Impact of salinity on the underwater noise generated by small scale air entrainment events

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Some part of the energy released in the wave breaking process is transformed into the energy of the noise. This sound depends on the water properties, however, there is a lack of reliable data concerning the underwater noise generated by less energetic events. The aim of this study was to understand the impact of salinity on the underwater noise produced during small scale air entrainment events, typical for low wind speed conditions. The tipping trough experiment was performed in a small tank to generate the small scale air injections. Four, linearly placed hydrophones HTI-96-MIN were used to record the acoustic noise accompanying this phenomenon. The bubble plume development, and underwater noise spectra, were compared for salty and fresh water. The potential energy of the modeled events resulted in different spectra, and salinity played an essential role in the emitted underwater noise.

Keywords: underwater noise, air entrainment, bubbles, bubble clusters

1. Introduction

The wave breaking phenomenon converts part of the wave energy into acoustic underwater noise [1], [2] that occurs in the broad frequency range, from 100 Hz up to about 50000 Hz [3]–[5].

Bubbles generate a substantial part of the natural component of the noise in the ocean, as a result that newly-born bubbles are mechanically excited and emit short, almost harmonic pulses of sound at their radial resonance frequencies. Also, high density bubble pockets produce sounds at frequencies equivalent to the resonance frequency of the bubble plume oscillating as a whole.

Processes related to underwater noise emission depend on various properties of the sea water, such as salinity, which modifies the amount of bubbles and their size distribution, produced by the air entrainment events [6]–[8]. The comparison of the underwater sound generated by breaking waves in fresh and salt water was performed by many scientists [6], [9], [10]. It was shown, that significant differences between dependent on water properties noise spectra were clarified due to the sizes of the entrained bubbles [10].

However, the part of the underwater noise spectrum generated during the smallest air entrainment events, has rarely been taken as a research subject. The formation of bubbles beneath breakers, their number and their fragmentation depend on the physical and chemical properties of water. Previous research [7], [11] has investigated this processes in fresh water and salt water, but for relatively energetic events [9], [12]–[14]. A question arises, if these kinds of happenings, with comparable energy, produce corresponding noise in ocean water, the brackish water of the Baltic Sea, or at least in fresh water in lakes.

It was recognised, that very low energy breaking events accompanied by bubble production, are common in the environment, and can make a significant difference in the noise emission. For this reason, the knowledge of the noise at low wind conditions and the number and size of born bubbles would be important.

The purpose of this study is an investigation of the underwater noise produced by small scale air injection events, and analysis of the impact of salinity on the sound emitted during this process. A similar experiment was carried out by Carey et al. [15] with the use of a tipping trough. This kind of equipment enables generation of air entrainment events under controlled conditions. Results of this research will help to understand the influence of salinity on the noise generated at the spot of the small scale air entrainment events.

2. Methodology

The experiment was designed to study the influence of various physicochemical properties of the water on the generation of underwater noise. The research was performed in a small tank (150 cm×50 cm×60 cm). Small scale air entrainment events were modeled with the tipping trough attached to a height adjusting rack, with a possibility to control its height above the water surface (Fig 1).

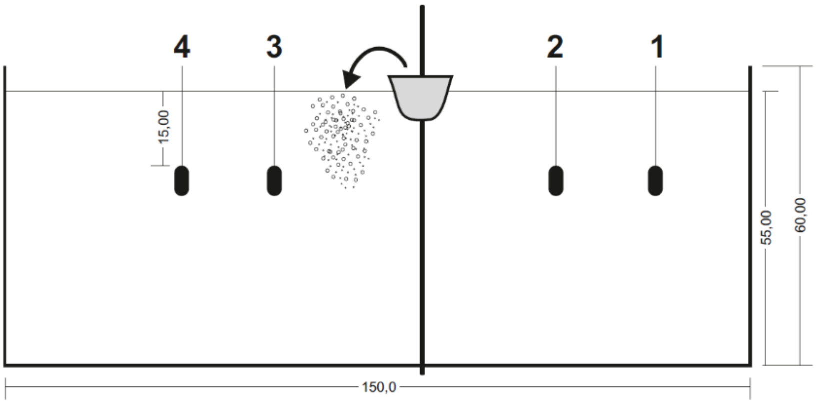

Fig 1. The setup of the conducted experiment.

Here, two different types of water were used: fresh water and salty water, with the salinity comparable to the Baltic Sea brackish water (8.5 PSU). Salty water was obtained by mixing fresh water with a proper amount of coarse sea salt. Air injection events were conducted for three different heights of the tipping trough, listed in the first column of the

Table 1. In the following columns of this table, the number of experiment repetitions for fresh water (Tab 1., second column) and salty water (Tab 1., third column) are presented.

Tab 1. Number of repetitions of the air entrainment events made from three heights of the tipping trough for fresh water and salty water.

Height of the tipping trough	Fresh water	Salty water
0.02 m	9	7
0.03 m	9	7
0.05 m	9	9

Underwater noise was recorded using four HTI-96-MIN hydrophones, located within the longer axis of the tank. Transducers have -170 dB re 1V/µPa sensitivity. The frequency response of this hydrophone is 2-30000 Hz and covers the frequency range of the sound spectrum generated by wind-driven noise. A high resolution camera was employed to document the bubble's injection processes and support further analysis.

Amplified and filtered signal was recorded with sampling frequency of 44.1 kHz in the fresh water and 96 kHz in the salty water. The analysis was performed in MATLAB. Power spectra density (PSD) was calculated using the Fast Fourier Transform (FFT) algorithm and the acoustic pressure in different measurement conditions was analyzed. For each case, data of 1.2 s duration, corresponding to the course of air entrainment events, were considered. According to each case of the study (see Tab 1), gathered data were averaged. Records collected with hydrophone number 4 were analyzed, and the results are presented in the paper. The choice of this hydrophone was justified by diminishing hydrodynamic turbulences and close distance to bubble plumes.

3. Results

Each of the air entrainment events generated a quickly diminishing burst of noise in the water. However, their duration, noise level and form of spectra depended on the height of the tipping trough and salinity (Fig 2). Measurements carried out at 0.02 m (Fig 2, a) and 0.03 m (Fig 2, b) in the fresh water case revealed a higher amount of acoustic energy released then in the salty water case. It is clearly observed in the lower frequency range, up to about 1 kHz. We assume that in this condition, the main source of the sound was the oscillations of single bubbles with radius over 3 mm, more abundantly present in the fresh water. The size of resonant bubbles corresponding to a particular frequency is presented on the upper horizontal axes in the Fig 2.

Peaks observed in the higher frequency range (starting from about 2 kHz), were caused by transient sound and resonant frequencies in the water tank. Therefore, the analysis was focused in the frequency range below 2 kHz.

For both water types, 0.05 m height of the tipping trough (Fig 2, c) revealed higher values of PSD. The noise spectrum in the lower frequency range computed for the salty water case exceeded the fresh water spectra. The observed phenomenon is probably related to the fact that here, more amounts of tiny bubbles were produced. These bubbles tended to create clusters that radiated sound in much lower frequencies than small, single bubbles usually do [9].

Spectrograms of the underwater noise registered for fresh and salty water (Fig 3), in more detail confirmed conclusions mentioned above for Fig 2 in the lower frequency range.

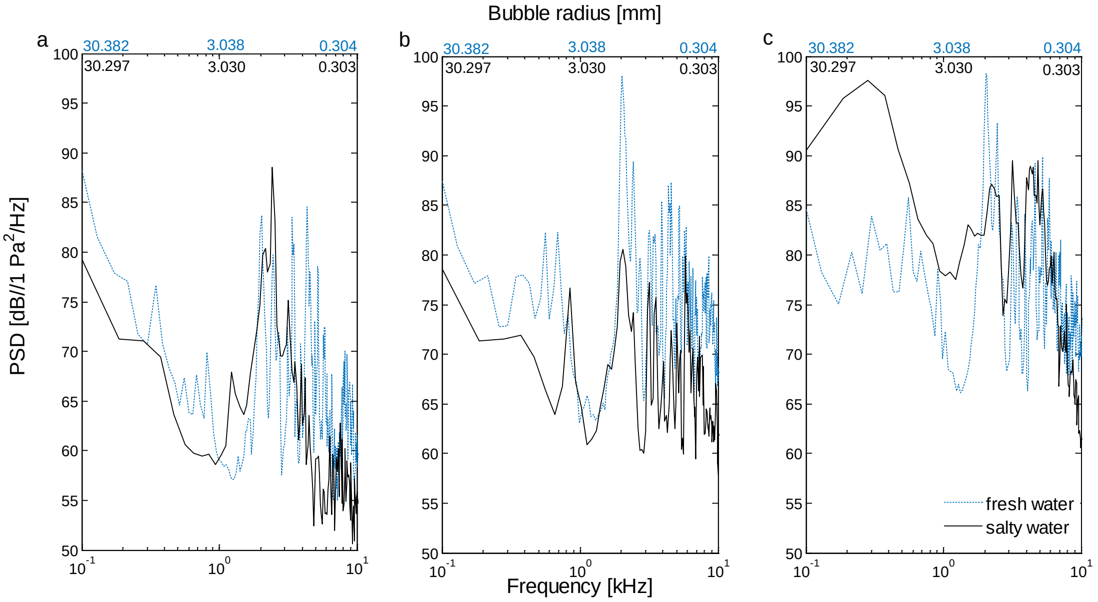

Fig 2. The comparison of power spectra density between fresh water (dashed blue line) and salty water (solid line), for three heights of the tipping trough position: 0.02 m (a), 0.03 m (b), 0.05 m (c). The upper horizontal axis express the logarithmic scale of bubble size observed in fresh water (upper blue) and salty water (lower black).

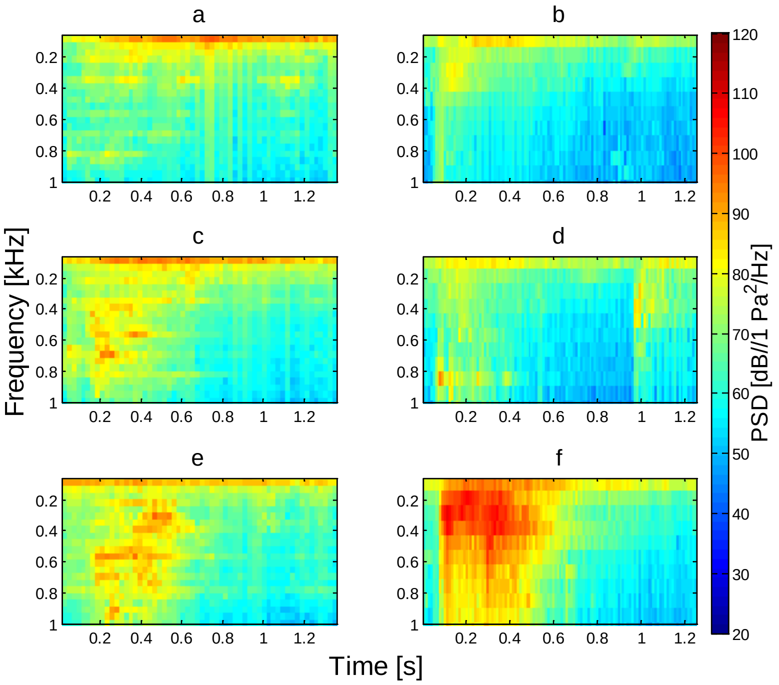

Fig 3. Spectrograms of the underwater noise in fresh water for 0.02 m (a), 0.03 m (c), 0.05 m (e) and salty water for 0.02 m (b), 0.03 m (d), 0.05 m (f).

To avoid impact of resonances, the frequency range was limited to 1 kHz, so the relationship of the height of the air entrainment generation and the spectra are clearly visible. As the height of the tipping trough increases, we observe slow, but steady, growth of the underwater noise generated after the air injection in fresh water cases (Fig 3. a, c, e). On the other hand, we notice a dramatic and rapid change in the energy of sound emitted in the case of the highest (0.05 m) position of tipping trough for the salty water (Fig 3. b, d, f).

We suppose that the reason of this form of noise spectra is caused by the surface tension on the air-water boundary. Particular heights of the air injection generation corresponded to different potential energy of the pouring water mass. Due to the lower value of the surface tension occurring in fresh water, the energy of the modeled events was enough to overcome surficial effects and inject more amount of air into the water body. The presence of salt increases the strength of the ion bounds, so the surface tension value raises. Because of this effect, only a small amount of the injected air was able to create a few, single bubbles in the lower positions of the tipping trough. The energy of poured water from the 0.05 m height, caused air entrainment events sufficient to overcome surface effects and generate more bubbles and bubble clouds, that emitted a high amount of underwater noise. This process explains that rapid difference in the level of the radiated noise. A consequence of the phenomena mentioned above were larger values of PSD noticed for fresh water during lower heights of the air injection generation, and greater for salty water under the highest position of the tipping trough.

4. Discussion

The similar experiment was performed by Carey et al. [15], and this method was adapted to our research, but with the use of different salinity and height of the tipping trough. These transformations resulted in modifications in the underwater noise emission. In their research, authors [15] observed a higher amount of small bubbles created in the salty water and attributed this phenomenon to the raised noise level. As a result, higher energy of the sound was released in the low frequency range, and exceeded the fresh water spectra. Similar observations were made throughout our experiment.

In the range of 100-1000 Hz, Carey et al. [15] estimated the spectral slope for fresh water and salty water as 12 dB/octave. In our study, spectral slopes varied, according to a particular height of the tipping trough and salinity. The fresh water case revealed a stable decrease of the spectral slope with increasing height of the tipping trough. The largest spectral slope value was estimated as 8 dB/octave for 0.02 m height of the tipping trough. A reverse situation was observed for salty water. The spectral slope for 0.05 m was very steep, and was computed as about 11 dB/octave in the range 300-1000 Hz. This state was associated with less energetic events modeled during the experiment, and the presence of bubble clusters radiating low frequency noise.

5. Summary

Small scale air entrainment events influence the underwater noise spectra and contribute to its magnitude. The differences of the physical properties of the fresh water and salty water is reflected in the produced sound emission. What’s more, surface tension controlled the underwater noise production, associated with various potential energies of the poured water mass. Because of that, the smallest air injections released higher amount of energy in the fresh water case. The most energetic events in salty water were able to overcome the surface tension, and finally entrain more amounts of small bubbles, which created clusters radiating sound in the low frequency range.

Despite of some disadvantages, such as resonant frequencies, laboratory experiments are crucial to broaden the knowledge about air entrainment events. It gives a possibility to control different properties of the water medium, and examine their influence on the underwater sound. All the more that, the anthropogenic noise occurs at the same frequency range, often with a higher magnitude, as the frequencies of our interest. So this type of research is especially important for the small scale injection events.

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