Density of air-bubbles below the sea surface,
theory and experiments

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Air-bubbles are usually found below the sea surface down to a depth of some meters. The bubble size mostly ranges between 1 mm and 10 μm.

Air-bubbles possess a resonance-frequency depending on the bubble radius. At resonance bubbles show a large (acoustic) scattering cross-section. The density n(R) of bubbles as a function of bubble-radius R (expressed in number of bubbles per m^3 per μm radius interval) can be calculated from the scattered intensity. In our case back-scattering is used.

The layers below the sea surface are insonified vertically from below. The duration T of the emitted signal is to be taken short ($<$ 1 ms) in order to mutually separate the scattered energy from bubbles at different depths and from the surface. On the other hand the bandwidth should be small enough in order to limit the interval of radius of the resonating bubbles. So a CW-pulse is chosen as the incident signal.

The total scattered energy of one bubble appears to be an integral over the radial frequency ω in the band of the incident CW-pulse. The integrand contains as factors the scattering cross-section for the bubble (at frequency ω)$\sigma_s(\omega)$ and the spectrum of the CW-pulse.

The total scattered energy from bubbles (with different radii R) in a small volume ΔV with bubble density (R) is expressed as an integral over R. This integral can be approximated by an integration over the resonance peak of $\sigma_s(\omega)$.

The scattered energy of a (finite) volume below the sea surface gives at the receiver rise to a signal which is spread in time. It appears from calculation that the sound intensity at any time t in the "bubble-part" of this received signal (before the "surface-part" of it) originates from a bubble layer of thickness $\frac{c.T}{2}$ (c= sound speed; T= CW-pulse length) at a depth depending on the time of reception t.

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The calculations described above lead with some approximations to an expression of the bubble density n(R) as a function of depth. This expression contains the following factors:
The source level of the projector together with the 3dB-widths of its main lobe, the received level, the mean frequency ω, the CW-pulse length T, the shear viscosity of sea water and the distance from the bubble layer to the projector. (Thermal acoustic damping of bubble oscillations is not taken into account.)

Measurements have been performed in the North Sea. Projectors of 6.3, 10, 23.3 and 50 kHz, together with some hydrophones, have been mounted on a platform fixed on the sea bottom.

Some results will be presented.

ABSTRACTS

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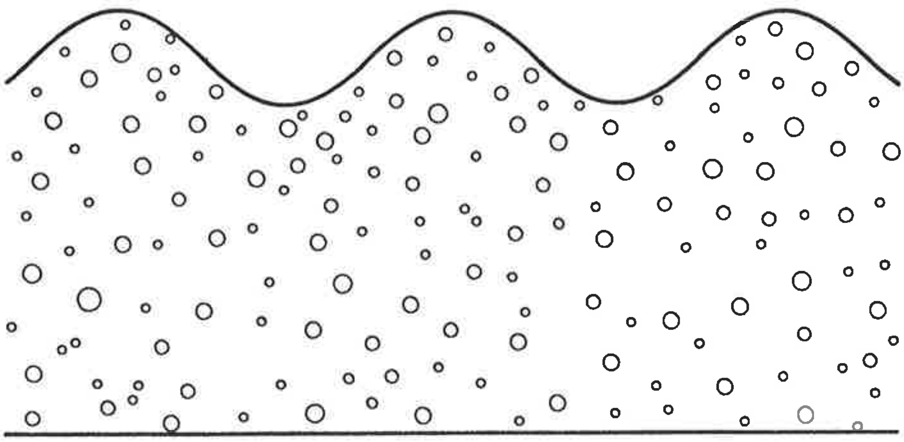

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