International Journal of Research and Review
Vol. 11; Issue: 1; January 2024
Website: www.ijrrjournal.com
Review Paper *E-ISSN: 2349-9788; P-ISSN: 2454-2237*

Review of Density and Ultrasonic Velocity of Various Complexes and Its Applications

Kirti Kohar[1], Marvi Gupta[1], Hariti Mehta[2]

[1,2]Department of Chemistry, Post Graduate Govt. College for Girls, Sec-11, Chandigarh, India

Corresponding Author: Veneeta Anand

DOI: https://doi.org/10.52403/ijrr.20240147

ABSTRACT

This review paper delves into the fundamental principles, measurement techniques, and diverse applications of ultrasonic velocity and density. Ultrasonic velocity serves as a crucial parameter in various fields such as materials science, acoustics, and medical diagnostics whereas density is used for identifying substances, quality control, analyzing mixtures, assessing purity, explaining buoyancy, determining concentrations, calibrating instruments, monitoring pollution, and understanding reactivity. This paper provides an in-depth exploration of the underlying concepts, different measurement methods, and the wide-ranging applications of ultrasonic velocity and density. The ultrasonic velocity and density data have also been used to evaluate various acoustic parameters such as isentropic compressibility, apparent isentropic molar compressibility, solvation number of the solute and relative association.

Ultrasonic velocity measurements are found to be useful for on-line assessment of the extent of degradation of mechanical properties associated with precipitation of intermetallics.

Keywords: Density, Ultrasonic velocity

INTRODUCTION

Density is a fundamental physical property that quantifies the amount of mass per unit volume within a substance. It is a measure of how closely packed the particles or molecules are in a material. The concept of density is widely applicable across various scientific fields and industries, from physics and chemistry to engineering, geology, and biology.

Density can be influenced by temperature and pressure changes. As substances experience temperature changes, their molecular motion and spacing can alter, leading to changes in density. Similarly, under varying pressure conditions, the arrangement of particles within a substance may compress or expand, causing density to change.

Density is important in solubility because it influences how well a electrolyte dissolves in a given solvent. Because their molecular structures are compatible, substances with similar densities are more likely to dissolve in one another. They are critical for establishing a solution's concentration.

Ultrasonic velocity can be employed to investigate concentration-dependent effects and complex solvation behaviour. Changes in velocity with changing concentrations or solvents reveal how the complex interacts with its surroundings and how solvent molecules surround and influence the complex structure.

The way ultrasonic velocity changes during solvation can give details about the nature of solute-solvent interactions. Stronger contacts, such as hydrogen bonding, can cause more pronounced variations in velocity, showing that solvation has a greater influence.

Ultrasonic velocity measurements can be conducted at different temperatures and

pressures to investigate how solvation effects change under varying conditions.

By comparing ultrasonic velocity measurements of different solvents with the same solute, researchers can assess how solvation effects vary based on solvent properties. This aids in understanding the role of solvent polarity, size, and other factors in solvation processes.

REVIEW OF LITERATURE

In 1962, J.A. Cahill and A. D. Kirshenbaum, calculated the density of liquid copper from its metling point. A knowledge of the density of liquid metals which melt at temperatures exceeding I000°K has become extremely important to many branches of scientific investigation. It has been noted, however, that many of these data for even our most abundant metallic elements have not been measured over a temperature range. Copper, which ranks high in importance and abundance among the common metals, is in this category. It is a liquid at atmospheric pressure over a temperature range of 1500°K. (m.p. = 1356°K)[1]. The density was determined in an argon atmosphere by immersed sinker method in the temperature range of 1356 to 2500°K. Below the temperature of 2100°K, molybdenum sinkers coated with zirconium dioxide and zirconium oxide crucibles were employed however graphite sinkers and crucibles were used to 2500°K. Carbon tube resistance furnace was used as temperature source in these measurements [2]. By using this method, the density was successfully calculated as 7.992 gm/cm^3 at the melting point i.e. 1356°K.

In 1970, research was conducted to determine sound velocity in aqueous non electrolyte solution in relation to water structure. The plot of velocity of aqueous solution of hexamethylenetetraamine (HMT), Urea and N, N dimethylformamide (DMF) against temperature gives parabolic curve similar to that of pure water. It was found for dilute solutions, the V(T) curve changes in systematic manner with concentration, keeping the parabolic form nearly the same as that for the water. In these curves the maximum height of sound velocity is higher than that for the pure water and temperature at maximum point is lower than for water. The maximum value decreases with thr increasing temperature. It was concluded that the maximum velocity observed for some aqueous solution at certain concentration at constant temperature does not correspond to decrease in compressibility resulting from water – solute association, but is attributed to the balance between the relative magnitude of the structural compressibility of water cluster and ordinary compressibility of the non-associated water molecules and solute. The sound velocity of acetamide and DMF is 1404.4 m/sec at 65°C and 1478.8 m/sec at 20°C respectively and shows a negative temperature coefficient.

In 1975, C.O. Ruud, had conducted measurements on Density of liquid copper and copper alloys to a precision of 0.1%. For this, he had used graphite pycnometer fitted with a pressure valve to maintain the vacuum of 10^-4 Torr. Density was measured between 20-200°C above the the melting temperature. The basic purpose of this research was to generate density data for commercial copper alloys. The data are reported so as to comply, With the equation,

P=a +b (T - Tm)

Where p is in g/cm 3 (10-3kg/m3), a and b are constants, and T and T m are the temperature of the liquid metal and the melting temperature in K, respectively.

In 1984, researchers had calculated the ultrasonic velocity using phase slope and cross correlation method. Ultrasonic velocity measurements are widely used to determine properties and states of materials. There has been an Increasing use of ultrasonic velocity measurements for nondestructive characterization of material microstructures

and mechanical properties [3 to 7]. Therefore, it is Important to have appropriate practical methods for making velocity measurements on a variety of material samples. The purpose of this report is to deal with those cases where pulse-echo signals are weak or distorted by attenuation and other factors that render them unsuitable for the overlap approach. This report describes ultrasonic velocity measurement methods based on computer digitization of broadband pulse-echo waveforms. Three digital methods are compared: (1) overlap, (2) phase-slope, And (3) cross-correlation. The digital overlap method is an effective way to automate the analog overlap method. The overlap method requires Input of Information concerning echo Inversions, peak selection, etc. Once overlap criteria are established, the digital time domain method simulates a manual overlap based on visual Inspection of analog waveforms. However, even digital signal manipulation of time domain signals can be problematic if the waveforms are subject to noise, attenuation, and similar factors. The frequency domain phase-slope method eliminates problems encountered in the time domain, e.g., the need to account for echo Inversions. In addition, it provides convenient criteria for selecting an appropriate frequency range in cases where the major portion of the phase spectra of the echoes are mutually linear. Generally, for nonlinear dispersive cases, the phase-slope method can determine group velocities as functions of frequency [8]. However, if signal-to-noise ratio is low, poor results are obtained. The advantages of the cross-correlation method are apparent when the signal-to-noise ratio is low and/or random noise is superimposed on the echoes. One of the demonstrated properties of the cross-correlation function is that it is (statistically) weighted by dominant frequencies common to the waveforms being correlated [9,10]. Therefore, the cross-correlation function returns a group velocity within the frequency bandwidth of the signals analyzed. With the cross-correlation method, effects of random noise, extraneous signals, etc. are minimized.'

In 1994, researchers had compared the ultrasonic velocity of copper (1) salts in acetonitrile and benzonitrile. A range of concentrations of the electrolytes in AN and BN was produced by diluting stock solutions of appropriate concentrations. The results were obtained at three different temperatures, at 298, 308 and 318°K. It was found that ultrasonic velocity decreases with increasing temperature [11]. The graph was plotted between ultrasonic velocity and molarity of different electrolytes in AN and BN. The graph came out to be linear. It was also found that ultrasonic velocity in AN are smaller than in BN which indicates that the ions are more strongly solvated in acetonitrile than in benzonitrile.

Similarly, in 1995, the ultrasonic velocity of copper 1 salts was studied in cyanobenzene, pyridine and cyanomethane. The purpose of the study was to investigate the solvation of copper 1 in these solvents. Ultrasonic velocity of CuClO4 was measured at several concentration of salts in the range 0.01-0.45 mol/kg in cyanobenzene, pyridine and cyanomethane at 298, 308 and 318°K. All these plots of ultrasonic velocity vs molarity came out to be linear. It was found that CuClO4 shows stronger structural effect in cyanomethane and relatively weaker in cyanobenzene and pyridine [12].

In 2004, ultrasonic sound velocity measurements in the sample of soft material through under- resonance excitation was studied by JEAN-JACQUES AMMANN, † VICTOR APABLAZA, BELFOR GALAZ, and CAROLINA FLORES. As ultrasonic velocity determination is a valuable characterization technique, providing important information on elastic properties of materials. Elastic properties are of central interest for biologic tissue characterization and quantitative echography. This is clearly not easily achievable for soft materials, such as

biologic soft tissues or tissue-mimicking phantoms. From this consideration, previous works have established that sound velocity can be determined in through-transmission configuration without thickness measurement through the time-of-flight determination of specimen-reflected echoes in plane parallel-surfaced specimens. It is shown here that the amplitude and shape of these specimen echoes can be significantly improved by working in the tone-burst mode at an excitation frequency below the transducer resonance. This is particularly valuable for materials presenting a low acoustic contrast with the surrounding medium, usually water, such as tissue mimicking materials and water-based phantoms, making the specimen echo time-of-flights and, consequently, the sound velocity determination, more reliable [13].

In 2007, Sunita R. Dandwate, studied the ultrasonic velocity of binary mixture of DMSO with methanol, ethanol, and propanol by using ultrasonic interferometer. The chemicals used for various binary mixtures were AR/GR grade [14]. The various techniques used to measure the ultrasonic velocity are optical method, aousto-optical method, Pulse method, Interferometer. The ultrasonic velocity measurements were done at room temperature (25°C) by a single crystal ultrasonic interferometer operating at frequency 2MHz [14]. It was concluded that for every sample of binary mixture i.e. Methanol, ethanol and propanol with DMSO; when proportion of DMSO decreases, the corresponding ultrasonic velocity through the mixture also decreases [14]. There is decrease in velocity of ultrasonic waves with decrease in density of binary liquid mixture. It was concluded that ultrasonic velocity of liquid depends upon the structural arrangement in liquid as well as on intermolecular interaction [14].

Sven Eckert, Gunter Gerbeth, and Vladimir I. Melnikov had also measured the ultrasonic velocity in liquid metals using the acoustic wave guides. Their aim was to develop ultrasonic sensor which can work up to maximum temperatures of about 800°C. Stainless steel was selected as wave guide material. Steel resists against a number of metallic melts at these high temperatures.A new type of an integrated ultrasonic probe for measurements with the ultrasound Doppler velocimetry (UDV) was developed. The use of this integrated sensor enables the possibility to apply the UDV for velocity measurements in hot, metallic melts up to about 600-800°C. This approach has opened a new field for applications of UDV. It represents a powerful measuring technique for investigations of the velocity structure in liquid metals, thus improving the poor measuring situation for such kind of opaque fluids. The reliability of the sensor has been demonstrated with successful measurements in PbBi at 300°C and CuSn at 650°C [15].

In 2015, Rymantas Kazys, Reimondas Sliteris, Regina Rekuviene, Egidijus Zukauskas and Liudas mazeika had done the research on measurement of density of liquid in extreme condition using the ultrasonic techniques. As density is an important mechanical property of liquid. This is a fundamental parameter for the quality of the final product and a very significant factor affecting the production cost and profitability of the manufacturing process [16 and 17]. Basically, in their research they had analysed the influence of geometry and material parameter of the measurement system (transducer, waveguide, matching layer) on measurement accuracy.

For density measurement in extreme condition, the steel wave magnitude with the pressed aluminium powder matching layer is used. For density measurements in extreme condition, they proposed the measurement method in which the ultrasonic signals, reflected from the tip of the waveguide contacting the measured liquid are exploited [18]. In-process measurements may be on-line or in-line [19 and 20]. The method they used was suitable for on-line density measurements. In their work,

they mainly focused on the density measurement technique itself, but the technique's performance in extreme condition was not investigated in detail [21].

In 2018, the density of copper in liquid form was calculated using the newly developed instrument based on Archimedes principle. The copper used for experiment was 99.9% pure which was preliminary cleaned using sandblasting to remove the surface oxides. It was found that this cell has a high potential for calculating liquid steel density. It was suitable for conducting measurements of liquid metal at h high temperature from 700 to 1520°C. However, the accuracy of density measurement decreases with temperature below 700°C due to oxidation of the melt surface. This cell was successful calibrated and the density of copper was measured with an over estimation of approximately 0.5% for copper [22].

In 2019, S. FAROOK BASHA and M. SYED ALI PADUSHA, conducted a research on ultrasonic studies of molecular interactions of synthesized mannich bases hydrazine carboxamide (MPH), and (morpholino)(thiophen-2-yl) methyl) nicotine hydrazide (MTN) in a polar aprotic solvent dimethyl sulphoxide (DMSO) at different temperatures. Dimethyl sulphoxide (DMSO) is an effective solvent and widely used for the synthesis of organic compounds. Compounds which contain amide moieties (urea, acetamide, Semi and thiosemicarbazide, phenyl urea) are easily soluble in water. But, in some synthesis water may not be used as a solvent because of several reasons. In such cases, DMSO is used instead of water. This colourless liquid is an important polar aprotic solvent that dissolves both polar and non-polar compounds and is miscible in a wide range of organic solvents as well as water. Through oxygen it may have the chances to form hydrogen bonding with other molecules. Keeping in this view , binary liquid mixture containing DMSO and MPH/MTN at five different concentrations was prepared and the parameters were studied at three different temperatures . It has been observed that, as the concentration increases, velocity decreases. This decrease in velocity is due to increased association between the solute and the solvent molecules. The compounds MPH and MTN have NH-CO-NH arrangement, this may interact with solvent molecules (DMSO). This shows the existence of hydrogen bonding present in the liquid mixture. Further, it has been observed that when temperature increases velocity decreases, this may be attributed to the increased vibration or collision between the solvent and solute molecules [23].

In 2019, S. R. Gaur R, P. Phase, S.B.Hiwale , conducted a study on ultrasonic velocity and density of Naratriptan Hydrochloride at different temperatures. In their experiment, densities were determined by using a 25 cm3 bicapillary pycnometer and calibrated with deionized double distilled water with a density of 996.0 kg ·m-3 at a temperature of 303.15 K. The pycnometer was thermostatted in a transparent walled water bath (maintained constant to ± 0.01 K) for 15 min to attain thermal equilibrium, and the liquid level in the two arms was obtained with a traveling microscope which could read to 0.01 mm. The precision of the density measurements was estimated to be ± 0.0003 g ·cm-3. For Ultrasonic Velocity, a single crystal variable path interferometer has been employed for the measurements of ultrasonic velocity of aqueous solutions. The test solution in the cell is allowed to thermally equilibrate. The micrometer was rotated very slowly so as to obtain a maximum or minimum of anode current. It was concluded that as the concentration of the solute increases, the density and the ultrasonic velocity also increases, which in turns, comfirmed the increase of cohesive force because of small intermolecular interactions. It was also found that ultrasonic velocity decreases with the increase in free length and vice versa [24].

Declaration by Authors
Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Kirti Kohar, Marvi Gupta, Hariti Mehta. Review of density and ultrasonic velocity of various complexes and its applications. *International Journal of Research and Review*. 2024; 11(1): 431-437.
DOI: *https://doi.org/10.52403/ijrr.20240147*

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