ULTRASOUND INTERACTIONS WITH BIOLOGICAL FLUIDS

Alina Rogojanu, Mihaela Dulcescu, Dana-Ortansa Dorohoi

Faculty of Physics, "Al. I. Cuza" University, 11 Carol I Blvd., Iaşi –RO-700056, Romania

Abstract: *The ultrasound interactions with biological fluids are analyzed by the liquid compressibility coefficient and by the absorption coefficient of the mechanical waves in the process of their propagation through hemoglobin solutions of different concentrations.*

Keywords: *ultrasound interactions, absorption coefficient, hemoglobin solutions.*

Introduction

Ultrasounds [Diaconu, 2005] are elastic waves with frequencies higher than 20 KHz and smaller than $10^9 - 10^{10}$ Hz. The inferior limit is delimitated by the human ear, while the superior limit is dependent on the physical nature of the propagation medium. An essential parameter determining the superior limit of frequency are the intermolecular or/and inter-atomic distances in the propagation media. So, only ultrasounds with frequencies smaller than 10^6 Hz can be transmitted in the gases at normal pressure, while in liquids and solids the ultrasound frequency limit can be near $10^9 - 10^{10}$ Hz.

The existence of the elastic forces between the particles composing the condensed media makes possible the transmission of the local perturbation produced by ultrasound through the substance and the vibration motion propagates as elastic wave. The ultrasound produces local variation of some macroscopic parameters such as pressure, temperature, density, or of some punctual parameters such as particle position, velocity or acceleration.

In liquid media, in which the cohesion forces are very weak, the ultrasounds have predominant character of the longitudinal waves. The ultrasound propagation can be approximated by an adiabatic process [Diaconu, 2005; Carstensen 1959], because changes of heat are not possible between the component parts of the liquid having different temperatures in the propagation process (the comprised zones have higher temperatures than the rarefied ones). From the thermodynamically point of view, in the adiabatic processes, the entropy is a constant parameter. The liquid adiabatic coefficient of compressibility in an adiabatic process is given by the relation (1):

$$\beta = -\frac{1}{V}\frac{\partial V}{\partial P} = \frac{1}{\rho u^2} \qquad (1)$$

In relation (1), ρ is the liquid density and u is the ultrasound velocity.

Experimental

In order to obtain the hemoglobin solutions the following substances were used:

- Anticoagulant for blood keeping into liquid state – Sodium oxalate, Sodium citrate, heparin;
- Toluene or chloroform;
- Reactive and substance for precipitation;
- Distilled water.

The blood is collected on anticoagulant and the erythrocytes are washed until the plasmatic proteins are completely eliminated. 1ml washed erythrocytes are treated with 1,5 ml distilled water and 0,4 ml toluene or chloroform in a rubber doped test tube of the centrifuge. One continuously and strongly stirred by 5-6 minutes, then one centrifuged 20 minutes at 3000-5000 cycles/minute [Carstensen 1959; Rapa 2003].

Solutions of different concentrations of hemoglobin in distilled water were used.

The ultrasound velocity, the absorption coefficient and the density of the studied solutions were determined.

The solution density was determined using a picknometer.

The velocity and the absorption coefficient were determined by using an ultra-acoustic interferometer (Figure 1).

The piezoelectric transducer *Q* emits longitudinal ultrasounds with a fixed frequency.

They are reflected by the mirror *R*, which can be shifted on the vertical direction with a micrometer *Mc*. For a given distance d between the emitter Q and the mirror R stationary waves appear in the liquid:

$$d = n\frac{\lambda}{2}(n = 1,2,\dots) \qquad (2)$$

In (2) λ is the ultrasound wavelength in the studied liquid.

The transducer has double role as emitter and as receptor. On the emitter surface there appears a nod of amplitude when the direct and reflected waves are in opposite phase and a maxim of amplitude when they are in phase. When the transducer is hampered in its vibratory motion it will absorb maxim energy from the high frequency primary electric generator. This fact is indicated by the ammeter *A* which indicates a maxim value for the electric current. The situation is repeated when the reflecting piston is moved by distance equal with a half-wave.

From equation (2) it results the following relation:

$$u = \frac{2Df}{n} \qquad (3)$$

Because:

$$\lambda = \frac{u}{f} \qquad (4)$$

D is the distance read on the micrometer corresponding to a displacement between n+1 maxima (or minima) shown by the ammeter, *f*- is the ultrasound frequency, the same with the frequency of the high frequency generator. If the incident wave on transducer Q is in phase with those reflected by the mirror, the vibratory motion of the transducer is favored and the energy obtained from the electric generator is minim. In this case the electric current indicated by the ammeter is minim. In order to determine the ultrasound velocity one can use the situations corresponding to the minima.

The ultrasound intensity is proportional with the intensity of the electric signal registered at the ammeter. So, at the distance d in solution, relation (5) is true.

$$I = I_0 e^{-2\alpha d} \qquad (5)$$

In relation (5) I_0 is the intensity measured at d = 0; d is the distance of ultrasound propagation; α is the ultrasound absorption coefficient.

From the ratio of the intensities at two distances d_1 and d_2;

$$I_1 = I_0 e^{-2\alpha d_1} \qquad (6)$$

and

$$I_2 = I_0 e^{-2\alpha d_2} \qquad (7)$$

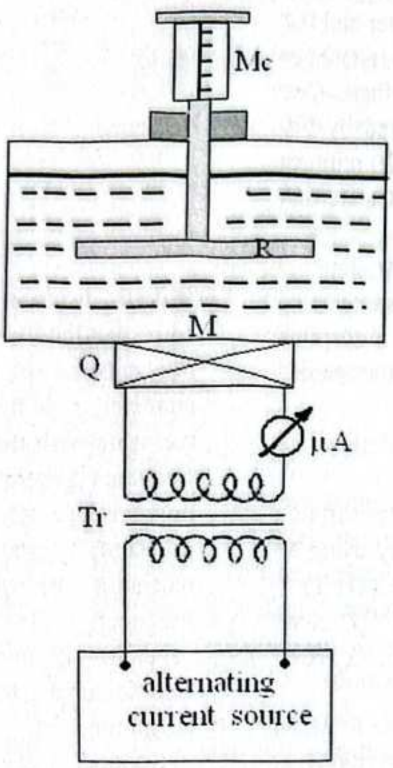

Figure 1 Ultrasound interferometer.

one obtains the ultrasound absorption coefficient for the studied solution.

$$\alpha = I\frac{1}{2(d_2-d_1)}\ln\frac{I_1}{I_2} \tag{8}$$

The absorption coefficients were determined by measuring the two electric currents given by the ammeter and the distances d_1 and d_2 for which the intensities were evaluated.

Results and discussion

The measured values of the ultrasound velocity and the hemoglobin solutions absorption coefficients are given in Table 1, from which it results an increase in the ultrasound velocity by increasing concentration.

Table 1 Ultrasound velocity in hemoglobin solutions (f=1 MHz)

Nr crt	Concentration (g/cm^3)	$u(m/s)$	$\rho(g/cm^3)$	$10^{10}\beta_{ad.}(m^2/N)$	$\alpha(dm^{-1})$
1	5	1520,0	1.060	4.0833	0,64
2	10	1530,1	1.065	4.0106	0,74
3	15	1541,5	1.070	3.9330	1,82
4	20	1562,4	1.080	3.7931	3,00
5	25	1581,7	1.085	3.6840	3,80
6	30	1602,1	1.090	3.5743	5,20
7	40	1619,1	1.095	3.4837	7,10

From Table 1 it also results an increase in the absorption capacity is shown with the hemoglobin concentration. A decrease of the adiabatic compre-ssibility of studied solutions when the hemoglobin concentration increases is evident from the data contained in table 1.

The increase in the absorption coefficient with hemoglobin concentration would be explained by the great value of this coefficient for hemoglobin, compared with the water coefficient. The compression capacity of ultrasound is smaller in the solutions with high hemoglobin concentration. The hemoglobin/water interactions are stronger than the water/water interactions as demonstrates the smaller values of hemoglobin solution compressibility compared with the corresponding value estimated for water.

Conclusion

Our measurements show an increase of the ultrasound propagation velocity and of absorption coefficient with concentration in aqueous solutions of the hemoglobin. Concomitantly, a decrease in the adiabatic compressibility of the solutions with the hemoglobin concentration increasing was evidenced.

References

Ilie Diaconu, Dana Ortansa Dorohoi, Ultrasunetele. Aplicații în medicină, Editura Tehnopress, Iași, 2005

E. L. Carstensen and H. P. Schwan, Absorption of sound arising from the presence of intact cells blood, J. Acoust. Soc. Amer., 1959, 31(2), 185

A. Râpă, L. Oancea, D. Dorohoi, US propagation through Hemoglobin solution, PIM Conference, 2003, Cluj, Romania