PHY307 LABORATORY REPORT

EXPERIMENT-3

ULTRASONIC INTERFEROMETER

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CONTENTS

Abstract

This experimental study focuses on employing an ultrasonic interferometer to measure the ultrasonic velocity in a liquid medium and, consequently, determine the compressibility of the liquid. Ultrasonic interferometry is a precise and non-destructive technique widely used for characterizing the acoustic properties of materials. In this experiment, a high-frequency ultrasonic wave is passed through the liquid sample in the sample, and the resulting standing waves between the parallel metallic reflector and the quartz crystal are analyzed.

The experimental setup includes a precision ultrasonic interferometer, a sample chamber and RF Generator(2 MHz) cum micro-Ammeter. The ultrasonic interferometer consist of transducer crystal at the bottom of the cell, which is driven by a crystal controlled oscillator fixed frequency. Ultrasonic wave is transmitted to the liquid in contact with the transducer and reflected back from the metal plate, placed at a distance from the transducer in the liquid. The reflective wave is received by the same transducer and a meter indicates the position of the metal reflector is at node or anti node. Stationary wave is formed in the liquid.

The results obtained through this experiment provide valuable insights into the acoustic behavior of the liquid under investigation. Moreover, the method's accuracy and reliability are assessed, demonstrating the feasibility of ultrasonic interferometry for determining both ultrasonic velocity and compressibility of liquids.

1 Theory

1.1 Ultrasonic Waves

Ultrasonic waves are mechanical waves with a frequency higher than the upper limit of human hearing, typically above 20,000 hertz (Hz). They are a type of sound wave, but unlike audible sound waves, humans cannot perceive them without the aid of specialized equipment. Ultrasonic waves have a wide range of applications in various fields due to their unique properties and behaviors.

- **Frequency and Wavelength:**
  - **High Frequency:** Ultrasonic waves have frequencies ranging from 20,000 Hz to several gigahertz (GHz). Their high frequency means they have short wavelengths, allowing them to propagate through materials with fine structures and small particles.

  - **Short Wavelength:** The wavelength of ultrasonic waves is shorter than that of audible sound waves, making them ideal for detecting small objects and flaws in materials.
- **Generation and Detection:**
  - **Transducers:** Ultrasonic waves are generated and detected using transducers, which can convert electrical energy into mechanical vibrations and vice versa. Piezoelectric crystals are often used in transducers for generating and detecting ultrasonic waves.

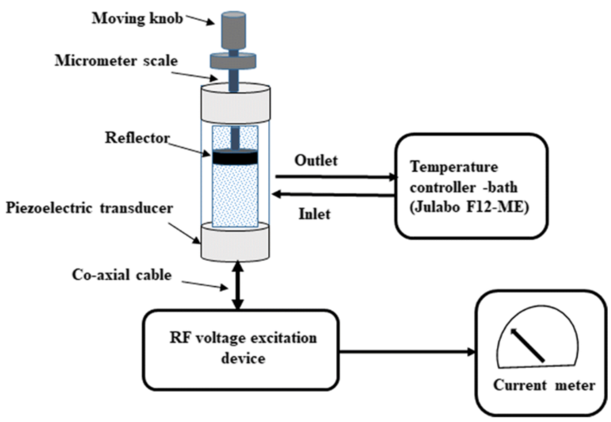
  - **Pulse-Echo Principle:** In applications like ultrasonic testing, a pulse of ultrasonic waves is generated by a transducer. When these waves encounter a boundary or a defect within a material, they are reflected back to the transducer, following the pulse-echo principle. By measuring the time it takes for the echo to return, properties of the material or the presence of defects can be determined.

1.2 Ultrasonic Interferometer

Ultrasonic, thermo-physical and thermodynamic properties of liquid mixtures are of great significance in obtaining an in depth knowledge of inter and intra-molecular interactions, structural and physiochemical behavior and also in verifying various liquid state theories which attempt in estimating the properties of liquid mixtures. Systematic study of thermodynamic properties of solutions with a new type of multi-frequency ultrasonic interferometer is done for precise measurement of the velocity of sound in liquids. The path length in the cell is varied by motion of a reflector, at the electrical reaction of the cell upon the oscillator is used to fix standing wave position at a standard frequency, and their locations are determined with a suitable cathetometer.

An Ultrasonic Interferometer is a simple and direct device to determine the ultrasonic velocity in liquid with a high degree of accuracy. In an ultrasonic interferometer, the ultrasonic waves are produced by the piezoelectric methods. At a fixed frequency variable path interferometer, the wavelength of the sound in an experimental liquid medium is measured, and from this one can calculate its velocity through that medium. The ultrasonic cell is consists of a double walled brass cell with chromium plated surfaces having a capacity of 10 ml. The micrometer scale is marked in units of 0.01 mm and with a digital display which can measure with a least count of 0.001 mm and has an overall length of 25 mm. Ultrasonic waves of known frequency are produced by a quartz crystal which is fixed at the bottom of the cell. There is a movable metallic plate parallel to the quartz plate, which reflects the waves. The waves interfere with their reflections, and if the separation between the plates is exactly an integer multiple of half wave length of sound, standing waves are produced in the liquid medium. Under these circumstances, acoustic resonance occurs. The resonant waves are a maximum in amplitude, causing a corresponding maximum in the anode current of the piezoelectric generator.

$$\textbf{Ultrasonic Velocity}(v) = 2 \times f \times \frac{\lambda}{2}$$
$$\textbf{Compressibilty}(\beta)= \frac{1}{\rho v^2}$$



2 Results and Calculations

2.1 Experimental Data

2.1.1 For Distilled Water

S No.	Minima(mm)(M_i)	$\lambda/2$ (mm)($M_{i+1} - M_i$)
1	0	0.385
2	0.385	0.386
3	0.771	0.387
4	1.158	0.392
5	1.55	0.376
6	1.926	0.381
7	2.307	0.382
8	2.689	0.385
9	3.074	0.388
10	3.462	0.391
11	3.853	0.369
12	4.222	0.389
13	4.611	0.373
14	4.984	0.378
15	5.362	0.372
16	5.734	0.39
17	6.124	0.389
18	6.513	0.397
19	6.91	-
	Average $\lambda/2$	0.383

$\lambda_{DW} = 7.66 \times 10^{-4} m/s$

Table 2.1. Position of the Minimas of Standing Waves formed in **Distilled Water** and their consecutive differences

2.1.2 For Glycerol

S No.	**Minima(mm)(M_i)**	$\boldsymbol{\lambda/2}$ **(mm)**$(M_{i+1} - M_i)$
1	1.085	0.47
2	1.555	0.467
3	2.022	0.448
4	2.47	0.487
5	2.957	0.47
6	3.427	0.468
7	3.895	0.466
8	4.361	0.468
9	4.829	0.469
10	5.298	0.46
11	5.758	0.48
12	6.238	0.467
13	6.705	0.495
14	7.2	-
	Average $\lambda/2$	0.470

$\lambda_G = 9.4 \times 10^{-4} m/s$

Table 2.2. Position of the Minimas of Standing Waves formed in **Glycerol** and their consecutive differences

2.1.3 For Paraffin

S No.	**Minima(mm)**(M_i)	$\lambda/\mathbf{2}$ **(mm)**$(M_{i+1} - M_i)$
1	0	0.35
2	0.35	0.342
3	0.692	0.36
4	1.052	0.342
5	1.394	0.352
6	1.746	0.366
7	2.112	0.347
8	2.459	0.346
9	2.805	0.354
10	3.159	0.342
11	3.501	0.336
12	3.837	0.34
13	4.177	0.326
14	4.503	0.343
15	4.846	0.345
16	5.191	0.335
17	5.526	0.344
18	5.87	0.357
19	6.227	0.351
20	6.578	-
	Average $\lambda/2$	0.346

$\lambda_p = 6.92 \times 10^{-4} m/s$

Table 2.3. Position of the Minimas of Standing Waves formed in **Paraffin** and their consecutive differences

2.2 Calculation of Ultrasonic Velocity in Liquids

2.2.1 For Distilled Water

f(Frequency from RF Generator) = 2 MHz

Velocity(v_{DW}) $= 2 \times f \times \lambda/2$

$v_{DW} = 2 \times 2 \times 10^6 \times 0.383 \times 10^{-3} = 1532\, m/s$

2.2.2 For Glycerol

f = 2 MHz

Velocity(v_G) $= 2 \times f \times \lambda/2$

$v_{DW} = 2 \times 2 \times 10^6 \times 0.470 \times 10^{-3} = 1880\, m/s$

2.2.3 For Paraffin

f = 2 MHz

Velocity(v_P) $= 2 \times f \times \lambda/2$

$v_{DW} = 2 \times 2 \times 10^6 \times 0.346 \times 10^{-3} = 1384\, m/s$

2.3 Calculation of Compressibility of Liquids

2.3.1 For Distilled Water

ρ_{DW}(Density of Distilled Water)= 997 kg/m^3

$$\beta_{DW} = \frac{1}{\rho_{DW} v_{DW}^2} = \frac{1}{997 \times 1532 \times 1532} = 4.273 \times 10^{-10} m^2/N$$

2.3.2 For Glycerol

ρ_G(Density of Glycerol)= 1261.3 kg/m^3

$$\beta_G = \frac{1}{\rho_{DW} v_{DW}^2} = \frac{1}{1261.3 \times 1880 \times 1880} = 2.243 \times 10^{-10} m^2/N$$

2.3.3 For Paraffin

ρ_P(Density of Paraffin)= 930 kg/m^3

$$\beta_P = \frac{1}{\rho_{DW} v_{DW}^2} = \frac{1}{930 \times 1384 \times 1384} = 5.613 \times 10^{-10} m^2/N$$

2.4 Error Calculation

2.4.1 Error in Ultrasonic Velocity(v)

The least count of the measuring instrument(Digital Screw Gauge) is 0.001 mm($\Delta\lambda$).

$$\frac{\Delta v}{v} = \frac{\Delta\lambda}{\lambda}$$

$$\Delta v = v \frac{\Delta\lambda}{\lambda}$$

$$\Delta v_{DW} = v_{DW} \frac{\Delta\lambda}{\lambda_{DW}} = 1532 \times \frac{0.001 \times 10^{-3}}{7.66 \times 10^{-4}} = 2m/s$$

$$\Delta v_G = v_G \frac{\Delta\lambda}{\lambda_G} = 1880 \times \frac{0.001 \times 10^{-3}}{9.4 \times 10^{-4}} = 2m/s$$

$$\Delta v_P = v_P \frac{\Delta\lambda}{\lambda_P} = 1384 \times \frac{0.001 \times 10^{-3}}{6.92 \times 10^{-4}} = 2m/s$$

2.4.2 Error in Compressibility(β)

$$\Delta\beta = |\frac{\partial\beta}{\partial v}| \times \Delta v = \frac{2}{\rho v^3} \times \Delta v$$

$$\Delta\beta_{DW} = \frac{2}{\rho_{DW} v_{DW}^3} \times 2 = \frac{2}{997 \times 1532^3} \times 2 = 1.11 \times 10^{-12} m^2/N$$

$$\Delta\beta_G = \frac{2}{\rho_G v_G^3} \times 2 = \frac{2}{1261.3 \times 1880^3} \times 2 = 4.77 \times 10^{-13} m^2/N$$
$$\Delta\beta_P = \frac{2}{\rho_P v_P^3} \times 2 = \frac{2}{930 \times 1384^3} \times 2 = 1.622 \times 10^{-12} m^2/N$$

Thus the final values obtained

- **Ultrasonic Velocity in Distilled Water : 1532 ± 2 m/s**
- **Ultrasonic Velocity in Glycerol: 1880 ± 2 m/s**
- **Ultrasonic Velocity in Paraffin: 1384 ± 2 m/s**
- **Compressibilty of Distilled Water: (4.273 ± 0.011)** $\times 10^{-10} m^2/N$
- **Compressibilty of Glycerol: (2.243 ± 0.005)** $\times 10^{-10} m^2/N$
- **Compressibilty of Paraffin: (5.613 ± 0.016)** $\times 10^{-10} m^2/N$

3 Discussion and Conclusions

The conducted experiment employing the ultrasonic interferometer for measuring ultrasonic velocity in a liquid and investigating the compressibility of the liquid has yielded significant insights into the acoustic properties of the studied medium. It was found that the ultrasonic velocity is **higher** in **denser liquid** and the liquid which is **less denser**, have lower ultrasonic velocity in it, has **greater** compressibility.

From this we can understand, Sound is a mechanical wave and travels by compression and rarefaction of the medium. Its velocity in an elastic medium is proportional to the square root of Tension in the medium. A higher density leads to more elasticity in the medium and hence the ease by which compression and rarefaction can take place. This way the velocity of sound increases by increase in density.

Firstly, the ultrasonic interferometer, with its intricate setup involving a transducer crystal, fixed-frequency oscillator, and metal reflector, demonstrated its efficacy in generating and detecting ultrasonic waves within the liquid sample. By harnessing the principles of interference, stationary waves were created, allowing for the determination of nodal and antinodal positions.

Secondly, the precise measurement of the ultrasonic velocity in the liquid was achieved by varying parameters such as the distance between the transducer and the metal plate, and by observing corresponding changes in interference patterns. This velocity measurement is invaluable in understanding the medium's acoustic behavior and can serve as a basis for further studies in material characterization and fluid dynamics.

Furthermore, the experiment provided valuable data for calculating the compressibility of the liquid. Compressibility, a fundamental property indicating the medium's response to pressure changes, was accurately determined using the obtained ultrasonic velocity data and the bulk modulus equation. This information is essential for a wide array of applications, including the design and optimization of hydraulic systems and fluid-based technologies.

In conclusion, this experiment not only showcased the robustness and precision of ultrasonic interferometry in studying the acoustic properties of liquids but also highlighted its importance in scientific research and industrial applications.

4 Precautions

1. Do not switch on the generator without filling the experimental liquid in the cell.
2. Remove experimental liquid out of cell after use. Keep it cleaned and dried.
3. Avoid sudden rise or fall in temperature of circulated liquid to prevent thermal shock to the quartz crystal.
4. While cleaning the cell care should be taken not to spoil or scratch the gold plating on the quartz crystal.
5. Give your generator 15 seconds warming up time before the observation.