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ULTRASONIC VELOCITY MEASUREMENT OF LIQUIDS BY THE DUAL TECHNIQUE MODE

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ABSTRACT

Of the various techniques available for the measurement of ultrasonic velocity, the optical method and interferometric method appear to be most widely used. An experimental set up with a provision to measure ultrasonic velocity both by optical and interferometric method is described in this paper.

Key words: Ultrasonic velocity, optical diffraction, interferometry

INTRODUCTION

The measurement of velocity of sound and its applications in the study of chemical equilibria [1,2] have received large attention in recent years. Recently several novel methods for the determination of the stoichiometry and stability constant of the complexes from the ultrasonic data based on (i) colligative property (ii) excess/deficit property and (iii) apparent concentration difference [2 A] suitable for both mono and continuous variation techniques have been proposed. In order to assess the usefulness of these methods, a number of complex forming systems have been chosen for study and the ultrasonic velocity of those systems was determined by the dual technique mode described in this communication.

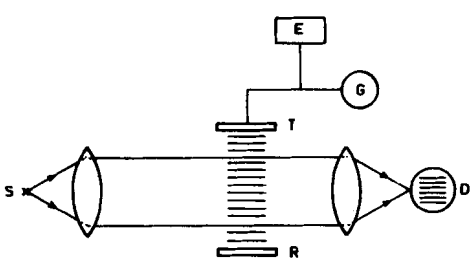
Of the various techniques available for the measurement of ultrasonic velocity (U.S.V.) the optical method and interferometric method appear to be the most widely used. Numerous reports are available in literature [1-22], giving details of these experimental techniques. An attempt is made in this work to set up an ultrasonic velocity measurement system which has provision to measure the ultrasonic velocity both by optical and interferometric methods. Such a two-in-one unit enables the experimenter to simultaneously measure the ultrasonic velocity in solution by these two different methods that could prove useful for cross checking the experimental data and for the enhanced reliability of the results.

EXPERIMENTAL

Broadly, the constituent parts of the set up, consist of the cell, the transducer, and the detector systems. As could be seen from the block diagram of the set up shown in figure 1 the cell and the transducer constitute the common parts to both the measurement techniques while the detection part is different for the optical and interferometric methods (as demanded by the different principles on which these methods are based). A photograph of the set up is given (figure 2).

A transducer with a frequency of 2.5 MHZ is chosen based on its satisfactory performance in both optical and interferometric methods as reported earlier [22-27].

For optical method a cubical stainless steel cell of side 5 cm, open at the top and having one set of opposite walls fitted with optically plane glass plates for the transmission of light from sodium vapour lamp has been used. It has a polished bottom which acts like a reflector (for interferometric method) and has a provision for keeping the experimental liquid at a constant temperature with the help of an outer jacket for circulating water from an external thermostat.



S - MONOCHROMATIC SOURCE
D - DIFFRACTION PATTERN AS VIEWED THROUGH MICROMETER EYE PIECE
T - PZT TRANSDUCER
R - REFLECTOR (BOTTOM OF THE CELL)
G - ULTRASONIC GENERATOR
E - ELECTRICAL ARRANGEMENT FOR DETECTION OF NODE

FIG-1. SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET UP

The transducer used is a piezo electric ceramic lead zirconate titanate (PZT). The advantages of PZT over quartz crystal that is commonly used are (i) large frequency band width (ii) high electro-acoustical conversion efficiency (iii) low impedance [29] and (iv) a considerable increase in output due to its high conversion efficiency [4, 27, 30, 31]. With PZT, low input voltages are sufficient and highly sensitive detection equipment is

considered not necessary. Further, the possibility of applying low voltages to the crystal reduces the errors due to thermal effects within the crystal. Also the adjustments are simple and not critical especially for very accurate adjustment of parallelism between the transducer and reflector [29].

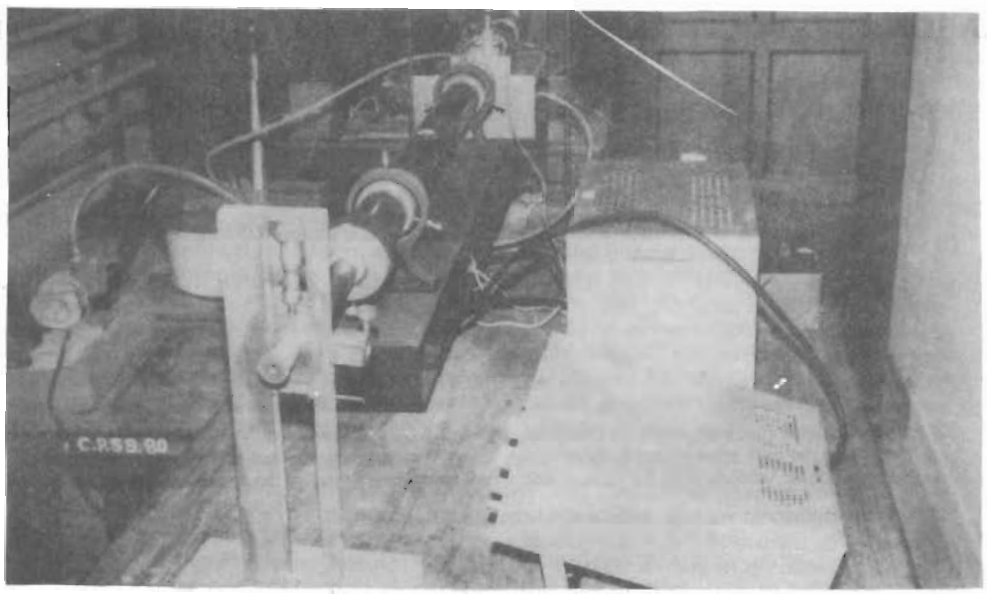


Fig. 2: Photograph of the experimental set up

The transducer used is in the form of the cylindrical probe of diameter two centimetres, with only one face of the ceramic exposed and the other face perfectly insulated. The diameter of the transducer is so chosen that it is large compared to acoustic wave length [30]. The transducer is attached to a precision micrometer (of least count of 0.01 mm) with which the vertical displacement of the probe inside the solution can be measured during the interferometric measurements.

Measurement by the optical diffraction method

In this method [8, 9] a parallel beam of ultrasonic waves in a transparent medium acts as a diffraction grating for light. The periodic variation of refractive index produces a grating with a spacing equal to the acoustic wave length λ and moving with the speed of sound. However, the speed of sound is negligible compared with that of light and the grating is effectively stationary. The diffracted light if viewed in a telescope shows a number of diffraction images of the slit.

The acoustic wave length is λ is related to distance (Y_n) of the 'n'th order of diffraction maximum from the central image by

$$\lambda \quad \frac{n \lambda_l D}{Y_n} \qquad \ldots . (1)$$

where λ_l is wave length of light used and D is the distance between the telescope objective and crosswire of the eye piece. If u_e is the velocity of the ultrasonic waves in the solution and N is the frequency of the waves then

$$u_e = \frac{N n \lambda_l D}{Y_n} \qquad \ldots . (2)$$

The ultrasonic oscillator is connected to the tranducer which is placed on the free surface of the liquid in the cell. When the oscillator is switched on, the ultrasonic waves are propagated in the solution in the cell. The dial of the osciallator is adjusted to match its frequency with the natural frequency of the transducer (N) so that reasonant vibrations are produced. A number of diffracted images appear on either side of the central image in the field of view of the telescope. The distance of the different order diffraction images from the zero order image, are measured with the help of an external eyepiece attached with a micrometer having least count of 0.01 mm capable of moving along the vertical direction. At the frequency employed there is an excellent resolution of the diffracted images at least upto third order. Hence the accuracy obtainable related to the precision to which "Y_n" can be measured and could be kept high, maintaining all measurments to third order.

Measurement by Interferometric Method

The principle used in the measurement of ultrasonic velocity (u_e) is based on the accurate determination of acoustical wave length. Ultrasonic waves of known frequency (N) are produced by the PZT transducer which is placed at the top of the cell touching the free surface of the liquid. These waves are reflected by the bottom of the cell which is parallel to the exposed face of the transducer. If the separation between these two (viz. face of transducer and bottom of the cell) is exactly an integral multiple of wavelength of sound, standing waves are formed in the medium. This acoustic resonance gives rise to an electrical reaction in the generator driving the PZT and the anode current of the generator becomes maximum [4]. When the distance is now decreased or increased by one half wave length ($\lambda/2$) or multiple of it, anode current again becomes maximum. From the knowledge of the multiple of half wave length(s) and the distance contained in the same length (l), one can find the wave length by the reaction

$$s \frac{\lambda}{2} = l \qquad \ldots . (3)$$

and hence the acoustical wave length (λ) can be determined which is $\lambda = (\frac{2l}{s})$. From the knowledge of acoustical wave length and frequency (N) one can find the velocity of sound in the medium (u_e) using

$$u_e = N \lambda = N (\frac{2l}{s}) \qquad \ldots . (4)$$

The transducer attached to the micrometer is slowly moved inside the solution till the anode current is a maximum. The total distance (l) thus moved by the micrometer for covering the given number of nodes (s) is measured. The value of acoustical wave length and hence the velocity in the solution are computed using the eq. (4)

Checking up the performance of the set up with measurements of ultrasonic velocity of water

In the optical method, confining measurements to the third order, on either side of the central, maximum, the distance between them are determined ($2 Y_3$). By repeating each measurement for six times, the average value of $2 Y_3$

is found and in the case of water the average value was 6.110 mm. Using a measured value of distance between telescope objective and the crosswire of the eye piece (D) which is equal to 105 cm, the value of wave length of light used (λ_p) being 5893×10^{-8} cm and with a frequency of the transducer 2.5 MHZ, the velocity of sound in water has been computed and found to be 1519 ms^{-1}

In the interferometric method the distance (l) corresponding to 50 number of nodes has been measured. For enhanced reliability, the average value of 'l' obtained from six sets of individual measurements has been used. Using the measured value of 'l' which is found to be equal to 15.195 mm, velocity of water has been computed and found to be 1519.5 ms^{-1}. It has, thus, been seen that the measured velocities of water using the optical and interferometric methods are in good agreement with each other as well as with the reported value [33] (viz. 1520.1 Ms^{-1}).

The accuracies obtainable are respectively $\pm$ 1 ms^{-1}, $\pm$ 1.5 ms^{-1} for both interferometric and optical methods. Ultrasonic velocity data for aqueous solutions of EDTA (Table I) and Pb $(NO_3)_2$ (Table II) by the dual technique are given.

Table I: Ultrasonic velocity for aq. EDTA

EDTA in water pH = 3.0; Temp = 35°C

Concentration of EDTA M	U.S.V. (ms^{-1})	
	Optical method	Interferometric method
Water	1519	1519.5
0.01	1522	1522.0
0.02	1525	1524.5
0.03	1527	1527.0
0.04	1530	1530.0
0.05	1533	1532.5

Table II: Ultrasonic velocity for lead nitrate solution
pH = 1.6; Temp = 35°C

Concentration of $Pb(NO_3)_2$ M	U.S.V. (ms^{-1})	
	Optical method	Interferometric method
Water	1519	15195
0.02	1517	1517.0
0.04	1515	1515.0
0.06	1512	1512.5
0.08	1510	1510.0
0.10	1508	1507.5

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