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Dispersions of CuO Nanoparticles in Paraffin Prepared by Ultrasonication: A Potential Coolant

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Abstract. In this study, CuO nanoparticles of rod shape were synthesized with sol gel method, the thermal conductivity of CuO nanoparticles in paraffin were investigated up to a volume fraction of 7.5 % of particles. The nanofluid was prepared by dispersing CuO nanoparticles in paraffin by using high intensity ultrasonic equipment. The mean diameter and shape of CuO nanoparticles was confirmed with TEM and XRD and it was rod shape 25 nm. While the thermal conductivity of nanofluids has been measured with KD2 pro analyzer based on transient hot wire methods. The effective thermal conductivity of CuO nanoparticles in paraffin was measured at room temperatures The experimental results showed that the thermal conductivity increases with an increase of particle volume fraction, and the enhancement was observed to be 20 % over the base fluid for a nanofluid with 3% volume fraction of CuO nanoparticles.

Keywords: Sol Gel method, Engineering suspension, Ultrasonication, Thermal conductivity.

1. Introduction

Nanofluids are liquid suspensions of particles with dimensions between 1-100 nm. After the pioneering work of Choi [1], nanofluids become advance heat transfer fluids. Their potential benefits and applications in many industries from electronics to transportation have attracted great interest from many researchers both experimentally and theoretically. Efforts in research in the nanofluids area has increased annually since 1995; and confirmed with related research papers publication in Science Citation Index journals. Few papers [2,3] provide a detailed literature review of nanofluids various parameter including synthesis, potential applications, and experimental and analytical analysis of effective thermal conductivity, effective thermal diffusivity, and convective heat transfer.

Published results show an enhancement in the thermal conductivity of nanofluids, in a wide range even for the same host fluid and same nominal size or composition of the additives. Since this enhancement cannot be explained with the existing classical effective thermal-conductivity models, such as the Maxwell [4] or Hamilton.Crosser [5] models, this also motivates a wide range of theoretical approaches for modelling these thermal phenomena. Reported results show that the particle volume concentration, particle material, particle size, particle shape, base fluid material, temperature, additive, and acidity play an important role in enhancement of the thermal conductivity of nanofluids.

Masuda et al. [6] first presented the effect of the fluid temperature on the effective thermal conductivity of nanoparticle suspensions. They reported that for water-based nanofluids, consisting of SiO_2 and TiO_2 nanoparticles, the thermal conductivity was not much more temperature dependent than that of the base fluid. Contrary to this result, Das et al. [7] observed a two-to-four fold increase in the thermal conductivity of nanofluids, containing Al_2O_3 and CuO nanoparticles in water, over a temperature range of 21 ^{0}C to 51 ^{0}C. Several groups [8, 9] reported studies with different nanofluids, which support the result of Das et al. [7]. For the temperature dependence of the relative thermal conductivity (ratio of effective thermal conductivity of

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nanofluids to thermal conductivity of base fluid), although a major group of publications showed an increase with respect to temperature, some of the other groups observed a moderate enhancement or temperature independence [6,10,11]. To draw a clear conclusion, more experimental research is needed for both the thermal conductivity and viscosity of nanofluids.

In this article, we report experimental measurements of the effective thermal conductivity using the transient hot wire method based KD2 pro thermal conductivity analyzer for CuO paraffin nanofluids, at room temperatures. The results show that the effective thermal conductivity of nanofluids increases as the volume fraction of the particles increases but not anomalously as indicated in the majority of the literature, and this enhancement is very close to that predicted by the Hamilton.Crosser model [5].

2. Experimental

The rod shape CuO nanoparticles were synthesized by using an aqueous solution of copper salt of sulphate (Fisher scientific). The copper salt was hydrolyzed with the help of hydrolyzing agent. At the end of hydrolysis copper hydroxide was formed which on heating in 120 ^{0}C atmosphere produces CuO nanoparticles. The schematics of reaction have been shown as equation 1 and 2. In presence of continuous magnetic stirring drop-wise addition of 0.1 M NaOH was added to aqueous copper salt.

$$CuSO_4 + 2NaOH \longrightarrow Cu(OH)_2 + Na_2SO_4 \quad (1)$$

$$Cu(OH)_2 \longrightarrow CuO + H_2O \quad \text{(on heating to 75 }^{0}\text{C)} \quad (2)$$

CuO nanoparticles in reaction mixture were separated with the help of high speed centrifugation.

A two-step method was used to produce CuO paraffin based nanofluids with concentrations of CuO nanoparticles from 1 vol% to 7.5 vol%, without any surfactant. In the first stage, dry CuO nanoparticles, with an average primary particle size of 25 nm in diameter were mixed in paraffin. The next step was to homogenize the mixture using ultrasonic vibration (1200W Chromtech Taiwan) to break down the agglomerations.

A transient hot wire (THW) system was used for the thermal conductivity enhancement study. The THW system used in KD2 system (Decagon Devices, USA) infers thermal conductivity from the temperature response of a thermocouple a short distance away from an electrically heated wire. The relationship between the temperature change and the thermal conductivity is [12 - 17].

$$T(t) - T_{ref} = \frac{q}{4\pi k}\left[\ln(t) - \gamma - \ln\left(\frac{a^2}{4\alpha}\right)\right] \quad (3)$$

Where T(t) is the temperature at time t, T_{ref} a reference temperature, k the thermal conductivity, q the electric power applied to the hot-wire, γ the Euler's constant, a the wire radius, and α is the thermal diffusivity of the test fluid. This shows that $\Delta T = T - T_{ref}$ and ln(t) are linearly related with a slope $m = q/4\pi k$. Linearly regressing ΔT on ln(t) yields a slope, after rearranging, gives the thermal conductivity as

$$k = \frac{q}{4\pi m} \quad (4)$$

Where, q is known from the supplied power. Therefore, the thermal conductivity of nanofluids can be determined by measuring the rate at which the temperature rises with time.

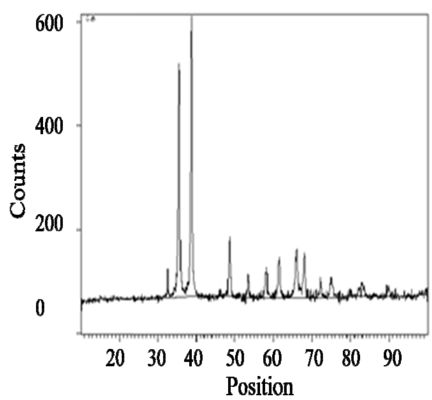

Fig. 1: XRD graph for CuO nanoparticles prepared with single step chemical synthesis method.

3. Results And Discussion

Fig. 1 represents the XRD pattern and can be readily compared with JCPDS data (JCPDS files no. 048-1548) for confirming product is CuO nanoparticles, the presence of any impurity compound other than CuO is not observed. The average crystalline size of samples was estimated from the XRD peak broadening using the Scherrer formula was found to be 28.7 nm.

Fig. 2 presents the TEM image of a typical sample of the CuO nanoparticles. It appears that the product consists of rod-shaped nanoparticles. All the nanoparticles are dispersed very well with small aggregation. The diameters estimated from the TEM image are in the range of 25 nm radius.

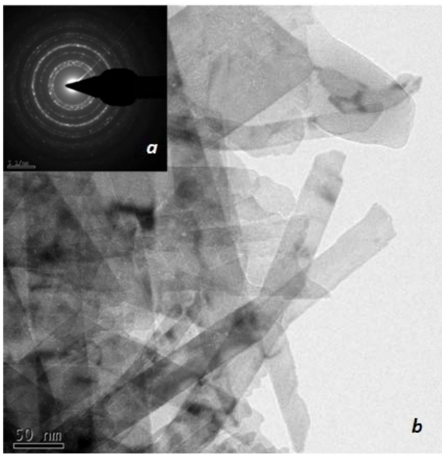

Fig. 2: (a): Select-area electron diffraction (SAED) of as prepared CuO nanoparticles (b): Typical TEM micrograph for synthesized rod shaped nanoaprticles

The thermal conductivity of the fluid was measured after the nanofluid was settled for more than 20 min to eliminate the effects caused by ultrasonic oscillation, which are responsible for apparent thermal conductivity. The effective thermal conductivity of CuO paraffin nanofluids with concentrations of (1.0, 2.0, 3.0, 4.0, 5.0 and 7.5) vol% were measured at room temperatures.

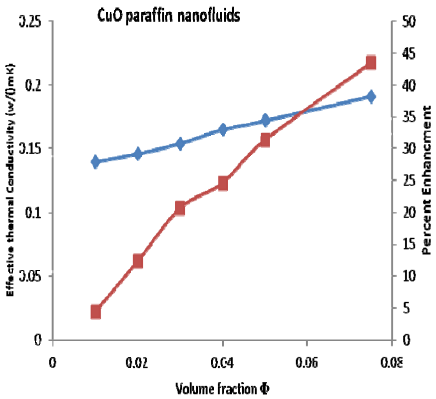

Fig. 3: CuO paraffin nanofluids effective thermal conductivity and percent enhancement in thermal conductivity

Recently, we have reported experimental data for the relative thermal conductivity at room temperature for water and ethylene glycol as base fluids [18], which shows good agreement with selected models predication. In literature thermal conductivity data show anomalous enhancement of CuO. nanofluids, which cannot be explained with classical models such as Maxwell [4], Hamilton.Crosser [5], or Bruggeman [19], from Fig. 4 it can be seen that our data show reasonably good agreement.

Bruggeman [19] proposed a model to analyze the interactions among randomly distributed particles by using the mean field approach

$$k_{eff}=\frac{1}{4}[(3\emptyset-1)k_p+(2-3\emptyset)k_{f+}k_f/4\sqrt{\Delta} \quad (5)$$

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

Where. $\emptyset$ is the particle volume fraction of the suspension and k_f and k_p are the thermal conductivities of the base fluid and particles, respectively.

On the basis of the Maxwell model, Hamilton and Crosser presented a shape factor n, given by n = 3/ Ψ with Ψ the sphericity; Ψ = 0.7 for cylindrical particles

$$k_{eff,Hamilton} = \frac{k_p+(n-1)k_b-(n-1)[k_b-k_p]\emptyset}{k_p+(n-1)k_b+[k_b-k_p]\emptyset} k_b \quad (6)$$

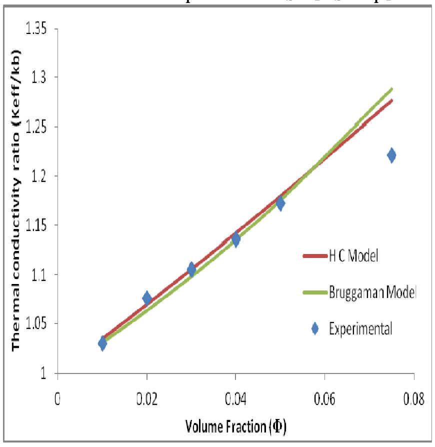

Fig. 4: Comparison of ratio of experimental thermal conductivity ratio and model predicated ratio.

4. Conclusion

Rod-shaped CuO nanoparticles were synthesized with simple efficient two steps normal temperature chemical route sol gel method; the shape and morphology of nanoparticles confirmed with XRD and TEM. The thermal conductivity of CuO nanoparticles in paraffin nanofluids was measured using a transient hot wire method for volume fractions ranging from 1.0% to 7.5%. The data showed that the thermal-conductivity enhancement was in relatively good agreement with the Hamilton–Crosser model. KD2 pro thermal conductivity analyzer was demonstrated as it required small amounts of sample size and was rapid and accurate. Measurements of thermal conductivity were made at room temperatures and shows increase with addition of nanoparticles to base fluids the results indicate that, as the volume fraction of nanoparticles in the suspension increased.

5. References

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