Acoustic cavitation thresholds in NaCl-water solutions

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Introduction

The content of components and salts of the water used in the common technological processes and particularly in the seawater can deeply influence the characteristics of the different cavitation effects. Erosion and light emission due to cavitation are generally higher in salt water than in distilled water.

The acoustic emission and the light emission allow to study the characteristics of these phenomena in different cavitation development stages, i.e. at the inception, in a developed stage and at the desinence. In this paper, the pulsed ultrasonic cavitation technique [1-3] was employed to study the subharmonic 1/2 sound-emission thresholds and the threshold for light-emission, both at the incipience and at the desinence as a function of the salt concentration of the solutions of NaCl in distilled water. The same technique was used earlier to measure the light and the subharmonic 1/2 sound-emission and to study the cavitation efficiency in the cell [4].

AKULICHEV [5] has already found by steady irradiation, that the cavitation threshold in some salt-water solutions at a particular salt concentration, diminishes by about ten percent with respect to the cavitation threshold in distilled water. He has explained this by the ions distribution on the surface of the nuclei. The role of a solute added to the water has been widely discussed in the review paper by WALTON and REYNOLDS [6]. More recently, ROY *et al.* [7] have studied the dependence of the cavitation thresholds in NaI and KI water solutions as a function of the salt concentration.

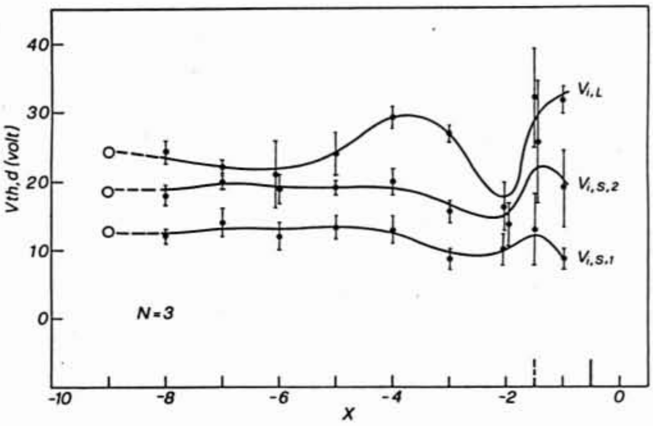
In this paper, the dependence of the cavitation thresholds has been studied by pulsed irradiation. This allowed us to evidence three thresholds: two for subharmonic sound emission and one for light emission. In fact, the pulsed method allows to excite nuclei of different radius by varying the duty ratio. The bigger is the value of the inverse duty ratio, the smaller are the nuclei excited in the incipient threshold.

Experimental setup

The block diagram of the apparatus can be found in Ref. [3]. The low power radiofrequency generators are modulated by a pulse generator whose pulse time and duty ratio can be varied. The mixed signal amplified by the Class A RF power amplifier drives the piezoceramic transducer. The cell is 160 cm^3 in volume, with a piezoceramic concave transducer of 0.7 MHz frequency. The maximum energy density is present in a central region of the cell, away from the walls. The maximum of the pressure amplitude at 200 V transducer voltage is 40 bar in a volume of about 1.5 cm^3 around the focal spot. The cell contains a thermocouple, a 3 mm × 3 mm piezoceramic hydrophone with sensitivity 1.8 V/bar and a photomultiplier. The pulsed ultrasound beam was characterized by pulse time τ, repetition rate υ and inverse duty ratio $N = 1/\tau\upsilon$.

Mesures des seuils de cavitation acoustique dans les solutions aqueuses de NaCl

L'émission acoustique de subharmonique 1/2 et de lumière dans les solutions aqueuses de NaCl a été étudiée par la technique de la cavitation ultrasonique à impulsions en fonction de la concentration. Les résultats expérimentaux concernant les seuils du bruit et de lumière sont analysés pour expliquer l'influence de la concentration du sel.



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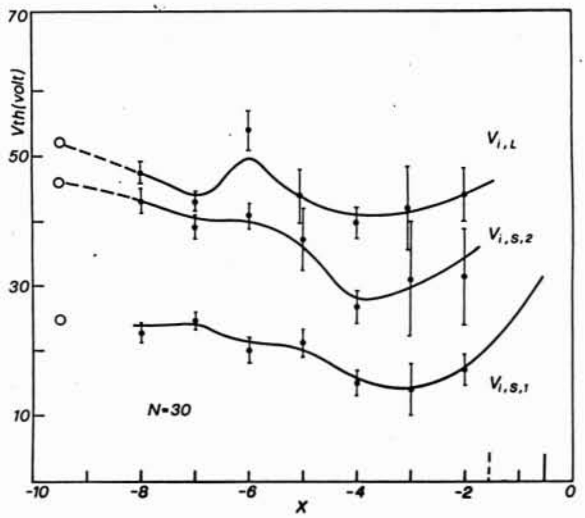

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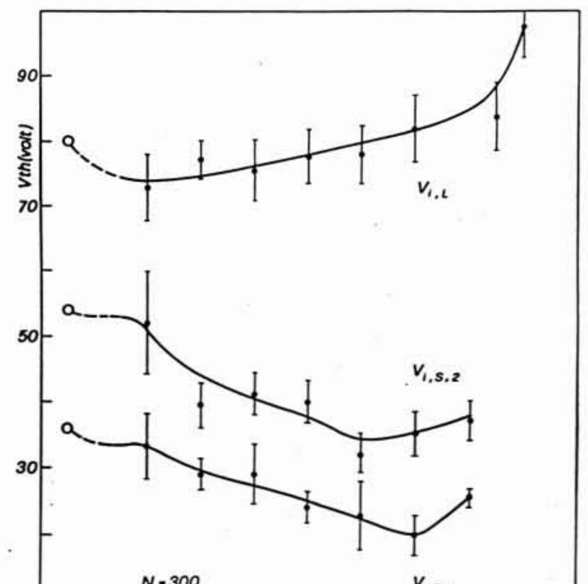

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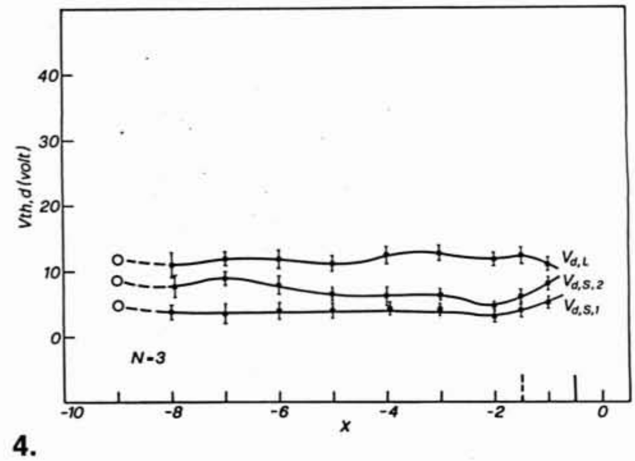

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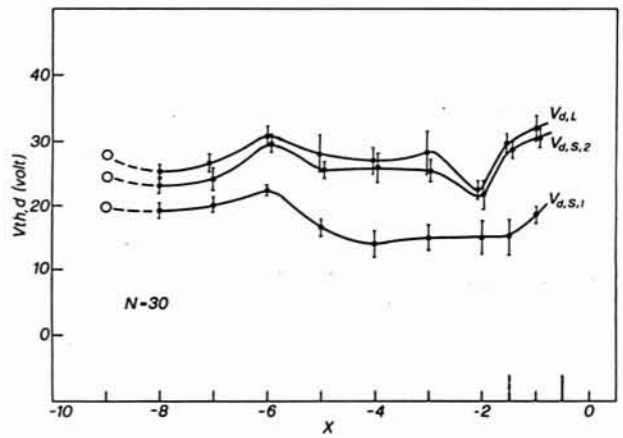

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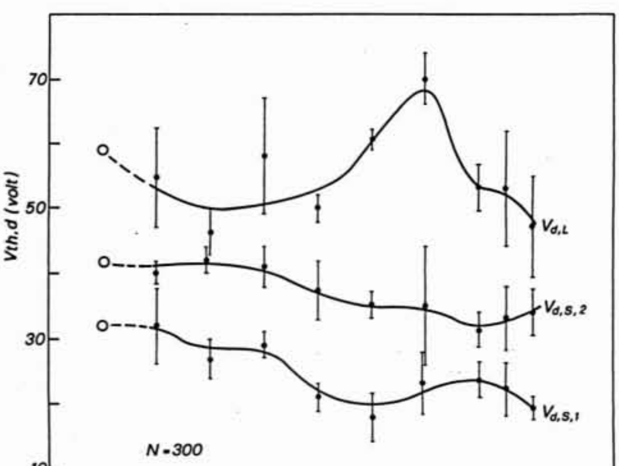

6.

1. *Transducer-voltage incipient thresholds for subharmonic 1/2 sound emission, V_{IS1} and V_{IS2}, and sonoluminescence, V_{IL} as a function of salt concentration x. The following values were used for pulsed ultrasound: $\tau = 3$ ms, $f = 0.7$ MHz, $N = 3$. The dashed mark of x indicates the seawater concentration, the thick mark indicates the saturation concentration at room temperature. Open circles indicate the values of pure water.*

2. *Same as in figure 1, with $N = 30$.*

3. *Same as in figure 1, with $N = 300$.*

4. *Transducer voltage desinent thresholds for subharmonic 1/2 sound emission, V_{dS1} and V_{dS2}, and sonoluminescence, V_{dL} as a function of salt concentration x. The following values were used for pulsed ultrasound: $\tau = 3$ ms, $f = 0.7$ MHz, $N = 3$. The dashed mark of x indicates the seawater concentration, the thick mark indicates the saturation concentration at room temperature. Open circles indicate the values of pure water.*

5. *Same as in figure 4, with $N = 30$.*

6. *Same as in figure 4, with $N = 300$.*

In this work, the concentration of the solutions is indicated by means of the quantity $x = \log_{10}[m_{NaCl}/m_{water}]$, that is by a quantity proportional to the molality in a logarithmic scale.

The measurements refer to solutions whose concentration varies from $x = -8$ up to $x = -1$; pulse time $\tau = 3$ ms, sound frequency $f = 0.7$ MHz and inverse duty ratio $N = 3$, $N = 30$ and $N = 300$. Due to the very high dilution, double distilled and filtered water of high purity was used. The *figures 1, 2 and 3* show the thresholds at incipience for $N = 3$, $N = 30$ and $N = 300$ respectively. The *figures 4, 5 and 6* refer to the desinent thresholds for the corresponding N-values, 3, 30 and 300.

Each value is the mean of about seven measurements. The reported error is the standard deviation, *i.e.* the mean quadratic error.

As evidenced in the figures, an accurate analysis of the output signal from the hydrophone indicates that the phenomenon of subharmonic 1/2 sound emission presents two threshold values V_{IS1} and V_{IS2}. The first one, V_{IS1}, is connected with the signal of one or a few bubbles in the focal region of the transducer. The second threshold appears at a higher voltage, V_{IS2}, in correspondence to a second step in the hydrophone signal, about one order of magnitude higher than the first step of the subharmonic component of the hydrophone signal. Still higher is the transducer voltage V_{IL} needed to excite sonoluminescence. The thresholds at desinence are found in reverse order by decreasing the transducer voltage.

Experimental results and discussion

As it results from *figure 1* to *figure 3*, the thresholds increase with increasing N. This is due to the fact that, using the same rate of increasing the transducer voltage (0.6 dB/s) for reaching the threshold value and the same pulse time τ, the total irradiation time is inversely proportional to the inverse duty ratio N. The phenomenon can be explained considering both the population distribution, well represented by a differential bubble concentration with respect to the radius, proportional to R^{-3} (where R is the bubble rest radius), and the Blake threshold which strongly increases by decreasing the radius of the bubbles.

The desinent thresholds, for the same phenomenon and the same duty ratio *(fig. 4* to *fig. 6)*, are lower than the incipient thresholds. This is a consequence of the dramatic change in the total number and in the distribution on radius of the population of nuclei and bubbles after some time of permanence above the incipient light threshold.

The dependence of the incipient thresholds values on the concentration is more pronounced for bubbles of smaller radius *(fig. 3)* than for bubbles of bigger radius *(fig. 1* and *fig. 2)*. Whatever is the value of N it can be observed that it exists a value of the concentration at which the threshold shows a minimum value. This minimum is more pronounced for the smaller bubbles than for the bigger ones. The minimum value of the thresholds for every N moves from higher to smaller concentrations passing from V_{IS1}, V_{IS2} to V_{IL} (*i.e.* from the lower to the higher threshold).

The behaviour of the desinent threshold is much more complicated and less regular than that of the incipient thresholds due to the much more complicated spectral nuclei distribution on the radius and their bigger volume concentration.

The parameters that influence the nuclei population are the surface tension σ, the density ρ, the viscosity coefficient η and the maximum relative gas content α. The parameters σ, ρ and η increase approximately by 12 %, 20 % and 70 % respectively passing from the distilled water to the saturated solution; on the contrary, α decreases by more than one order of magnitude from the distilled to the salt saturated water. This explains the increase of the threshold values at values of x higher than that corresponding to the minimum. The decrease in the thresholds from the values of distilled water to the minimum values can be explained by the ions distribution on the surface of the nuclei as suggested by Akulichev [5].

The detailed structure of the thresholds at medium and high N, is not very easy to be interpreted. In particular, quite puzzling are the fluctuations in proximity of the sea water concentration (dashed mark on the x axis). This could be of interest for the analysis of erosion, noise and vibrations produced by cavitation in ship propellers.

A role is certainly played by the opposite effects of the decrease of the relative gas content at high concentrations and of the decrease of the Blake threshold due to the effect of charged surfactants at the interface [8]. This fact could explain some intermediate minima in the thresholds.

Other effects can be connected with charged surfactants: for example, at very low concentrations, the charges can be asymmetrically distributed on the bubble surface, so increasing the probability of a non spherical collapse with fragmentation, etc...

In the case of erosion, an influence on erosion rate could be connected with the electrochemical potential difference generated by cavitation [9].

References

[1] IERNETTI G. — « Pulsed Ultrasonic Cavitation Part I : Cavitation Noise, Luminescence, Thresholds, Nuclei Distribution », *Acustica, 23,* 189 (1970).

[2] IERNETTI P., CIUTI P. — « Pulsed Ultrasonic Cavitation Part II : Light Emission », *Acustica, 59,* 121 (1985).

[3] CARPENEDO L., CIUTI P., FRANCESCUTTO A., IERNETTI G., JOHRI G.K. — « Space-Time Interaction of two Ultrasonic Fields and Sonoluminescence During Transient Cavitation in Distilled Water », *Acoustic Letters, 10,* 178 (1987).

[4] DEHZKUNOV N.V., IERNETTI G., PROHKORENKO P.P., FRANCESCUTTO A., CIUTI P. — « Sonoluminescence and Subharmonic Generation in a Cavitation Zone of Aqueous Sodium Chloride Solutions », *Journ. of Eng. Phys., 51,* 1052 (1986).

[5] AKULICHEV V.A. — « Hydratation of Ions and the Cavitation Resistence of Water », *Sov. Phys. Acoust., 12,* 144 (1966).

[6] WALTON A.J., REYNOLDS G.T. — « Sonoluminescence », *Advances in Physics, 33,* 595 (1984).

[7] ROY R.A., ATCHLEY A.A., CRUM L.A., FOWLKES J.B., REIDY J.J. — « A Precise Technique for the Measurement of Acoustic Cavitation Thresholds and Some Preliminary Results », *J. Acoust. Soc. Am., 58,* 1799 (1985).

[8] ATCHLEY A.A. — « The Blake Threshold of a Cavitation Nucleus having a Radius-Dependent Surface Tension », *J. Acoust. Soc. Am., 85,* 152 (1988).

[9] DEHZKUNOV N.V., FRANCESCUTTO A., IERNETTI G. — « Electrochemical Potential Difference Generated by Ultrasound », *Proc. 19th International Towing Tank Conference,* Madrid, 1990, Vol. 2, pp. 87-88.