Acoustic Study on the Interactions of Coconut Oil Based Copper Oxide Nanofluid

M. Nabeel Rashin and J. Hemalatha

***Abstract*—**Novel Coconut oil nanofluids of various concentrations have been prepared through ultrasonically assisted sol-gel method. The structural and morphological properties of the copper oxide nanoparticle have been analyzed with respectively and it revealed the monoclinic end-centered structure of crystallite and shuttle like flake morphology of agglomerates. Ultrasonic studies have been made for the nanofluids at different temperatures. The molecular interactions responsible for the changes in acoustical parameter with respect to concentration and temperature are discussed.

***Keywords*—**Cutting Fluid, Molecular Interaction, Nanofluids, Ultrasonic

I. Introduction

NANOFLUIDS are novel suspensions of nano-solid particle in base fluids. A very small amount of guest nanoparticles, when dispersed uniformly and suspended stably in host fluids, can provide dramatic improvements in the thermal properties of host fluids [1]. The nanoparticle may be metallic (e.g. Cu, Fe, Au), nonmetallic (Al_2O_3, CuO, ZnO) or different forms of carbon (fullerene, graphene). The carrier fluid may be water, vegetable oils (e.g. coconut, rapeseed or canola), organic liquids (e.g. butanol, ethylene glycol) or polymeric solutions [2]. The term nanofluid was introduced by Choi for describing this new class of nanotechnology based heat transfer fluids that exhibit thermal properties superior to those of carrier fluids or conventional particle fluid suspensions [3].

There is a great attraction toward nanofluids due to their enhanced thermal conductivity compared with bulk fluids. Nanofluids offer promising heat transfer applications which is of major importance to industrial sectors including transportation, power generation, micro-manufacturing, engines, thermal therapy, heating, cooling, ventilation, air conditioning loud speakers, bearings, MEMS, optoelectronic devices etc [4]–[6].

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Even though, conventional cutting fluids can be used to remove heat from the cutting zone and to reduce heat generation by reducing friction, it requires large amounts of cutting fluids. Also these fluids are very often enhanced with anti-wear, anti-corrosion or emulsifying agents [7]. Hence most industries are looking to reduce costs of fabricating, maintaining, and disposing of coolants. It demands creation of a novel cutting fluid which can act as an effective alternative. Nanofluid, possessing unique properties that can cater these demands, can play a great role here. It can provide both cooling and lubrication action and hence can be used for cutting process.

Also, properly primed nanofluids can surpass conventional cutting fluids with respect to thermal conductivity, convective heat transfer coefficient, critical heat flux, viscosity, and wettability [2].

Xavior and Adithan [8] investigated the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel with carbide tool using three different types of cutting fluids including coconut oil. Ojolo *et al.* [9], found the effect of some straight biological oils (groundnut oil, coconut oil, palm kernel oil and shear butter oil) on cutting force during cylindrical turning of three materials (mild steel, copper and aluminium) using tungsten carbide tool. Krishna et al. [10], examined the performance of nanoboric acid suspensions in SAE-40 and coconut oil during turning of AISI 1040 steel with cemented carbide tool (SNMG 120408) and they concluded that, cutting temperatures, tool flank wear and surface roughness decreased significantly with nanolubricants compared to base oil due to the lubricating action of boric acid and that in all the cases, coconut oil-based nano-particle suspensions showed better performance compared to SAE-40 based lubricant and it was because of better lubricating properties of the base oil. Lawal *et al.* [11] made a review on vegetable oil-based metalworking fluids in machining ferrous metals.

This paper is devoted to the systematic experimental study on the response of nanofluids to the ultrasonic wave propagation for the basic understanding of how the nanoparticles behave in fluids and how they interact with each other and with fluid. Preparing homogeneous nanofluid and attaining a deeper understanding of particle–fluid, particle–particle interactions as functions of concentration and temperature are the main concern.

II. EXPERIMENTAL

A. Materials and methods

The chemicals Copper Nitrate (Cu $(NO_3).3H_2O$), Sodium Hydroxide (NaOH), Acetone ($(CH_3)_2$ CO) were purchased from Merck. The chemicals were used as purchased without further treatment.

The synthesis of coconut oil based copper oxide nanofluid consists of a pre-synthesis of nano-copper oxide particle proceeded by ultrasonically assisted synthesis.

B. Synthesis of Copper Oxide Nanopowder

The CuO nanopowder was synthesized by sol-gel technique [12]. This involves reacting aqueous solution of copper nitrate with sodium hydroxide at pH 9.5 at room temperature. The resulting gel was washed several times with distilled water and acetone and followed by an annealing of 200^0C for 3 hours. The annealed samples were cooled slowly to room temperature.

C. Synthesis of Coconut Oil Nanofluid

Appropriate amount of synthesized CuO nanopowder samples were mixed in coconut oil without using surfactant. No surfactant was used since it reduces surface property of nanoparticle. The mixture was sonicated for one hour using ultrasonicator in order to get homogenous suspension without any phase separation. It is evident that the ultrasonic treatment to the fluids increases the stability of the suspension. Nanofluids of various concentrations (0.5 to 2.5 wt %), prepared through this method for further studies are shown in the Fig 1.

Fig. 1 Coconut oil based nanofluids of various concentrations

III. CHARACTERIZATION

The crystalline structure, phase composition and crystallite size of copper oxide were identified from XRD patterns obtained using Cu Kα radiation (λ = 1.541Å) for 2θ value ranging from 10° to 80° in X-ray diffractometer (Model Rigaku Ultima III). The morphology of the nano-copper oxide sample was obtained using High Resolution Scanning Electron Microscope-F E I Quanta FEG 200. Nanofluids were subjected to ultrasonic studies at different temperatures (35, 45 and 55°C). Appropriate temperatures were maintained by circulating hot water through the outer jacket of the ultrasonic cell by using thermostatically controlled water bath. The velocity values of ultrasonic wave propagation through nanofluid samples were measured using single frequency continuous wave ultrasonic interferometer (Model F81, Mittal Enterprises, India) with an accuracy of ± 0.05 % at frequency of 2MHz. Density of the fluid was determined using specific gravity bottle (5 cc) with accuracy of ± 2 parts in 10^4.

IV. RESULTS AND DISCUSSION

A. Structural Studies

The XRD pattern of the copper oxide nanopowder is shown in Fig. 1 exhibits typical reflections of (110), $(\bar{1}11)$, (111), $(\bar{2}02)$, (020), (202), $(\bar{1}13)$, (022), (220), (311) and $(\bar{2}22)$ planes indicating the monoclinic end-centered structure of CuO. The strong and sharp reflection peaks indicate the high degree of crystallinity of the nanoparticles. All the peaks match well with the standard JCPDS 89-2529. No secondary peaks are detected in XRD pattern which ensures the phase purity of CuO.

The average grain size is obtained using Debye Scherrer equation [13] and the lattice constants of CuO are calculated using the inter planar spacing [14]. The estimated values of crystallite size and lattice constants of CuO are 20 nm and a = 4.732, b = 3.423, c = 5.068 Å, α = γ = 90^0, β = 99.7^0 respectively. The axial ratio of the monoclinic structure is found to be a/b: 1: c/b = 1.4: 1: 1.5.

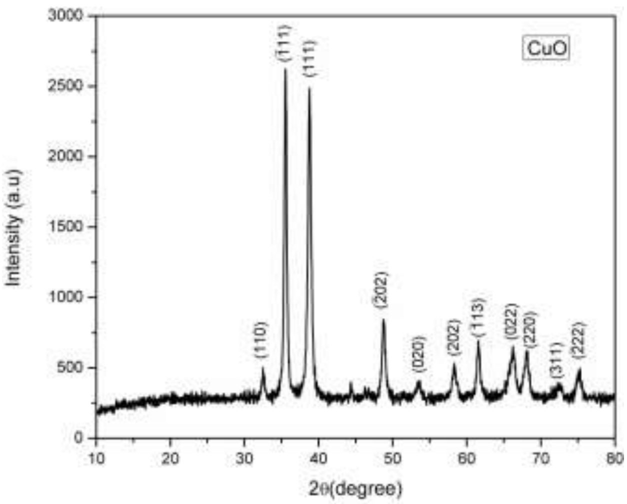

Fig. 1 XRD of Copper oxide nanoparticle

B. Morphological Studies

The High Resolution Scanning Electron Microscopic image of nano-copper oxide powder is shown in the Fig.2. The nano-copper oxide particles are agglomerated in to uniform shuttle like flakes. This is because the small nanocrystals posses large surface energy, which leads the nanocrystals to aggregate in order to lower their surface energy during crystal growth [15].

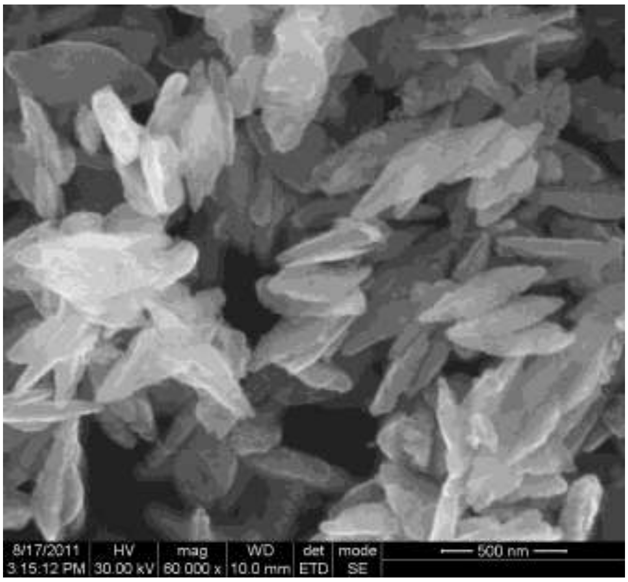

Fig. 2 HRSEM image of Nano-Copper oxide

A. Acoustical Studies

The acoustical parameters like adiabatic compressibility (β) and acoustic impedance (Z) were calculated using the velocity (v) and density (ρ) data obtained through experiments. The adiabatic compressibility of the samples was determined using the Newton–Laplace's relation [16], [17]

$$\beta = \frac{1}{\rho v^2} \qquad (1)$$

The characteristic acoustic impedance was calculated for all the samples using the relation [18]

$$z = \rho v \qquad (2)$$

1. Effect of concentration

The variation of ultrasonic velocity with concentration is shown in the Fig. 3a. The ultrasonic velocity slightly decreases with the increase of nanoparticle concentration at lower concentrations. But at 1.5 Wt% there is a sudden decrease in velocity followed by slight increment with loading of nanoparticle.

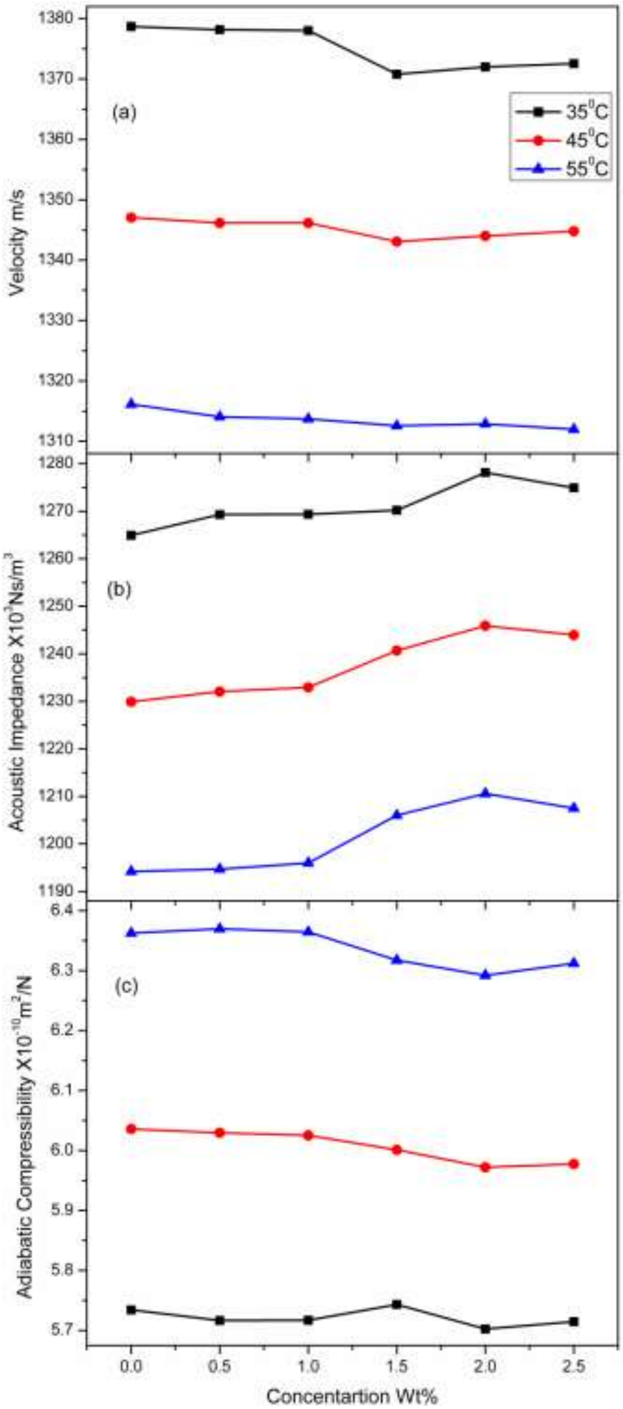

Fig. 3 Plots of a) Ultrasonic velocity versus concentration b) Acoustic impedance versus concentration and c) Adiabatic compressibility verses concentration for nanofluids at various temperatures

With the addition of nanoparticle to the base fluid the particle–fluid interaction increases which in turn, reduces ultrasonic velocity. Also with increase of nanoparticle concentration there is an increase in density which also contributes to the reduction in velocity.

A favorable combination of these effects at 1.5 Wt% leads to a hop in the velocity curve. Further if we increase nanoparticle concentration, the particle–particle interaction increases which can be understood by the rise in velocity. As mentioned above, an increased nanoparticle concentration can enhance density effect on velocity, but it is predominated by the effect of strong inter–particle interaction. Hence, the concentration 1.5 wt% can be considered as a critical concentration above which particle-particle interaction dominates the particle-fluid interaction.

The variation of acoustic impedance with concentration is depicted in the Fig. 3b. There is a small increase in acoustic impedance at lower concentration, but as concentration increases beyond 1.5 Wt% one can see a significant increase in acoustic impedance. The acoustic impedance is the coefficient of proportionality between pressure and velocity of the particles in the sound wave. This reveals a significant reduction in particle velocity beyond critical concentration. Further reduction observed in the acoustic impedance is attributed to the variation in density and compressibility.

The variation of adiabatic compressibility with concentration is illustrated in the Fig. 3c. The change in the compressibility values of the nanofluids with respect to that of the base fluid is found to be negligible at low concentrations and it becomes considerable at critical concentration. This fact further confirms a strong particle-particle interaction at higher concentration.

2. Effect of Temperature

The variation of ultrasonic velocity with respect to temperature is shown in the Fig. 4a. It is clear that sound velocity decreases with the increase of temperature which follows the common behavior of non-aqueous liquids.

With the increase of temperature there is a reduction in density which tends to increase velocity. Also, the more rapid movement of the molecules at higher temperatures favors the suspension of the particles in the fluid and hence it improves the compressibility (Fig.4c). As the effect of compressibility effect dominates that of density, the velocity decreases.

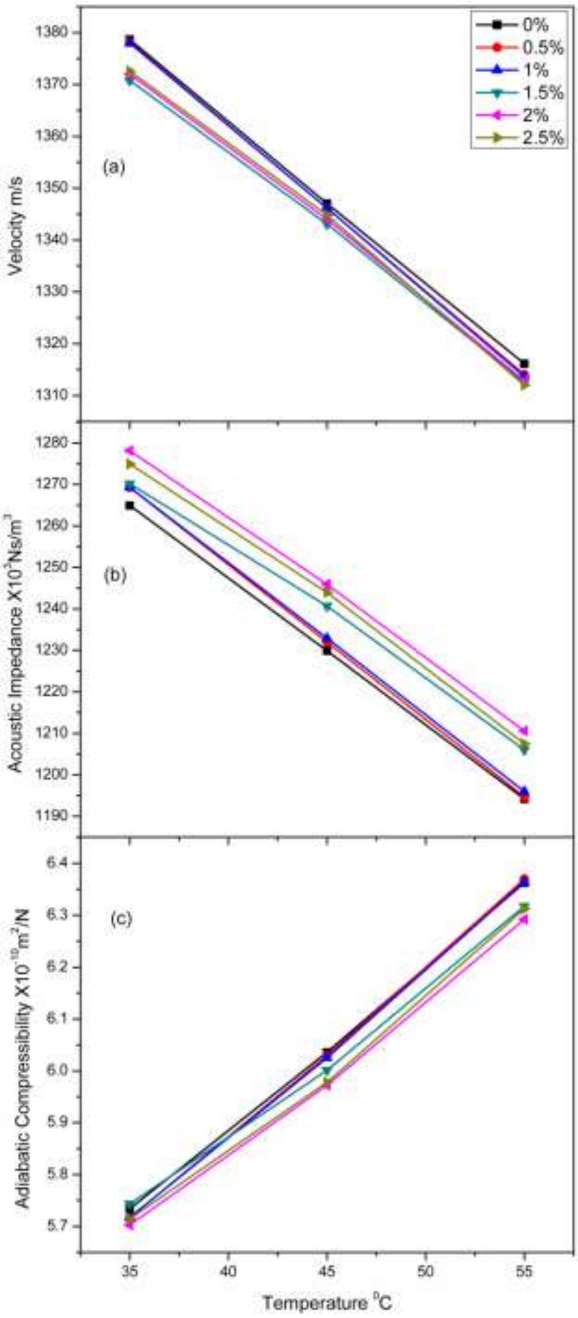

Fig. 4 Plots of a) Ultrasonic velocity versus temperature b) Acoustic impedance versus temperature and c) Adiabatic compressibility verses temperature for nanofluids of different concentrations.

V. Conclusion

Stable nanofluids of various concentrations of CuO in coconut oil have been prepared without using surfactants and they have been examined using ulrtrasonic wave. The acoustical parameters and their variations with respect to the concentration and temperature have been analyzed. The investigation leads to the understanding of the molecular interactions taking place between the particles and the fluid. It is found that the nano particles interact well with the base fluid at low concentrations. But beyond 1.5 wt% the particle-particle interaction becomes dominant than the particle fluid interaction. At elevated temperatures, due to the rapidity of the movement of the molecules the effect of particle-particle interaction is subsided and hence the fluids have good particle-fluid interaction at higher concentrations also.

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