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Ultrasonic Studies of Molecular Interaction in Al_2O_3 - Water Nanosuspension

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Abstract: ***Nanofluids - a simple product of the emerging world of nanotechnology - are suspensions of nanoparticles in conventional base fluids such as water, oils, or glycols. In the present paper uniform suspension of Al_2O_3 nanoparticle in water of different concentration have been prepared. The*** ultrasonic velocity, ***absorption***, density and viscosity measurements were ***carried out in the concentration range of 0.2 wt % to 1.0 wt % and temperature range between 293^0K to 313^0K*** at frequencies of ***2 MHz and 10 MHz.Ultrasonic velocity and absorption measurements are carried out by MHF-400 high frequency pulser receiver. To maintain desired accurate constant temperature Plasto Craft thermostat with accuracy of ± 0.1^0C in temperature range -10^0C to 95^0C is used. Variations of these parameters are interpreted in terms of intermolecular interactions. The variation of acoustic and thermodynamic parameters indicates different kind of molecular interactions, physico-chemical behaviour and their strength.***

Keywords: **N**anofluid, Ultrasonic velocity, density, Aluminium Oxide, Acoustical parameters

1. Introduction

One of the emerging miniaturization techniques is the nanofluid technology which meets the shortcomings of the earlier used bulk fluids and conventional base fluids. There is a great attraction towards nanofluids because they are proved to be far more superior when compared to the conventional bulk fluids. Nanofluids exhibit large thermal conductivity compare to traditional (base) fluids and are suitable for heat transfer applications[1-2-3].

Nanofluids offer promising heat transfer applications which is of major importance to industrial sectors including transportation, power generation, micro-manufacturing, electronics, engines, thermal therapy, heating, cooling, ventilation and air conditioning. Many of the reported anomalous enhancements in thermal conductivities in nanofluids were non-reproducible[4]. Recent experimental studies suggest that nanofluids exhibit thermal conductivity enhancement within Maxwell's limit[5-6-7]. The fundamental understanding of exact mechanisms responsible for the anomalous values of ultrasonic wave propagation is unclear because of the lack of molecular level understanding of the ultrafine particles .

A systematic study on the nanofluids is required for the basic understanding of how the nanoparticles behave in fluids and how they interact with each other and with fluid. A analysis of the nanofluids will enable us to choose fluids with superior properties over conventional fluids. This paper is devoted to the systematic experimental study on the response of suspensions of nano-Al_2O_3 particles in water to the ultrasonic wave propagation. Preparing the stable and homogeneous suspensions of nanoparticles and attaining a deeper understanding of particle–fluid interaction are the main concern.

2. Experimental

Nanofluids of Al_2O_3 were prepared by dispersing the Al_2O_3 nanoparticles uniformly in distilled water. The nanoparticle of Al_2O_3 was purchased from Aldrich. The nanopowders of Al_2O_3 thus obtained were dispersed in water to obtain Al_2O_3 nanofluids of concentration 0.2, 0.4, 0.6, 0.8 and 1 Wt%. The major problem is the rapid settling of the particles which is highly undesirable for many practical heat-transfer/cooling applications. Nanoparticles stay suspended much longer due to smaller size. Even then making stable nanofluids is challenging in lab-scale research. But long term stability of the nanofluids could be a practical issue. Long term stability of nanoparticle suspensions is critical to fully appreciate the benefits of nanofluids[8]. To achieve uniform dispersion of the particles ultrasonic wave was passed through the fluid for 35 h with the help of sonicator. It is evident that the ultrasonic treatment to the fluids increases the settling time of the suspension. Prior to each measurement, the nanofluid was ultrasonicated for 40-45 min to break and deagglomerate clustered nanoparticles.

The velocity values of ultrasonic wave propagation through the Al_2O_3-water nanofluid samples in different ratios were measured by MHF-400 high frequency pulser receiver (supplied by Roop Telsonic ultrasonix Ltd.) at frequency of 2 MHz and 10 MHz at different temperatures . The viscosity of the suspensions was carried out by measuring the times of flow of the fluids using Ostwald's viscometer with an accuracy of ±0.2%. The density of the fluids was measured by using specific gravity bottle (5 cc) with an accuracy of ±2 parts in 10^4. All these measurements were performed for the fluids of all concentrations at five different temperatures 293^0K,298^0K,303^0K,308^0K, 313^0K. The constant temperatures was maintained by circulating water from a thermostatically controlled water bath with accuracy of $\pm 0.1^0C$. The velocity, density, viscosity measurements were

repeated several times for accuracy and the average of five continuous consistent values.

Results and Discussion

The acoustical parameters like adiabatic compressibility(βa), relaxation time (τ) and classical absorption (α/f^2) were measured for nanofluids using the velocity (u), density (ρ) and viscosity (η) data obtained through the experiments. The adiabatic compressibility of the samples was determined using the Newton–Laplace's relation[9-10]:

$$\beta a = {}^{1}/_{\rho . u^{2}}$$

The decay of ultrasonic wave while propagation was obtained using Stokes relation [11] of attenuation:

$$\alpha/f^2 = {}^{8\eta . \pi^2}/_{3\rho . u^2}$$

The relaxation time is given by:

$$\tau = \frac{4}{3}\eta . \beta a$$

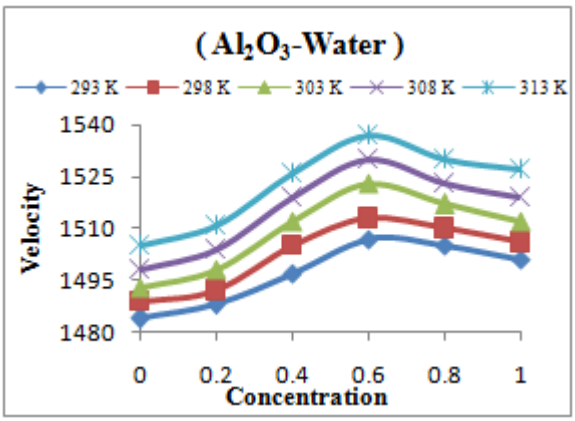

Figure 1: Variation of velocity with molar concentration at 2 MHz

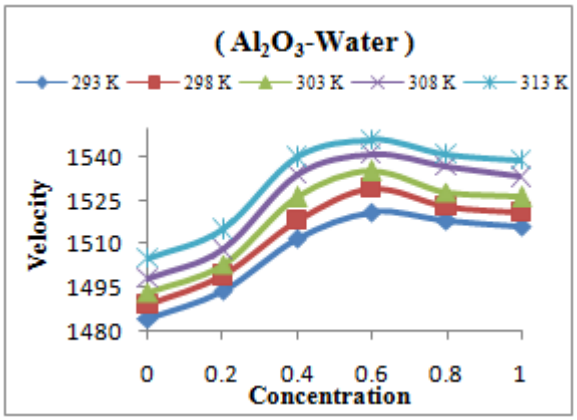

Figure 2: Variation of velocity with molar concentration at 10 MHz

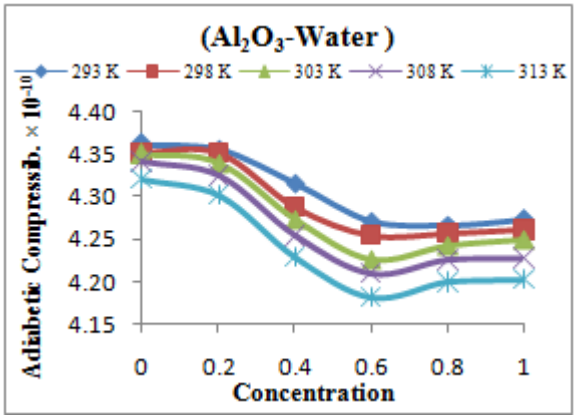

Figure 3: Variation of Adiabetic Compressiility with molar concentration at 2 MHz

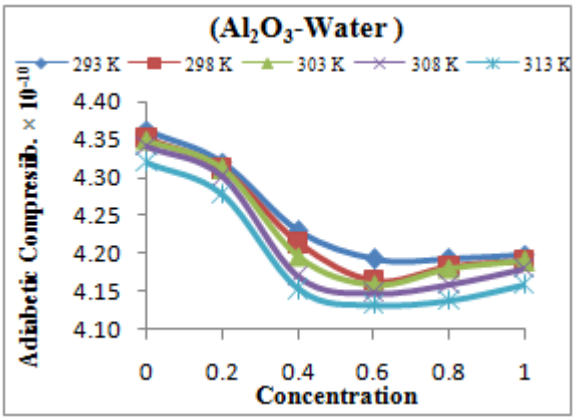

Figure 4: Variation of Adiabetic Compressibility with molar concentration at 10 MHz

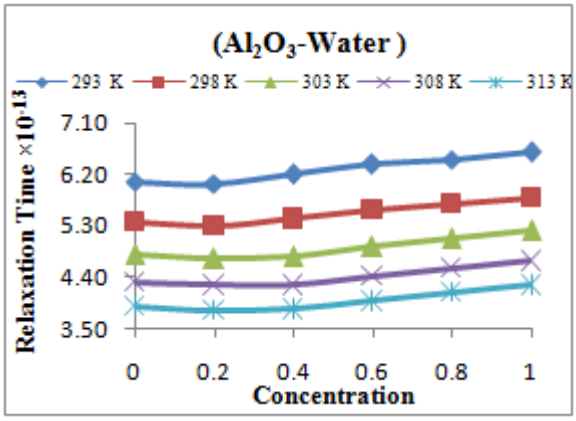

Figure 5: Variation of Relaxation Time with molar concentration at 2 MHz

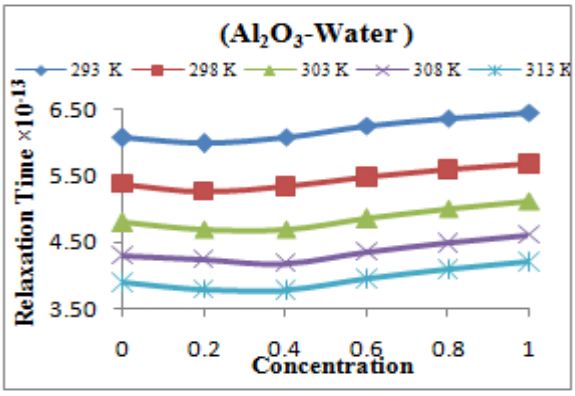

Figure 6: Variation of Relaxation Time with molar concentration at 10 MHz

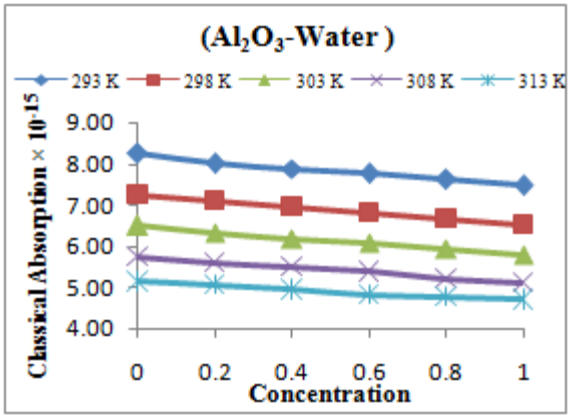

Figure 7: Variation of Classical Absorption with molar concentration at 2 MHz

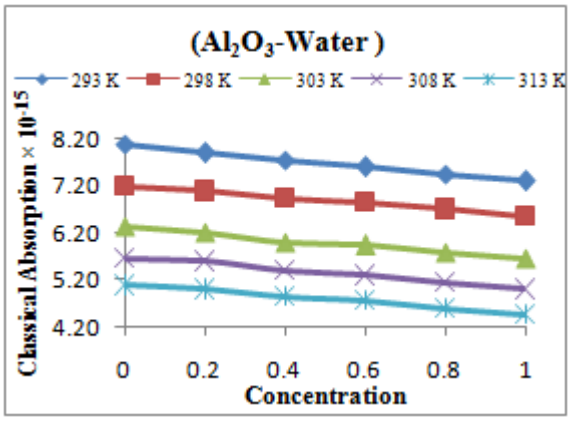

Figure 8: Variation of Classical Absorption with molar concentration at 10 MHz

Fig. 1 and 2 shows the non linear variation of ultrasonic velocity with different molar concentration.These variations depend on structural changes due to intermolecular interactions in short regions around the molecules of solute and solvent. Above the concentration 0.6%, the velocity value decreases indicating the decrease in the nanoparticle–fluid interaction and increase of particle–particle interaction[12].

Fig. 3 and 4 shows the non linear variation of adiabetic compressiblity with different molar concentration. Above the concentration 0.6%, the adiabetic compressibility value increases indicating the increase in the nanoparticle–fluid interaction and decrease of particle–particle. Adiabatic compressibility increases at higher molar concentration indicates the enhancement of degree of association among the solute and solvent molecules. Intermolecular distance increases with decrease in molar concentration.The non linear variation of adiabatic compressibility indicates complex formation in the mixture. Adiabatic compressibility shows an opposite effect to ultrasonic velocity[13].

Fig.5 and 6 shows the variation of relaxation time with different molar concentrtion. Relaxation time increases with increase in molar concentration .

Fig.7 and 8 shows variation of classical absorption with different molar concentration.Classical absorption decreases with increase in molar concentration. The decrease in classical absorption at higher concentration is due to the formation of hydrogen bonds.

The velocity of nanofluids observed as a measure of concentration is seen to have a different trend as it increases to a maximum value up to 0.6 Wt% above which it starts decreasing. The velocity values of nanofluids are highly greater than at a particular concentration of 0.6%. The possible reasons for the linear increase in the ultrasonic velocity at lower concentrations up to 0.6% of these nanofluids are the low values of density and attenuation. Moreover, the nanosized alumina has the surface catalytic effect because of the formation of hydrogen bonds with water. Also, when the nanosized alumina and water molecules interact with each other through secondary forces of attraction, there will be a formation of hierarchical structure which further enhances the velocity.

Thus the decrease in compressibility, increase in viscosity and less density favour higher velocity of the ultrasonic waves at lower concentrations of nanofluids. So it is evident that there is a strong particle– fluid interaction favouring an increase in velocity below the concentration 0.6%. Above this concentration, the velocity value decreases indicating the decrease in the nanoparticle–fluid interaction and increase of particle–particle interaction. It is understood through all the acoustical parameters that in nano Al_2O_3-Water fluid the agglomeration starts at 0.6 Wt% and the particle–particle interaction becomes predominant leading to a decrease in the velocity value. We may also reason out the behaviour at higher concentrations by observing the increasing compressibility values which do not favour the ultrasonic wave propogation. So we can conclude that the concentration range from 0.2 to 0.6% in which the nano Al_2O_3–fluid interaction is highly suitable for nanofluid applications.

3. Conclusions

In the present investigation homogeneous suspensions of nanosized Al_2O_3 in water were prepared in various concentrations with the help of ultrasonication. The acoustical study including ultrasonic velocity, adiabatic compressibility, relaxation time and classical absorption were made for all the fluid samples at temperatures 293,298,303,308,313^{0}K. From the analysis of the above parameters it is evident that the particle–fluid interaction increases with increase of concentration up to a critical concentration of 0.6 Wt% above which the particle–fluid interaction weakens due to strong particle–particle interaction and thereby agglomeration. The possible reason is presented below. At low concentration range the inter particle distance is longer and hence the particle–fluid interaction dominates. But at higher concentrations as the inter particle distance decreases due to the availability of more number of particles, the particle–particle interaction is strengthened.

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