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

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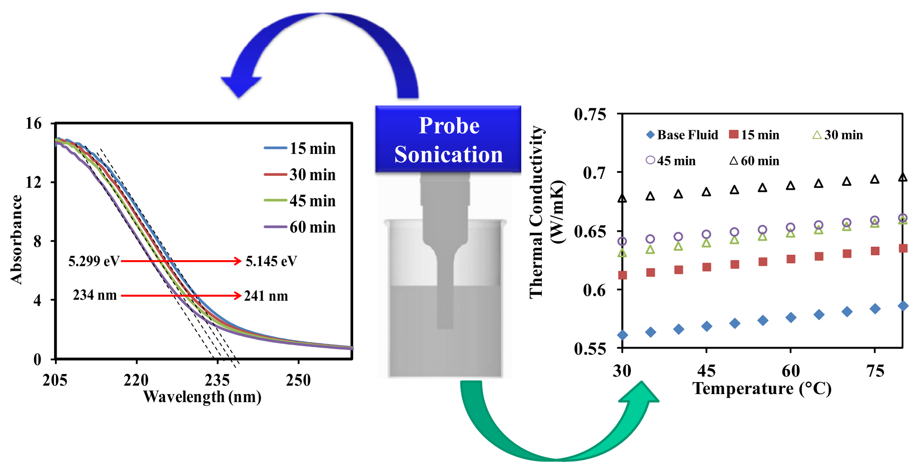
HIGHLIGHTS

- 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



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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

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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 nano-flash 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

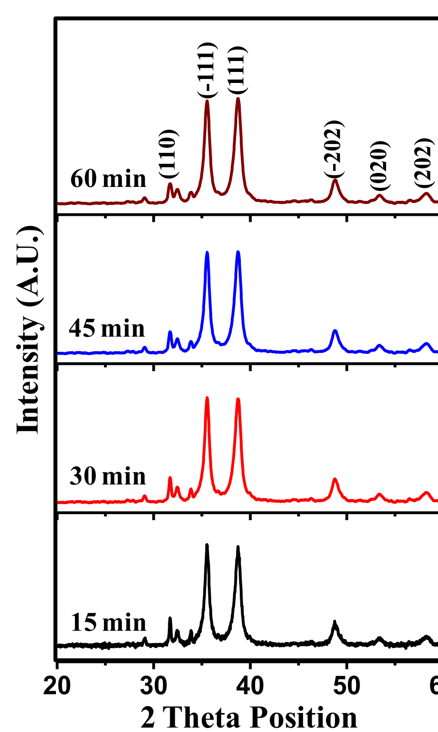

Fig. 1. XRD patterns of CuO nanoparticles recovered from probe sonicated nanofluids at different time interval.