Effect of ultrasonication in synthesis of gold nano fluid for thermal applications

G Nath 1# and R Giri 1
Department of Physics, Veer Surendra Sai University of Technology,
Sambalpur768018, Odisha, India
E-mail: ganesh_nath99@yahoo.co.in

Abstract. Ultrasonly synthesized nanofluids are efficient coolant and heat exchanger material has demonstrated its potential in various fields and thermal engineering. The computation of different acoustical parameter using the ultrasonic velocity data of gold nanofluids are taken in estimation of thermal conductivity. The computational and experimental measured values of thermal conductivity are well agrees. The results execute ultrasonically synthesized gold nanofluids is an economic and efficient technology for explaining the increase of thermal conductivity of nanofluids in suitable optimum conditions.

Keywords: Gold nanofluids, acoustical parameter, ultrasonic wave, thermal conductivity

1. Introduction

The heat transfer performance and conductivity of traditional heat transfer fluid can be increased by suspending of nanosized solid particles in to it. Enhancement in heat transfer property of nanofluid is basically influenced by various mechanisms like Brownian motion, sedimentation, dispersion of solid particles, diffusionphoresis, thermaphoresis, gathering at liquid/solid interface and transport of ballistic phonon [1].Moreover, there is till today the lack of proper mechanism in enhancement for transfer of heat is not clearly established. This confirms that the enhancement of thermal conduction might be increased by viscosity, the decrease of specific heat of nanofluids [2-6].The unique physical and chemical properties of Gold nanoparticles (GNPs) and bio-compatibility make these nanoparticles to be a novel material for different thermo physical phenomena in thermal industry and gold-based pharmaceuticals [7-8] even if its high cost. The synthesis of nanofluids involves many controversies in its phase settlement of solid and liquid particle due to re-agglomeration phenomena which s well understood by suitable ionic or surfactant conditions and degree of compatibility of nanoparticles with base fluid. Thus sonochemical technique particularly ultrasound have better phisisibility in this regard for better control of nanoparticles morphology due to its interaction with atomic and subatomic region of the medium. In ultrasonic technique, the acoustic cavitation plays the key role to activate the fluid by three different processes like formation, growth and collapse of bubbles in liquid. Thus this method widely used in production of nanosized material due to its unusual properties in unique conditions (temperatures 5000K, pressures >20 MPa) and cooling rates (>109 K s⁻¹) which facilitates to form the smaller particle of different shapes [9-10]. In addition with this the acoustic properties of nanofluid determined by ultrasonic method have numerous applications in nuclear power generation industries and predicting the effectiveness of foghorns and describing the acoustics of bubbly etc. The unusual physical and chemical properties of nanofluid enables them for potential applications in optoelectronic nanodevices, catalyst and chemical sensors [11].In the present work the gold nanoparticles are synthesized by citrate reduction process with the aided of sonication technique. The acoustic studies have been performed to study the variation of ultrasonic velocity which helps in explaining the thermal behaviour of gold nanofluid particularly thermal conductivity by both calculated and measured value [12].

2. Experimental details

2.1 Material and methods
Chloroauric acid (HAuCl₄) procured from Sigma Aldrich, sodium citrate (C₆H₅Na₃O₇) and DI water purchased from CDH chemicals Pvt. Ltd, have been used for synthesis of spherical gold nanoparticle and nanofluid. These materials have been used without any further purification.

2.2 Synthesis of gold nanoparticles

The chloroauric acid of \((5.0 \times 10^{-6} \text{ mol})\) and 200ml of DI water was taken in two conical flasks to prepare the aqueous chloroauric acid solution. The concentration of HAuCl₄ was fixed in 0.25 mM. The ultrasonic bath containing water 2.5L (Emocolite, 125 kHz, 60 W) was fixed at temperature of 80 °C. Due to the sonication effect, the temperature of the water slightly rises and kept constant between 80 °C to 85 °C during synthesis nanofluids which favours to produce smallest possible size of gold nanoparticles in citrate reduction method [13]. For stirring and heating the aqueous HAuCl₄ solutions the flask containing solution placed for 10 min in ultrasonic bath. The sodium citrate (C₆H₅Na₃O₇) was added to aqueous HAuCl₄ solutions after 10 minutes of the sonication in the ratio 1: 3.5 to synthesize the smallest GNPs [14]. The gradual changes in colour indicate the synthesis of Au nanoparticles as shown in Figure 1.

![Figure 1. Formation of aqueous gold nanofluid.](image)

The sonicated solution was divided into five different concentrations like 1ml, 2ml, 3ml, 4ml and 5ml and each concentration again placed in ultrasonic bath for different time like 10, 30 and 60 min. The sonicated nanofluids are kept for 24 h under normal light to study the stability. The colours of the solutions are changed in to dark purple or reddish violet. The freshly prepared gold nanoparticles are subjected for centrifugation and redispersing with DI water, purified by filter papers for 3-5 days to separate the residual reactants and stabilizer if any. The final synthesized nanofluids stored in closed container for characterization and acoustical and thermal conductivity measurement.

3. Result and discussions

The synthesized gold nanofluids are immediately characterized by UV-visible spectrometer for confirmation of nano size. 3mL of DI water mixed with 1mL of synthesized gold nanofluids to prepare a diluted solution for UV-visible spectrum analysis. The spectra recorded gives the peak about \(\lambda_{\text{max}} = 520\text{nm}\) and \(\lambda_{\text{max}} = 540\text{nm}\) confirms that GNPs are spherical in shape [14] as shown in Figure 2.
UV-visible spectroscopic analysis has been supported by TEM studies to analyze structural characteristics of gold nanofluids. Figure 3 (a) and (b) shows TEM image of gold nanoparticles obtained from sonication time for 30 min is more uniform than that for 90 min. in the scale bar of 500 nm, which reveal that the particles are nearly spherical in shape of size form 10-15 nm. Thus it is possible to produce more smaller and regular spherical shape of gold nanoparticles in ultrasonication as it initiates the homogeneous reaction.

The SEM images of the gold nanofluid as shown in Figure 4(a) and (b) indicate that the particle shape and size changes significantly with the aid of ultrasonication. The analysis of SEM images of the gold nanoparticles indicates that the particles are smaller and more regularly arranged due to ultrasonic effect which establishes that ultrasonic irradiation is a powerful tool in formation of nanostructures.
TEM analysis and SEM studies of gold nanofluid indicates that the most of the physical properties including thermal conductivity are influenced due to the shape, size and morphological arrangement [15] as well as the interfacial layer mechanism which is well understood by the analysis of ultrasonic wave through the fluid media. Since ultrasonic velocity and its related acoustic parameters are well sensitive to the local structure of the atomic and subatomic region, it can be applied to the present case to examine the thermal behaviour of the gold nanofluid. Ultrasonic velocity measurements of the prepared nanofluids are carried out using Nanofluid interferometer at a fixed frequency of 2 MHz. Density of the fluids are measured using specific gravity bottle (10cc). Viscosity of the fluids are measured using Ostwald viscometer. The acoustical factors like compressibility ($\beta$), surface to surface distance between the particles ($L_s$) and impedance ($Z$) were calculated using ultrasonic velocity ($C$) and density ($\rho$) data collected from experiments. The ultrasonic wave velocity as shown in Figure 5 shows a non linear behavior with increase in concentration of gold nanofluid. The non linear behaviour of ultrasonic velocity is due to interaction between the constituent nanoparticles with base fluid. It is observed that as concentration of gold nano particle suspension in water increases heteromolecular interactions in the constituents becomes stronger. The adiabatic compressibility ($\beta$) and intermolecular free length($L_s$) shows the reverse trends as that of ultrasonic velocity. The non-linear variation of adiabatic compressibility (Figure 6 and Figure 7) with molar concentration indicates the presence of phase separation in nano suspension which supports the behavior of ultrasonic wave velocity. Increase in acoustic impedance shows the association between the gold nanoparticle and base fluid and decrease in acoustic impedance shows the dissociation of nanoparticles in nano suspension.

![Figure 4. SEM image of gold nanoparticles.](image-url)
Figure 5. Variation of ultrasonic velocity ($C$) with gold nanofluids.

Figure 6. Variation of $\beta$ in gold nanofluids.

Figure 7. Variation of $L_f$ in gold nanofluids.

Figure 8. Variation of acoustic impedance ($Z$) with gold nanofluids.
3.1 Thermal conductivity of gold nanofluids

The nanoparticles are ultrafine in size for which they can fluidize easily. These nanoparticles will be treated as common pure fluid if it is assumed that there is no slip between discontinuous phase of ultrafine particle and continuous phase of liquid. Assuming the nanofluids to be common fluid, the equation of motion, equation of continuity and energy equations can be extended directly to the nanofluid. Under this condition the energy equation for incompressible flow of a pure fluid without viscous dissipation can be described by the heat transfer phenomena of the nanofluid given by the equation (1)

\[ \frac{\partial T}{\partial t} + \nabla \cdot \mathbf{u} T = \nabla \cdot (\alpha \nabla T) \] (1)

Thus in nanofluid case this equation (1) can also be valid to describing the thermal properties. The thermoelastic loss of the nanofluid incorporated from equation (1) can be computed from the ultrasonic velocity data and frequency of the ultrasonic wave given as

\[ \alpha = \frac{\omega^2 \gamma}{2KT} \left( \frac{2}{\rho C^5} \right) \] (2)

where K is thermal conductivity, \( \omega \) (≈2πν) is frequency of the ultrasonic wave, \( \gamma \) is Gruneisen number, T is the temperature. Thermal conductivity of fluids was also measured using KD2 PRO instrument and also calculated using equation (2). The thermal conductivity of nanofluid increases with the increase of particle concentration which may be due to the suspension of nanoparticles in base fluid. The basic mechanism for such variation of thermal conductivity is due to agglomeration and large adjustment of gold nano particles within the base fluid like water.

![Figure 9. Variation of thermal conductivity in gold nanofluids.](image)

From the profile it is observed that the thermal conductivity of gold nanofluids varies non linearly though it increases with the particle concentration and shows a significant increase at about 3ml. From the physical property of nanoparticles it is confirm that lower the surface to volume ratio higher is the
thermal conductivity due to confinement of Plasmon resonance reaction at the solid-liquid interface. Again, increase in the surface area of the nanoparticles in higher concentration leads to slightly decrease in thermal conductivity of the particles.

4. Conclusion

The gold nanofluid synthesized by citrate reduction process following one-step method. Ultrasonic method has established its advantages for synthesis of gold nanofluids and can be applied to synthesis of any other metallic and non-metallic nanofluids. Study of acoustic parameters is also providing significant information about the particle-particle, particle-fluid interaction. The variation of acoustic parameter and calculation of attenuation constant helps to calculate the thermal conductivity which is well agrees with that of the measured values. The thermal conductivity of gold nano fluid is increased to a large value for high particle concentrations which is well demonstrated by effect of ultrasonication.

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6. References

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