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Acoustic Investigation of ZnO-NPs using Nondestructive Technique: A Novel Application using Bio-solvent

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Abstract

The present investigation deals with thermo acoustic study of colloidal dispersion of Zinc Oxide nanoparticles (ZnO-NPs) in water and *Aloe Vera* juice (Bio-solvent). The data are presented for four different ZnO nanofluids of varying concentrations with base fluid as water and *Aloe Vera* juice prepared by ultra-sonication method. The synthesized nano-particles were prepared by wet chemical method in aqueous media and characterized by Powder X-ray Diffraction method (PXRD) and UV-Spectroscopy. The density and ultrasonic velocity (USV) of binary solutions of ZnO nanofluid are measured at 2 MHz frequency and 301.15K temperature. The acoustic parameters such as adiabatic compressibility, acoustic impedance, intermolecular free length and bulk modulus are calculated using experimental values can make them suitable for use as heat transfer fluids.

Key words

Acoustic study of ZnO nanofluids, ZnO-NPs in *Aloe Vera* juice, *Aloe Vera* as a Bio-solvent.

1. Introduction:

The term 'Nanofluid' was first presented by Argonne National Laboratory to illustrate the colloidal suspension of nanoparticles in a base fluid.[1] Some base fluids have very low thermal conductivities. These are water, ethylene glycol and engine oil. Thermal performance of the base fluid can be altered due to the addition of small quantity of nanoparticles.[2] The main role of nanoparticles dispersed in base fluid for heat transfer has an important effect on the rate of thermal conductivity coefficient. Due to extremely large surface to volume ratio and thus have great potential in heat transfer applications. Nanofluids have wide range of applications like electronics, medical field and transportations. For industrial applications, it is important to develop nanofluid with high stability. The stability mechanism of nanofluids is based on DLVO theory established by Derjaguin, Landau, Verwey and Overbeek. Ultrasonic method is one of the non destructive testing (NDT) technique[3] and can be used to determine acoustical properties of nanofluids. Nanofluids are accepted to have great impact on industrial applications in the future.[4] However, a literature survey on nanofluids also indicates that ultrasonic speed can be utilized to evaluate the thermal conductivity of pure fluids and nanofluids.[5] Ultrasonic testing parameters are significantly affected by changes in microstructural properties of materials. In constitution of our earlier investigations on *Aloe Vera* juice, it is clear that its ultrasonic velocity is very close to water. There for an effort has been made to consider *Aloe Vera* juice as a base fluid for the preparation of nanofluids of Zinc oxide nanoparticles (ZnO-NPs) and evaluating different thermoacoustic parameters using ultrasonic velocity. This paper deals with the importance of material characterization by non destructive testing (NDT) and the effect of material properties on acoustic parameters.[6]

2. Material and Method

2.1 Synthesis of NPs and preparation of binary solutions

To prepare ZnO Nanoparticles for acoustic study, the aqueous solution of zinc nitrate (0.3M) and KOH solution (0.6M) were prepared with double distilled water. The KOH solution was added drop wise into zinc nitrate solution at room temperature 301.15K under continuous stirring. The white suspension so obtained was centrifuged for 25 minutes and washed three times with distilled water and absolute alcohol. Finally the product was dried and calcinated at 400 ^{0}C.[7]

The binary solutions of Zinc nano particles with required concentrations such as 0.5 wt%, 1.0 wt%, 1.5 wt%, and 2.0 wt% were prepared by dispersing a specific amount of ZnO-NPs in water and pure *Aloe Vera* juice (AV juice) respectively and assigned as S1, S2, S3 and S4.[8]

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2.2 Method of USV measurement

The ultrasonic velocity for all the binary mixtures of ZnO-NPs + Water and ZnO-NPs + AV juice have been measured by a single crystal multi-frequency ultrasonic interferometer (Nanofluid interferometer NF-10X) at 2 MHz frequency and 301.15K temperature. The temperature was controlled by circulating hot water around the liquid cell from thermostatically controlled constant temperature (±0.01K) water bath. The procedure of ultrasonic velocity measurement is described elsewhere.[9] Apart from this density and ultrasonic velocity data were used to calculate adiabatic compressibility (β_a), Acoustic impedance (Z), Intermolecular free length (L_f) and Bulk Modulus (K) by using following relations:

$$U = \lambda * f \quad (1)$$

$$Z = \rho U \quad (2)$$

$$\beta_a = 1/\rho U^2 \quad (3)$$

$$L_f = K\sqrt{\beta_a} \quad (4)$$

$$K = 1/\beta_a \quad (5)$$

Where λ is wavelength, f is frequency, ρ is density and U is ultrasonic velocity for the nanofluid samples, K is Jacobson's temperature-dependent constant [K= (93.875+0.375T) X 10^{-8}].

2.3 Characterization

Fig.1 shows the PXRD pattern of synthesized ZnO nano particles. Panalytical's X'Pert Pro diffractometer is used for structural identification with anode Cu, K-α-1 radiation and (λ=1.5405Å) wavelength at room temperature. The characteristic absorption maxima of synthesized ZnO-NPs were obtained by PerkinElmer UV-Visible spectrophotometer. The ultrasonic velocity for all the nanofluids has been measured by a single-crystal multi-frequency variable-path ultrasonic interferometer at 2MHz frequency. The densities of all fluids were measured by specific gravity bottle with doubled distilled water at temperature 301.15K

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3. Results and Discussion

According to the PXRD Fig. 1 shows the intensity and position of peaks that revels ZnO-NPs are successfully formed. All the diffraction peaks from the prepared ZnO-NPs can clearly index to ZnO-NPs. In this diffraction patterns, the peaks at 2θ are in an excellent agreement with a (JCPDS. No. 36-14151). No peak from other impurities is observed[10]. The ultraviolet absorption spectra of synthesized ZnO-NPs are shown in Fig. 2. It revels strong absorption peak at λ-337 nm within the absorption range 200-800 nm which corresponds to the formation of ZnO-NPs. Band gap can be calculate with the help of taue plot. The value of band gap is $E_{g\,=}$ 3.16 eV.

The values of ultrasonic velocities (USV) measured in prepared nanofluids of various concentrations in water and in *Aloe Vera* juice are listed in Table no. 1. In Fig.3 the ultrasonic velocity (U) curves indicate that the ultrasonic velocity increases with increase in concentration in both the base fluids (Water and *Aloe Vera* juice). It is due to the influence of dispersed NPs on the velocity of ultrasonic wave propagation. It may be attributed due to more surface area of NPs due to which more base fluid molecules can be absorbed on its surface. It favors free movement of NPs from one point to another point. It is also found that USV in AV juice is higher than in water. This clearly indicates that there is strong solute-solvent interaction favoring increasing velocity. Agglomeration of NPs is also responsible for increase in ultrasonic velocity with increasing concentration. Fig. 4 indicates adiabatic compressibility (β_a) of ZnO-NPs + Water and ZnO-NPs + AV juice binary solutions of different concentrations (S1, S2, S3 and S4). It is observed that adiabatic compressibility decreases with increase in concentrations of the binary system. The structural changes alter the compressibility. These decrease shows that the system is becoming more compact. The intermolecular forces operating between solute and solvent molecules, results show variation in the values of adiabatic compressibility.

Fig.5 indicates the value of Acoustic impedance (Z). The increasing values of acoustics impedance indicate that there is significant interaction between the NPs and base fluid. From Fig. 6 it is observed that acoustic impedance increases with increase in concentration of nanofluids. The value of Z is higher in *Aloe Vera* juice than in Water at the same concentration. Fig.6 indicates the intermolecular free length of ZnO-NPs + Water and ZnO-NPs + AV juice nanofluid. It is an important physical property of liquid media which mainly affect the sound velocity. It is

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observed that L_f decreases with increase in concentration. It is also found that L_f is decreasing more in ZnO-NPs + AV juice system than in ZnO-NPs + Water system at same concentration. It means there is strong solute-solvent interaction is present in ZnNPs-AV juice and weak solute-solvent interaction is present in ZnNPs- water system. Fig. 7 shows the values of bulk modulus (K) of the binary systems at different concentrations mentioned above. It determines how much a system is compressible. It is considered as a descriptor of elastic properties. Once the pressure is released, a compressed material returns to its original volume. From the figure it is clear that the bulk modulus increases with increase in concentration. The value of K is quite higher for ZnO-NPs + AV juice system than in ZnO-NPs + Water system. A high value of K indicates that the system resist compression. It also proves strong solute-solvent interaction in ZnO-NPs + AV juic system.

Table No.1-Measured values of USV of ZnO-NPs in Water and *Aloe Vera* juice

Sample	USV in H_2O (U) (ms^{-1})	USV in AV juice (ms^{-1})
S1	1500.21	1508.84
S2	1502.31	1509.17
S3	1504.01	1511.19
S4	1505.64	1512.21

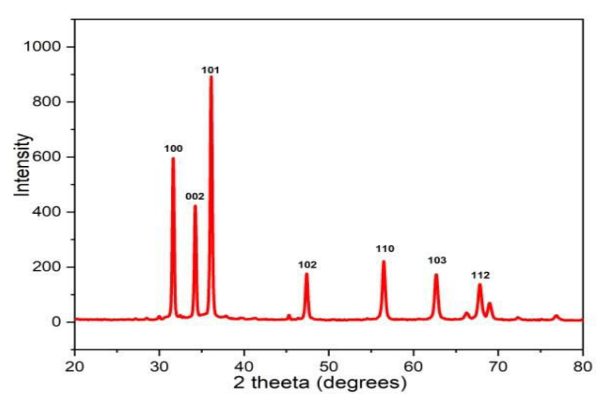

Fig.1 PXRD pattern of Zno nanoparticle

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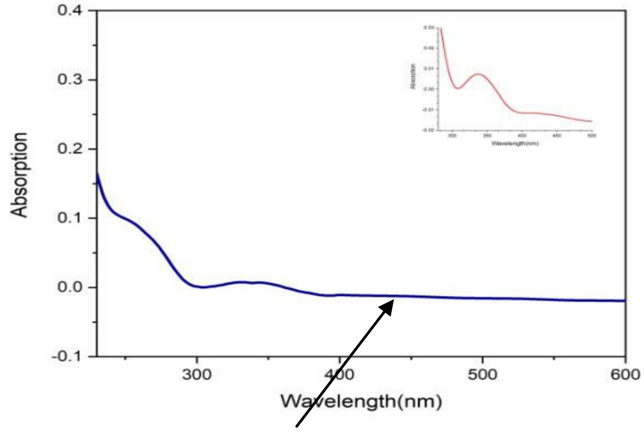

Fig.2 UV spectra of ZnO NPs

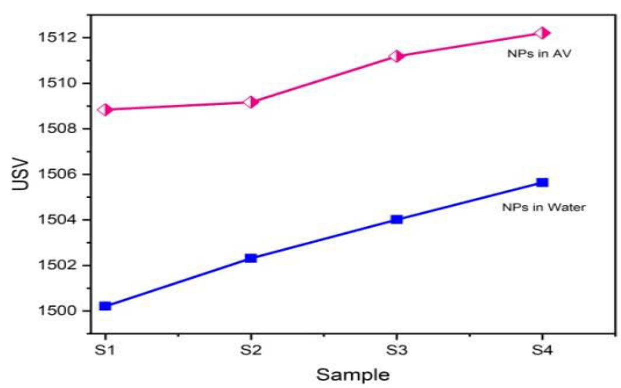

Fig.3 Ultrasonic velocity (USV) of ZnO NPs in Water & AV juice

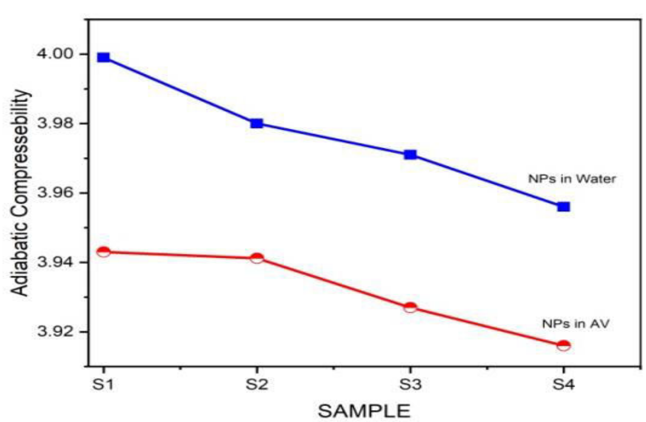

Fig.4 Adiabatic Compressibility (β_a) of ZnO-NPs in Water & AV juice

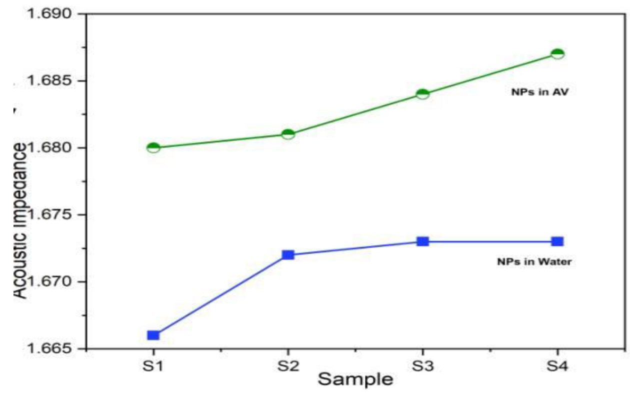

Fig.5 Acoustic Impedance (Z) of ZnO-NPs in Water & AV juice

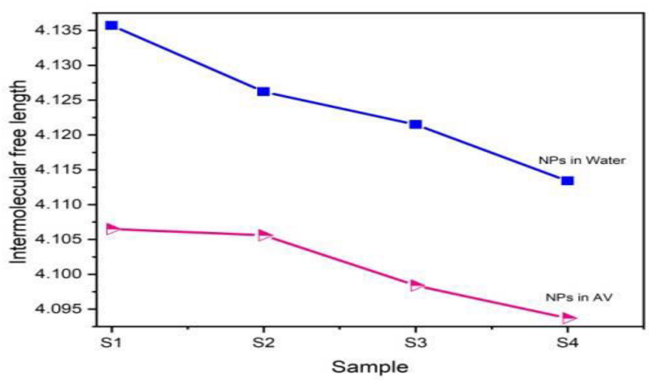

Fig.6 Intermolecular free length (L_f) of ZnO-NPs in Water and AV juice

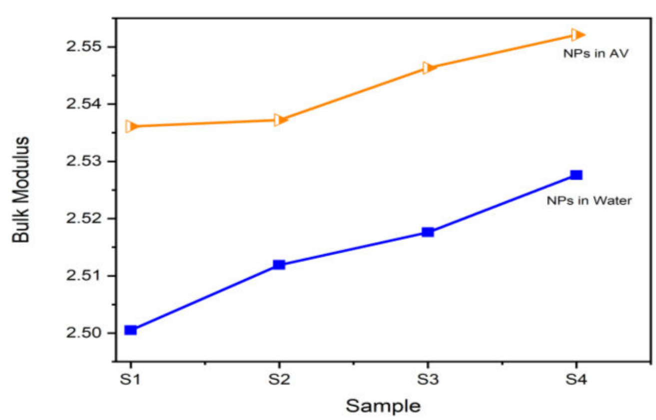

Fig.7 Bulk modulus (K) of ZnO-NPs in Water and AV juice

4. Conclusion

Zinc oxide nanoparticles were successfully synthesized by wet chemical method. UV- Visible spectrum confirms the formation of Zinc oxide nanoparticles. From UV analysis the band gap is found to be 3.16 eV. Thermoacoustic investigation of ZnO-NPs + Water and ZnO-NPs + AV juice at different concentrations has been determined experimentally. Strong solute-solvent interaction is present in ZnO-NPs + AV juice and weak solute-solvent interaction is present in ZnO-NPs + water at same concentrations.

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