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Investigation of the process of emulsion droplets coalescence in an inhomogeneous alternating electric field in the presence of an asphaltene interfacial film at the oil–water interface

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The behavior of a „water–in–oil"emulsion stabilized with asphaltenes under the action of an inhomogeneous alternating electric field has been studied. The experimental technique was based on the use of microfluidics, optical microscopy, and high-speed video filming. The dependences of quantitative estimates of the parameters characterizing the dynamics of the emulsion destruction on the frequency and amplitude of the applied field have been obtained. The technique will be useful in developing efficient methods for breaking emulsions and modifying the existing technologies for separating oil emulsions into phases.

Keywords: asphaltenes, emulsion, electric field, coalescence, optical microscopy, high-speed video filming, microfluidic device.

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Investigations of emulsions exposed to the electric field belong to an area of active research [1]. The major part of them is aimed at solving the tasks of separating oil emulsions into individual phases. The task of the oil emulsion separation involves a problem consisting in the presence on the interfacial surface of asphaltenes, resins, or paraffins that improve the emulsion stability. An important and promising technique for oil emulsions separation is electrical impact [2,3]. At present, a wide application has been gained by the microfluidic experimental techniques in the scope of which the electric field is used to control microobjects of disperse systems [4]. The advantage of the microfluidic techniques is the possibility of detailed investigation of processes occurring in disperse systems at the microscale level. In this work a system of microelectrodes was used, with the aid of which electric field was created in the cell under study by analogy with technological solutions applied in microfluidics. The main goal of this work was to study the dynamics of destruction of the model asphaltene emulsion under the impact of inhomogeneous alternating electric field. As a research object, there was used an emulsion of the „water–in– oil"type consisting of water microdroplets 1–100 μm in size suspended in tetradecane and covered by the asphaltene shell. The presence of the asphaltene shell around the water droplets was revealed by using atomic force microscopy. The technique is presented in paper [5]; it consists in studying shelled droplets on the glass surface after evaporation of the fluid within the droplet.

To study the electric field effect on the emulsion, an experimental setup was designed and assembled; its schematic diagram is given in Fig. 1. An important setup component is the experimental cell *5* fabricated from two transparent glass substrates between which there is a Teflon gasket 100 μm thick. In the Teflon gasket, a rectangular channel is cut into which the studied fluid is pumped through the inlet port in the upper substrate. Configuration of the electrodes is presented in the Fig. 1 inset.

As the lower substrate, a glass with an ITO (indium tin oxide) electrically conductive layer was used; on its surface, sawtooth electrodes were etched by the photolithography method with the distance of 200 μm between the vertexes. The experimental cell was put on the stage of microscope IX71 (Olympus). The electrode system was supplied with alternating two-polar voltage from the arbitrary–shape signal generator 33522A (Agilent Technologies); the voltage was amplified with amplifier Tabor 9100 (Tabor Electronics, Ltd.). The applied voltage amplitude (peak–to–peak value) was varied in the range of 75–300 V, while the frequency was varied in the range of 0.05–15 kHz. The high–speed video recording of the experiment was performed using camera FASTCAM SA5 (Photron) with the speed of 250

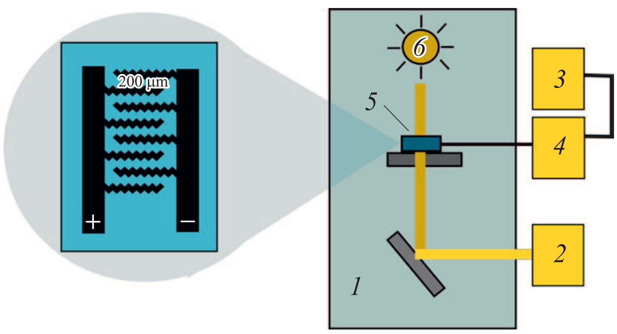

Figure 1. Schematic diagram of the microscope-based experimental setup. *1* — mirror, *2* — high-speed camera, *3* — signal generator, *4* — amplifier, *5* — experimental cell, *6* — light source.

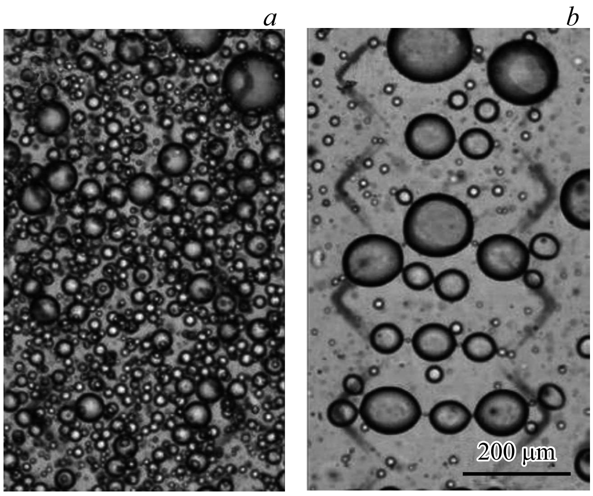

Figure 2. Characteristic patterns of the emulsion droplets distribution prior to (a) and after (b) the electric field impact upon the emulsion microstructure at the field frequency of 0.05−15 kHz and voltage of 75−300 V.

frames per second. Images of the emulsion microstructure prior to and after exposure to the electric field were obtained from the video record of the process of the field action upon the emulsion (Fig. 2). The exposure time was 5 s in all the experiments. In the course of investigation it was found that the main variations in the studied emulsion microstructure lasted split of second independently of the applied field frequency and voltage. Fig. $2, a$ shows that prior to the impact the emulsion droplets were uniformly distributed over the observed cell region. Experiments in the frequency range of 0.05−15 kHz and voltage range of 75−300 V showed that, once the electric field is switched on, the droplets begin moving within the inter-electrode space where they collide each other and coalesce, thus forming larger droplets (Fig. $2, b$).

All the images were processed using code ImageJ so as to count the number of droplets and determine their diameters. To determine the impact efficiency, the following parameters were introduced: $N = (N_2 - N_1)/N_1$ characterizing

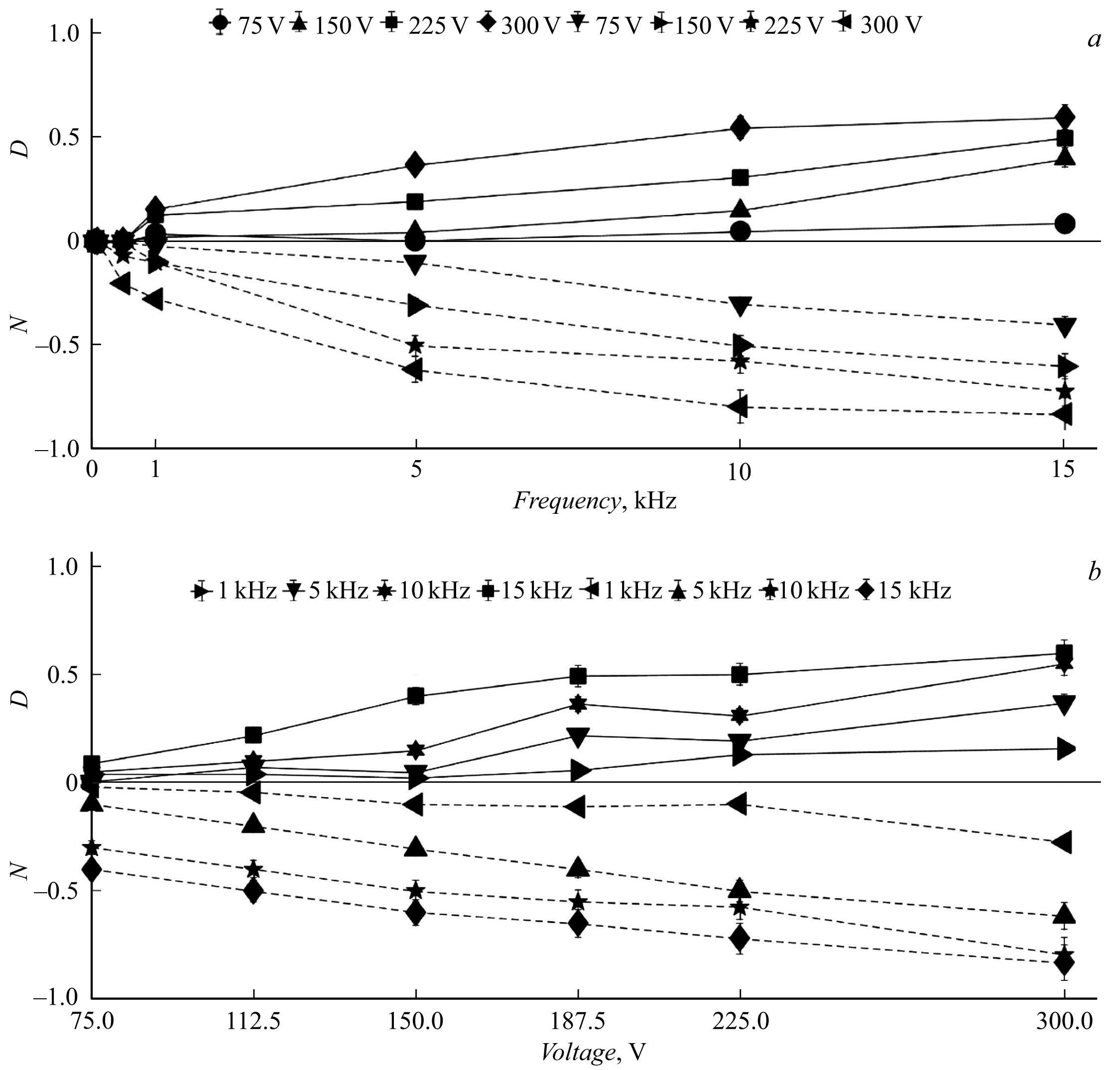

Figure 3. Relative variations in the droplet number (N) and relative variations in the average droplet diameter (D) versus the electric field frequency (a) and voltage (b).

the droplet number variation after 5 s (N_2) with respect to that in the initial state (N_1) and $D = (D_2 - D_1)/D_1$ characterizing the relative variation in the average droplet diameter after 5 s (D_2) with respect to that in the initial state (D_1).

Fig. 3 presents dependences of these parameters on the frequency and voltage of the applied electric field. Fig. 3, *a* shows that an abrupt stepwise change in the droplet relative diameter D to 18% and in droplet number N to 30% takes place at the field frequency of up to 1 kHz and maximum voltage of 300 V. The frequency increase to 5 kHz results in changing the relative droplet number N up to 60% and diameter D up to 38%. Further increase in the frequency to 10 and 15 kHz leads to enhancement of intensity of relative variation in the droplet number and diameter: $N = 80\%$, $D = 58\%$ and $N = 82\%$, $D = 60\%$, respectively. Thus we can state that the maximal variations in parameters N (decrease in the relative number of droplets) and D (increase in the relative average diameter of droplets) occur at the signal frequency of 5−10 kHz and voltage of 187.5−300 V.

The results of this work with asphaltene emulsions are somewhat different from those obtained earlier in [6] when emulsion droplets stabilized with detergent Span 80 were studied and intense emulsion separation was shown to occur in the electric field voltage range of 75−300 V and frequency range of 0.1−1 kHz. Comparing the results of those two works, it is possible to notice that coalescence of droplets stabilized by asphaltenes needs an order of magnitude higher electric field frequencies.

Therefore, the presented experimental results have shown that the increase in the applied electric field voltage leads to enhancement of the coalescence. Contrary to the case of emulsions stabilized by detergents like Span 80, the impact of inhomogeneous alternating electric field on emulsions extracted from oil by asphaltenes is of a nonlinear stepwise character. In the case under consideration, the most intense effect is observed in the frequency range of 1−10 kHz. The duration of the emulsion microstructure modification does not exceed 1 s.

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Conflict of interests

The authors declare that they have no conflict of interests.

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