Analysis of hydrodynamic properties of a gas phase in water by hydroacoustic method

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Abstract. The paper deals with the existing methods for determining the hydrodynamic properties of the gas phase in a liquid medium. Most modern sonar methods belong to the class of active methods. In a number of hydrodynamic systems, their use is not desirable; therefore, passive methods are used. These methods are still not well developed. In this work, the authors show the experimental studies of the noise of air bubbles in water. In conclusion, the paper points that the noise emitted by bubbles is due to three processes at once: exfoliation, floating and collapse.

1. Introduction

At the present time, the number of industrial technologies based on the use of hydromechanical systems containing substances in different phase states, primarily gas and liquid, is growing. The dynamics of the processes occurring in such systems have been the subject of many studies for many years [1–3]. Much attention in such works is paid to the dispersed composition of the gas phase in a liquid medium, since this parameter is key in the design and calculation of most hydromechanical systems [4, 5].

Methods for determining the dispersed composition of the gas phase in a liquid medium can be divided into three types: optical, photometric and acoustic. Optical and photometric methods are most common [6–9], but they have one major drawback: they are applicable only in optically transparent media, i.e. they are not suitable for measuring the size distribution of air bubbles in turbid liquid media. Therefore, acoustic methods are considered more versatile.

Most modern acoustic methods for determining the distribution of bubbles in size are based on measurements of the attenuation and velocity of an acoustic wave passing through a layer of a bubble cloud. These methods are called active and are well described in [10–12]. But this approach has one minor drawback. An acoustic wave generated to irradiate a bubble cloud can affect bubbles. This phenomenon can be seen in the results of [13]. The authors of this work conducted a series of experiments, while changing the intensity of the emitted acoustic wave and in each of the experiments obtained different results. Thus, in a number of cases, where the maintenance of regimes with a certain bubble size is especially important, the use of active methods is unacceptable. Therefore, it is preferable to use passive methods that do not affect the dynamics of the studied processes.

Passive methods are based on the fact that air bubbles in water are sources of acoustic signals. They emit an acoustic signal due to the variable pressure of the gas inside the bubble.

In 1933, Minauer showed that under adiabatic conditions (the heat exchange between the bubble gas and the liquid is insignificant) the frequency of the acoustic signal \( f \), a gas emitted by a bubble depends on its size as follows:
\[ f = \frac{1}{R} \left( \frac{3\gamma P}{(2\pi)^2 \rho} \right)^{1/2}, \]  \hspace{1cm} (1)

where

- \( f \) – sound wave frequency emitted by a bubble;
- \( P \) – absolute liquid pressure;
- \( \gamma \) – gas specific heat coefficient;
- \( \rho \) – liquid density;
- \( R \) – bubble radius.

This expression is valid for spherical bubbles. The shape of the bubbles usually changes during the ascent. Depending on the size, they may take the form of a sphere, an oblate spheroid of a spherical segment, or a mushroom cap. In [14], a criterion is presented, in accordance with which bubbles can be considered approximately spherical, if the condition:

\[ R < \delta_\alpha, \]  \hspace{1cm} (2)

where

- \( R \) – bubble radius;
- \( \delta_\alpha \) – capillary constant.

According to this characteristic, bubbles in water are shaped as spheres, if their radius is \( R < 2.7 \) mm.

The most complete description of bubble acoustics was given by Leighton (1994). According to Leighton and Walton, the spectrum of the sound emitted by the bubbles can be used to determine their size.

The essence of passive methods is that the noise emitted by bubbles is measured, and the size of the bubbles is calculated from equation 1. Later this idea was developed in [15–20]. However, it is worth noting that these works do not take into account the fact that air bubbles in water emit noise not only during pulsations during ascent, but also when detached from the aerator and collapsing at the boarder “water-air”.

2. Statement of problem

As mentioned before, the noise emitted by a bubble can be divided into 3 stages:

1) exfoliation noise;
2) floating noise;
3) collapse noise.

Since in most cases we are dealing with a cloud of bubbles, rather than single bubbles, using the passive acoustic methods for determining the size of bubbles creates the problem of mixing the noise of all three stages. Due to the fact that the bubbles are continuously generated in a sufficiently large number, it is impossible to separate these stages in time. It is important to note that to determine the size of the bubbles; we need to select exactly the floating noise.

3. Experimental procedure

To separate the noise of the bubbles into components, an experimental setup was assembled. Its scheme is shown in figure 1. The installation consists of a vertically arranged pipe (2) made of organic glass. The diameter of the pipe is 54 mm and the length is 1000 mm. Inside the tube, at the very bottom there is a porous fine-bubble aerator (3). Next to, it is a hydrophone (4) of type 8103 from Bruel&Kjaer. Another such hydrophone (5) moves freely along the entire height of the pipe. Both hydrophones are connected to the Pulse LAN-XI multichannel analyzer. At the upper end of the pipe is fixed tank (1). A hole with a diameter of 15 mm is drilled at the bottom of this tank.
Figure 1. Schematic diagram of the experimental setup: 1 – collapse noise separation tank; 2 – vertical tube; 3 – fine-bubble porous aerator; 4, 5 – hydrophones type 8103 Bruel&Kjaer; 6 – air compressor; 7 – Pulse LAN-XI multichannel analyzer.

The experiments were carried out as follows. With the help of a compressor (6), air was supplied to the pipe through a fine-bubble aerator. The bubbles came off the aerator and floated up through the pipe. The collapse of bubbles occurred at the “water-air” boundary in the reservoir (1). The bottom of this tank serves as a cover for the upper end of the pipe, and it isolates the collapsing noise.

During the entire experiment, a constant flow of air through the aerator was maintained; therefore, it can be argued that the formation of bubbles was steady. The noise emitted by the bubbles was recorded from the hydrophones (4) and (5) connected to the multi-channel analyzer (7). The position of the hydrophone (5) has changed. The height of its installation varied from 0 to 1000 mm with a step of 100 mm. Next, the recorded signals were processed with Fast Fourier Transform (FFT) and the spectra of noise emitted by bubbles were plotted.

4. Results
The results of the experiments are presented in figure 2. The graphs show the noise spectra measured by a hydrophone (5). It moved along the height of the pipe from 0 to 1000 mm in increments of 100 mm. It was assumed that in this way, the contribution of the noise of sticking bubbles will be less and less, due to the increasing removal of the hydrophone from the aerator.

After analyzing the results of the experiments, it can be noted that when the hydrophone is removed from the aerator, the noise level decreases. You should also pay attention to the fact that the spectrum of noise, measured directly at the aerator, has a high frequency component, up to about 3.5 kHz. Further, this component gradually disappears (see graphs at $h = 100...400$ mm).

In the plots with $h > 400$ mm, the spectrum can be described as noise up to 2 kHz. That it is the noise of oscillations of bubbles during the ascent and the noise from 2 to 3.5 kHz, which can be seen in the graphs at $h < 400$ mm, is due to the sticking of bubbles.
5. Conclusions
According to the results of the conducted experiments we can concluded that the noise during the detachment of bubbles from the aerator is more broadband than the noise during ascent. In our case, it turned out that, depending on the height of the hydrophone, the noise spectrum is up to 3.5 kHz or up to 2 kHz.

Thus, clearly showing that the noise emitted by bubbles is due not only to fluctuations during ascent, but also to noise when detaching from the aerator, we conclude that the existing passive acoustic methods for determining the gas phase in water require substantial modifications.
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