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URGENT COMMUNICATION

Initiation of Combustion of a Gas Mixture by an Electric Explosion of an Electrolyte

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Abstract: Initiation of combustion of a stoichiometric propane–oxygen mixture in a bubble located in an electrolyte near a dielectric or metallic wall is performed in experiments. It is demonstrated that combustion in the bubble is initiated by an electric explosion-breakdown of a thin electrolyte layer along the bubble boundary.

Keywords: electric explosion of an electrolyte, discharge in a gas, breakdown in a vapor–gas medium, initiation of combustion.

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To optimize the parameters of ignition of combustible bubbles in water for creating heat generators where the fuel is burned directly in the water-based heat-carrying medium, it is necessary to know the mechanism of ignition of combustible mixtures in bubbles by an electric discharge. We tried to solve this problem in experiments described in this paper. Combustion of an acetylene–oxygen bubble was initiated in [1, 2] by an electric discharge in the gas between the metallic electrode and electrolyte. The mechanism of this initiation was not clear, though the main hypothesis was the model of an electric breakdown in the bubble neck over the perimeter of the metallic tube from which the bubble was blown out. To verify this hypothesis, special experiments were performed with inert and combustible bubbles with an electric explosion of a thin electrolyte layer located on the dielectric–liquid–gas interfaces.

Figure 1 illustrates the arrangement of the first series of experiments aimed at studying discharges and breakdowns in a tube with inert and combustible bubbles. The test cell was a transparent silicon tube with two tubular metallic electrodes. The electrolyte was poured through the orifices in the electrodes, and a bubble with a necessary composition and size was blown into the tube; an electrolyte meniscus was formed between the bubble and the tube. The distance between the electrodes was varied from 5 to 20 mm. The inner and outer diameters of the silicon tube were 2.5 and 3.5 mm, respectively. A capacitor storage with a capacity of 8 μF was used. The inherent inductance of the setup was 3 μH. The experiments were performed at voltages U = 300–1800 V. The electrolyte was a 1% solution of sodium chloride or potassium carbonate. In all experiments, the shadowgraphs were taken simulta-

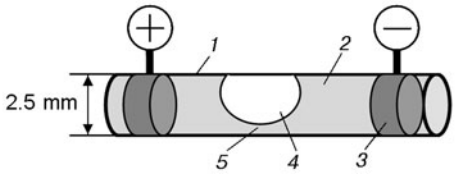

Fig. 1. Arrangement of the experiment: (*1*) transparent silicon tube; (*2*) electrolyte; (*3*) metallic electrodes; (*4*) gas bubble; (*5*) electrolyte meniscus between the bubble and the tube.

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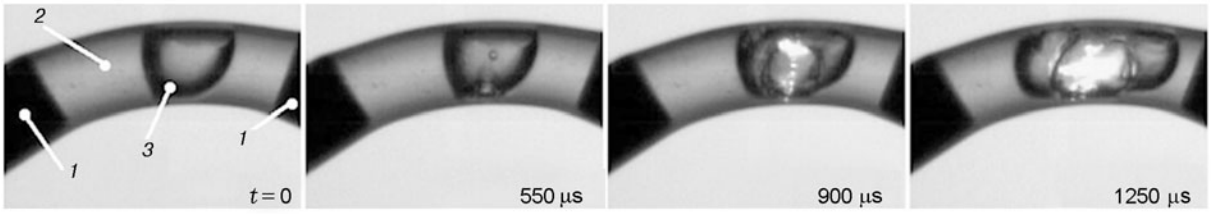

Fig. 2. Dynamics of an electric explosion of a thin electrolyte layer on the boundary of the air bubble: (*1*) electrodes (anode on the left and cathode on the right); (*2*) electrolyte (1% solution of NaCl); (*3*) air bubble ($U = 1200$ V); the filming rate is 20 000 frames/s (the exposure time is 41 μs).

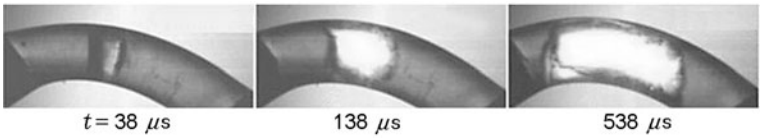

Fig. 3. Dynamics of hydrodynamic processes of combustion initiation in a propane–oxygen bubble ($U = 1750$ V; the filming rate is 20 000 frames/s; the exposure time is 41 μs).

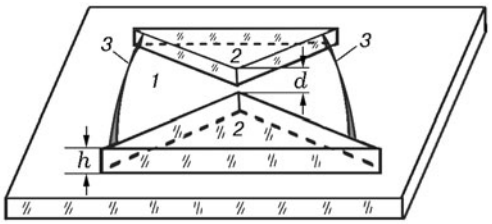

Fig. 4. Bath for studying the electric discharge and breakdown in a thin electrolyte layer: (*1*) electrolyte; (*2*) bath walls (made of glass); (*3*) metallic electrodes; d is the width of the electrolyte waist and h is the bath height.

neously with recording the current and voltage on the electrodes by a TDS-210 oscillograph.

Figure 2 shows the frames that illustrate the evolution of electrohydrodynamic processes in the silicon tube with an air bubble in a 1% aqueous solution of sodium chloride. It follows from these frames that heating of the liquid meniscus by the current leads to explosive boiling of the liquid near the lower part of the bubble with ejection of droplets and vapor into the air bubble. The breakdown regions have the character of diffusion streamers gliding on the tube surface. After that, the luminescent region expands and displaces the electrolyte through the tubes of the metallic electrodes. When the expanding bubble touches the metallic electrodes, a through breakdown occurs, now between the metallic electrodes. On the average, the velocity of motion of the bubble boundary along the tube axis does not exceed 1 m/s. It should be particularly noted that the luminescent region does not fill the entire space of the expanding bubble before the through breakdown. As the initial voltage on the capacitor is increased to 1800 V, the qualitative dynamics of the breakdown remains unchanged, and the duration of the initial stage of the meniscus explosion decreases.

Figure 3 shows individual frames illustrating the dynamics of initiation of ignition and combustion of a propane–oxygen bubble in the tube. In contrast to the processes proceeding in the air bubble, the luminescence in the case with the propane–oxygen bubble is observed in the entire volume of the growing bubble. This fact testifies that the ignition took place in the interval of 38–79 μs after the voltage was applied (see the first frame). The mean velocity of motion of the bubble boundary along the tube axis is 5 m/s, which is five times the velocity of this boundary in the experiments with the air bubble at the same initial voltage. Radial expansion of the silicon tube is observed (see Fig. 3). Thus, the change in the bubble expansion dynamics,

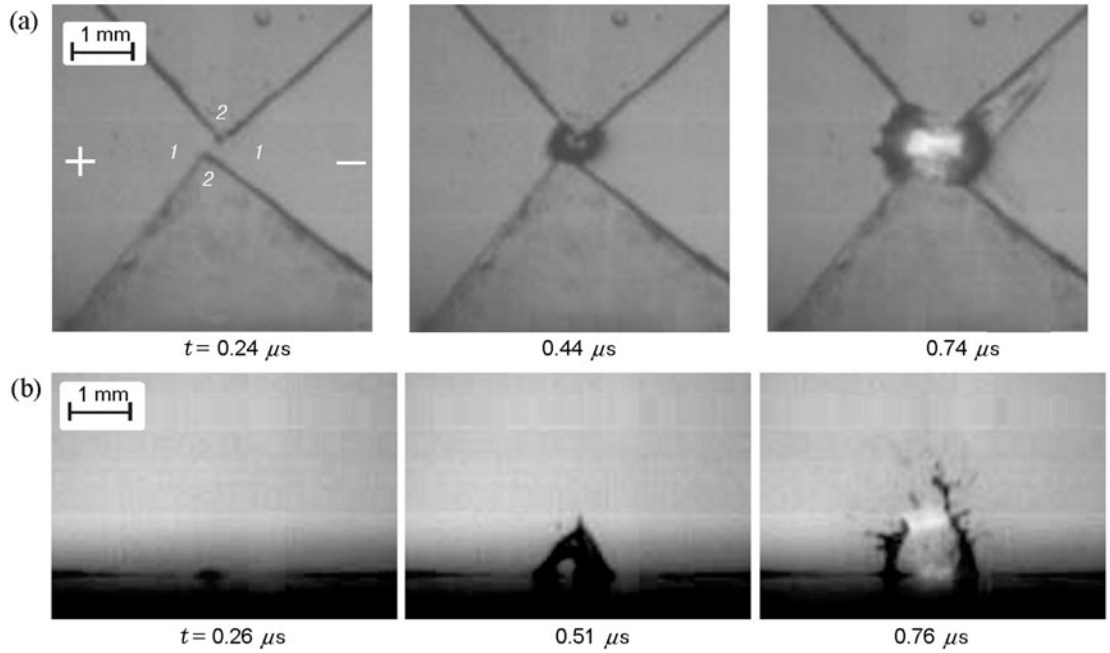

Fig. 5. Evolution of the breakdown after the electric explosion of the gap between the sectors of the flat layer of the electrolyte (1% solution of NaCl): (a) top view; numbers *1* and *2* correspond to the same numbers in Fig. 4 (U = 1200 V); (b) side view; U = 1100 V; the filming rate is 20 000 frames/s; the exposure time is 41 μs.

the luminescence in the entire bubble volume, and radial expansion of the tube testify to a gas explosion. If the combustible gas was not ignited, the bubble growth rate corresponded to values obtained in the case of the breakdown in the air bubble. The minimum voltage at which the gas ignition could be initiated in this case was 1500 V. The threshold of gas ignition in the tube depends on two parameters: initial voltage on the capacitor and electrolyte meniscus size. In experiments arranged in this manner, we were not able to control the minimum meniscus thickness.

The second series of model experiments was performed to study the evolution of the electric discharge and breakdown in thin electrolyte layers with a controlled size of the explosion region. A special bath was made of glass for that purpose, which is schematically shown in Fig. 4.

The bath consisted of two sectors filled by the electrolyte and had an open gap (electrolyte waist) of width d between the vertices of these sectors. The side walls of the bath were two glass plates of height h. The metallic electrodes made of stainless steel in the form of segments of rings with a curvature radius of 8 mm were arranged symmetrically with respect to the electrolyte waist. By varying the plate height h, we determined the thickness of the electrolyte layer poured into the bath up to the upper edge of the bath. The width d of the gap between the sectors was changed by mounting the glass plates *2*. The first frame in Fig. 5a shows the real top view of the bath filled by the electrolyte.

Figure 5 illustrates the dynamics of the breakdown (Fig. 5a, top view) and the evolution of the electric explosion of the electrolyte waist with the breakdown (Fig. 5b, side view) in the experiment with a 1% solution of sodium chloride with the layer thickness $h \approx 100$ μm ($\pm 20\%$) and the electrolyte waist width $d = 0.35$ mm. It should be noted that the current amplitude depends on the initial voltage and on the electrolyte layer thickness. In these experiments, the voltage was not observed to decrease before the breakdown beginning.

It follows from the frames and oscillograms obtained in the experiments that the decrease in the current value coincides with the breakdown of the electrolyte waist, which corresponds to an increase in the resistance owing to the fracture of the electrolyte and the beginning of the breakdown between the liquid electrodes being formed. The electrolyte waist is broken from inside owing to overheating of the electrolyte by the current with formation of a bubble and its subsequent growth until the free surface of the liquid is broken. The energy input to bubble formation and its growth up to the electrolyte waist breakdown were determined by integrating the voltage and current oscillograms until the instant when the current decreased. For the recorded current oscillograms, this instant corresponds to $t \approx 0.45$ ms. The instant of the bubble

formation beginning was estimated on the basis of the current oscillogram as $t \approx 0.5$ ms with ignored heat transfer to the glass substrate, which is greater than heat transfer along the electrolyte layer by an order of magnitude. Based on the results of integration of the oscillograms, the energy input to the bubble is 0.07 J ($\pm 30\%$), which corresponds to heating of $2 \cdot 10^{-4}$ g of water to a temperature of 100 °C.

As a whole, it follows from the experimental results that the breakdown is developed after the electrolyte waist is broken by the vapor bubble. After the electrolyte waist is broken, an electric breakdown occurs in the vapor–gas gap δ between the liquid electrodes. At the initial instant of the current conductor breakdown, the intensity $E = U/\delta$ of the electric field between the liquid electrodes reaches a threshold value of the gas breakdown in the bubble. Breakdowns are also observed above the bath height h between the splashes of the electrolyte (see Fig. 5b, $t = 0.46$ ms). After that, the breakdown process transforms to a quasi-steady mode of the discharge between the liquid electrodes with some features of an arc discharge. The arc discharge arising in the gap between the liquid electrodes provides quasi-steady values of the electric field intensity E, with the mean value $E \approx 1$ kV/mm. As the breakdown transforms to a quasi-steady mode, the boundaries of the liquid cathode and anode are seen to be shifted to the cathode sector. The distance between the liquid electrodes δ stays approximately at a level corresponding to $E \approx 1$ kV/mm. At later stages of the discharge, as the voltage on the electrodes decreases, the gap in the arc discharge also decreases. The mean value of the electric field intensity remains at a level of $E \approx 1$ kV/mm, i.e., the gap width decreases in proportion to the decrease in voltage.

Based on the results of frames taken during the experiments and of the recorded current and voltage oscillograms, we can estimate the energy of gas ignition in the bubble in each experiment. It is determined by the energy necessary for evaporation of the electrolyte layer and for the breakdown. Gas combustion is initiated after the breakdown of the electrolyte waist owing to ionization of the gas at the place where the electrolyte current conductor is broken. Thus, for instance, for experiments of the first series, the total energy spent on evaporation and ionization in the case of ignition of a stoichiometric propane–oxygen mixture did not exceed 0.1 J. As a result, the energy of gas ignition by the breakdown arising between the liquid electrodes moving apart was smaller than 0.03 J.

Thus, we demonstrated by our experiments that a thermal explosion of a thin electrolyte layer initiates breakdowns in the vapor–gas medium in the discontinuities formed in the electrolyte current conductor, which ensure the ignition of the combustible gas mixture.

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