Marine Hydrocarbon Seeps

Natural hydrocarbon seeps are found in varying intensity along most continental shelves. These seeps emit gas, oil, or a mixture of both from seafloor vents. Free bubbles rise from the sea bed into the water columns and form gas plumes. Bubble clouds are registered by standard shipboard sonar as hydroacoustic anomalies in back scattering. Interest in this natural phenomenon has been provoked for the following reasons. First, the gas plume is a direct indicator of methane (generally, gas hydrate) deposits in the ocean floor. Second, the bubble mechanism of gas transfer into the atmosphere plays an important role. Bubble-mediated transport for a natural hydrocarbon seep is a complex process dependent upon many parameters. Some seeps are little more than gentle emanation of bubbles from a few vents, while others bubble vigorously from dense vent clusters. This research seeks to provide the necessary theoretical background to allow modeling of gas bubble streams and to solve inverse problem of evaluation of parameters of gas vents on the base of the data of echo-sounding.

The results obtained during the study of this natural phenomenon involve three research areas: (i) the structure and time history of gas seeps, (ii) development of remote sensing techniques (passive and active) for acoustical diagnostics of gas plumes, (iii) contact methods for registration of bubble size distribution within the seep.

a. Structure and time history of rising bubble cloud

The essential theoretical result of the first (i) research area is derivation of the Fokker-Plank equation describing variations in space and time bubble size distribution in random velocity flow accounting bubble dissolution. This equation takes the form that is distinguished from one derived in previous studies by the presence of additional terms. It was found that random velocity pulsation lead to the spreading of bubble distribution over the sizes. The partial analytical solutions have been found describing dynamics of dissolution of ascending gas bubbles. An explanation has been proposed for the structure of gas plume observed in the Peter the Great beach.

Maksimov A.O., Sosedko E.V. Dynamics of dissolution of ascending gas bubbles in a random flow. *In: Marine technologies.* Institute of Marine Technology Problems FEBRAS: Vladivostok . 2001, **4**, 193-203.

Using the equations describing bubble gas transfer and motion the occurrence of anomalies in concentrations of gas inclusions has been predicted. The inhomogeneity of bubble rise velocity with depth results in that the growth of bubble concentration occurs at the horizon with minimal velocity. One can draw a close analogy to the effect, arising in the theory of transport flows, when at braking “car-jam” occurs and, on the contrary, at acceleration decreasing of concentration takes place

Maksimov A. O. «Car-jam» effect in forming gas flare by ascending bubbles*. In: Marine technologies* .
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Vladivostok . 2003,
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Maksimov A. O. “Car-jam” effect and concentration anomalies in rising bubble plume. *PICES Scientific Report Series. Proceedings of the 3rd Okhotsk SeaWorkshop*
. 4-6 June, 2003, Vladivostok , Victoria : PICES, 2004. 67-70.

In order to get new insight into the problem of distribution of dissolved gas near the gas seeps, we analyzed two limiting cases: a) small depth and spreading seeps when the vertical gas flow transferred by rising bubbles and by diffusion is constant and b) the gas plume which has small cross section in comparison with sea depth. A new physical quantity - the horizon of dissolution appears in the problem. For narrowbubble size distribution emitted by vents the bubbles will dissolve at about the same depth, i.e. in a thin layer. This depth is not only the special point in the profile of the concentration of dissolved gas, but is also the “car-jam” point for the rising bubble distribution Any substances carried by the bubbles, e.g. sediments, contaminant particles, bacteria, etc will be deposited in this layer.

Maksimov A.O., Polovinka Yu.A. Bubble Distribution at Gas Seeps. *Fifth Workshop on Russian-German Cooperation in the Sea of Okhotsk-KurileIsland System*
. 26-28 May, 2004. Vladivostok . P. 34.

(ii) Development of remote sensing techniques (passive and active) for acoustical diagnostics of gas plumes

The method for evaluation of parameters of gas vents on the base of the data of acoustical echo-sounding has been proposed as the part of this research area. The intensity of back scattering signal with supposed dominant contribution of resonant bubbles provides registration of population of these bubbles with depth. These data used as initial conditions for the system of equations describing the growth and dissolution of arising gas bubbles. Inversion of the solution along the trajectories in the space of bubble sizes and depth provides the finding of bubble size distribution at the bottom – near the gas vents. The possibility to detect the horizon of dissolution on the data of back scattering from gas plume has been analyzed.

Maksimov A.O., Sosedko E.V. Evolution of back scattering from rising bubble plume. *In: Ocean Acoustics* (dedicated to the 85th anniversary of L.M. Brekhovskikh) M.: GEOS, 2002. 237-241.

Maksimov A.O. Acoustics of marine hydrocarbon seeps. *Proceedings of the 5-th World Congress on Ultrasonics*, Universite 6, Paris : 2003. 229-232.

Along with the traditional (active) acoustical technique for sensing gas vents a passive one has been proposed. It is based on analyzes of noise spectra near venting field at the frequencies corresponding to the natural (collective) oscillations of bubble plume. A rising bubble plume forms an effective acoustic waveguide that possesses normal modes. The noise frequency spectrum has several peaks related to the lowest-mode frequencies of the bubble plume. Explicit expressions for the frequencies of these modes have been derived and their dependence on plume size and gas volume fraction has been analyzed. The model is extended to prediction of average number of vents at the base of the gas flare and an average number of bubbles generated per unit time by one vent on the base of the measured sound spectral density and the solution of the Helmholtz equation.

Maksimov A.O. Spatial Distribution of Noise near Marine Hydrocarbon Seeps. *Transaction (Doklady) of the RAS / Earth Sciences* 2004,

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Maksimov A.O. Spectrum and spatial correlation of noise near marine hydrocarbon seeps. *Proceedings of the XV Session of the Russian Acoustical Society*
, 15-18 November, 2004, Nizhniy Novgorod, GEOS, 2004,
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Maksimov A.O. Noise spectra of gas seeps. *Acoust. Physics,* 2005, **51**(3), 324–332.

(iii) Contact methods for registration of bubble size distribution

The conventional, linear methods of "acoustic spectroscopy" based on the dominant contribution of the resonant bubbles in back scattering are not effective in the determination of bubble size distribution near the vents in deep-sea. In order to derive a new technique providing bubble detection with low quality factor and in deep ocean, the possibility of synergetic use of nonlinear and resonant characteristics of bubble oscillation has been analyzed. The investigations considered issues associated with transient regime of nonlinear bubble oscillations in the vicinity of the fundamental and the subharmonic resonance of breathing mode, the peculiarities of bistable bubble oscillation, the features of individual spectral bands of the acoustical radiation. Along with the dynamics of a single bubble the studies of the spectral bands of acoustical resonator filled with bubbly liquid have been performed.

Maksimov A.O., Leighton T.G., Sosedko E.V. Nonlinear transient bubble oscillations // *Nonlinear Acoustics at the Begining of the 21st Century*
edited by O.V. Rudenko & O.A. Sapozhnikov. MSU, Moscow, 2002,
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, 987-990.

Sosedko E.V. Peculiarities of nonlinear resonances and their manifestation in acoustics of inhomogeneous media. Ph.D Thesis POI FEBRAS RAS.Vladivostok , POI. 2003. 132 p.

The electrochemistry can be used to monitor mass transfer enhancements due to buoyancy rise and oscillations of a bubble. Acoustoelectrochemistry incorporates the effect of acoustic fields on the investigation and facilitation of chemical processes through the application of a suitable electrochemical system and the measurement of an appropriate electrochemical current. In this novel technique derived by our U.K.colleagues the motion of the gas liquid interface was monitored by observing the current at a Pt microelectrode positioned close to the gas/liquid boundary of a gas bubble. The problem of parametrically driven bubble shape oscillations (Faraday ripples) has been given full consideration. The theory of microstreaming which is induced when a single bubble is driven acoustically in the regime of parametric generation of Faraday waves has been derived and explained the features of the mass transfer enhancements produced by an oscillating gas bubble.

Maksimov A.O., Leighton T.G. Transient processes near the threshold of acoustical driven bubble shape oscillations. *ACUSTICA - Acta Acustica.* 2001,**87**(3), 322-332.

Leighton T.G., Birkin P.R., Maksimov A.O., Watson Y.E. A review of mass flux observations in liquids as a result of Faraday waves on gas bubble walls. *Proc. R. Soc. Lond*. 2005. (in preparation).