DYNAMIC PROPERTIES OF FOAM STRUCTURE ELECTRICAL CONDUCTIVITY DISTRIBUTION ALONG HEIGHT

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Experimentally obtained temporal characteristics of electrical conductivity (resistance) distributed on the height of the foam layer are presented. The construction of an electrical conductivity measuring complex based on the principle of volt-ampere method and sequentially interrogating many measuring conductivity sensors distributed along the height of the sample are considered. The result in the form of a graph is displayed in the indicator screen faster than the foam structure disintegrates. The proposed complex performs 4 measurement cycles in less than 5 seconds, which is sufficient to measure foam structure changes. The formation of gradient high-resistivity layers in the upper part of the sample is detected, that is the reason for the increased emissivity of foam formations detected during remote sensing of the sea surface. The resistance between probes in the surface layer reaches levels exceeding 8 megohms.

Keywords: dielectric constant, electrical conductivity, foam, foam structure, liquid foam.

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1. Introduction

Interest in the physical properties of water foams is primarily due to the discovery of the phenomenon of the effect of increasing emissivity of the sea surface covered with foam formations. The complexity of the phenomenon is evidenced by the fact that research has been ongoing for decades and has not lost its relevance at the present time [1-4]. In this case, remote sensing methods are considered, which makes it possible to obtain exclusively integral characteristics. The study of the electromagnetic properties of foam formations depending on their dispersion is a relevant task in experimental physics. Laboratory measurements are required to obtain information about the details of the process. The properties of artificially created foam are determined by the foaming ratio, which is the ratio of the volume of finished foam to the volume of foam solution used to create it. Electromagnetic parameters of foam can be measured by known microwave facilities [5].

A special cell based on sliding lines [6] made it possible to obtaine experimental results of the reflection and attenuation of electromagnetic waves with a wavelength from 30 m to 24 cm in foam water structures of foaming ratio from 10 to 85 units without additives and with salt additives with a concentration of 1, 4, and 6 percent [7, 8].

We have investigated foam structures in biconical resonators in wide multiplicity ranges and in waveguides. Based on the measurements of voltage standing wave ratio (VSWR) and wave attenuation in waveguides filled with foam samples, the values of dielectric permittivity and dielectric loss in samples of these foam structures were calculated.

Measurements in the range of 2-4 GHz by means of biconical resonators of foam structures gave the values of dielectric permittivity and losses in the range from 1.79 to 1.84 and from $7.4 \cdot 10^{-3}$ to $1.1 \cdot 10^{-2}$, respectively [9].

Measurements [10, 11] of the reflectivity of foam formations in the 38-52 GHz range using a measuring and computing complex [12] showed that the reflective properties were strictly dynamic in nature. A decrease in reflectivity is observed over 15-25 minutes, remaining at an acceptable level for 1 and even 4 hours [11]. This is ensured by the spontaneous emergence of a gradient structure instead of a homogeneous foam structure, when large foam bubbles are concentrated in the upper layers of the foam, bubbles of minimal size in the lower layers, and bubbles of medium size in the middle layers.

This experimental result dictates the need for dynamic measurements at different points along the height of the foam sample, which can be most simply carried out by layer-by-layer measurement of DC conductivity. A special electronic measuring device with many pairs of electrodes allows to automatically obtaine the characteristics of foam resistance (electrical conductivity) along height [13].

Therefore, the purpose of this study is to check the accuracy of the special electrical conductivity measuring complex (ECMC) using test samples and to obtain temporal height foam structure parameters distribution.

2. Electrical conductivity measuring complex and its testing

ECMC (Fig. 1. (a)) consists of a 40 cm high special dielectric and transparent column of 40 pairs of probes, located at a height of 1 cm from each other and electrically connected to the switching system (CS) and to the system unit of the computer (SB) for measurements, data transmission and processing The signal processed by a special program is displayed in the required form on the monitor. For test measurements, a set of reference resistors are connected to the input of CS, and for measurements of foam structure, a measuring column filled with a sample of the foam structure is connected to the input of the CS.

Fig. 2 shows the results of measuring the resistivity distribution over height for a foam structure sample (with a multiplicity of 35) for 15 minutes after its creation. These results allowed us to estimate the limits of resistivity variation, i.e., the need to ensure resistivity measurements ranging from kiloohms for the lower layers to megaohms for the upper layers. This requires appropriate tuning of the measurement channels. The presence of high resistivity in the upper layers confirms high heat losses and, consequently, an increase in emissivity, i.e., radio brightness temperature, as observed during remote sensing of the ocean surface. From Fig. 2 (a) it is clear that the foam sample has two segments of linear gradient structure with different inclinations (from 21 to 31 probe and from 31 to 37 probe), the measurement error (Fig. 2 (b)) significantly increased in the upper layers with high level of resistance.

Calibration results with error estimates are shown in Fig. 3. From Fig. 3(b), it is evident that for values above 40 MΩ, there is a slight increase in relative measurement error to 0.1%, which is associated with a significant decrease in signal amplitude. The shape of the curve in Fig. 3(a) has not been corrupted. The time of measurement, processing of results, and display on the monitor in the required format depends on the value of the measuring resistance and does not exceed 5 seconds. This fact ensures the ability to track changes in foam properties over time.

The important point of the study is preparing a foam sample. The foam was prepared from aqueous solution based on surface-active alkyl sulfate additives PO-Al-05 of 6% concentration. Aeration is made with special equipment. Fig. 1 (b) shows a photo of structure of short-lived foam sample in the initial period of its formation with an initial foaming ratio of 35 units. The size of the foam bubbles is 0.01 – 1.2 mm and less. Fotos for another sample with foaming ratio of 45 units are presented in Fig. 1 (c), (d).

At the initial moment of time, the diameter of the bubble shape irregularities is in the range of 0.2 – 1.0 mm, and the shape of the bubbles is spherical. As such, an image of the structure of the quasi-homogeneous foams along the entire surface of the glass is given. Fig. 1 (d) shows a very changed image of the structure of the foam sample after 15 min in comparison to the homogeneous sample of foam in Fig. 1 (c). It becomes clear that the sample from a homogeneous structure turned into a sample with a gradient structure, in which the smallest bubbles are located at the bottom; the largest bubbles are located at the top. The diameter of inhomogeneities in the shape of bubbles is within 0.2 mm (at the bottom) and 2.0 mm (at the top), which is due to the influence of gravitational forces.

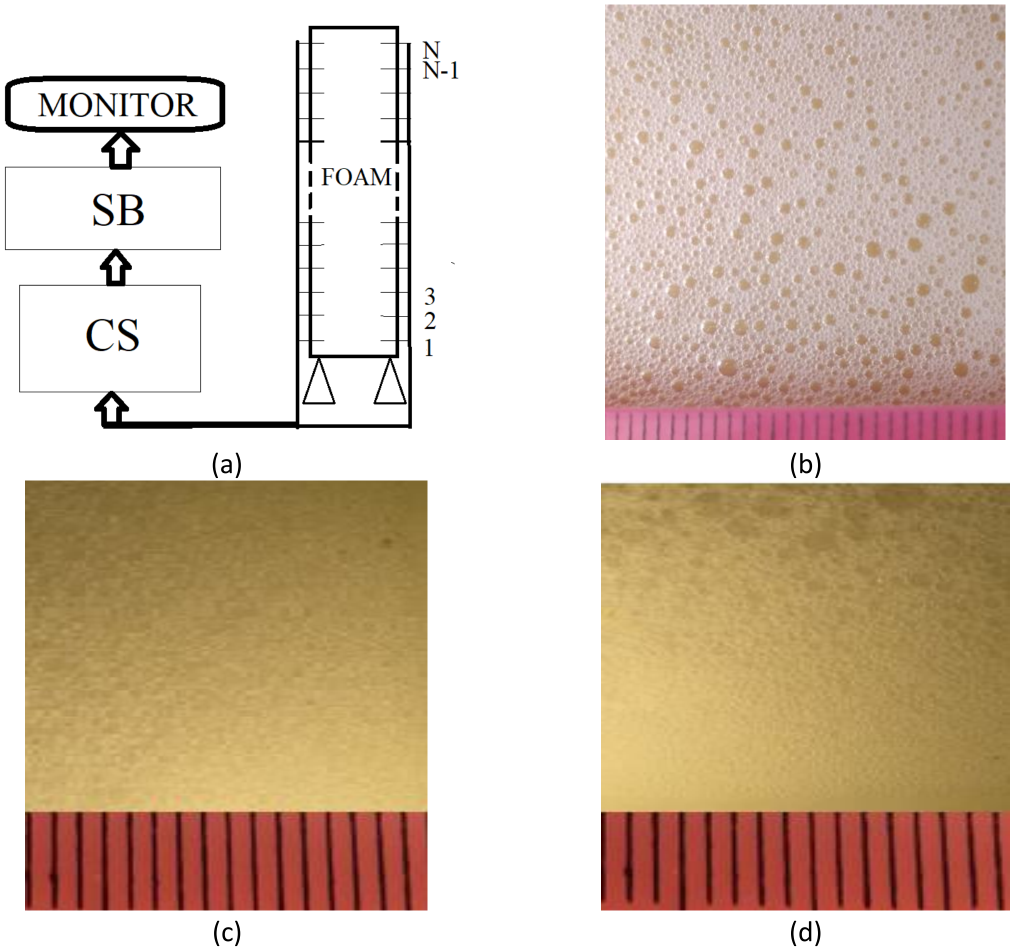


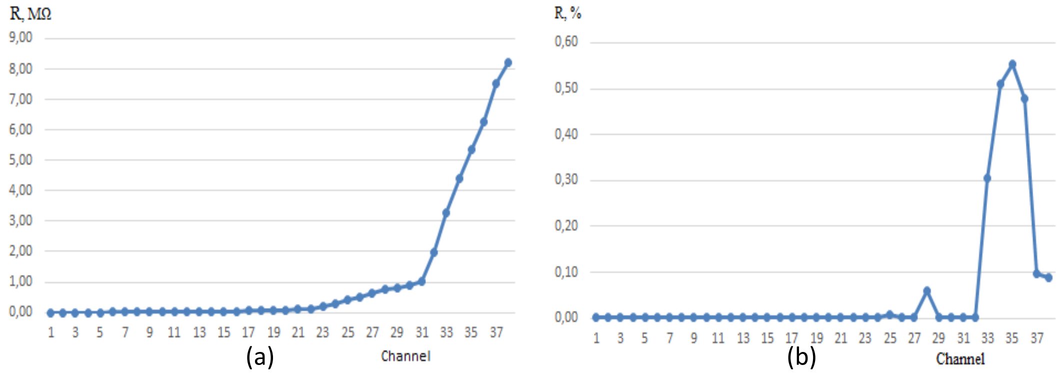
Fig.1. Experimental equipment and samples: (a) Simplified scheme of electrical conductivity measuring complex (ECMC); (b) Photo of the foam structure with foaming ratio of 35 units at the initial time of its existence (0 minutes); (c) Photo of the foam structure with foaming ratio of 45 units at the initial time of its existence (0 minutes); (d) Photo of the foam structure with foaming ratio of 45 units at the time of its existence of 15 minutes.

3. Foam measurements

Fig. 2 shows the formation of gradient structures, but does not provide information on the process of formation of such a structure. Fig. 4 shows the temporal dependence of resistance in the region of small values of resistance (lower part of the sample), where the process of formation of high-resistance layers occurs.The experimental results show that the foam medium is structurally inhomogeneous and can be considered as a transitional multilayer object, the electrical characteristics of which vary both in space (in height) and in time. The values of the electrical resistance in the samples under study lie in a wide range: from 100 Ω to 1.2 MΩ and above.

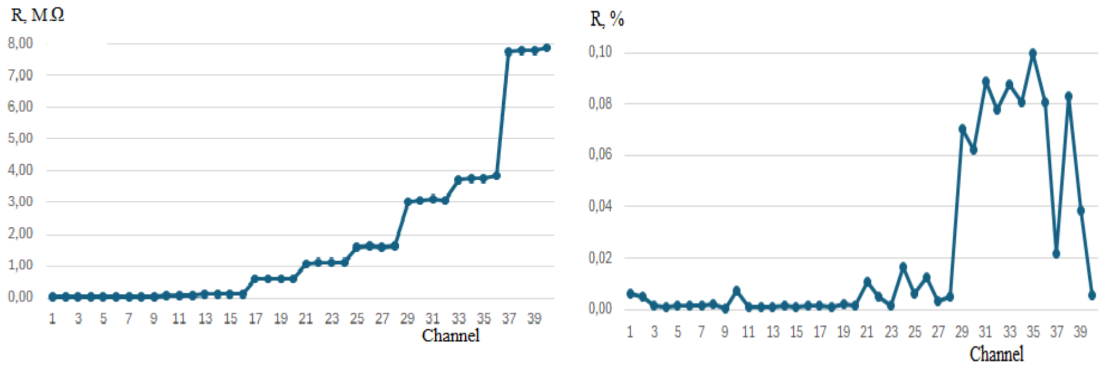
Fig. 4 presents the results of experimental measurements for different time points after foam formation: graph 1 – after 5 min, graph 2 – after 10 min, graph 3 – after 15 min, graph 4 – after 20 min and graph 5 – after 25 min.

Graph 1 (5 min after the start of foam formation) shows approximately constant level of resistance near 30 kΩ. In the zone bordering the air environment (33–39 probes), a gradient layer is located, in which the resistance increases from 54 to 146 kΩ.



(a) (b)

Fig.2. Test verification results of foam: (a) Measurement results for foam sample with foaming ratio of 35 units at the time of its existence of 15 minutes. (b) Foam sample measurement repeatability error results.



(a) (b)

Fig.3. Test verification results: (a) Test sample measurement results. (b) Test sample measurement repeatability error results.

Graph 2 (10 min after foam formation). From 1 to 22 probes, the resistance dependence is almost uniform, with the region with a value of about 100 kΩ dominating. In the zone of 25–29 channels, the resistance between probes rapidly increases from 420 kΩ to 1.5 MΩ and more. To better visualize the processes in the lower part of the sample, data values above 1.5 MΩ were limited.

In the area of channels 23–25, the initial formation of a defect was recorded in the form of a sharp growth and the appearance of the step of a locally compacted layer with a characteristic resistance value of about 420 kΩ. Further, this defect is traced in graphs 3 and 4 in the range of channels 8–6 and even in graph 5 – in the form of a pronounced heterogeneity in the area of channel 4.

Graphs 3, 4 and 5 (15, 20 and 25 min). For these time points, the foam structure is already difficult to be unambiguously represented in the form of clearly delimited layers.

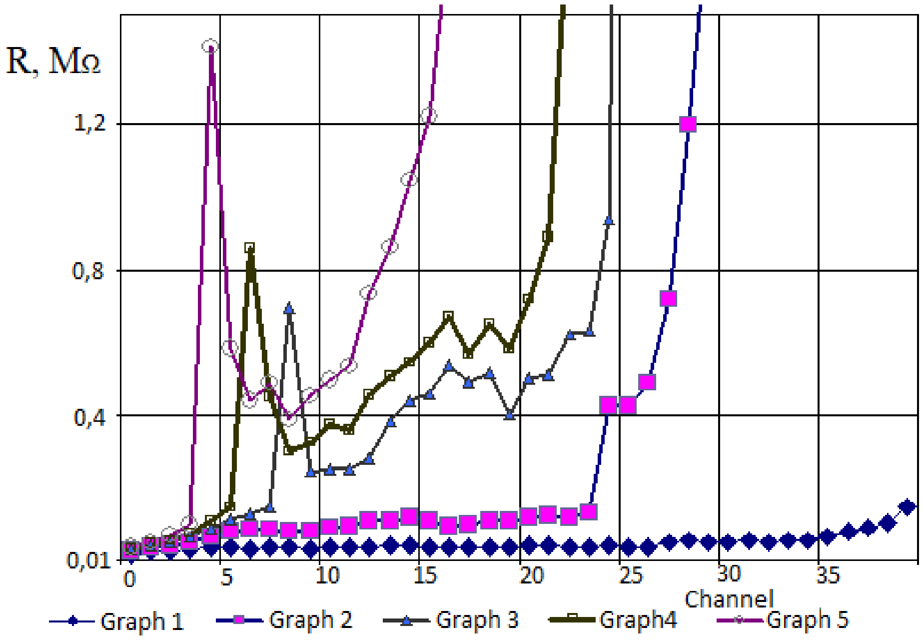


Fig. 4. Temporal dependence of electrical resistance versus the channel number.

The analysis of graphs 3–5 allows us to trace the dynamics of the movement of defects along the thickness of the foam. All defects move downward, which at first glance may seem illogical. However, this is explained by the fact that the force of gravity of the upper layers exceeds the Archimedes' buoyancy force. In the process of moving downward, the defects gradually lose their liquid phase, become more gas-filled, and decrease in size. At the same time, the upper boundary of the sample also moves downward. In other words, with an increase in the time of existence of the foam sample, it gradually collapses, and its total thickness decreases.

Thus, the presented results reflect the main features of the change in the electrical conductivity and structure of the foam during its degradation.

4. Conclusions

It is shown that the proposed measurement method and the experimental setup used allow us to form foam samples up to 40 cm high and measure temporal characteristics of the electrical resistance (electrical conductivity) along the height of the sample at 40 points with a relative error of no worse than 3%. A highly resistive region is formed in the upper part, which increases the emissivity of the foam formation. After 15 minutes, a relatively uniform high-resistivity region forms, covering more than 10 cm of the upper part of the structure, which explains the results obtained in [10].

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