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Measurement of liquid characteristics using ultrasound resonator

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ABSTRACT

Physical characteristics of liquids and their accuracies were determined using an ultrasound resonator. For the beginning the influence of different experimental settings (different liquids, different cells, kind and area of used transducers, its position and different ways of their sticking in the cells walls) to obtained frequency spectra were studied. On the base of these experiments the proposal of an optimal experimental setting was prepared. The fluid physical property characterisation was obtained on the base of swept frequency acoustical interferometry. The positions of local frequency maxima and its widths were assessed and analysed. Sound speed, attenuation and liquid density were calculated. The accuracies of them were established. Additionally, the prepared experimental set-up was used for student's laboratory education.

THEORETICAL INTRODUCTION

The swept frequency acoustical interferometry was developed for non-invasive testing identification of chemicals in sealed containers or containers where direct access to the chemical is not possible. A large number of chemicals can be identified. These chemicals are identified on the base of obtained characteristics that were established on the base of ultrasonic interferometry which does not require contact between the ultrasonic transducers and the fluid under investigation [1]. On the basis of this method liquid characteristics like speed of sound, sound attenuation, liquid density can be calculated.

In the experimental setup the cell filled with measured liquid is equipped with two transducers. The first transducer is used as the transmitter to which an electrical signal is applied to generate sound pressure waves. The second transducer is used as a receiver to detect the standing waves. The principle of this method is based on passing and reflecting of ultrasound waves in multilayer space. The simplest case occurs in three layer space.

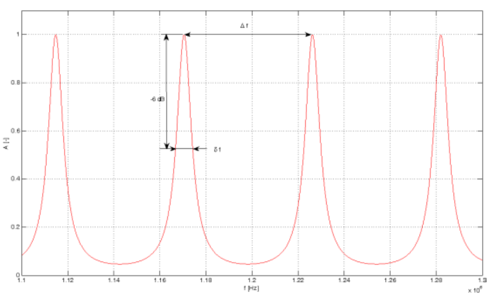

Figure 1. Frequency spectra

Obtained spectrum is a composition of a series of equidistant resonance peak that is observed in case that swept frequency signal is generated and that signal cover in frequency a wide frequency range (see fig. 1).

The wavelength of that standing wave is an integral number of half-wavelength [1]. The speed of sound in the liquid can be calculated from following equation

$$c_l = 2L\Delta f, \quad (1)$$

where L is the width of the cell, Δf peak to peak distance. For the determination of sound attenuation the reference liquid with known characteristics should be measured. For this purposes water has been usually used. The sound attenuation α_l for the unknown liquid can be determined from the following equation

$$\alpha_l = \frac{\pi}{c_l}(\delta f - \delta f_0) - \frac{\pi}{c_l}(\delta f_r - \delta f_{r0}) + \frac{c_r}{c_l}\alpha_r, \quad (2)$$

where α_r is attenuation coefficient of reference liquid, c_r speed of sound of reference liquid, c_l speed of sound of testing liquid, δf and δf_r are measured half-power bandwidth for testing and reference liquid, δf_0 and δf_{r0} are extrapolated width as $f^2 \rightarrow 0$ for testing and reference liquid. From the slopes $(\delta f - \delta f_0)/f^2$ and $(\delta f_r - \delta f_{r0})/f^2$ attenuation coefficient factor $\alpha_0 = (\alpha_l/f^2)10^{17}$ (np s^2/cm) can be calculated [2].

The liquid density ρ_l can be determined from the equation

$$\rho_l = \delta f \frac{\pi c_w \rho_w L}{2c_l^2}, \quad (3)$$

where c_w is sound speed in wall material and ρ_w its density. These methods of measurement is described in [1] for cylindrical containers or containers with liquid in annular spaces and in [2] for glass container with parallel walls.

Theoretical introduction for students measurement

Very easy apparature has been prepared for educational purposes. In the first case a rectangular cell was prepared. In our case the middle space is water and the boundary spaces are glass walls of the cell (see fig. 2).

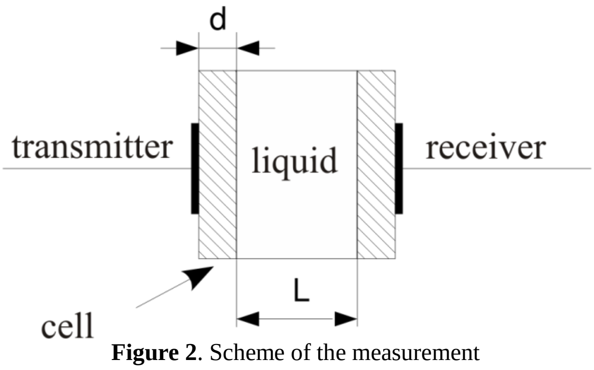

Figure 2. Scheme of the measurement

The frequency sweep signal from the generator goes in to the input of an ultrasound transducer. The transducer changes that signal to ultrasound waves. Ultrasound waves goes through the glass cell to the water and then goes through the second glass wall of the cell to the output of ultrasound transducer. From the influence of different acoustical impedance of glass and water (approximately of one order) it is created an acoustical resonator in the cell.

As it is known from the theory of circuits the system has the maximum transmission between input and output in the case of resonance. Resonance occurs in the case that all multiples of half sound waves ultrasound waves are equal to the width of the cell

$$n\frac{\lambda}{2} = L, n \in N. \quad (4)$$

The wave length is connected to velocity of ultrasound waves in water and to its frequency. It is possible by knowing the length of L and from the frequency distinction Δf in sequence of following local maxima to calculate the velocity ultrasound waves in water by use of the equation (1).

The quality of resonator is affected by the difference of acoustical impedances of water and glass wall of cell. In general applies, that the quality of resonator is increasing with the increasing of difference of these impedances, because most amount of energy ultrasound waves is reflected from the boundary liquid - wall back to liquid. The rate difference of these impedances is expressed by parameter σ

$$\sigma = \frac{z_w}{z_l} + \frac{z_l}{z_w}, \quad (5)$$

where z_w is acoustical impedance of wall (glass) and z_l is acoustical impedance of water. The equation for acoustical impedance is

$$z = \rho c, \quad (6)$$

where ρ is the density and c is the velocity of sound in material. The quality of resonator is not dependent on the parameter σ only, but on the attenuation of ultrasound waves in water, which is depending on the frequency.

Transmission function of this resonator is described by the following equation

$$T = \frac{1}{\frac{\sigma^2-4}{4}\sin(kL)+\frac{\sigma^2-4}{4}\alpha_l{}^2L^2+\sigma\alpha_l L+1}, \quad (7)$$

where $k = \frac{\omega}{c_l}$.

MESUREMENT

For the measurements the rectangular glass cell filled with distillate degassed water has been used. Water was used as a reference liquid. Then carbon tetrachloride has been used as a liquid for other characteristics determination. The width of the cell L is equal to 13 mm. Piezoelectric circular transducers 20 mm in diameter have been used. They have been stick in a parallel way on the glass cell (see fig. 3).

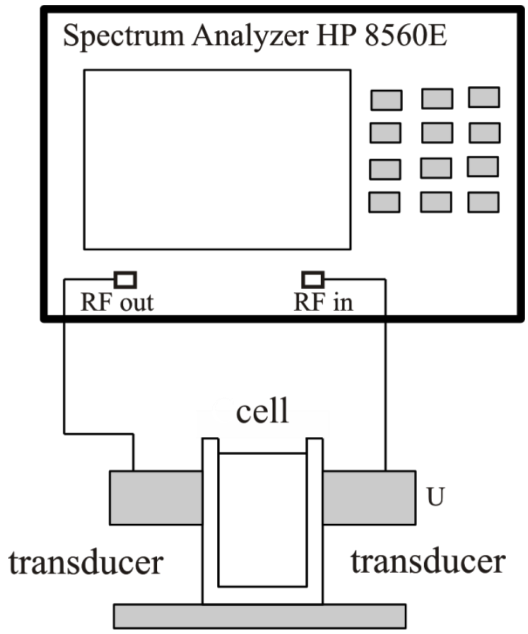

Figure 3. Scheme of the measurement

The measuring card Spectrum Analyzer HP 8560E has been used for transducer excitation and spectra measurement. Signal processing has been made in system Matlab.

RESULTS

The obtained parameters were compared to known values. You can see the comparison between measured and calculated spectra on the fig. 4. The theoretical curve has been calculated on the base of the equation (7).

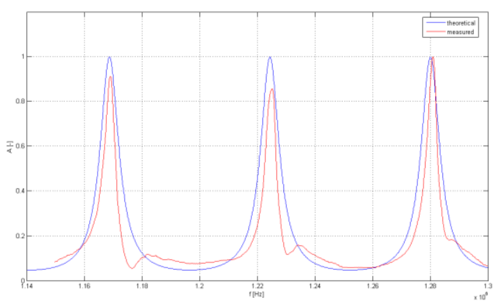

Figure 4. Frequency spectra

Velocity c_l was calculated on the base of the equation (1) and compared to the tabular value. For carbon tetrachloride attenuation α_l and density ρ were calculated on the bases of equations (2) and (3) and then compared to known values (see [3]).

CONCLUSION

On the base of swept frequency acoustical interferometry sound speed, attenuation and density of specific liquid were determined. For the beginning the rectangular measured cell was used. Additionally, the prepared experimental set-up was used for student's laboratory education.

Different shaped cells are planned to be used. For the future experiments more precise rectangular shaped cells and spherical cells are going to be prepared.

ACKNOWLEDGMENT

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REFERENCES

1 D. N. Sinha, "Nonivasive identification of fluids by swept-frequency acoustic interferometry", *United States Patent, US00 5767407A* (1998)
2 W. Han, D. N. Sinha, K. N. Springer, D. C. Lizon, "Non-invasive measurement of acoustic properties of fluids using ultrasonic interferometry technique", *8th International Symposium on Non Destructive Characterization of Materials*, Boulder, CO June 15 – 20 (1997)
3 G. W. Willard, "Ultrasonic absorption and velocity measurements in numerous liquids", *J. Acoust. Soc. Am.*, vol. 12, pp. 438-448, January (1941)