Physical Science International Journal
10(1): 1-8, 2016, Article no.PSIJ.24520
ISSN: 2348-0130

SCIENCEDOMAIN *international*
www.sciencedomain.org

Calculation the Thermal Conductivity of Nanofluids Containing Aligned Ultralong Single Walled Carbon Nanotubes

Nguyen Manh Hong[1,2], Bui Hung Thang[1*] and Phan Ngoc Minh[1,2]

[1]Institute of Materials Science, Vietnam Academy of Science and Technology, A2 Building, 18 Hoang Quoc Viet Street, Cau Giay District, Hanoi 122102, Vietnam.
[2]Center for High Technology Development, Vietnam Academy of Science and Technology, 2B Building, 18 Hoang Quoc Viet Street, Cau Giay District, Hanoi 122102, Vietnam.

Authors' contributions

This work was carried out in collaboration between all authors. Authors BHT and NMH designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author PNM managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/PSIJ/2016/24520
Editor(s):
(1) Dibya Prakash Rai, Department of Physics, Pachhunga University College, India.
(2) Christian Brosseau, Distinguished Professor, Department of Physics, Université de Bretagne Occidentale, France.
Reviewers:
(1) Raahul Krishna, Gharda Institute of Technology, University of Mumbai, India.
(2) Ariffin Samsuri, Universiti Teknologi Malaysia, Malaysia.
(3) Imdat Taymaz, Sakarya University, Turkey.
Complete Peer review History: http://sciencedomain.org/review-history/13711

Original Research Article

Received 23rd January 2016
Accepted 27th February 2016
Published 15th March 2016

ABSTRACT

The thermal conductivity of carbon nanotubes (CNTs) depends on their length and the diameter. At room temperature, the thermal conductivity of CNTs increases as its length increases as well as its diameter decreases. Aligned long single-walled carbon nanotubes (AL-SWCNTs) are expected to be an ideal candidate for heat transfer materials owing to their small diameter, very long length and high thermal conductivity. In this work, we propose a theory model for thermal conductivity of AL-SWCNTs in nanofluids. The calculation results showed that the thermal conductivity enhancement of AL-SWCNTs nanofluids was about 18.5 times higher than that of MWCNTs nanofluids. The calculation results have confirmed the advantage of the AL-SWCNTs as excellent additive for nanofluids.

**Corresponding author: E-mail: thangbh@ims.vast.vn, thangbh@ims.vast.ac.vn;*

Keywords: Aligned long SWCNTs; additive; nanofluid; thermal conducvitity.

1. INTRODUCTION

Since the discovery of the carbon nanotube (CNT) in 1991 [1] there have been extensive studies of its physical and chemical properties. Carbon nanotubes (CNTs) have attracted much attention because of their unique structure and remarkable mechanical, thermal and electrical properties [2-6]. Single-walled carbon nanotubes (SWNTs) are nanometer-diameter cylinders consisting of a single graphene sheet wrapped up to form a tube [7]. Yu [8] and Pop [9] and their coworkers measured the thermal conductivity of SWCNTs, and found that the thermal conductivity is near 3500 W $m^{-1}K^{-1}$ at room temperature for an SWCNT. Fujii et al. [10] found in the experiment that the thermal conductivity of a carbon nanotube at room temperature increases as its diameter decreases. Mingo et al [11] found that the thermal conductivity of CNTs increases as its length increases, and thermal conductivity of CNTs reached about 4000 W $m^{-1}K^{-1}$ at 316 K with the tube length reaching one meter. However, long CNTs in composite are usually crooked; this reduces the effective thermal conductivity of CNTs [12]. Therefore, aligned long single-walled carbon (AL-SWCNTs) become the most ideal material for heat transfer owing to their small diameter, large length, unique thermal conductivity, and high orientation for heat transfer [13].

In recent years, the problem of heat dissipation with features and strengthening functions of products has become more significant. Many approaches can improve the cooling system performance. The most feasible one is to enhance the heat transfer (dissipation) performance through the working fluid without modifying the mechanical designs or key components of the system. Recent studies have shown that the thermal conductivity of the suspension which contains suspended metallic or nonmetallic nanoparticles can be much higher than that of the base fluid, and it was called as “nanofluid” [14]. On this basis, adding certain kinds of nanomaterials into base fluid is considered to be a novel approach to enhance the thermal conductivity in heat transfer medium [15]. Results showed that the thermal conductivity enhancements of nanofluids could be influenced by multifaceted factors including the volume fraction of nanoparticles, the tested temperature, thermal conductivity of the base fluid, nanoparticle size, pretreatment process, and the additives of the fluids [16,17]. CNTs have been used as additives in liquids to increase the thermal conductivity, one of the most important issues in industry [18]. Owing to their very high thermal conductivity (above 2000 W/m.K compared to thermal conductivity of Ag 419 W/m.K) [19], CNTs become ones of the most suitable nano additives to fabricate the nanofluids for thermal dissipation in many industrial and consumer products [20,21]. Experimental results of Hwang et al. [22] indicated that the thermal conductivity of MWCNTs nanofluids increase about 28% with 1% volume concentration of MWCNTs in ethylene glycol. Lifei Chen et al. [23] also indicated that the thermal conductivity of MWCNTs nanofluids was about 10% with 1% volume concentration of MWCNTs in distilled water.

As mentioned above, AL-SWCNTs own small diameter, large length, unique thermal conductivity, and high orientation for heat transfer, therefore AL-SWCNTs are most ideal additive for nanofluids. However so far there are no experiment and theories on AL-SWCNTs nanofluids. In this paper, we present the first calculation results on thermal conductivity enhancements of several AL-SWCNTs nanofluids.

2. CALCULATION METHODS

There are some more models for predicting the thermal conductivity of CNT-nanofluids [24]. Traditional composite models, such as Maxwell [25], Hamilton–Crosser [26], Jeffrey [27], Davis [28], etc., were proved to be inadequate, as they grossly under predicted the experimental data. The Yingsong Zheng model [29] uses the average length efficiency of CNTs for calculations; however it is difficult to determine the average length efficiency in fact. In the Rashmi Walvekar model [20], the calculation results are very high compared to the experimental results. In the S.U.S Choi model [30], an empirical parameter α must be used for calculations. Therefore, it still has to be based on experimental results to select the value of the empirical parameter α in order to achieve accurate calculations. Similarly, the Seyed Masoud Hosseini model [31] must use three empirical parameters for calculations. The Venkata Sastry model [32] has an important face for calculations because of the randomness of the orientation of each CNT and the length of the CNT participating in percolation. On the other hand, the Venkata Sastry model must use the interfacial thermal conductance, which is an empirical parameter with wide ranging values, so it still has to be based on experimental results in order to select the value of interfacial thermal conductance for calculations.

In 2004, a model for thermal conductivity of nanofluids is derived from Hemanth et al. [33] which is given for nanoparticle suspensions. This model assumed that there are two parallel paths of heat flow through the suspension, one through the liquid particles and the other through the nanoparticles. In this model, the effective thermal conductivity is expressed as [33]:

$$k_{eff} = k_m \left[1 + \frac{k_p \varepsilon r_m}{k_m (1-\varepsilon) r_p} \right] \tag{1}$$

where k, r denote the thermal conductivity and radii; ε denote the volume fraction of the nanoparticles. Subscripts “*m*” and “p” denote quantities corresponding to the liquid medium and solid nano particles, respectively.

In 2008, Sarit K Das et al. [34] used the expression (1) for thermal conductivity enhancement in carbon nanotubes suspensions denoting the liquid molecule radii and CNTs diameter to be r_l and r_s as well as volume fraction of the nanoparticles as ε and the volume fraction of the liquid as (1 – ε). The effective thermal conductivity of CNTs nanofluids is expressed as [34]:

$$k_{eff} = k_l \left[1 + \frac{k_s \varepsilon r_l}{k_l (1-\varepsilon) r_s} \right] \tag{2}$$

where, subscripts “*l*” and “*s*”, denote quantities corresponding to the liquid medium and carbon nanotubes, respectively.

However, calculated results of the Sarit K Das el al. are higher than the experimental results. This is because the shape of CNTs are cylindrical rather than spherical, and CNTs are very good thermal conductors along the tube but good insulators laterally to the tube axis. Therefore, we developed a modified model for accurately predicting the CNT-nanofluids’ thermal conductivity, which takes into consideration cylindrical shape as well as good thermal conductors along the tube of CNTs.

As we already know, CNTs are very good thermal conductors along the tube, but good insulators laterally to the tube axis. On the other hand, CNTs disperse in nanofluids in all direction randomly. Therefore, by calculation we obtained the effective thermal conductivity of CNTs ($k_{eff\text{-}CNT}$) by the following equation [24]:

$$k_{eff-CNT} = \frac{1}{2} k_{CNT} \tag{3}$$

In modified model, we replace the thermal conductivity of CNTs (k_{CNT}) with the effective thermal conductivity of CNTs ($k_{eff\text{-}CNT}$) for all calculations. On the other hand, when using cylindrical shape of CNTs in the model, we also obtained the effective thermal conductivity of CNT-nanofluids as follow [24]:

$$\frac{k_{eff}}{k_l} = 1 + \frac{2}{3} \frac{k_{eff-CNT} \varepsilon r_l}{k_l (1-\varepsilon) r_{CNT}} \tag{4}$$

From equation (3) and equation (4) we obtained the effective thermal conductivity of CNT-nanofluids as follow [24]:

$$\frac{k_{eff}}{k_l} = 1 + \frac{1}{3} \frac{k_{CNT} \varepsilon r_l}{k_l (1-\varepsilon) r_{CNT}} \tag{5}$$

where, subscripts “*l*” and “*CNT*”, denote quantities corresponding to the liquid medium and carbon nanotubes, respectively. The our modified model was compared to some experimental data of several other research groups, and the results show that modified model has correctly predicted the trends observed in experimental data. The modified model was published in Physics of Fluids in March 2015 [24].

Equation (5) shows that: The thermal conductivity of CNTs nanofluids strongly depend on diameter, volume fraction, and thermal conductivity of CNTs. As we know, thermal conductivity of SWCNTs higher than that of MWCNTs, and thermal conductivity of a carbon nanotube increases as its diameter decreases as well as its length increases [10,11]. In other hand, the thermal conductivity of CNTs nanofluids also depend on effective length of CNTs (as Fig. 1) [12]. Therefore, AL-SWCNTs are the best additives for nanofluids. According to the dependence of thermal conductivity of SWCNTs on its length and diameter, (which were reported by Yu et al. [8], Fujii et al. [10] and Mingo et al. [11]) and the model of Sarit K Das et al. [34], we calculated thermal conductivity enhancement of AL-SWCNTs nanofluids by using our modified model.

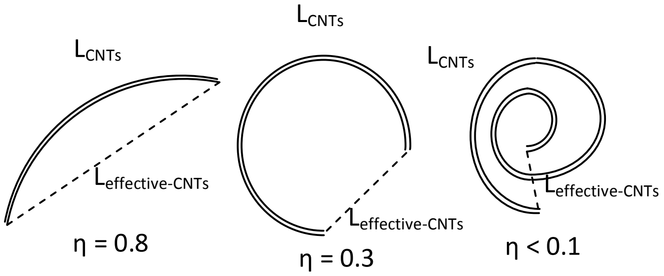

Fig. 1. The effective length of some types CNTs

3. RESULTS AND DISCUSSION

3.1 Thermal Conductivity of AL-SWCNTs Based Distilled Water

The diameters of SWCNTs in our calculation were 3nm, 9.8 nm, 16.1 nm, and 28.2 nm, respectively; the lengths of SWCNTs were in the range of 2.76 – 3.70 µm. Table 1 shows the dependence of thermal conductivity of SWCNTs on its diameters at room temperature. In the calculation, thermal conductivity of distilled water (DW) and the radius of water molecule were 0.6 W/mK and 0.1 nm, respectively. The volume concentrations of SWCNTs in DW were in the range of 0.1% – 1% (equivalent to $\varepsilon = 0.001$ - 0.01). Because the volume concentration of SWCNTs in nanofluids is very small, therefore the correlation between the volume concentration of SWCNTs and thermal conductivity of nano fluids in equation (5) is linear. Furthermore the influence of SWCNTs structure (including diameter and length) to the thermal conductivity of the nanofluids is important issue for discussion. Therefore, we focus investigated the dependent of nanofluid's thermal conductivity on SWCNTs structure. Fig. 2 shows the dependence of thermal conductivity enhancement of AL-SWCNTs nanofluids on diameter and volume concentration of AL-SWCNTs.

Table 1. The dependence of thermal conductivity of SWCNTs on its diameters at room temperature

Diameter of SWCNTs	Thermal conductivity of SWCNTs	References
3 nm	2800 W/mK	[8]
9.8 nm	2100 W/mK	[10]
16.1 nm	1600 W/mK	[10]
28.2 nm	500 W/mK	[10]

Fig. 2 showed that the thermal conductivity enhancement of SWCNTs based DW increased as volume concentration of SWCNTs increased. At 1% of volume concentration, the thermal conductivity enhancements of SWCNTs based DW were 104.7%, 24.1%, 11.2%, and 2% corresponding to diameters of SWCNTs were 3 nm, 9.8 nm, 16.1 nm, and 28.2 nm, respectively. These results indicated that thermal conductivity of SWCNTs based DW increased as diameter of SWCNTs decreased. In order to predict the effect of AL-SWCNTs length to the thermal conductivity of AL-SWCNT based DW, we choose 3 nm of the AL-SWCNTs diameter, and from 3 µm to 200 µm of the AL-SWCNTs lengths. Table 2 shows the dependence of thermal conductivity of AL-SWCNTs on its length at room temperature. Fig. 3 shows the dependence of thermal conductivity enhancement of AL-SWCNTs nanofluids on length and volume concentration of AL-SWCNTs.

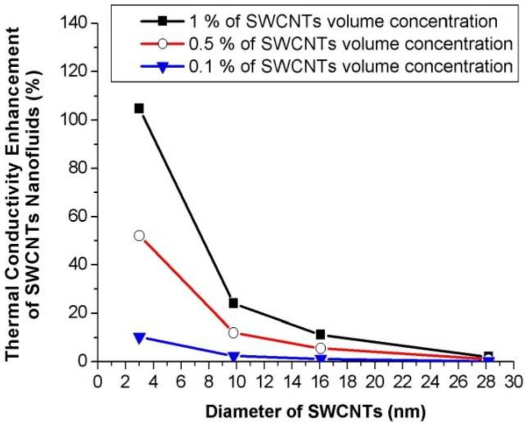

Fig. 2. The dependence of thermal conductivity enhancement of AL-SWCNTs based DW on its diameter

Fig. 3 show that the thermal conductivity enhancement of AL-SWCNTs based DW increased as concentration of AL-SWCNTs increased. At 1% of volume concentration, the thermal conductivity enhancements of AL-SWCNTs based DW were 104.6%, 112.2%, 134.7%, 145.9%, 153.4%, 172.1% and 187.1% corresponding to the lengths of AL-SWCNTs were 3 μm, 10 μm, 20 μm, 30 μm, 40 μm, 80 μm and 130 μm, respectively. These results indicated that thermal conductivity of AL-SWCNTs based DW increased as length of SWCNTs increased. However, thermal conductivity enhancement of AL-SWCNTs based DW reached saturated value at 187.1% when length of AL-SWCNTs reached 130 μm. Experimental data of Hwang et al. [22] and Lifei Chen et al. [23] indicated that the thermal conductivity enhancement of MWCNTs based DW was about 10% as volume concentration of MWCNTs was 1%. Therefore, thermal conductivity enhancement of AL-SWCNTs nanofluids was 18.7 times higher than that of MWCNTs nanofluids at 1% of CNTs volume concentration.

Table 2. The dependence of thermal conductivity of AL-SWCNTs on its length at room temperature

Length of AL-SWCNTs	Thermal conductivity of AL-SWCNTs	References
~ 3 μm	2800 W/mK	[8], [11]
10 μm	3000 W/mK	[11]
20 μm	3600 W/mK	[11]
30 μm	3900 W/mK	[11]
40 μm	4100 W/mK	[11]
80 μm	4600 W/mK	[11]
130 μm	5000 W/mK	[11]
170 μm	5000 W/mK	[11]
200 μm	5000 W/mK	[11]

3.2 Thermal Conductivity of AL-SWCNTs Based Ethylene Glycol

Similarly, we calculated the thermal conductivity enhancement of AL-SWCNTs based ethylene glycol (EG) with the diameter and length of AL-SWCNTs were 3 nm and 3 μm - 200 μm, respectively. In the calculation, thermal conductivity of EG and the effective radius of EG molecule were 0.26 W/mK and 0.12 nm, respectively. The volume concentrations of AL-SWCNTs in EG were in the range of 0.1 % – 1%. Fig. 4 shows the dependence of thermal conductivity enhancement of AL-SWCNTs based EG on the length and volume concentration of AL-SWCNTs.

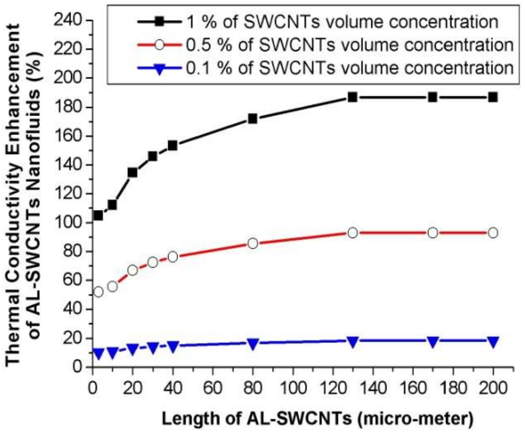

Fig. 3. The dependence of thermal conductivity enhancement of AL-SWCNTs based DW on its length and volume concentration

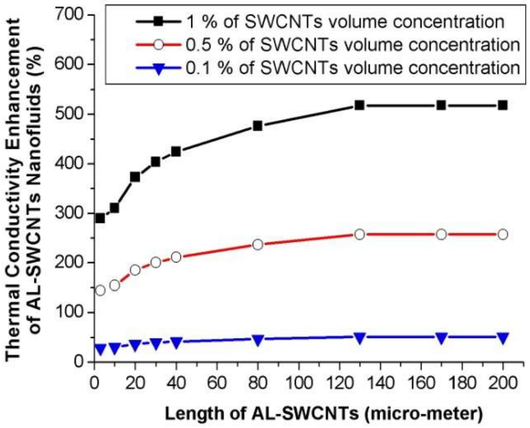

Fig. 4. The dependence of thermal conductivity enhancement of AL-SWCNTs based EG on its length and volume concentration

Fig. 4 showed that the thermal conductivity enhancement of AL-SWCNTs based EG increased as concentration of AL-SWCNTs increased. At 1% of volume concentration, the thermal conductivity enhancements of AL-SWCNTs based EG were 290.1%, 310.8%, 373.0%, 404.0%, 424.8%, 476.6% and 518.0% corresponding to the lengths of AL-SWCNTs were 3 μm, 10 μm, 20 μm, 30 μm, 40 μm, 80 μm and 130 μm, respectively. These results indicated that thermal conductivity of

AL-SWCNTs based EG increased as length of SWCNTs increased. However, thermal conductivity enhancement of AL-SWCNTs based EG reached saturated value at 518% when length of AL-SWCNTs reached 130 μm. Experimental data of Hwang et al. [22] indicated that the thermal conductivity enhancement of MWCNTs based EG was about 28% when volume concentration of MWCNTs was 1%. Therefore, thermal conductivity enhancement of AL-SWCNTs based EG was 18.5 times higher than that of MWCNTs based EG at 1% of CNTs volume concentration.

4. CONCLUSION

The thermal conductivity enhancements of AL-SWCNTs nanofluids were calculated and compared to that of MWCNTs nanofluids. The thermal conductivity enhancement of AL-SWCNTs nanofluids reached saturated values when length of AL-SWCNTs reached 130 μm. At 1% of CNTs volume concentration and 130 μm of CNTs length, the thermal conductivity enhancements of AL-SWCNTs based DW and AL-SWCNTs based EG were 187.1% and 777%, respectively. These results showed that the thermal conductivity enhancement of AL-SWCNTs nanofluids was about 18.5 times higher than that of MWCNTs nanofluids. The calculation results have confirmed the advantage of the AL-SWCNTs as excellent additive for nanofluids. We expected to hear about the experimental results on unique thermal conductivity of AL-SWCNTs nanofluids in near future. With unique thermal conductivity, the AL-SWCNTs nanofluids will open up the potential application in heat dissipation for high power electronic devices, engines and other heat transfer systems.

ACKNOWLEDGEMENTS

The authors acknowledge financial support from the Vietnam Academy of Science and Technology (VAST) under grant number VAST03.02/16-17. The authors also thank National Key Lab for Electronic Materials and Devices (Institute of Material Science) for financial support under grant number CSTĐ.01.15.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sumio Iijima. Helical microtubules of graphitic carbon. Nature. 1991;354:56-58. DOI:10.1038/354056a0
2. Valentin N. Popov. Carbon nanotubes: Properties and application. Materials Science and Engineering R. 2004;43(61–102).
3. Phan Ngoc Minh, Phan Hong Khoi. Carbon nanotube: A novel material for applications. Journal of Physics: Conference Series. 2009;187:012002. DOI:10.1088/1742-6596/187/1/012002
4. Sunil Kumar Singhal, Maneet Lal, Lata, Soumya Ranjan Kabi, Rakesh Behari Mathur. Synthesis of Cu/CNTs nanocomposites for antimicrobial activity. Adv. Nat. Sci.: Nanosci. Nanotechnol. 2012;3:045011:10. DOI:10.1088/2043-6262/3/4/045011
5. Bui Hung Thang, Pham Van Trinh, Nguyen Van Chuc, Phan Hong Khoi, Phan Ngoc Minh. Heat dissipation for microprocessor using multiwalled carbon nanotubes based liquid. The Scientific World Journal. 2013; 2013:Article ID 305957:6. DOI:10.1155/2013/305957
6. Bui Hung Thang, Le Dinh Quang, Nguyen Manh Hong, Phan Hong Khoi, Phan Ngoc Minh. Application of multiwalled carbon nanotube nanofluid for 450 W LED floodlight. Journal of Nanomaterials. 2014;2014:Article ID 347909:6. DOI:10.1155/2014/347909
7. Paul L. McEuen, Michael Fuhrer, Hongkun Park. Single-walled carbon nanotube electronics. IEEE Transactions on Nanotechnology. 2012;1(1):78–85.
8. Choongho Yu, Li Shi, Zhen Yao, Deyu Li, Arunava Majumdar. Thermal conductance and thermopower of an individual single-wall carbon nanotube. Nano Letters. 2005;5(9):1842-1846.
9. Eric Pop, David Mann, Qian Wang, Kenneth Goodson, Hongjie Dai. Thermal conductance of an individual single-wall carbon nanotube above room temperature. Nano Letters. 2006;6(1):96-100.
10. Motoo Fujii, Xing Zhang, Huaqing Xie, Hiroki Ago, Koji Takahashi, Tatsuya Ikuta, Hidekazu Abe, Tetsuo Shimizu. Measuring the thermal conductivity of a single carbon nanotube. Physical Review Letters. 2005;95:065502.
11. Mingo N, Broido DA. Length dependence of carbon nanotube thermal conductivity

and the “problem of long waves”. Nano Letters. 2005;5(7):1221-1225.

12. Song PC, Liu CH, Fan SS. Improving the thermal conductivity of nanocomposites by increasing the length efficiency of loading carbon nanotubes. Applied Physics Letters. 2006;88:153111.
13. Zhongfan Liu, Liying Jiao, Yagang Yao, Xiaojun Xian Jin Zhang. Aligned, ultralong single-walled carbon nanotubes: From synthesis, sorting, to electronic devices. Advanced Materials. 2010;22(21):2285–2310.
14. Yi-Hsuan Hung, Jyun-Hong Chen, and Tun-Ping Teng. Feasibility assessment of thermal management system for green power sources using nanofluid. Journal of Nanomaterials. 2013;2013:Article ID 321261:11. DOI:10.1155/2013/321261
15. Dong M, Shen LP, Wang H, Wang HB, and Miao J. Investigation on the electrical conductivity of transformer oil-based AlN nanofluid. Journal of Nanomaterials. 2013;2013:Article ID 842963:7. DOI:10.1155/2013/842963
16. Adnan M Hussein, Sharma KV, Bakar RA, Kadirgama K. The effect of nanofluid volume concentration on heat transfer and friction factor inside a horizontal tube. Journal of Nanomaterials. 2013;2013: Article ID 859563:12. DOI:10.1155/2013/859563
17. Kuo-Hsiung Tseng, Heng-Lin Lee, Chih-Yu Liao, Kuan-Chih Chen, Hong-Shiou Lin. Rapid and efficient synthesis of silver nanofluid using electrical discharge machining. Journal of Nanomaterials. 2013; 2013:Article ID 174939:6. DOI:10.1155/2013/174939
18. Ngoc Minh Phan, Hung Thang Bui, Manh Hong Nguyen, Hong Khoi Phan. Carbon-nanotube-based liquids: A new class of nanomaterials and their applications. Adv. Nat. Sci.: Nanosci. Nanotechnol. 2014; 5:015014:5.
19. Bui Hung Thang, Phan Ngoc Hong, Pham Van Trinh, Nguyen Van Chuc, Ngo Thi Thanh Tam, Phan Hong Khoi, Phan Ngoc Minh. Simulation of thermal dissipation in a µ-processor using carbon nanotubes based composite. Computational Materials Science. 2010;49:S302–S306.
20. Rashmi Walvekar, Ismail Ahmad Faris, Mohammad Khalid. Thermal conductivity of carbon nanotube nanofluid - Experimental and theoretical study. Heat Transfer—Asian Research. 2012;41(2):145–163.
21. Yulong Ding, Hajar Alias, Dongsheng Wen, Richard A. Williams. Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). International Journal of Heat and Mass Transfer. 2006;49(1–2): 240–250.
22. Hwang YJ, Ahn YC, Shin HS, Lee CG, Kim GT, Park HS, Lee JK. Investigation on characteristics of thermal conductivity enhancement of nanofluids. Current Applied Physics. 2006;6:1068–1071.
23. Lifei Chen, Huaqing Xie, Yang Li, Wei Yu, Nanofluids containing carbon nanotubes treated by mechanochemical reaction. Thermochimica Acta. 2008;477:21–24.
24. Bui Hung Thang, Phan Hong Khoi, Phan Ngoc Minh. A modified model for thermal conductivity of carbon nanotube-nanofluids. Physics of Fluids. 2015;27:032002.
25. Maxwell JC. A treatise on electricity and magnetism. Clarendon Press; 1873.
26. Hamilton RL, Crosser OK. Thermal conductivity of heterogeneous two-component systems. Ind Eng Chem Fundam. 1962;1(3):187–191.
27. Jeffrey DJ. Conduction through a random suspension of spheres. Proc Royal Soc London. 1973;A335:355–367.
28. Davis RH. The effective thermal conductivity of a composite material with spherical inclusions. Int J Thermo Phys. 1983;7:609.
29. Yingsong Zheng, Haiping Hong. Modified model for effective thermal conductivity of nanofluids containing carbon nanotubes. Journal of Thermophysics and Heat Transfer. 2007;21(3).
30. Yu W, Choi SUS. The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated Hamilton–Crosser model. Journal of Nanoparticle Research. 2004;6:355–361.
31. Seyed Masoud Hosseini, Abdolreza Moghadassi, Dale Henneke. Modeling of the effective thermal conductivity of carbon nanotube nanofluids based on dimensionless groups. The Canadian Journal of Chemical Engineering. 2011;89:183–186
32. Venkata Sastry NN, Avijit Bhunia, Sundararajan T, Sarit K Das. Predicting the effective thermal conductivity of carbon nanotube based nanofluids. Nanotechnology. 2008;19:055704:8.

33. Hemanth D, Hrishikesh E, Patel VR, Rajeev Kumar, T. Sundararajan, T. Pradeep, Sarit K. Das. Model for heat conduction in nanofluids. Physical Review Letters. 2004;93(14):144301.
34. Patel HE, Anoop KB, Sundararajan T, Sarit K Das. Model for thermal conductivity of CNT-nanofluids, Bull. Mater. Sci. 2008;31(3):387–390.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/13711