity of composites containing aligned spheroidal inclusions of finite conductivity, J. Appl. Phys., 79: 6761.
10. Bonnecaze, R.T. and J.F. Brady, 1990. A Method for Determining the Effective Conductivity of Dispersions of Particles, Proc. R. Soc. London, Ser. A., 430: 285-313.
11. Bonnecaze, R.T. and J.F. Brady, 1991. The Effective Conductivity of Random Suspensions of Spherical Particles, Proc. R. Soc. London, Ser. A., 432: 445-465.
12. Eastman, J.A., S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, 2001. Anomalously increased effective thermal conductivities of ethylene glycol based nanofluids containing copper nanoparticles, Appl. Phys. Lett., 78: 718-720.
13. Xuan, Y. and Q. Li, 2000. Heat transfer enhancement of nanofluids, Inter. J. Heat Fluid Flow, 21: 58-64.
14. Brailsford, A.D. and K.G. Major, 1964. The thermal conductivity of aggregates of several phases including porous materials, Brit. J. Appl. Phys., 15: 313-319.
15. Premkumar, T. and K.E. Geckeler, 2006. Nanosized CuO Particles via a Supramolecular Strategy, Small, 2(5): 616-620.
16. Lee, J., K.S. Hwang and S.P. Jang, 2008. Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3, International J. Heat and Mass Transfer, 51: 2651-2656.

17. Xue, Q.Z., 2003. Model for effective thermal conductivity of nanofluids, Phys. Lett. A., 307: 313-317.
18. Hwang, Y., J.K. Lee, C.H. Lee, Y.M. Jung, S.I. Cheong, C.G. Lee, B.C. Ku and S.P. Jang, 2007. Stability and thermal conductivity characteristics of nanofluids, Thermochimica Acta, 455: 70-74.
19. Xie, H., J. Wang, T. Xi, Y. Liu and F. Ai, 2002. Thermal conductivity enhancement of Suspensions containing nanosized alumina particles, J. Appl. Phys., 91: 4568-4572.