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MEASUREMENT OF ULTRASONIC VELOCITY IN METHANOL BY CAVITY RESONANCE METHOD

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The study of cavity resonance of the piezoelectric tubular transducer immersed in liquid has been exploited to evaluate the velocity of ultrasonic wave in methanol. Strong correlation has been proved between cavity resonance frequency and velocity of ultrasonic waves. The results are reported in the temperature range 10 – 50°C. The presented method is simple and permit the measurements of ultrasonic velocity of liquids at low frequencies.

1. Introduction

It is well known that the ultrasonic methods are particularly convenient for the study of physical parameters of liquids [1–5]. Specifically a large number of methods exist for measuring ultrasonic velocity in liquids. These methods include for instance ultrasonic interferometer, pulse technique (including superposition and echo overlap technique), sing around and phase comparison method etc. All these methods are limited to high frequencies. The ultrasonic velocity measurements have scarcely been made at elevated temperatures as well as under higher hydrostatic pressures and practically non existent at lower frequencies.

Most of the piezoelectric transducers used for the ultrasonic velocity measurements work in the frequency range about 1 MHz to several hundred MHz. Thus it is rather difficult to measure the velocity in lower frequency ranges i.e. 10 kHz.

It has been known since some time that radial motion of the cylinder walls can excite symmetrical cavity modes in the enclosed liquid column. This cavity resonance frequency is a function of the velocity of ultrasonic waves in liquid.

In the present study it has been shown that the cavity resonance method may be used to evaluate the ultrasonic velocity in liquid.

As the ultrasonic velocity data at various temperatures and pressures for methanol are available in the literature to appreciate the cavity resonance method, the study of cavity resonance frequency in methanol has been carried out versus temperature.

2. Theoretical

An open ended thin walled piezoelectric cylindrical tube vibrating in air shows a dominant radial mode of resonance. When the same tubular transducer is immersed in liquid besides the radial fundamental resonance, the appears a cavity resonance of the enclosed liquid medium. The angular frequencies of the cavity modes are given by [6]:

$$\omega_c^m = [(2m-1)\pi c_0]/(h+2\beta a), \qquad m = 1,2,3,\dots, \tag{1}$$

where h stands for the length of the tubular transducer, β is end correction, a is the inner radius of tubular transducer element and c_0 is the effective velocity of sound in liquid medium due to finite stiffness of the walls of the tubular transducer. The effective velocity c_0 depends on the ultrasonic velocity in open liquid c according to the following relation:

$$c_0 = c(1 + Ba/E_{11}t)^{-1/2}, \tag{2}$$

where E_{11} is the transverse Young's modulus, t is the width of the wall of tubular transducer and B is the bulk modulus of liquid.

$$B = \varrho c^2, \tag{3}$$

where ϱ is the density of liquid. The end correction can be approximated by the expression:

$$\beta = 0.633 - 0.106\omega_c a/c_0 . \tag{4}$$

Combining the equations (1)–(4), for $m = 1$, we arrive at the following expression:

$$\frac{1}{c^2} = \frac{1}{f^2}\left(\frac{h/2a + 0.633 - \sqrt{(h/2a+0.633)^2 - 0.212\pi}}{0.424\pi a}\right)^2 - \frac{2a\varrho}{E_{11}t}. \tag{5}$$

As it is clearly seen this expression represents a linear relation between c^{-2} and f^{-2}. The proportionality coefficient depends only on geometrical parameters of the transducer. Therefore by measuring resonance frequency one can readily evaluate velocity of the ultrasonic waves. Because the mechanical resonance affects the electrical resonance of the piezoelectric transducer [3] the resonance frequency may be evaluated by means of measurement of electrical parameters of the transducer like conductance G or impedance Z.

3. Experimental

The piezoelectric tubular transducer element – outer diameter 25.4 mm, inner diameter 18.85 mm and tube length 25.4 mm — fabricated from piezoelectric material NPLZT–5H (being equivalent to PZT–5H) has been used in our study. The fundamental resonance frequencies of this element in air, have been determined by plotting the variation of impedance (Z) and conductance (G) as a function of frequency. Similar plots were obtained after immersing the tubular transducer element first in deionised water and later in methanol.

These plots were used to determine cavity resonance frequencies as well as fundamental resonance frequencies.

We used methanol in our studies for two reasons. Firstly, it is well known medium studied by many research group. Hence there is a great deal of experimental data (gained at varying pressure and temperature) available in the literature [1]. Secondly, methanol is a non-conductive liquid so the piezoelectric tubular transducer can be safely immersed in it.

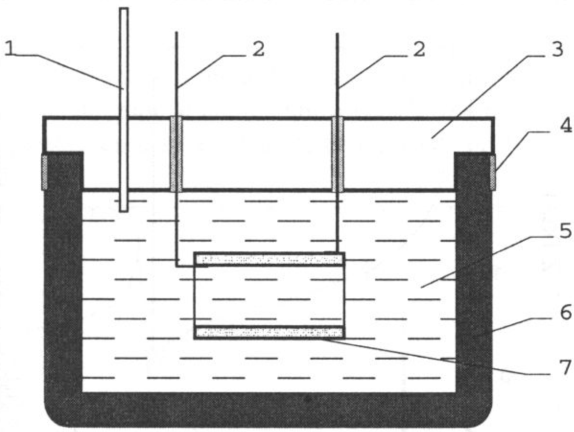

Fig. 1. Experimental setup. 1 – pipe; 2 – electric wires; 3 – aluminium cover; 4 – bandage; 5 – tested liquid; 6 – rubber container; 7 – tubular piezoelectric transducer.

Our measurements of cavity resonance have been carried out using special neoprene rubber container as depicted in Fig. 1. The top of the container is fitted with the aluminium alloy cover by clamp. Two isolated electric wire connection (2) were used for the measurement of required electrical parameters. The Hewlett Packard impedance analyzer 4192A LF was used for the measurements of impedances and conductances. The comparison between plots of impedance (Z) vs. frequency of the piezoelectric tubular transducer element in air (Fig. 2) and deionised water (Fig. 3) clearly indicate the cavity resonance at $\sim$ 20 kHz. Resonant maximum of the same frequency appears at the plot of conductance (G) vs. frequency (Fig. 4).

Similar observations with the different other liquids such as paraffin oil and methanol show the cavity resonances below 20 kHz. The ultrasonic velocities derived using Eq. (5)

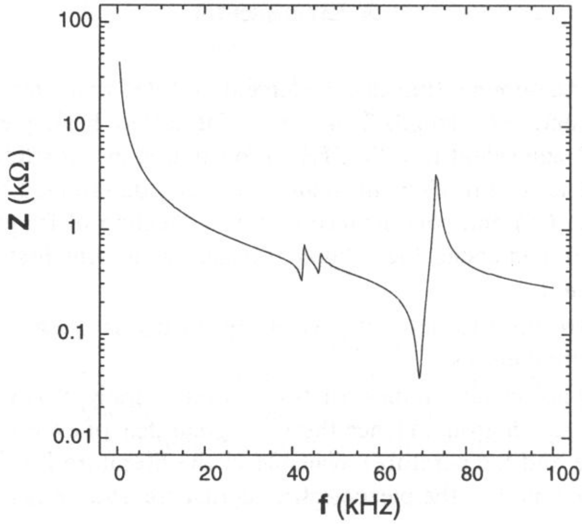

Fig. 2. Dependence of impedance Z of tubular transducer vs. frequency f in air.

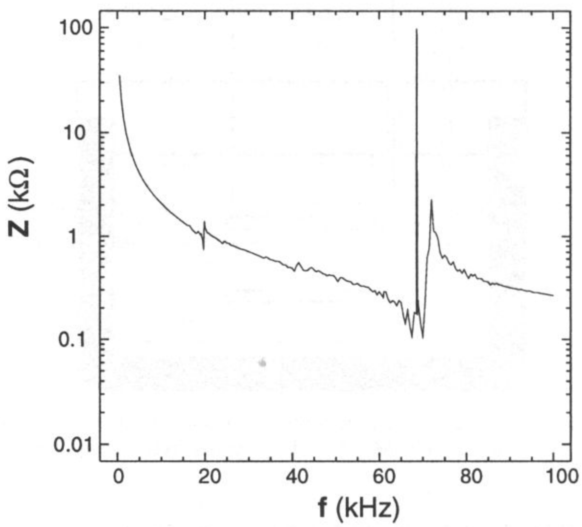

Fig. 3. Dependence of impedance Z of tubular transducer vs. frequency f in deionized water.

from measured cavity resonances are in quite good agreement with those reported earlier in the literature.

Further the cavity resonance in the liquid has been confirmed with direct measurement of transmitted acoustical wave by using hydrophone and test tank. The acoustical output power as a function of frequency has shown significant maximum value at the same cavity resonant frequency as measured by means of impedance/conductance vs. frequency plot.

The very sharp resonance (Fig. 5) is observed for radial mode vibration in air. After immersing the tubular transducer element in methanol one gets rather a complicated plot

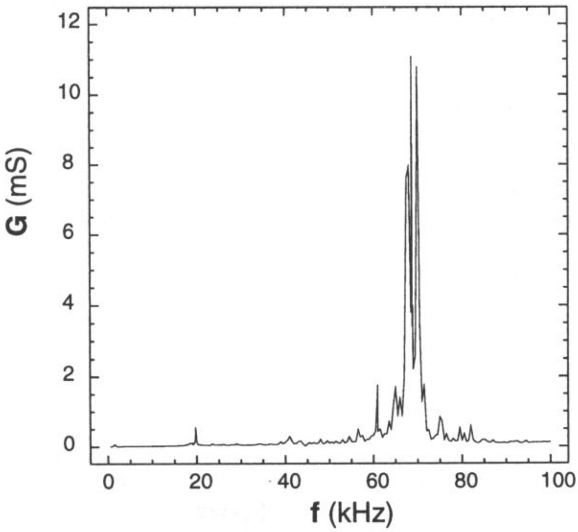

Fig. 4. Dependence of conductance G of tubular transducer vs. frequency f in deionized water.

(Fig. 6). It may be seen that there is an additional resonance frequency at about 14 kHz which was not present in the plot of conductance versus frequency in air. It reflects the cavity resonance of piezoelectric tube which is being used for evaluating the ultrasonic velocity in methanol.

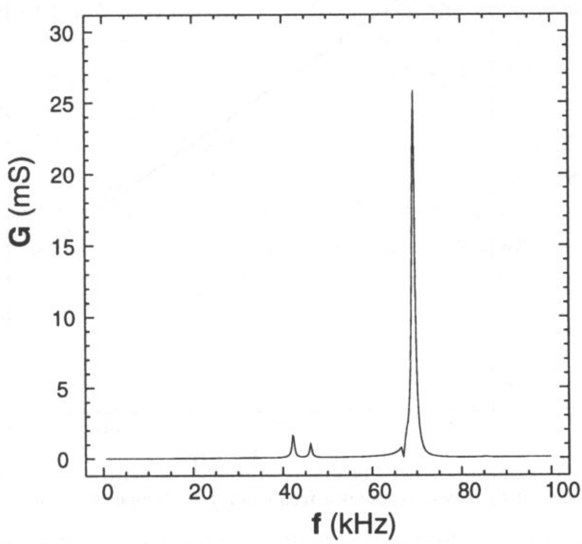

Fig. 5. Dependence of conductance G of tubular transducer vs. frequency f in air.

The measurement of the cavity resonance frequency of tubular transducer immersed in methanol have been carried out at constant normal pressure. The cavity resonance frequency measurements at different temperature indicate that the cavity resonance and sub-

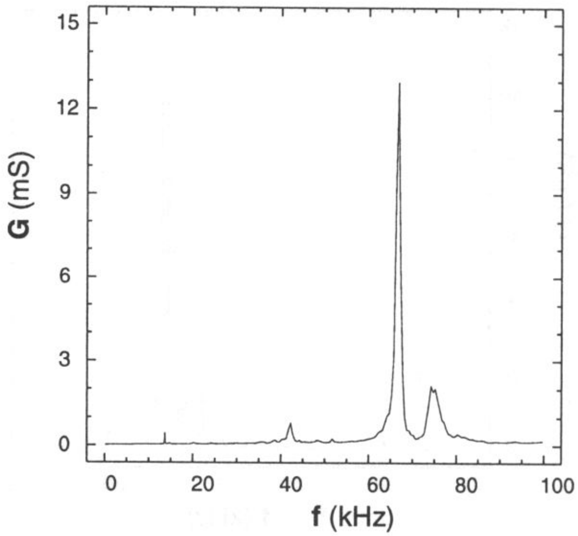

Fig. 6. Dependence of conductance G of tubular transducer vs. frequency f in methanol.

sequently the ultrasonic velocity (Eq. (5)) decreases with increase of temperature (Fig. 7). This result completely agrees with already published data [1].

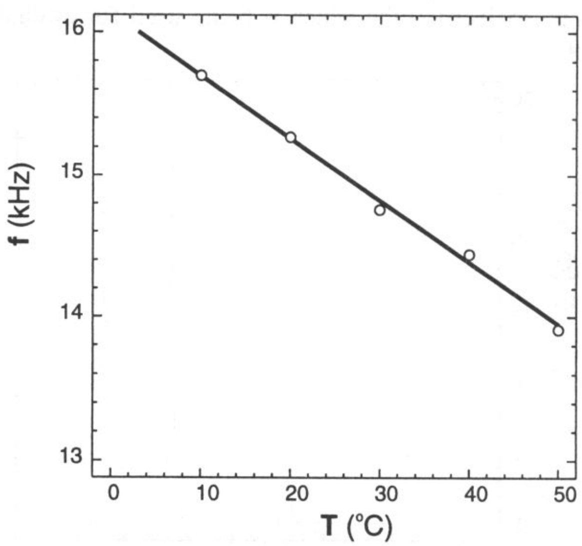

Fig. 7. Dependence of the cavity resonance frequency f vs. temperature of the methanol T.

Further the correlation between cavity resonance and ultrasonic velocity has also been checked theoretically and experimentally by plotting (Fig. 8) the inverse square of velocity ($1/c^2$) versus the inverse square of cavity resonance frequency ($1/f^2$). The values of velocity of ultrasonic waves taken from the measurements by WILSON and BRADLEY [1] and the plot $1/c^2$ versus $1/f^2$ a solid line was obtained by means of the least square fit.

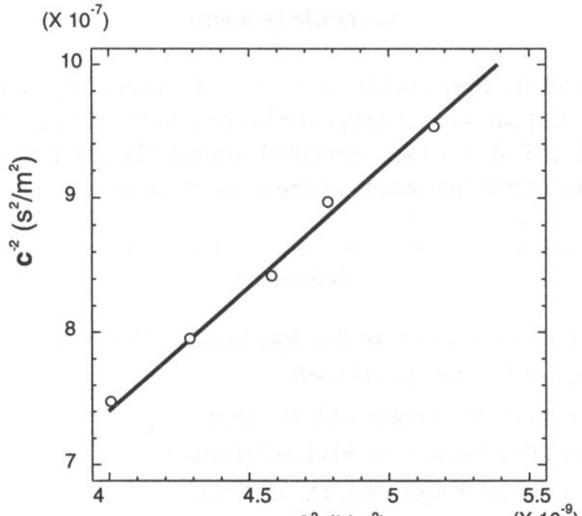

Fig. 8. Invert square of ultrasonic wave velocity in methanol against invert square of cavity resonance frequency.

Correlation coefficient for the both presented parameters is 0.997. The slope of the line obtained in experiment equals to 187.22. The theoretical value of the slope, evaluated by the equation (5) is 196.5 and is close to the experimental value. The slight discrepancies from linearity seen in Fig. 8 may be due to influence of the wave reflected from the walls of neoprene rubber container as the distance between transducer element and walls of the container was comparable with ultrasonic wavelength. Reflected wave affects the mechanical loading of the transducer.

The present studies indicate that the cavity resonance method which is simple technique may successfully be used for the measurement of ultrasonic velocity in the liquids. This method may serve as a very useful tool for the measurement of ultrasonic velocities in liquids particularly at fairly low frequency range which are rather difficult to access by other commonly used methods. We expect that this method can be also used with high pressure experiments.

4. Conclusions

In this work we performed ultrasonic investigation of liquids using cavity resonance method.

The main conclusion one can drawn from experimental results is that cavity resonance method may be successfully applied for ultrasonic investigation of liquids.

Our results indicate that it is is very useful technique, particularly, in the very low frequency regime.

We expect that this method can be also extended to investigate effects of higher hydrostatic pressure.

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