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THE MONITORING OF THE LIQUID-GAS MIXTURE PARAMETERS BY THE PASSIVE ACOUSTIC METHOD

[a]Stepan Gavrilev, [b]Mikhail Ivanov, [c]Semen Totunov

[a]Bauman Moscow State Technical University, Moscow, Russian Federation, stepan.tab92@gmail.com
[b]Bauman Moscow State Technical University, Moscow, Russian Federation, mivanov2005@mail.ru
[c]Bauman Moscow State Technical University, Moscow, Russian Federation, simongf@yandex.ru

Abstract: *The considers the actual problem of determining the dispersed composition of the gas phase in a liquid medium. The work uses a passive acoustic method based on the interaction between the vibration frequency of bubbles and their size. On the experimental setup, acoustic waves emitted by air bubbles in water were recorded using a hydrophone. The sizes of the bubbles were determined by the spectra of the recorded signal. In the course of the experiments, the bubble radius was varied from 1.7 to 2.4 mm. The spectrogram of the signal was used to estimate the intensity of the release of bubbles in the volume of the experimental apparatus. Using the technique of synchronous filming, a video recording of the process of bubbles allocation at the apparatus was made. The analysis of the recorded video showed the correspondence of the determination of the parameters of the liquid-gas mixture. There are proposed various application scenarios of the passive acoustic method in the oil and gas industry.*

Keywords: *passive acoustic method, acoustic bubble sizing, process monitoring*

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1. INTRODUCTION

The dispersed composition of the gas phase in a liquid medium is one of the key parameters in many technical systems [1-3]. Particular attention is paid to this parameter in the oil and gas industry. For example, while determining the regimes of gas-liquid flows in the boreholes of oil-producing wells. The flow regimes depend on the ratio of the "oil - water – gas" components. In the calculation methods, the initial data are not only the volumetric content of the gas phase in the flow, but also the sizes of gas bubbles [4, 5].

Together with this, the necessity to determine the dispersed composition of the gas phase is also present at the stage of primary processing of crude oil. The degassing process is an example of this. Gas and water are separated from oil for several reasons: the separated oil gas is used as a fuel and chemical feedstock; the hydraulic resistance decreases together with the decrease of the of oil, gas and water intermixing; the pressure fluctuations in pipelines are reduced during further oil transportation from separators to oil treatment units [6, 7]. For deeper degassing of oil, acoustic deaerators have been developed using ultrasonic transducers. The efficiency of such deaerators depends on the correctly selected mode of ultrasound irradiation of bubbles. The irradiation mode is determined depending on the dispersed composition of the gas phase in the oil-water mixture. Decreased efficiency of the degassing process could lead to negative consequences. Unseparated hydrocarbon gases have a corrosive and cavitation effect, which leads to a decrease in productivity and accelerated wear of oil pumping equipment. Therefore, the problem of controlling the parameters of the gas phase in oil and oil-water mixtures is urgent.

The most common methods for determining the disperse composition of the gas phase in a liquid medium are optical and photometric. But they are applicable only in optically transparent environments. Since in the oil and gas field, gas-liquid mixtures are not only turbid, but often there is simply no optical access to them, it is preferable to use acoustic methods [8]. The most promising are passive methods [9-11]. Unlike active ones, they are non-invasive, i.e. do not affect the liquid-gas mixture.

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 gas pressure inside the bubble.

Minnaert related the frequency of the sound $\boldsymbol{\omega_m}$, emitted by the bubble to its radius $\boldsymbol{R_0}$:

$$\omega_M = \frac{1}{R_0}\sqrt{\frac{3\gamma p_0}{\rho}} \tag{1}$$

where
$\boldsymbol{\omega_m}$ – circular frequency of the bubble;
$\boldsymbol{R_0}$ – average bubble radius;
$\boldsymbol{Y}$ – adiabatic coefficient;
$\boldsymbol{p_0}$ – fluid pressure;
$\boldsymbol{\rho}$ – density of the liquid, surrounding the bubble [12].

For an air bubble in water under atmospheric pressure at a temperature of 20 ° C, this expression is reduced to a simple form:

$$\nu_M = \frac{3,28}{R_0} \cdot [m \cdot Hz] \quad (2)$$

where
$\nu_M = \frac{\omega_M}{2\pi}$ — bubble oscillation frequency [Hz].

Expressions (1) and (2) reflect the inverse dependence of the bubble radius to the frequency of the sound emitted by the bubble:

$$R_0 = \frac{3,28}{\nu_M} \cdot [m \cdot Hz] \quad (2)$$

The passive acoustic method could be used to determine the presence of the gas phase, as well as its dispersed composition at various stages of oil production and processing.

For example, for a methane bubble in an oil-water mixture at a temperature of 20 ° C, expression (1) will take the form:

$$\nu_M = \frac{M}{R_0} \cdot [m \cdot Hz] \quad (4)$$

where
M=3,14..3,76 depending on the density of the oil-water mixture.

2. MATERIALS AND METHODS

To demonstrate the fundamental possibility of controlling the parameters of the gas phase in a liquid medium, an experimental apparatus was assembled. It is a transparent cube-shaped tank with dimensions of 28x28x28 cm (1), filled in with water to a level of 22 cm. A 30G injection needle (2) was installed at the bottom of the tank. Through this needle air is supplied from a balloon (6) for the means of bubbling. The measuring path consists of a Bruel & Kjaer type 8103 hydrophone and a Bruel & Kjaer type 4961 microphone (4) connected to a Pulse Lan-XI multichannel spectrum analyser. The process of bubbling in the net volume of the reservoir is recorded on a video camera (7). The microphone (4) is installed next to the video camera (7).

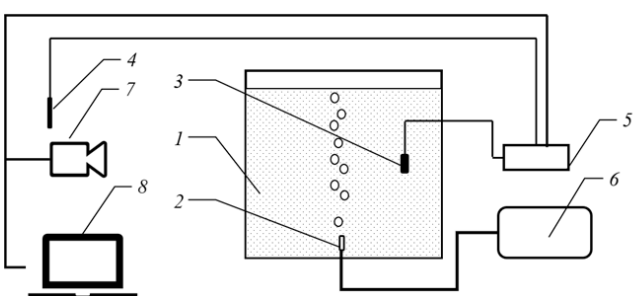

Fig. 1: Experimental apparatus diagram

The experiments were carried out as follows. The recording of the signals from the hydrophone and the microphone starts at the same time. Then the video recording with sound track on the camcorder starts. So that in the future it was possible to synchronize the recorded signals from the multichannel spectrum analyser and the video camera, a "clap" was created. After that, the shutter on the cylinder was opened for a short time, which led to a sharp increase in excess pressure in the „cylinder-injection needle" system. Due to this, air was forced through the needle and thus bubbles were generated. The size of the injection needle (2) was chosen so that the oscillation frequency of the bubbles, calculated by the Minnaert ratio, was less than the lower mode of the tank filled with water (<2679 Hz).

During each experiment, 4 tracks were recorded:
1. video sequence with a resolution of 1280x720 p and a frequency of 60 fps;
2. audio track from the microphone of the video camera (7);
3. audio track from the microphone (4);
4. audio track from the hydrophone (3).

Audio tracks were recorded with a sampling rate of 48 kHz.

The video track and the audio track from the hydrophone were synchronized by matching the "claps" recorded on the second and third audio tracks from the microphones. Then the spectra of signals from the hydrophone were calculated at different times. To minimize spectrum spreading, the Hamming window [13, 14] was used when calculating the spectrum.

3. RESULTS

The graph of the signal recorded by the hydrophone and its spectrogram are shown in Fig. 2. There are 5 characteristic points marked on it. The frames from the video sequence corresponding to these points are shown in Fig. 3. The moment the bubbles start is marked with point A. It is accompanied by a sharp increase in the noise level, followed by attenuation until the shutter is closed (point B). During this period of time, the intensity of bubbling is maximum. The splash before point A is a „clap" for recording synchronization.

Analysis of the recorded video showed that after closing the shutter, the release of bubbles from the injection needle does not stop immediately. Due to the residual excess pressure, bubbles continued to evolve. In this case, the intensity of bubble formation gradually decreases until the complete cessation of air flow through the needle. This can also be judged by the level of the recorded signal and the spectrogram (see section B-C „in Fig. 2).

The lower part of Fig. 2 shows video frames corresponding to regions 0, A, B, and C.

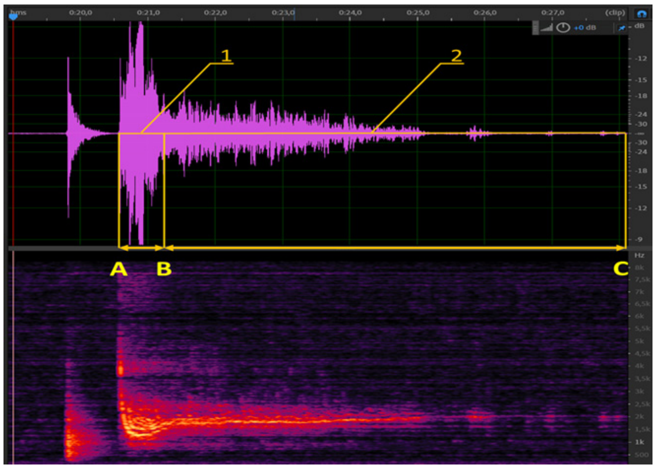

Fig. 2: A graph of the signal recorded by the hydrophone and its spectrogram

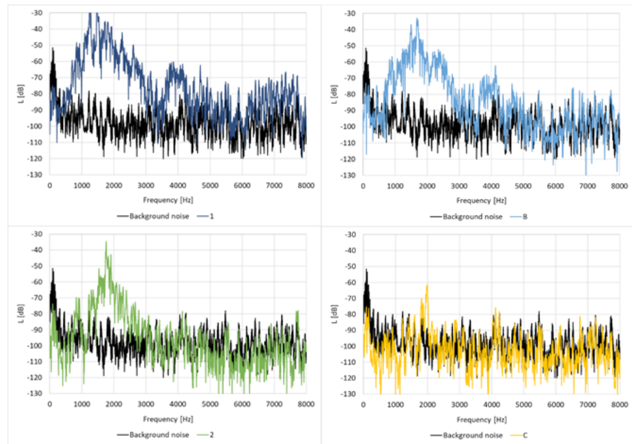

Fig. 4: Bubble signal spectra plots

Fig. 4 shows the signal spectra at different points in time corresponding to the points marked in Fig. 2: 1, B, 2 and C. With an open shutter (point 1), the main spectrum peaks fall at frequencies in the region of 1350 Hz, after closing the valve (point B) - 1680 Hz, at an intermediate moment of time until complete attenuation (point 2) - 1760 Hz, and at the final moment before the cessation of bubbling - 1990 Hz. Also, the spectra show peaks at frequencies from 3700 to 4100 Hz. They correspond to smaller bubbles, which can be seen in the frames shown in Fig. 3.

An increase in the frequency of peaks in the spectra reflects a decrease in bubble size. And this is true. It is obvious that with a decrease in the flow rate of air flow through the needle, the size of the bubbles decreases. Using expression (3), the sizes of the bubbles were estimated. Their radius over the entire time interval (A - C) decreased from 2.4 to 1.7 mm. The radius of small bubbles varied from 0.9 to 0.8 mm.

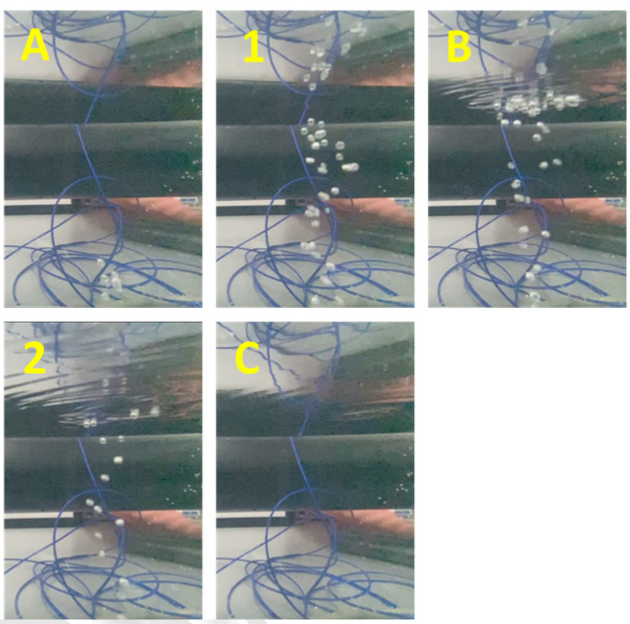

Fig. 3: Frames from the footage at various points in time

4. CONCLUSION

The possibility of determining the bubble size by a passive acoustic method is demonstrated. Under laboratory conditions, the acoustic signals emitted by the bubbles were recorded. Using synchronous video filming, the correspondence of the bubble parameter estimation based on the signal recorded by the hydrophone is shown. According to the spectrogram of this signal, it is possible to diagnose the dynamics of changes in the state of the liquid-gas mixture, namely: determining the moment when gas bubbles appear in a liquid medium, assessing the number and size of bubbles at any time intervals.

It is proposed to use such a technique to control the parameters of the gas phase in oil and oil-water mixtures at various stages of production and refining in order to:

1. determination of the regimes of liquid-gas flows in the shafts of oil-producing wells, in the calculation methods of which information on the dispersed composition of the gas phase is required;
2. selection of the parameter of the operating modes of acoustic deaerators;
3. monitoring the efficiency of the degassers;
4. detecting the presence of an unwanted gas phase in various sections of pipelines, etc.

REFERENCES

[1] Brennen, C.E.: Cavitation and bubble dynamics, 2013
[2] Ksenofontov, B.S., Yakushkin, V.P.: Multistage model of flotation and its use, 29th International Mineral Processing Congress, IMPC 2018, Canadian Institute of Mining, Metallurgy and Petroleum, Department of Ecology and Environment Protection, Bauman Moscow State Technical University, 2-ya Baumanskaya, 5, Moscow, 105005, Russian Federation, pp. 1063–1074, 2019
[3] Bunkin, N.F., Drozdov, A.N., Drozdov, N.A., Kozlov, V.A., Tuan, V.M., Fouilhe, V.L.: Suppression of the coalescence of gas bubbles in aqueous electrolyte solutions: dependence on the external pressure and velocity of gas flow through a column with liquid, Physics of Wave Phenomena, 25, no. 3, pp. 219–224, 2017
[4] Pedersen, S., Durdevic, P., Yang, Z.: Challenges in slug modeling and control for offshore oil and gas productions: A review study, International Journal of Multiphase Flow, 88, pp. 270–284, 2017
[5] Bannwart, A.C., Rodriguez, O.M.H., Trevisan, F.E., Vieira, F.F., de Carvalho, C.H.M.: Experimental investigation on liquid-liquid--gas flow: Flow patterns and pressure-gradient, Journal of Petroleum Science and Engineering, 2009
[6] Trujillo, F.J., Juliano, P., Barbosa-Cánovas, G., Knoerzer, K.: Separation of suspensions and emulsions via ultrasonic standing waves - A review, Ultrasonics Sonochemistry, 2014
[7] Saththasivam, J., Loganathan, K., Sarp, S.: An overview of oil–water separation using gas flotation systems, Chemosphere, 144, pp. 671–680, 2016
[8] Leighton, T.: Acoustic bubble detection - I: The detection of stable gas bodies, 1994
[9] Gavrilev, S.A., Tyurina, J.M., Ivanov, M. V.: A Passive Acoustic Method for Detection of Gas Bubbles Size Distribution in Water, Transactions on Engineering Technologies, Springer Singapore, Singapore, pp. 133–142, 2021
[10] Maksimov, A.O., Burov, B.A., Salomatin, A.S., Chernykh, D. V.: Sounds of marine seeps: A study of bubble activity near a rigid boundary, The Journal of the Acoustical Society of America, 136, no. 3, pp. 1065–1076,2014
[11] Manasseh, R., LaFontaine, R.F., Davy, J., Shepherd, I., Zhu, Y.-G.: Passive acoustic bubble sizing in sparged systems, Experiments in Fluids, 30, no. 6, pp. 672–682, 2001
[12] Minnaert, M.: XVI. On musical air-bubbles and the sounds of running water, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 16, no. 104, pp. 235–248, 1933
[13] Podder, P., Zaman Khan, T., Haque Khan, M., Muktadir Rahman, M.: Comparative Performance Analysis of Hamming, Hanning and Blackman Window, International Journal of Computer Applications, 2014
[14] Harris, F.J.: Multirate FIR Filters for Interpolating and Desampling, Handbook of Digital Signal Processing, Elsevier, San Diego, pp. 173–287, 1987

Stepan Gavrilev *is a research assistant at Bauman Moscow State Technical University. He specializes in hydroacoustics, safety management, industrial ecology, and biotechnology. He also takes part in the study of hydrodynamic processes in multiphase media using acoustic methods. Stepan Gavrilev is a co-author of patents and the author of over 10 scientific publications. He participated in all-Russian Conferences of Young Scientists ASO (Moscow, 2016-2020) and the World Congress on Engineering (London, 2019).*

Mikhail Ivanov *is Doctor of Engineering Science, Professor of the Department of Ecology and Industrial Safety, Head of International Scientific and Educational Cooperation, Head of the Vibroacoustic and Hydroacoustic Laboratory of the Bauman Moscow State Technical University. In 2012, Mikhail Ivanov defended his PhD thesis on „Ecology in chemistry and petrochemistry" with the theme: Vibroflotation treatment of oily wastewater as a way to reduce ecological damage to the environment. In 2018, he defended his doctoral thesis on „Vibroresonance technology of industrial wastewater treatment" in the specialty „Ecology in chemistry and petrochemistry" at the Russian State University of Oil and Gas.*
Mikhail Ivanov is the author of over 40 scientific publications, a member of the dissertation council of the University of Genoa in Mechanical Engineering, Energy and Management in Engineering, and a winner of the Golden Names of High School competition 2019.

Semen Totunov *is a master's student in the direction of technical acoustics of the Department of Technosphere Safety of BMSTU, engineer of the acoustic laboratory of BMSTU.*
Semen Totunov is a specialist in the calculation and design of noise protection screens, noise suppression at production facilities. He engages in the research of acoustic characteristics of new types of materials.