Applied Thermal Engineering 95 (2016) 271–274

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

A novel approach for enhancement of thermal conductivity of CuO/H_2O based nanofluids

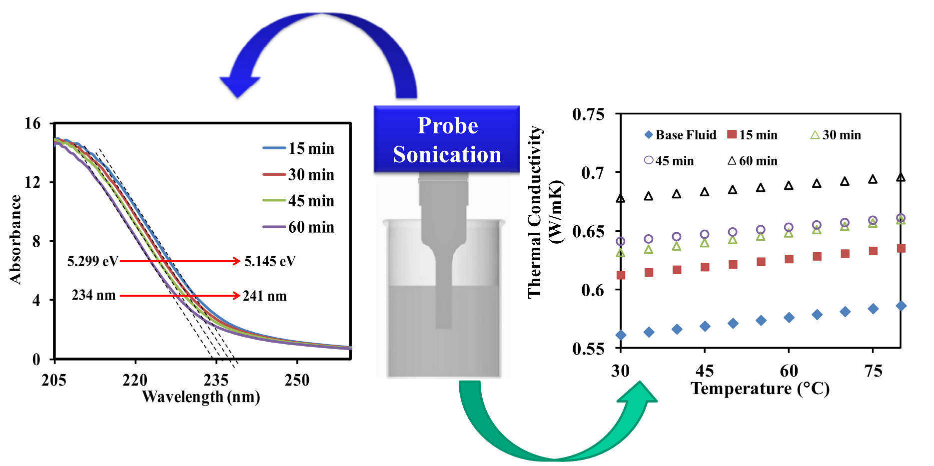
Kailash Nemade [a,*], Sandeep Waghuley [b]

[a] Department of Physics, Indira Mahavidyalaya, Kalamb 445401, India
[b] Department of Physics, Sant Gadge Baba Amravati University, Amravati 444 602, India

HIGHLIGHTS

- Probe sonication time increases thermal conductivity of nanofluid.
- Probe sonication time also leads to alteration of band gap.
- The prepared nanofluids are highly stable.
- It was found that these nanofluids are suitable for rapid cooling application.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 August 2015
Accepted 17 November 2015
Available online 25 November 2015

Keywords:
Thermal properties
Nanocrystalline materials
Nanofluid

ABSTRACT

Through this short communication, we reported enhancement of thermal conductivity of CuO based nanofluids via probe sonication time. The novelty of present work is that enhancement in thermal conductivity was achieved by simply increasing probe sonication time. The experimental results show that thermal conductivity increases smoothly with probe sonication time. This result indicates that thermal conductivity strongly depends on particle size. In addition, it is revealed that optical band gap of nanoparticles was successfully engineered over the range 5.145–5.299 eV as a function of probe sonication time. For the 60 min of probe sonication time, CuO based nanofluid achieved ~18% of enhancement in thermal conductivity over base fluid. The result of settling velocity and Brownian velocity of nanofluids shows that prepared nanofluids exhibit good stability. The thermal conductivity ratio of nanofluids suggested that as-prepared nanofluids exhibit good heat transfer characteristics. This finding makes CuO/H_2O based nanofluid attractive for rapid cooling application. The research concluded that more stable and efficient nanofluids can be obtained for heat transfer by applying probe sonication process.

1. Introduction

Conventional fluids such as water, propylene glycol, ethylene glycol, engine oil, mineral oil, silicon oil, etc. are generally used for convective heat transfer in various equipment related to thermal engineering. Currently, high prices of energy drive the

* Corresponding author. Tel.: +919049703051; fax: +91-7201-226129.
E-mail address: krnemade@gmail.com (K. Nemade).

http://dx.doi.org/10.1016/j.applthermaleng.2015.11.053
1359-4311/

implementation of energy saving techniques in industrial applications. In this context, nanofluids played very crucial role in various heat exchangers like plate heat exchangers, shell and tube heat exchangers, and double pipe heat exchangers. Lee et al. demonstrated the enhancement in thermal conductivity by 20% due to the addition of 4.0 vol% CuO nanoparticles in ethylene glycol [1]. Anoop et al. studied the convective heat transfer in nanofluid as a function of particle size. This study concludes that heat transfer rate increases with decreasing particle size [2]. Heris et al. investigated the convective heat transfer for CuO based nanofluids. In this case, convective heat transfers rate increase with concentration of oxide nanoparticles [3]. Zhu et al. reported synthesis of CuO nanofluid through novel approach by transforming an unstable $Cu(OH)_2$ precursor to CuO in water under an ultrasoniction subsequent to irradiating by microwave. As prepared CuO nanofluid has a higher thermal conductivity than those CuO nanofluids prepared by the dispersing method [4]. The coolant application of CuO based nanofluid was demonstrated by Anandan et al. In this investigation, wet-chemical reduction method was adopted for the synthesis of CuO nanoparticles, which exhibits outstanding cooling performance [5]. Rashin et al. reported the novel approach for enhancement of thermal conductivity in CuO–ethylene glycol nanofluids based on ultrasonication engineering. The comparative study for determination of thermal conductivity through ultrasonic method and transient line heat source technique indicates that both methods are in agreement with each other [6]. Buonomo et al. demonstrated the effect of temperature and sonication time on thermal conductivity of nanofluid by using nanoflash method. This study indicates that nano-flash technique rapidly and precisely measures thermal conductivity of nanofluids [7].The anomalous enhancement in thermal conductivity of Ar–Cu nanofluid is theoretically analyzed by Sun et al. using Green–Kubo formula and equilibrium-molecular-dynamics simulation. According to this study, anomalous enhancement in the thermal conductivity is a result of the strong coupling interactions between the fluid atoms [8].

The main objectives of the present study are to investigate experimentally the effect of probe sonication time on particle size, thermal conductivity of nanofluids and optical band gap of nanoparticles. To the best of our knowledge, this is the first report describing the effect of probe sonication time on thermal conductivity of CuO/H_2O based nanofluid. The main differentiation factor of the present paper is that we reduced particle size by using ultrasonication process, which directly affects thermal conductivity and optical band gap of nanoparticles. We performed detailed experimentation to analyze the effect of probe sonication time on viscosity, average hydrodynamic diameter, optical band gap and thermal conductivity.

2. Experiment

CuO nanoparticles were synthesized according to our previous report [9]. In this work, CuO nanoparticles were grown by spray pyrolysis technique from cupric nitrate solution in oxygen rich environment. As-synthesized CuO nanoparticles were used for preparation of nanofluids. The suspension between distilled water as base fluid and CuO nanoparticles were obtained by dispersing 0.5 vol% CuO nanoparticles in distilled water under rigorous magnetic stirring for 30 min. Different samples of CuO/H_2O nanofluids were prepared by altering the probe sonication time (PCi, 750-F). The structural purity of CuO nanoparticles was confirmed by using X-ray diffraction (XRD) (Miniflex-II, Rigaku) technique. For transmission electron microscopy (TEM) (Tecnai F-30107, Philips), CuO nanoparticles were separated from suspension by slow evaporation technique. The optical properties of nanofluids were analyzed by using ultraviolet-visible (UV-VIS) (Lambda-850, Perkin Elmer) spectroscopy. The thermal conductivity measurements were performed by using hot-wire method (KD2, Decagon Devices). Hydrodynamic particle size distribution for as-prepared nanofluids was estimated by using dynamic light scattering technique (NanoZS, Malvern).

3. Results and discussion

Fig. 1 shows the XRD pattern of CuO nanoparticles recovered from the suspension by slow evaporation technique. The diffraction peaks and relative intensity appears in a pattern exactly indexed to JCPDS Card No.:–45–0937. No other impurity peak presents in the pattern, which reflects the structural purity of dispersed CuO nanoparticles. The full width at half maxima of diffraction peaks increases with the increasing probe sonication time. This may be due to ultrasonication dose, which broken up agglomerated particles in smaller size. The average particle size of dispersed CuO nanoparticles is computed using the Scherrer's formula by nullifying broadening effecting [10]. The particle size of CuO nanoparticles ranges between 10.2 nm and 13.7 nm. It is observed that particle size decreases with probe sonication time.

UV-VIS spectroscopy was performed by taking the aqueous suspension of CuO nanofluids. Fig. 2(a) shows UV-VIS spectra of CuO nanofluid, probe sonicated for different time intervals. It is observed that samples show intense absorption tail in the range 234–241 nm. The absorption tail shows blue shift effect with an increase in probe sonication time. This indicates that particle size decrease with probe sonication time. The wavelength-energy relation is used to compute optical band gap (E_g), which ranges over 5.299–5.145 eV. This reveals that E_g tuning is possible with probe sonication time. Fig. 2(b) depicts the TEM images of CuO nanoparticles recovered from nanofluid suspension. TEM images directly show that average crystallite size decreases with increasing probe sonication time. This observation is in agreement with XRD and UV-VIS analysis.

Fig. 3(a) shows the influence of ultrasonication time on viscosity of nanofluids. It is observed that viscosity of nanofluids at 25 °C decreases linearly ($R^2 = 0.988$) with probe sonication time. This was

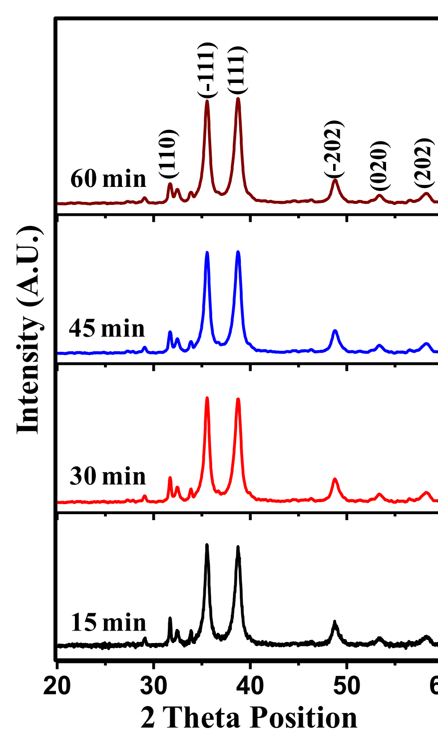


Fig. 1. XRD patterns of CuO nanoparticles recovered from probe sonicated nanofluids at different time interval.

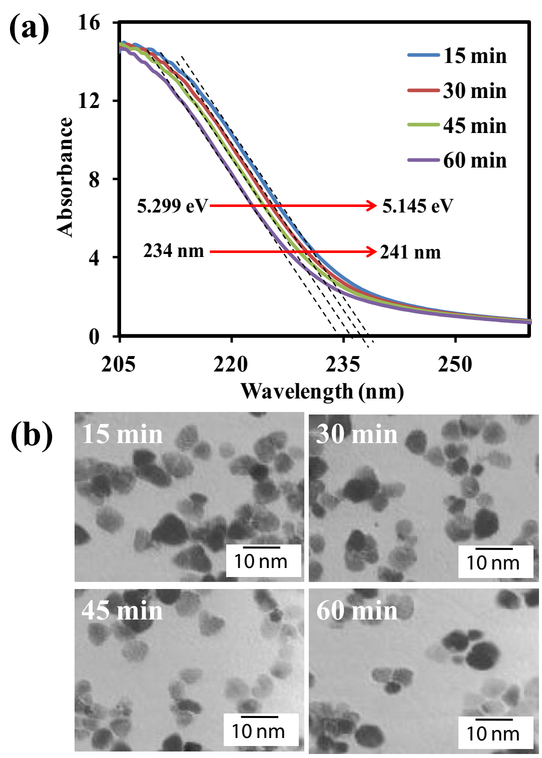


Fig. 2. (a) UV-VIS absorption spectra and (b) TEM images of CuO nanoparticles recovered from nanofluid.

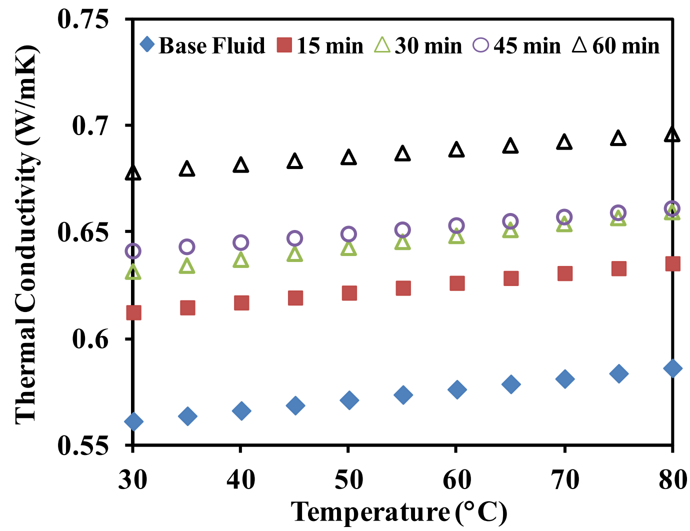


Fig. 4. Variation of thermal conductivity of CuO based nanofluid with temperature.

attributed to good dispersion of CuO nanoparticles in distilled water. This may be attributed to probe sonication process, which split up the agglomerate size particles. This result is satisfactorily supported by the average hydrodynamic diameter measurement. Fig. 3(b) shows that average hydrodynamic diameter decrease almost linearly ($R^2 = 0.978$) with increasing probe sonication time. This decrease in hydrodynamic diameter is attributed to rupture of layers of diffusion. The layers of diffusion played an important role in increase of hydrodynamic diameter of dispersed nanoparticle in base fluid. The stability of as-prepared nanofluids was analyzed by measuring settling velocity [11] and Brownian velocity [12] of nanoparticles at 27 °C. The average settling velocity of nanoparticles and Brownian velocity was estimated by using the average of hydrodynamic size, which was found to be 1.099×10^{-13} m/s and 9.93×10^{-3} m/s, respectively. The Brownian velocity is much greater than settling velocity of nanoparticles. This shows that prepared nanofluids exhibit good stability without any surfactant. The stability is attributed to effective probe sonication process of nanofluid. This also shows that stability of nanofluids can easily be achieved by probe sonication, without employing any time-consuming chemical process.

Fig. 4 shows the influence of temperature on thermal conductivity (k) of CuO based nanofluids. In order to achieve accuracy in measurements, the mean value of collected data was considered for the analysis. The average uncertainty in measurement of thermal conductivity was found to be ±1.2%. It is observed that thermal conductivity of as-prepared nanofluids increases with an increasing probe sonication time. The incessant collision between the particles and base fluid and large Brownian velocity results in thermal conduction. Generally, Brownian motion of the particles is more intense at a higher temperature [13]. In our case, Brownian velocity was found to be much higher in magnitude, due to lower average hydrodynamic diameter of CuO nanoparticle in nanofluid. Due to increase in temperature and reduction in particle size, collision rate between nanoparticles and molecules of base fluid increases. The high rate of collision generates quasi-convection small regions in nanofluid. Thus in the present case thermal conductivity increases with an increase in probe sonication time. In other words, thermal conductivity was increased with decreasing particle size. The nanofluid system probe sonicated for 1 h shows ~18% enhancement in thermal conductivity at 80 °C over base fluid.

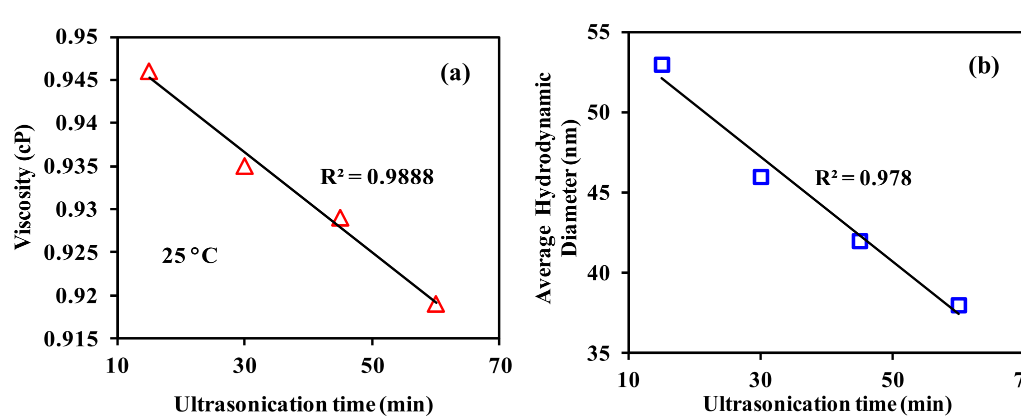


Fig. 3. Variation of (a) viscosity and (b) average hydrodynamic diameter of CuO based nanofluid as a function of probe sonication time.

Table 1
Thermal conductivity ratio of CuO based nanofluid at different temperature and probe sonication time.

Ultrasonication time (min)	k_{ratio}			
	45 °C	55 °C	65 °C	75 °C
15	1.088	1.087	1.086	1.084
30	1.125	1.124	1.124	1.124
45	1.137	1.134	1.131	1.129
60	1.201	1.197	1.193	1.189

The critical observation of Fig. 4 indicates that the enhancement in thermal conductivity is irregular for different time intervals of ultrasonication process. In this work, aggregation is considered for stationary state, also known as perikinetic aggregation. It is very well known that aggregation kinetics changes radically due to thermal vibration. This aggregation kinetics in moving state is known as orthokinetic aggregation effect. So, the irregularity in enhancement of thermal conductivity is attributed to orthokinetic aggregation effect [14]. To the best of author knowledge, no mathematical model firmly predicts about the relationship between aggregation and particle size in moving state. Mahbubul et al. reported a new view in this matter. The findings reported for alumina–water nanofluid indicate that during ultrasonication process, colloidal structure and viscosity of nanofluid drastically changes. This may also be the reason for irregularity in enhancement of thermal conductivity [15].

The thermal conductivity ratio (k_{ratio}) is calculated using the relation (Eq. (1)),

$$k_{ratio} = \frac{k_{nanofluid}}{k_{basefluid}} \tag{1}$$

where $k_{nanofluid}$ is thermal conductivity of nanofluid and $k_{basefluid}$ is thermal conductivity of base fluid. The thermal conductivity ratio of CuO based nanofluid is provided in Table 1. The thermal conductivity ratio of CuO based nanofluid is greater than one for all probe sonicated samples. The good thermal conductivity of CuO nanofluid might result in efficient heat transfer performance. The thermal conductivity ratio increases with probe sonication time.

Huminic et al. reported the heat transfer performance of 2% CuO nanoparticle dispersed in water of the order of 14%. The results obtained related to viscosity, Brownian velocity, average settling velocity and thermal conductivity are in good agreement with the results of Huminic et al. [16]. Hamilton et al. measured the thermal conductivity ratio for 0.001% CuO nanofluid dispersed nanofluid. This study shows that thermal conductivity ratio ranges between 1.02 and 1.04 [17]. Comparing our results with these recent reports, we succeed up to some extent in enhancement of thermal conductivity of CuO based nanofluid. In the present work, we achieve ~18% of enhancement in thermal conductivity with just 0.5 vol% CuO nanoparticle dispersed in water.

4. Conclusions

In summary, we successfully analyzed the influence of probe sonication time on thermal conductivity of CuO based nanofluids. This study concludes that there are strong relationships between the probe sonication time and the thermal conductivity. The XRD, UV-VIS and SEM analysis confirms the decrease in particle size with probe sonication time. During this study, it is also observed that E_g engineering is possible with probe sonication time. The much higher Brownian velocity of dispersed CuO nanoparticle shows that nanofluids acquire good stability. This study also indicates that stable nanofluids can be prepared by probe sonication process without any surfactant. It is predictable that this approach can be employed to other nanofluids for enhancement of thermal conductivity.

Acknowledgements

One of the authors, Dr. K.R. Nemade, is very much thankful to Dr. P.B. Mandavkar, Principal, Indira College, Kalamb for providing necessary academic help.

Nomenclature

Eg	Optical band gap, eV
k	Thermal conductivity, W/mK
vol %	Volume fraction, dimensionless quantity

Symbol

R^2	Linear fitting

Subscript

$k_{basefluid}$	Thermal conductivity of base fluid
$k_{nanofluid}$	Thermal conductivity of nanofluid
k_{ratio}	Thermal conductivity ratio

References

[1] S. Lee, S.U.S. Choi, S. Li, J.A. Eastman, Measuring thermal conductivity of fluids containing oxide nanoparticles, J. Heat Transfer 121 (1999) 280–289, doi:10.1115/1.2825978.
[2] K.B. Anoop, T. Sundararajan, S.K. Das, Effect of particle size on the convective heat transfer in nanofluid in the developing region, Int. J. Heat and Mass Transfer 52 (2009) 2189–2195, doi:10.1016/j.ijheatmasstransfer.2007.11.063.
[3] S.Z. Heris, S.G. Etemad, M.N. Esfahany, Experimental investigation of oxide nanofluids laminar flow convective heat transfer, Int. Commun. Heat Mass Transfer 33 (2006) 529–535, doi:10.1016/j.icheatmasstransfer.2006.01.005.
[4] H.T. Zhu, C.Y. Zhang, Y.M. Tang, J.X. Wang, Novel synthesis and thermal conductivity of CuO nanofluid, J. Phys. Chem. C 111 (2007) 1646–1650, doi:10.1021/jp065926t.
[5] D. Anandan, K.S. Rajan, Synthesis and stability of cupric oxide-based nanofluid: a novel coolant for efficient cooling, Asian J. Scientific Res. 5 (2012) 218–227, doi:10.3923/ajsr.2012.218.227.
[6] M.N. Rashin, J. Hemalatha, A novel ultrasonic approach to determine thermal conductivity in CuO–ethylene glycol nanofluids, J. Mol. Liq. 197 (2014) 257–262, doi:10.1016/j.molliq.2014.05.024.
[7] B. Buonomo, O. Manca, L. Marinelli, S. Nardini, Effect of temperature and sonication time on nanofluid thermal conductivity measurements by nano-flash method, Appl. Therm. Eng. 91 (2015) 181–190, doi:10.1016/j.applthermaleng.2015.07.077.
[8] C. Sun, W. Lu, B. Bai, J. Liu, Anomalous enhancement in thermal conductivity of nanofluid induced by solid walls in a nanochannel, Appl. Therm. Eng. 31 (2011) 3799–3805, doi:10.1016/j.applthermaleng.2011.07.021.
[9] K.R. Nemade, S.A. Waghuley, Optical and gas sensing properties of CuO nanoparticles grown by spray pyrolysis of cupric nitrate solution, Int. J. Mater. Sci, Engineer. 2 (2014) 63–66, doi:10.12720/ijmse.2.1.63-66.
[10] K.R. Nemade, S.A. Waghuley, Preparation of MnO_2 immobilized graphene nanocomposite by solid state diffusion route for LPG sensing, J. Lumin. 153 (2014) 194–197, doi:10.1016/j.jlumin.2014.03.039.
[11] K.S. Suganthi, V. Vinodhan, K.S. Rajan, Heat transfer performance and transport properties of ZnO–ethylene glycol and ZnO–ethylene glycol–water nanofluid coolants, Appl. Energy 135 (2014) 548–559, doi:10.1016/j.apenergy.2014.09.023.
[12] S. Manikandan, N. Karthikeyan, M. Silambarasan, K.S. Suganthi, K.S. Rajan, Preparation and characterization of sub-micron dispersions of sand in ethylene glycol-water mixture, Brazilian J. Chem. Engineer. 29 (2012) 699–712, doi:10.1590/S0104-66322012000400003.
[13] M. Xing, J. Yu, R. Wang, Thermo-physical properties of water-based single-walled carbon nanotube nanofluid as advanced coolant, Appl. Therm. Eng. 87 (2015) 344–351, doi:10.1016/j.applthermaleng.2015.05.033.
[14] R. Prasher, P.E. Phelan, P. Bhattacharya, Effect of aggregation kinetics on the thermal conductivity of nanoscale colloidal solutions (Nanofluid), Nano Lett. 6 (2006) 1529–1534, doi:10.1021/nl060992s.
[15] I.M. Mahbubul, T.H. Chong, S.S. Khaleduzzaman, I.M. Shahrul, R. Saidur, B.D. Long, et al., Effect of ultrasonication duration on colloidal structure and viscosity of alumina – water nanofluid, Ind. Eng. Chem. Res. 53 (2014) 6677–6684, doi:10.1021/ie500705j.
[16] G. Huminic, A. Huminic, Heat transfer characteristics in double tube helical heat exchangers using nanofluids, Int. J. Heat Mass Transfer 54 (2011) 4280–4287, doi:10.1016/j.ijheatmasstransfer.2011.05.017.
[17] R.L. Hamilton, O.K. Crosser, Thermal conductivity of heterogeneous two-component, Ind. Eng. Chem. Fundamen. 1 (1962) 187–191, doi:10.1021/i160003a005.