Low cost sonoluminescence experiment in pressurized water

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Abstract: We present a low cost design for demonstration and measurements of light emission from a sonoluminescence experiment. Using pressurized water introduced in an acrylic cylinder and one piezoelectric from an ultrasonic cleaner, we are able to generate cavitation zones with emission of light. The use of argon to pressurize the water improves the emission and the light can be seen at naked eye in a softlit ambient.

1. Introduction

Sonoluminescence is a phenomenon which is caused by acoustic energy concentration in a liquid medium. The acoustic energy is concentrated by the geometry of the system up to about 12 orders of magnitude [1-4], resulting in high-energy concentration zones in the fluid. The high energy density zones give rise to the formation of bubbles, by increasing the intensity of the acoustic wave, which begin to grow in amplitude. For a given threshold energy the bubble collapses in the compression cycle, resulting in the heating and ionizing of the gas, thus producing emission of light. On some geometric configurations a stationary oscillating bubble can remain synchronous with the stationary sound field [5], making it easy to study it by optical and spectroscopic methods. There are reports of measured temperatures up to 50,000°K [1] and even higher, which is of great interest for applications in high-speed/high-temperature chemical reactions [2]. The method we use to generate the acoustic stationary wave in the fluid employs a piezoelectric transducer. As a comment, there exists another method, purely mechanical, called liquid hammer [4].

2. Experimental setup

The experiment was built in a student laboratory using standard materials. We first experiment with a glass balloon, but it was difficult to obtain a stable configuration using one piezoelectric. Instead, the use of a cylindrical geometry reduces the mechanical and coupling problems and gives us more parameters to control. The scheme of the experiment is shown in figure 1, the cylinder oriented in the z-axis has an outer diameter of 100 mm, a wall of 5 mm thickness, and a length of 415 mm. This configuration can resist 2.5bar without problems. With the cylinder filled and pressurized we found it too hard to make measurements at different water levels, so we decided to use a 2 liter buffer vessel to improve the design. The power source for the piezoelectric was built ad-hoc in order to be able to control and fix the frequency output in a range of 20 to 60 kHz. A conventional autoresonance scheme did not match these requirements. The power output was typically 150 W at 600 V. The piezoelectric was coupled to the water through an aluminium disc that was cemented with epoxy resin. The water
facing side of this disc was worn away to an ellipsoid to focus the ultrasonic energy. Both the aluminium disc at the bottom and a polyamide disc at the top were sealed with silicon O-rings. To register light emitted we use a Hamamatsu photomultiplier and a digital oscilloscope Agilent with 2 channels and 100 MHz bandwidth.

![Experimental setup diagram](image)

**Figure 1.** Experimental setup.

### 3. Measurements

Before introducing the distilled water into the acrylic cylinder we made vacuum with a mechanical pump until stable conditions are reached. At this point we close the pump valve, and then we let the water run into the cylinder through the in-out valve. The amount of water filled into the cylinder and the steel vessel is approximately five litters. With the water filled we made vacuum again to degas it and during this process we applied low-power to the piezoelectric to improve the gas liberation. Finally, we close the vacuum valve and fill the system with the argon desired pressure. The water level is adjusted moving up or down the steel vessel.

The pressure was varied from 1 to 2.5 bar and the optimum emission of light was found at maximum pressure. Probably, at this pressure the argon concentration increases with time and the cavitation regime begins to change, until the emission of light ends. Lower pressures gives less cavitation power (less emission of light) but more stable operation. In the cases when the concentration of Ar is too high, an increase of the temperature can improve the behavior. We believe
that this change in temperature changes the concentrations of Ar nearer its optimum range. As also the
vapor pressure changes with temperature, we are not sure which process dominates.

We register different signals to show both the long time spectrum and the shape of an individual
pulse. In figure 2 can be seen the resulting spectrum obtained from the oscilloscope and converted to a
linear scale (Agilent show dB scale). Unexpectedly, there exists a very intense peak at half the
piezoelectric frequency, but we need more diagnostics in order to clarify this fact.

![Figure 2. FFT spectrum of light pulses. Frequency operation 42.7 kHz.](image)

Using the lowest time base scale of 5 ns/div we registered an individual light pulse in figure 3. Clearly the only conclusion that we can make is that the light pulse is well below the resolution of the
oscilloscope and the phototube, probably below the nanosecond scale. The noise (dark) pulses of the
phototube are below 0.1 V.

![Figure 3. Single emission pulse 100MHz bandwidth oscilloscope.](image)
We made several photographs of the emitted light with a Nikon DS100 camera and the best results were obtained taking 30 s exposure time. In order to show both the spot light and the experiment in the same exposition we illuminate the ambient with a soft light. The results are shown in figure 4. The piezoelectric is at the bottom of the picture.

![Figure 4. Light pulse from a bubble, taken with 30 s exposition time. A soft backlight was used to illuminate the experiment.](image)

4. Resonant model
We observe that there are two main resonance modes in the cylinder, the axial and the radial one. The addition of these modes fixes a discrete set of heights and frequencies to work with. A simple calculation can be made to obtain those conditions. If \( n \) and \( m \) are integers

\[
n = \frac{2rf}{c_s},
\]

\[
h = \frac{(m-\frac{1}{2})r}{n},
\]

where \( r \) is the radio of the cylinder, \( h \) the water level and \( c_s \) the speed of sound in water, and as the piezoelectric works in the range 40-44 KHz, the only possible value for the conditions of the experiment is \( n = 3 \). In this way \( h = (m-1/2)\times15 \text{ mm}, \) and so we can use different heights to experiment the resonant cavitation.

When the pressure of the system is increased we need to slightly increase the frequency to maintain the conditions of resonance. That can be explained assuming a little change in the sound velocity of water.

The shape of the cavitation zone changes with the argon dilution and we need almost one day with the argon pressurized to achieved emission conditions, but as we said before, if the Ar concentration in water is too high the cavitation regime changes and light emission stops.

5. 1D pressure model
We compute a one dimensional model in the \( z \)-axis taking into account the attenuation of sound with distance by a parameter \( \delta \). The constant pressure is represented by \( P_0 \) and the ongoing wave pressure from the piezoelectric by \( \Delta P \).

\[
P = P_0 + \Delta P_1 \cos(kz - \Omega t) + \Delta P_2 \cos(kz + \Omega t + \Phi)
\]

(1)

\[
\Delta P_1 = \Delta P \exp\left(-\frac{z}{\delta}\right)
\]

(2)
\[ \Delta P_z = \Delta P \exp \left( -\frac{2h-z}{\delta} \right) \]  

(3)

and for the dynamics we use

\[ \frac{dv_z}{dt} = \frac{1}{\rho} \left( \frac{\partial}{\partial z} p(z,t) - \alpha v_z \right) \]  

(4)

where \( \alpha \) is a friction (viscosity) coefficient, \( \rho \) an artificial density, \( h \) the water level, \( \Omega \) the angular frequency, \( k \) the wave number and \( \Phi = \pi - 2kh \) the shift phase of the reflected wave. This equation describes an hypothetical particle which moves due to the pressure gradients.

We solve (4) coupled with (1) using different initial conditions. As it can be seen in figure 5, the bubbles are trapped at the pressure antinodes \((dp/dz = 0)\).
condition \( \frac{dp}{dz} = 0 \) is less well satisfied. With this in mind, we can partially understand why the antinodes that are near the surfaces are the brightest ones.

6. Conclusions
We have presented a low cost experiment for the demonstration and study of sonoluminescence phenomena that allows to change the frequency, power, liquid level and gas type and pressure. It is the first experiment of this type built at the Mar del Plata University, and is very useful as a training experiment for advanced students. (Although is a good practice to show theoretical and numerical resolutions). In the future we expect to make an spectral analysis of the emitted light, and quantitative measurements of gas diluted in the water. There are few references to the use of a pressurized ambient, so it seems to be a good line to explore.

References
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