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Physico-Acoustic Study on Thermal Conductivity of Silver Nanofluid

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ABSTRACT

Low transmission of heat is one of the major problems for heat exchanger fluids in many industrial and scientific applications. This includes cooling of the engines, high power transformers to heat exchangers in solar hot water panels or in refrigeration systems. In order to tackle these problems in thermal industries, nanofluids could play a significant role as excellent heat exchanger materials for thermal applications. Silver nanofluids can be used abundantly for thermal applications due to their low cost and high thermal conductivity. The present article describes the green synthesis of the silver nanoparticles from AgNO3 powder using some plant product like tannic acid. The silver nanoparticles are characterized by XRD, UV-visible spectrophotometer, TEM. The silver nanofluids of different concentrations are prepared by means of water as the base fluid. The ultrasonic velocity is calculated for different concentration at room temperature. Acoustical parameters like compressibility, intermolecular free length and acoustic impedance are calculated using ultrasonic velocity, density and viscosity and the results are discussed in terms of intermolecular interactions between the nanoparticles and the base fluid. The variation of ultrasonic velocity and other calculated acoustic parameters are used to analyze in amplification of heat conductivity of silver nanofluids.

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1. Introduction

The intensification in heat conduction is a fundamental mechanism of nanofluids sustaining its challenges for the nanofluids researchers till date due to lack of proper scientific explanations. The conventional theoretical miniature does not successfully explain the amplification of the heat conduction property of nanofluids. It means that the rise in the heat conduction of nanofluid is not only due to conduction but also for other techniques making a remarkable increase in heat conduction. For instance, the surface area of the nanoparticles could be 1000 times more than that of micro-particles, and since the heat conduction takes place on the surface of the particles, the larger surface area of the nanoparticles increases the heat conduction capability of nanofluids explained by Das et al. [1]. Therefore, it is essential to understand the primary mechanism involved in the heat conduction in nanofluids and also the important factors which influence the heat flow (Mahmoodi and Esfe [2], Bozorgan and Shafai [3]). Enhancement in heat conduction of nanofluids encloses three major processes: nanolayer of the liquid at liquid/particle interface, Brownian motion in nanoparticles and nanoparticles gathering which are well understood by the analysis of interactions between the molecules of the same and other species in the system and it provides information of interacting properties in the molecules (Jamal-Abad et al. [4], Abdul Hakeem et al. [5]). There are many techniques used to understand such microscopic phenomena such as FTIR, NMR and spectroscopic methods, but out of which the nondestructive acoustic technique has imposed its vital significance in such area due to the propagation of highly directive and energetic interactive sound wave in the small specified region. Though the works are reported on heat conduction and

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viscosity of nanofluids (very few work is reported in acoustical properties of nanofluids by Singh, Pandey and Yadav [6], Hornowski et al. [7], Sayan [8], Motozawa, Iizuka and Sawada [5], Hemalatha, Prabhakaran and Nalini [9], Kiruba and Jeevaraj [10]). Substantial applications in metallurgy, as a good catalysis and large application as heat exchanger fluid, make Ag (silver) an unbeatable nanoparticle in nano research (Kiruba and Jeevaraj [11], Chen [12]). The present work encloses the analysis of the interaction of ultrasonic wave with suspended Ag dispersed in water in presence of the tannic acid as stabilizing and reducing agent. The interactions in nanofluid systems are analyzed from the computation of acoustical parameters. Finally, the heat transfer characteristics of nanofluid are discussed with reference to acoustical parameters.

2. Materials and method

Freshly prepared ice bathed aqueous solution of tannic acid (C76H52O46, Mw=1701, Sigma Aldrich) was used to synthesize silver nanofluids with a suitable amount of silver nitrate (AgNO3, 99.9%, Sigma Aldrich) in addition with a controlled amount K2CO3 using distilled water. Ag nanoparticles are synthesized by wet chemical process as in the studies of Yadav et al. [13], Cataldo et al. [14], Sri Kavya et al. [15]. During synthesis of nanofluids, silver nitrate solution was added with constant stirring for different weightfraction such as (0.1, 0.2, 0.3, 0.4 and 0.5) W_t% in heated aqueous mixture of tannic acid and K2CO3 powder at 300C temperature as shown in Fig. 1. The synthesized solution of nanofluids is subjected for ultrasonication to avoid cluster of nanoparticles and for stable suspension of nanofluid. The appearance of reddish brown color in nanoparticles indicates nearly 100% formation of silver nanoparticles from Ag ions. The synthesized nanofluids are characterized by UV-vis spectrophotometer (HITACHI) for spectral analysis. Ultrasonic nanofluid interferometer of frequency 2MHz was used for velocity measurements in freshly prepared nanofluids. The density measurements in stable nanofluids were done by 10cc specific gravity bottle and Ostwald viscometer was taken for viscosity measurements of silver nanofluids.

3. Stability Analysis of Silver nanofluid

The stability of silver nanofluid depends mainly on the pH of reducing agent. Tannic acid is a weak reducing agent which can be utilized to grow seeds in nanoparticles at room temperature. The pH Tannic acid is 7-8, which depends on its extent of dissociation. It also partially hydrolyzes into glucose and gallic acid units (Purohit and Murty [16]). Alkaline pH of Glucose makes it good stabilizing agent and a weak reducing agent. Due to this reason, the synthesized silver nanofluid maintains its stability with the increase in concentration of particles. This can be ascribed to the agglomeration of the nanoparticles as shown in Fig. 1.

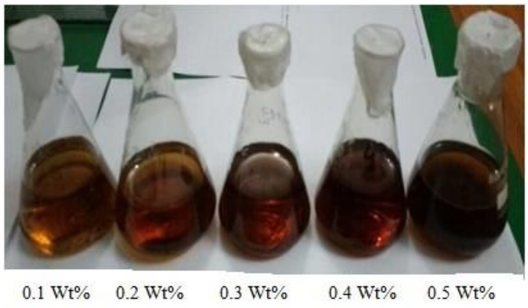

Figure 1. Synthesized silver nanofluid

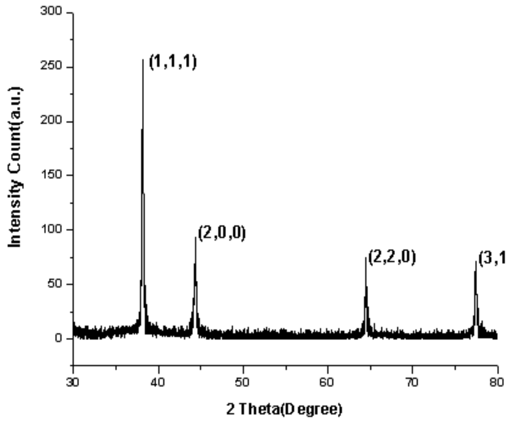

Figure 2. X-ray diffraction spectra of Ag nanoparticles.

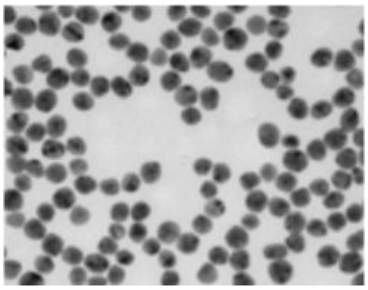

Figure 3. TEM images of silver nanoparticles

4. Results and discussions

The X-ray diffraction (XRD-6000, Shimadzu) analysis of nanoparticles is recorded in two theta range between 30^0 and 80^0 with a scanning rate of 0.6 ^{0}/sec. The diffraction spectra of silver nanoparticles shown in Fig. 2 indicates well-defined four sharp peak diffraction lines at $2\theta = 38.15°, 44.34°, 64.5°$ and $77.46°$. It confirms the crystal structure of silver nanoparticles.

TEM was used to investigate the morphology and particle size of silver nanoparticles operated at 200kV. From Fig. 3, it is clear that the Ag nanoparticles are spherical in shape and are more or less uniform in size and shape. The size of the nanoparticles is found to be approximately 16 nm.

The sample was prepared by placing a drop of silver nanofluid on glass plate and it is dried. Fig. 4 shows TEM image of silver nanofluid taken for 50x and 500x magnification. It is found that particles in nanofluid are agglomerated. Since agglomeration is related to stability of nanofluid, the more the agglomeration of nanoparticles, the more is the stability. They are capable of capturing photos in small sizes to reveal suspension situation inside the fluid after preparation [17]. The strong absorption peaks of UV-visible spectrum confirms the presence of silver nanoparticles as shown in Fig. 5. The absorption peak at 410 nm and 416 nm reveals the nanosize of Ag. Variation in wavelength corresponds to the Plasmon oscillation of conduction electrons in nanoparticles liquid suspensions. This indicates that size of Ag nanoparticles increases with increase of concentration. The shifting of peak toward shorter wavelength confirms the decrease in size of the nanoparticles.

The sound dependent parameters like compressibility (β), free length (L_f) and acoustic impedance (Z) were calculated using ultrasonic sound velocity (v) and density (ρ) data from experiments. The compressibility of sample was determined using Newton-Laplace‘s relation ($\beta = 1/\rho C^2$) based on the studies by Rawlinson and Swinton [18], Povey [19].

The velocity profiles as shown in Fig. 6 confirms that the ultrasonic velocity in nanofluid increases to a maximum value up to 0.2 wt% above which it starts decreasing indicating influence of dispersed particles on the ultrasonic wave propagation, which was investigated by Phadke et al. [20]. This variation in velocity profile is probably due to large surface area of nanoparticles for which more water molecules can be adsorbed on its surface by which the nanoparticles can move easily. Again the increase in ultrasonic velocity may due to formation of hierarchical structure causes by interaction of nano sized silver and micro sized water molecules, as concluded by Kiruba et al. [21]. The propagation of ultrasonic wave causes random movements of nanoparticles which is increased with increase in concentration of nanofluid and Brownian motion stops the fluid particles in suspension, leading to decrease in velocity.

The decrease in ultrasonic velocity indicates that the strength of particle- fluid and particle - particle interaction also decreases. Since addition of nanoparticles into the base fluid increases the density of nanofluid, it also reduces the particle velocity and it is favorably prominets at 0.2Wt% of nanofluid. Thus, 0.2 Wt% of silver nanofluids can be taken as critical concentration at which the dominancy of particle-particle interaction exist compared to particle-fluid interaction. The nanofluids system has a variable density region for which the medium opposes the propagation of ultrasonic wave which is computed by acoustic impedance of the medium. The profile of acoustic impedance shows (Fig. 7) the same trend as that of ultrasonic velocity which is supported by explanation in variation in ultrasonic velocity.

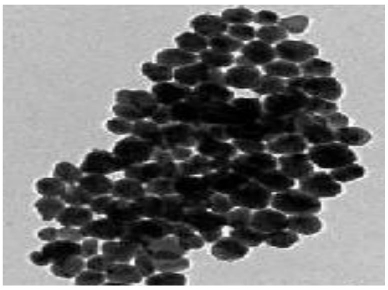

Figure 4. TEM images of silver nanofluids in water

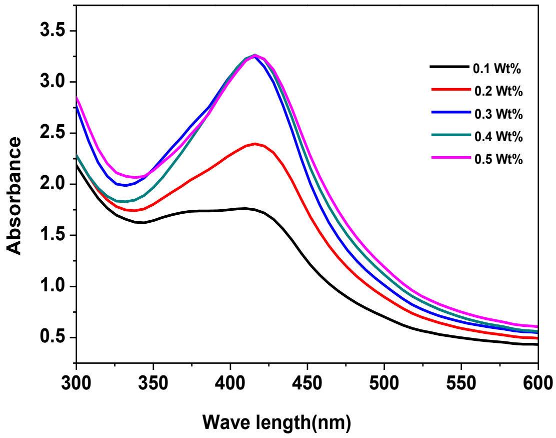

Figure 5. UV-Visible spectrum of silver nanofluids

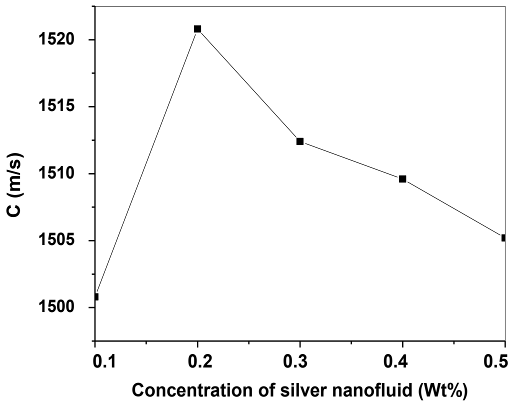

Figure 6. Variation of ultrasonic velocity of silver nanofluids

The variation of adiabatic compressibility and intermolecular free length with concentration is illustrated in the Fig. 8 and Fig. 9.

The change in the compressibility values and intermolecular free length of the nanofluids with base fluid is found to be negligible at low concentrations and it becomes considerable at critical concentration.

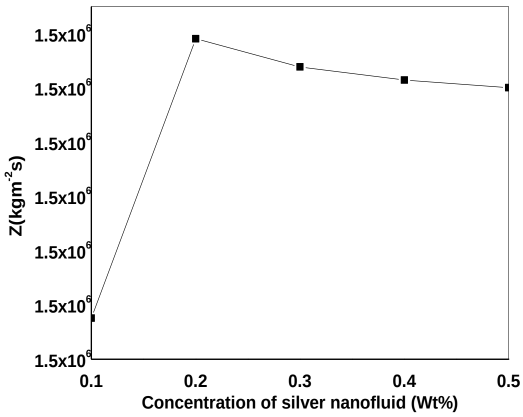

Figure 7. Variation of acoustic impedance of silver nanofluids

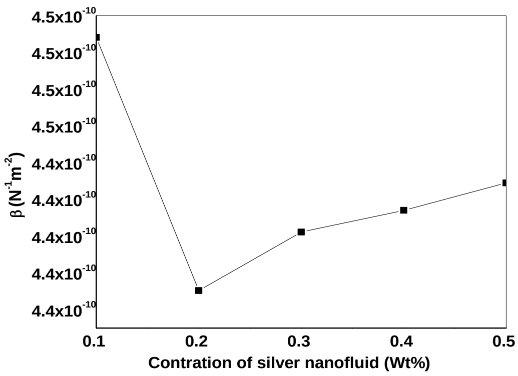

Figure 8. Variation of compressibility of silver nanofluids

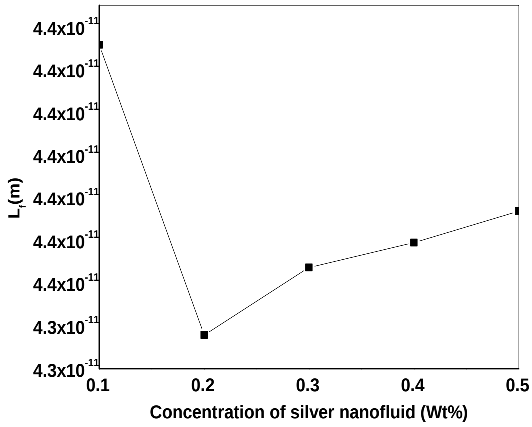

Figure 9. Variation of intermolecular free length of silver nanofluids

5. Thermal conductivity of nanofluid

The ultrafine size and fluidity character of nanoparticles make it convenience to treat like a fluid. In thermal equilibrium, the nanofluid can be treated as common pure fluid if it is assumed that there is no slip between the discontinuous phase of the nanoparticles and the continuous liquid medium. Hence the equations of continuity, motion, and energy for the pure fluid can be directly applicable to the nanofluid. Under the assumption of constant thermal properties, the energy equation for the incompressible flow of a pure fluid without viscous dissipation is also suitable to describe the heat transfer process of the nanofluid.

$$\frac{\partial T}{\partial t} + \nabla . uT = \nabla . (\propto_f \nabla T) \quad (1)$$

It means that the solutions for the single-phase fluid are also valid for the nanofluid in the identical application cases. However, it must be emphasized that the thermal properties appearing in Eq. (1) refers to those of the nanofluid. Thus, the dimensionless correlations of heat transfer of the pure liquid are applicable for the nanofluid which were also confirmed by Brinkman [22], Ozerinc [23], Das et al. [24]. Here the acoustical parameter like attenuation parameter calculated from the ultrasonic velocity data and frequency has been incorporated. Attenuation in propagation of ultrasonic wave due to thermo- elastic loss was computed by the expression:

$$\alpha = \frac{\omega^2 \langle \gamma_i^j \rangle 2KT}{(2\rho C^5)} \quad (2)$$

Here, γ_i^j is Gruneisen number, and other symbols have their usual meaning. Brownian motion of the suspended nanoparticles is one of the key factors for large enhancement of thermal conductivity performance and it was not considered in conventional thermal transport theory. Thermal conductivity of fluids was also measured using KD2 PRO and also was calculated using Eq. (2). At initial point, KD2PRO instrument is in equilibrium state for 30 seconds. It is followed by heating and cooling effect of needle sensor for 30 sec each. Then the instrument controller measures the experimental thermal conductivity by changing the temperatures. The needle sensor must be inserted properly in the sample fluid at centre without touching the sides of the wall of the measuring flask. The thermal conductivity of nanofluid increases with the increase of particle concentration (Fig. 10) which may be due to the suspension of nanoparticles in binary mixture base fluid as is clear from the variation of other acoustical parameter. The basic mechanism for such variation of thermal conductivity is due to agglomeration and large adjustment of silver nanoparticles within the base fluid like water.

Particle size is one of the major factors affecting the thermal conductivity. The increase in the particle size increases the thermal conductivity values. As stated by Iyahraja *et al.*, the heat conduction of nanofluid is enhanced from 13 % to 54 % for the particle size of 20 nm [25]. Again, the enhancement in heat conduction of the nanofluids with reduction in particle size may be attributed to high specific surface area and Brownian motion of the nanoparticles. The decrease in particle size helps in increasing the surface area per unit volume. This increase in surface area affects the heat transfer, which ultimately increases the effective transfer of heat from nanoparticles to the base fluids. Also, the decrease in particle size increases the Brownian motion velocity which produces additional paths for the flow of heat in the fluid which also increases the thermal conductivity of the nanofluids which was mentioned by Patel et al.[26]. As the weight fraction of the silver nanoparticles varies from 0.1 % to 0.5 %, the thermal conductivity shows a linear variation with the concentration of the nanoparticles as discussed by Paul *et al* [27]. The second factor affecting the thermal conductivity is the stability of the nanofluids. This also increases the thermal conductivity of fluids. The stability of the nanofluids can be infuenced by controlling the parameters like coagulation of the nanoparticles which can be achieved by the addition of surfactants, by agitation and by changing pH values of the suspension. Addition of surfactant prevents the contact between the successive two particles as the repulsive force dominates the attractive force of the particles according to the investigation of Xuan et al. [28].

6. Conclusions

Silver nanoparticles are synthesized by the wet chemical method which is the cheapest and simplest processes using plant product and no harmful byproduct is produced. Characterization of silver nanoparticles by XRD, TEM UV/Vis confirms the nano size of the synthesized of Ag nanoparticles. The estimated size of the nanoparticles is found to be 16 nm. The acoustical characterization of silver nanofluids successfully explains the thermal conductivity which is well agreed with that of measured by KD2 PRO instrument. Such acoustical characterization of silver nanofluids is to be expected well explain the heat transfer properties for different thermal applications in industry.

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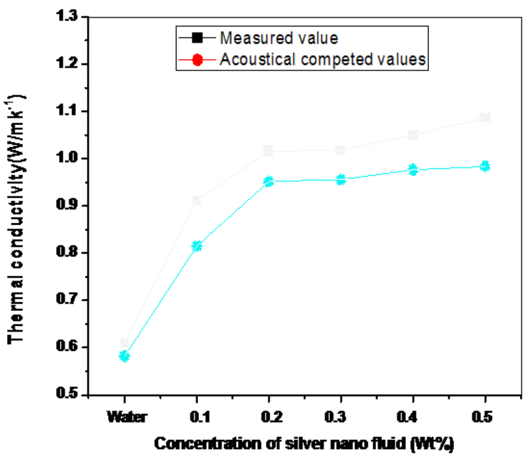

Figure 10. Variation of thermal conductivity of silver nanofluids at temperature 40°C.

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