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The Propagation of Ultrasonic Wave in Phenol

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Abstract— The study investigates ultrasonic wave propagation in phenol and water, focusing on velocity determination and adiabatic compressibility calculations. Using an ultrasonic interferometer and high-frequency generator, the experimental observations reveal notable differences in ultrasonic velocities and compressibility for the two liquids. The results show higher ultrasonic velocity and lower compressibility for water compared to phenol. This analysis provides valuable insights into the acoustic and molecular properties of the studied liquids, contributing to advancements in material characterization through ultrasonic techniques.

Keywords— Ultrasonic Interferometer, Adiabatic Compressibility, Ultrasonic Velocity, Phenol, Water.

I. INTRODUCTION

Ultrasonic technology has emerged as a promising alternative to conventional techniques for the characterization of acids. This review highlights ultrasound as a cost-effective, efficient, convenient, and flexible approach, potentially addressing the growing demands of the acids industry. Traditional methods for the characterization of acids often involve complex procedures and high operational costs, whereas ultrasonic techniques offer simplicity and rapid data acquisition.

Phenolic compounds, a key group of secondary metabolites prevalent in plant species, exhibit significant structural diversity. These compounds can exist in various forms, such as glycosides, aglycones, free-bound or matrix-bound, and range from monomers to polymers. Their distribution in plants is non-uniform, and their stability is highly variable, complicating the extraction process. Employing unsuitable extraction techniques may adversely impact the recovery of phenolic compounds, underlining the importance of selecting appropriate methods to maximize yields from plant matrices. This review also emphasizes the significance of extraction strategies—both conventional and unconventional—for obtaining phenolic compounds.

Ultrasonic wave velocity and adiabatic compressibility are vital acoustic parameters extensively used to investigate the physicochemical properties and molecular interactions in liquid systems. These parameters offer insights into the structural dynamics, intermolecular forces, and thermodynamic behaviour of binary and ternary liquid mixtures. In particular, the phenol-water system has attracted significant attention due to its hydrogen-bonding capabilities and unique amphiphilic nature, which facilitate various types of molecular interactions. The comparative analysis of ultrasonic wave velocity and adiabatic compressibility in phenol and water provides an effective approach to understanding the structural arrangements and thermodynamic properties of such mixtures, which is critical for applications in chemical, pharmaceutical, and material sciences.

Ultrasonic wave velocity is a sensitive tool for characterizing molecular interactions. It depends on the density, compressibility, and structural organization of molecules in a liquid system. The phenol-water system exhibits significant variations in ultrasonic velocity due to the formation of hydrogen bonds between water molecules and the hydroxyl group of phenol. Such interactions influence the medium's acoustic impedance and compressibility, revealing crucial details about molecular arrangements.

Recent research has extensively investigated the behavior of ultrasonic waves in phenolic compounds, particularly their role in extraction techniques and material assessment [1]. A review conducted and analyzed the ultrasonic degradation of phenol and its derivatives in aqueous solutions, emphasizing the role of cavitation-induced free radicals in breaking down these substances [2]. Another study focused on optimizing ultrasonic-assisted extraction of phenolic compounds from Mentha piperita, utilizing response surface methodology to improve both yield and antioxidant activity [3]. Research examined Justicia spicigera leaves, illustrating that ultrasound-assisted extraction provides a faster and more effective method compared to traditional approaches. Similarly, an investigation in the same year compared various extraction techniques for obtaining phenolic compounds from walnut shells, revealing that ultrasound-assisted extraction, particularly with an ultrasonic probe, notably enhanced efficiency [4]. A study explored how ultrasonic wave propagation, specifically through compression and rarefaction cycles, significantly improved the extraction of phenolic compounds, demonstrating an increase in total phenolic content. These studies collectively highlight the effectiveness of ultrasonic waves in facilitating phenolic compound extraction and degradation, offering valuable insights for optimizing extraction processes and improving efficiency [5]. The use of ultrasonic techniques extends to material science and nanotechnology, where the understanding of molecular interactions aids in developing advanced materials and composites. These diverse applications highlight the relevance of ultrasonic studies in both fundamental and applied research.

A. Material and Method

Phenol (C_6H_6O) is an aromatic compound where a hydroxyl (-OH) group is directly bonded to a benzene ring. It is typically a colorless to white crystalline solid with a characteristic sweet, tar-like odor, though it may develop a pink hue upon oxidation. Phenol has a melting point of 40.5°C and a boiling point of 181.7°C, and it dissolves moderately in water (8.3 g/100 mL at 20°C) due to hydrogen bonding. It exhibits weak acidic properties ($pK_a \approx 9.95$) because the phenoxide ion formed upon losing a proton is stabilized through resonance. The hydroxyl group enhances the ring's reactivity, making phenol more susceptible to electrophilic

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substitution reactions such as halogenation, nitration, and sulfonation, primarily at the ortho and para positions.

Hydrogen bonding contributes to its relatively high melting and boiling points compared to hydrocarbons of similar size. Phenol is widely used as a raw material in the production of resins, antiseptics, dyes, and pharmaceutical products.

B. Ultrasonic Interferometer

An ultrasonic interferometer is a device used to measure the velocity of ultrasonic sound waves in liquids and determine their physical properties such as adiabatic compressibility. The principle involves generating standing waves in the liquid by superimposing incident and reflected ultrasonic waves, which leads to variations in acoustic pressure.

Experimental Setup

The ultrasonic interferometer consist of :

1. High-Frequency Oscillator: Generates ultrsonic wave in the range of 1 – 5 MHz.

2. Measuring Cell: Holds the liquid sample and has a quartz crystal at the bottom to generate ultrasonic waves.

3. Movable Reflector: Adjusted to create standing waves by reflecting ultrasonic waves.

4. Micrometer Screw: Precisely moves the reflector to detect changes in pressure.

5. Voltage Meter: Measures the corresponding changes in amplitude to determine standing wave patterns.

Procedure

1. Sample Preparation: Fill the measuring cell with the liquid sample without air bubbles.

2. Calibration: Turn on the oscillator and set the desired frequency.

3. Standing Waves: Adjust the micrometer screw to vary the distance between the quartz crystal and the reflector, observing the formation of standing waves.

4. Pressure Maxima: Record the positions of successive maxima of acoustic pressure using the micrometer scale.

5. Velocity Calculation: Use the distance between maxima (equal to half the wavelength) and the oscillator frequency to calculate the velocity (v) of the ultrasonic waves using

Adiabatic compressibility: Adiabatic compressibility refers to the ability of a fluid to undergo a relative volume change in response to variations in pressure, while maintaining thermal equilibrium.

It is mathematically represented as the inverse of the bulk modulus (β). The adiabatic compressibility of a given material can be determined using a specific mathematical equation.

C. (a)

1) Observation Table

Now, the value of ultrasonic velocity with standard deviation (max &min) of water at 2MHz frequency is shown in the table.

S. No	Micrometer readings corresponding to max /min (mm)	I (μm)	d = λ/2
1	0.10	84	
2	0.26	76	
3	0.48	84	0.38
4	0.52	77	
5	0.64	62	
6	0.92	76	0.40
7	1.06	80	
8	1.30	66	
9	1.42	81	0.36
10	1.58	84	
11	1.74	72	
12	1.96	82	0.38
13	2.06	78	
14	2.28	59	
15	2.42	78	0.36

Average of difference (λ/2) = d = 0.376 mm

Now Velocity (v) = λ× f = 1484 m/ sec

Adiabatic compressibility

$$\beta = 1/\rho v^2 \ = 4.55\times10^{-10}\ Nm^{-2}$$

2) Now, the value of ultrasonic velocity with standard deviation (max &min) of phenol at 2MHz frequency is shown in the table.

S. No	Micrometer readings corresponding to max /min (mm)	I (μm)	d = λ/2
1	0.12	84	
2	0.26	76	
3	0.44	84	0.32
4	0.54	77	
5	0.66	62	
6	0.84	76	0.30
7	1.02	80	
8	1.16	66	
9	1.30	81	0.28
10	1.58	84	
11	1.74	72	
12	1.90	82	0.32
13	2.04	78	
14	2.28	59	
15	2.32	78	0.28

Average of difference (λ/2) = d = 0.30 mm

Now, Velocity (v) = λ× f = 1200 m/sec

Adiabatic compressibility

$$\beta = 1/\rho v^2 = 6.56\times10^{-10}\ Nm^{-2}$$

Fig.1 shows that the measured ultrasonic velocity in distilled water is 1484 m/s, which is notably higher than the ultrasonic velocity in phenol, recorded at 1200 m/s. This difference indicates that water, as a medium, is less compressible and supports faster propagation of sound waves compared to phenol. The higher velocity in water can be attributed to its hydrogen bonding network, which results in a denser and more structured molecular arrangement, facilitating efficient energy transfer through the medium. Conversely, phenol's molecular structure, with its hydroxyl group attached to an aromatic ring, creates less cohesive intermolecular interactions compared to water, leading to a slower propagation of ultrasonic waves.

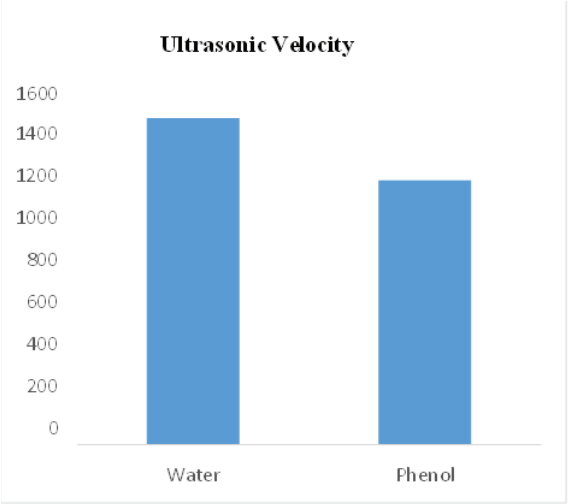

Fig. 1. Comparison of ultrasonic velocity in water and phenol.

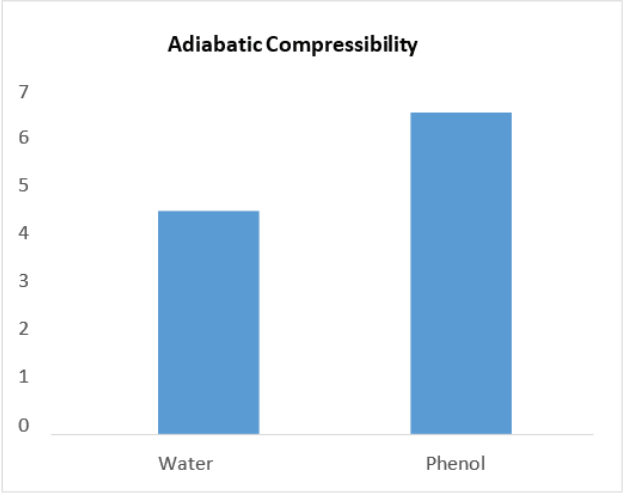

Fig. 2. Comparison of adiabatic compressibility of water and phenol.

Fig. 2 shows that the adiabatic compressibility of distilled water is calculated as 4.55×0^{-10} Nm^{-2}, while that of phenol is 6.56×10^{-10} Nm^{-2}. This indicates that water exhibits greater compressibility compared to phenol under similar conditions. The higher adiabatic compressibility of water suggests that its molecular structure allows for more significant volume changes under pressure. Phenol, with its larger molecular size and strong hydrogen bonding, demonstrates lower compressibility, reflecting its comparatively rigid molecular framework.

II. Conclusion

The study conclusively demonstrates that phenol, with its lower ultrasonic velocity and greater adiabatic compressibility, exhibits significant differences from water in terms of acoustic properties. These findings underscore the effectiveness of ultrasonic wave analysis in understanding molecular interactions and the structural characteristics of liquids.

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