ELECTRICAL, LASER AND ACOUSTIC BREAKDOWN OF A LIQUID, RESEMBLANCE AND DISTINCTIONS

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Abstract: For the first time, the analysis of generality and distinction of the physical phenomena occurring in a liquid at nonlinear absorption of pulse energy of different kinds (electric, laser, acoustic) is presented. These problems are analyzed from position of transformation of one kind of energy into others. Physical and hydrodynamic phenomena are investigated at focusing of single laser pulse into water, single acoustic wave into water, and various ways of localization of energy in a liquid under action single pulses of electric energy. Mechanisms of electric, laser and acoustic-shock breakdowns of a liquid are compared.

INTRODUCTION

In the present work, the transformation of energy at powerful pulse action ($t \sim 10^{-9}$ to 10^{-6}s) on a liquid media in the case of laser and acoustic radiations and also an electric current is analyzed from the uniform point of view. The action considered kinds of energy on condensed media is accompanied by explosive phenomena, particularly, break of liquid media uniformity (cavitation). Generally, this process for liquid media can be named as breakdown of a liquid. Below, considering the action of electric current on a liquid media, the term "breakdown of a liquid" will mean the processes concerning to "pre-breakdown" ("partial discharge") phenomena only, but not to short circuit of a discharge gap between electrodes by conducting channel.

EXPERIMENTAL SETUP

Fig. 1. presents the schemes of experiments for investigations of breakdowns of liquids: a) laser, b) acoustic, c) electric breakdown in an aperture of dielectric diaphragm, d) electric multi-center breakdown, e) electric breakdown on the surface of two identical metal electrodes.

GENERALIZING PARAMETERS

In order to compare thresholds of breakdown of liquids under action of different kinds of energy, it is necessary to introduce generalizing parameters. Such parameters may be specific power I [Wt/cm^2], and specific energy q [J/cm^2]. The indexes ($_l$), ($_a$) and ($_e$) will denote the parameters concerning laser, acoustic and electric energies, according to breakdowns of liquid, respectively. The index ($_0$) will concern thresholds of breakdown of a liquid.

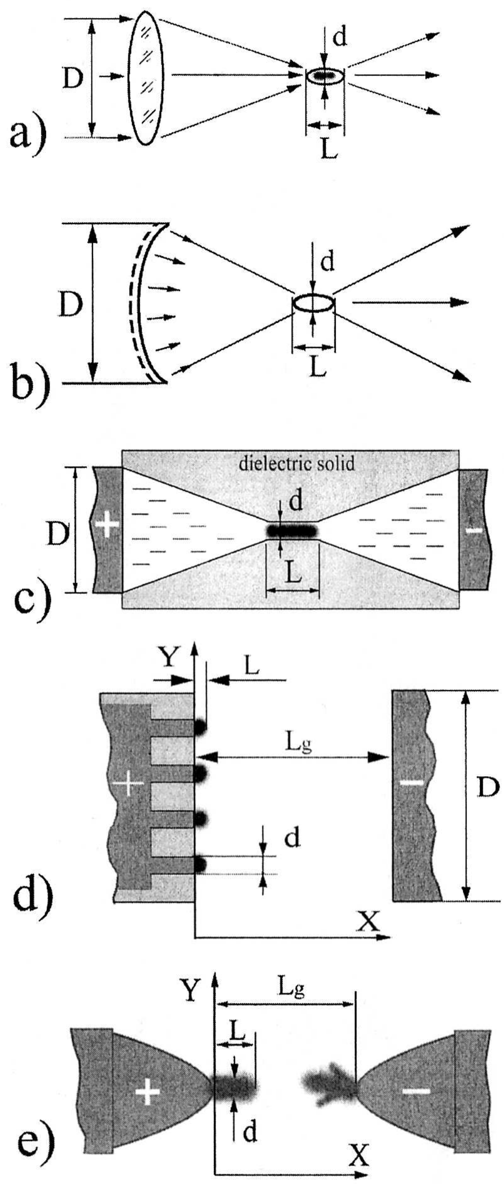

Fig. 1.

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EXPERIMENTAL RESULTS

Laser breakdown of a liquid (l)

During the researches of laser breakdown of a liquid, it was theoretically supposed (1962), that laser breakdown is similar to high-frequency electric discharge. However, experimental researches have shown, that laser breakdown in real condensed media is closer to the mechanism of thermal explosion. Breakdown occurs due to absorption of laser radiation, Mandelshtam-Brillouion and Raman radiation on microparticles and micro-bubbles of gas [1-3].

Near threshold of laser breakdown of a liquid I_{l0}, q_{l0} only one bubble and one shock wave are formed. At increasing of radiation power higher than threshold values ($I_l > I_{l0}$, $q_l > q_{l0}$), the length of the breakdown region along the axis of laser radiation L increases [3,4]. The cleaner a liquid is and the less dissolved gas it has, the higher threshold of laser breakdown is. High-speed photo-records shown, that formation of "big" pulsing bubble occurs as a result of coalescence of micro-bubbles chain, Fig. 2. (F = 2.5 cm, Q_l = 0.4 J, t = 50 ns.)

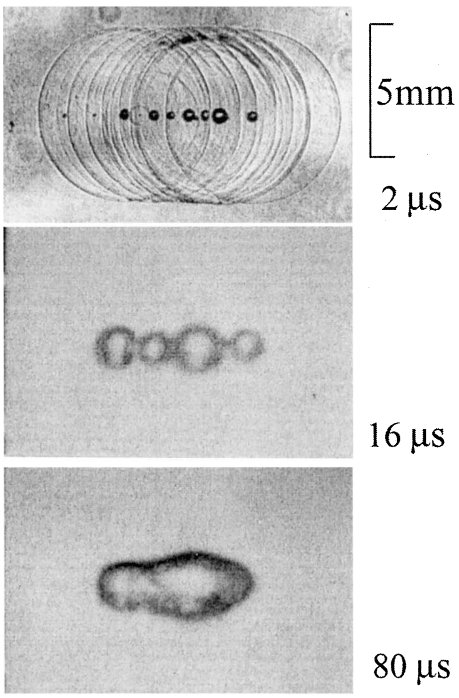

Fig. 2.

Thus, size of the formed bubbles is proportional to the specific power of laser radiation I. The intensity of light radiation in focal area is distributed according to Gauss law and has effective diameter $d_0 = F \cdot \alpha$ (α is the divergence of laser beam, F is the a focal length of a lens). At increasing of energy of light, the merging of microbreakdowns is provided. The share of the light energy transformed into a hydrodynamic below, may reach 60 %. At putting in focus of an absorbing element, light-hydrodynamic efficiency increases.

Acoustic-shock breakdown of a liquid (a)

At focusing of powerful single acoustic wave (pressure $|P| > 10$ MPa, duration of a half wave $t \sim 1\,\mu s$) in focus nonlinear process of absorption of acoustic energy is developed. This process is also accompanied by the explosive hydrodynamic phenomena. Thus, in focal area, the cluster of bubbles is formed, similar to that at initial stage of laser breakdown. This phenomenon was named as an acoustic-shock breakdown of a liquid, by analogy to laser and electric breakdown, because to similarity of hydrodynamic processes [5].

For acoustic focusing systems as well as for optical focusing systems, the minimal cross diameter d_0 of formation area of initial breakdown in the form of cluster of bubbles is determined as $d_0 = F\,\lambda/D$ (λ is the length of a wave, D is the diameter of acoustic generator). The size of formed bubbles correlates with distribution of pressure field in focal area. At increasing of wave intensity in focus I_a and specific energy q_a corresponding:

$$I_a = P^2/\rho c \qquad (1)$$

$$q_a \approx I_a\, t \qquad (2)$$

here: P is the pressure in focus, ρ is the density of a liquid, c is the speed of a sound, t is the duration of acoustic pulse.

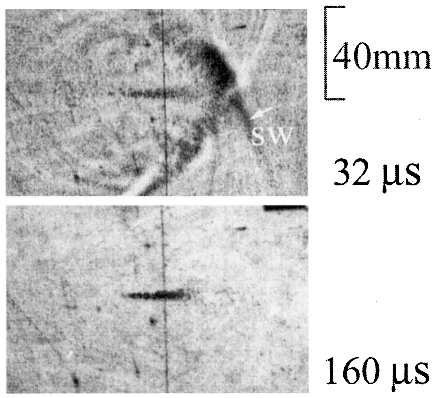

Fig. 3

Fig. 3 presents separate frames of shadow records of acoustic-shock water breakdown for F = 170 mm, D = 220 mm, P = 40 MPa, t = 2 μs.

At later stages, the big pulsing bubble is formed from cluster of bubbles, as well as at optical breakdown. At the initial stage of breakdown of a liquid, the nonlinear effects accompanied by stimulated acoustic radiation are observed. The secondary acoustics waves, were generated by a zone of cluster of bubbles [5,8]. These effects are similar to effects of stimulated scattering, which accompanies laser breakdown.
At presence of boundary surfaces with wave resistance $\rho_{\_}c_{\_}$ smaller than that of researched liquid ρc, more effective absorption of an acoustic pulse occurs. For example, at focusing an acoustic wave on a free surface of water, the compression wave is emitted from zone of cluster of bubbles. It means that the initial acoustic wave was effectively absorbs by a free surface as well as the opaque barrier absorbs laser radiation at laser breakdown.

Electric breakdown of a liquid (e)

Let is consider the basic electro discharge systems where the breakdown of a liquid with acoustic and shock waves and bubbles generation occurs.
1) The closest performing of experiments to laser and shock-acoustic breakdown is an electric breakdown of a liquid, which occurs in a hole of diameter d of in a dielectric plate with, (Fig. 1c). Such breakdown of a liquid was named as discharge in diaphragm [6]. In this case the breakdown occurs between two liquid electrodes. These experiments similar to experiments on explosion of wires. In the experiments on discharge in diaphragm, it is easy to determine threshold values of electric breakdown of a liquid using generalized parameters I, and q:

$$q_e = I_e\, t \qquad (3)$$

$$I_e \approx 4U\, i/\pi{\cdot}d^2 = Uj \qquad (4)$$

here: U is the voltage , i is the current, j is the density of the current in the gap, t is the duration of current pulse.
For example, for d = 0.5 mm, L = 50 μm the threshold value of specific energy for breakdown of water (+ 1,5 % NaCl) was q_{e0} =1.6 J/cm^2.
The advantage of this research method of breakdown of a liquid before known researches of pre-breakdown phenomena on electrodes is that in diaphragm breakdown effects on border of electrodes, which complicate researches of real breakdown of a liquid due to electrochemical processes on electrodes are excluded.
2) Multi-center electric breakdown of a liquid is a breakdown of a liquid, (appropriate to classical pre-breakdown phenomena) near to a multitude (n) of metal electrodes with diameter d (Figs. 1d, 4). In this case the discharge with breakdown of a liquid occurs between metal electrodes and a liquid electrode (electrolyte). Such multi-center breakdown of a liquid is realized under condition of $(D/d)^2/n > 10$, $L_g >> L$, (D is the diameter of an opposite electrode in electrolyte). In such systems, localization of energy-release with appearing of shock waves and cavities formation ocurs on concentrators of diameter d, contacting with a liquid [7]. Thus, the condition should be satisfied for each electrode:

$$4U\, i/\pi{\cdot}d^2 > I_{e0} \qquad (5)$$

$$I_e\, t > q_{e0} \qquad (6)$$

Where, I_{e0} , q_{e0} are the threshold values of breakdown of used a liquid.
The example of such breakdown on a surface of multi-center electrode is presented in Fig. 4, photographed in a mode open bibb of the photo-camera.

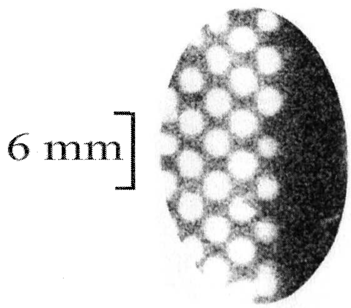

Fig 4

On the basis of the advanced idea of multi-center breakdowns in electrolytes, the devices for generation of acoustic waves with set geometry of radiators [9] are developed in Institute of Hydrodynamics of Siberian Branch of Russian Academy of Science.
3) Electric breakdown of a liquid occurs on two opposite electrodes of identical geometry and area (Figs. 1e, 5). In this case the conditions (3), (4) may be satisfied for both electrodes, and breakdown of a liquid on a surface of both electrodes may occur simultaneously.

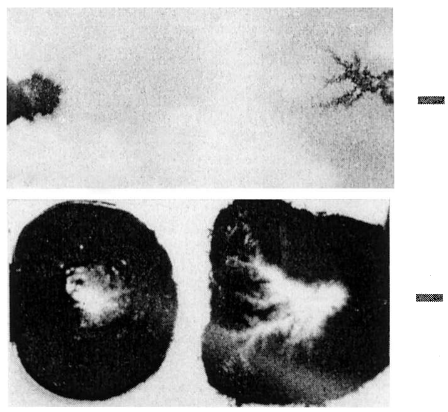

Fig 5

Fig 5 (A.A. Buzukov's photo) shows that the breakdown of a liquid with formation of cavities occurs on both electrodes. Available difference in geometry of development of cavities on opposite electrodes concerns problems about the mechanism of streamer development but this question is not considered here. It is necessary to note the main point that localization of electric energy absorption occurs with simultaneous growth of cavities. The difference may be determined by accuracy of identical electrodes manufacturing. Thus, it is necessary to take into account a number of cycles of electrodes operation, as while in service, on electrodes metal "moustaches" in the form of microneedles of diameter $d^* \approx 10$ to 50 μm can grow. On these micro tips, the current flows density of which j, is greater than that on a surface of all electrodes. It provides higher specific capacity on micro tips $I_e^* > I_{ed}$, on each electrode. After the big number of breakdowns initial processes on the electrodes became similar to the processes shown in Figs. 1d, 4. Therefore, identical conditions on electrodes can be only for the first breakdowns. In contrast, breakdown in diaphragm does not depend on the processes occurring on electrodes surface.

SUMMARY

It is possible to determine the following basic physical similarities and differences of the considered phenomena:

1. At laser, acoustic and electric action on a liquid, the phase transitions formation of cavities, and radiation of shock waves are observed.
2. The generalizing parameters introduced, specific power I, and specific energy q allow to compare threshold values of breakdown of liquids for different kinds of energy. For example, the result of experiments show that a threshold of breakdown of water the same purity for laser power q_{l0} is close to that electric power q_{e0} (Figs. 1a, 1c): $q_{e0} \approx q_{e0} \approx 1$ J/cm^2. However, for acoustic energy (Fig. 1b), the threshold of breakdown of the same quality of water was $q_{p0} \approx 10^{-3}$ to 10^{-2} J/cm^2. Such a significant difference of threshold parameters shows that acoustic breakdown of a liquid is more economic energetically in comparison with laser and electric ones owing to exception of media heating processes.
3. At electric and laser actions on a liquid, the threshold of breakdown of a liquid depends on the concentration of sol particles in a liquid. At laser and electric breakdowns, there is a thermal liquid heating at initial stage. The dissociation and ionization of matter occur due to high temperature and in the result the vapor-gas bubble are formed.
4. At acoustic action on a liquid, the threshold of breakdown basically depends on gas content in a liquid. At the first stage of such breakdown of a liquid, the bubbles may consist mainly of rarefied vapor. Heating of gas in bubble may occur only at its collapse.
5. It s necessary to take into account that the results obtained in the present work on measurements of the threshold values of breakdown of water q_0 have relative character. Absolute values of thresholds of breakdowns of liquids depend on concentration of sol and gas content in liquids. The purity and the uniformity of a liquid are key condition, as for electric, laser and acoustic breakdowns. Micro particle and micro bubbles are the initiating centers of energy absorption for the considered kinds of processes.

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