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Electric Discharge in Liquids under the Effect of Vibration

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***Abstract:** In this study, plasma discharge in liquids at intensive ultrasonic field above the cavitation threshold has been proven to be of great interest for initiation of various physical and chemical processes. The feature of arc discharge in liquid media is the localization of plasma region near the electrodes and "falling" form of volt-ampere characteristics. In the region of intensive cavitation, the fraction of gas-vapor component in the liquid exists, therefore it can be assumed that the electric breakdown in the cavitation region should become easier, which can result in the initiation of various forms of discharges.*

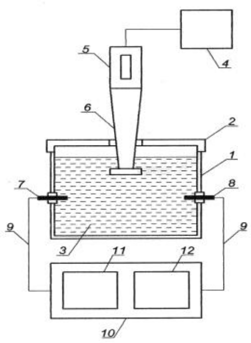
***Keywords:** discharge, vibrations, ultrasound, plasma.*

I. INTRODUCTION

Arc discharge in aqueous electrolytes, which is widely used in engineering, is at present the only known form of stationary plasma discharge in liquid media [1]. In recent years, such discharge is used in physicochemical studies and in the synthesis of various materials. The specific feature of arc discharge in liquid media is the localization of plasma region near the electrode ends and "falling" form of volt-ampere characteristic. At the same time, when ultrasonic cavitation is applied to a liquid, its phase composition and physical properties dramatically change, and this can lead to some specific features of the formation of electric discharge in the liquid. In the region of intensive cavitation, the fraction of a gas-vapor phase in the liquid has a significant value [2 – 3], therefore it can be assumed that the electric breakdown in the cavitation region should become easier, which can result in the initiation of different forms of discharge.

II. EXPERIMENTAL PROCEDURE

To carry out experiments, a setup was designed and constructed, a block diagram of one of the variants of which is shown in the Fig. 1, and the electric circuit of the initiation of quasistationary discharge in the liquid cavitating under the effect of ultrasound is given in the Fig. 2.



Scheme of installation for excitation of the discharge in a liquid. 1 – working chamber, 2 – cover, 3 – working liquid medium, 4 – ultrasonic generator, 5 – magnetostrictive transducer, 6 – titanium waveguide, 7,8 – electrodes, 9 – conductors, 10 – power supply, 11 – voltage source of initiation impulse, 12 – voltage source of stable glow of plasma discharge.

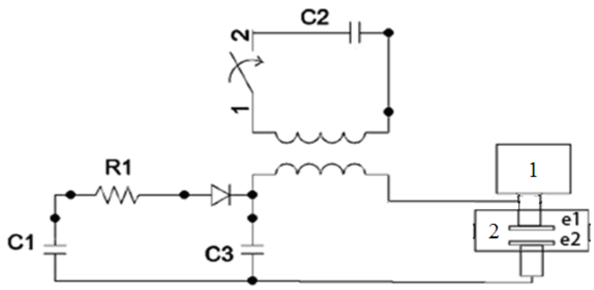


Fig. 2. Power supply scheme of pulse discharge. 1- ultrasonic generator, 2 – reaction chamber.

An ultrasonic generator with a magnetostrictive transducer provides the regulation of output acoustic power up to 2 kW in the frequency range 15-27 kHz. The parameters of acoustic equipment allow one to implement the intensity of an ultrasonic field in the working volume of liquid up to 10 W/cm2 and to vary cavitation regime in a wide range. The characteristics of cavitation (amplitude of acoustic noises, their spectrum) were controlled using an IC-3M cavitation meter.

A quasistationary pulse-periodic discharge (see Fig. 2) is provided by a capacitor C1 with capacity 50-100 microfarad, which is charged to voltage U = 400 – 800 V. The initiation of discharge is performed with a high-voltage pulse on the secondary winding of a pulse transformer TX1 during the commutation of a capacitor C2 in the primary winding of this transformer using a controlled discharger. Typical parameters of discharge circuit are as follows: the charging voltage of the capacitor C2 is 5-10 kW, and the TX1 transformer ratio is 4:1.

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Discharge current was measured using resistive shunts, and voltage was measured using a resistive divider connected to discharge electrodes. Current and voltage oscillograms were registered by a Tektroniks-TDS 2014 oscillograph.

Main experiments were performed using deionized water and chemically pure dodecane.

A study of the chemical composition of liquid hydrocarbons was conducted using a chromatograph «Kristall 2000m». At that, a plasma-ionization detector (24.91 Hz) was used.

A chromatographic column was 1 m in length and 1 mm in diameter; it operated in the temperature range from 35 to 235 ºC at a heating rate of 15 deg/min. The evaporator temperature was 300 ºC, and the detector temperature was 350 ºC. The excessive pressure of carrier gas was 70 kPa. The flow rates of carrier gas, hydrogen and air were 10 ml/min, 20 ml/min and 200 ml/min, respectively.

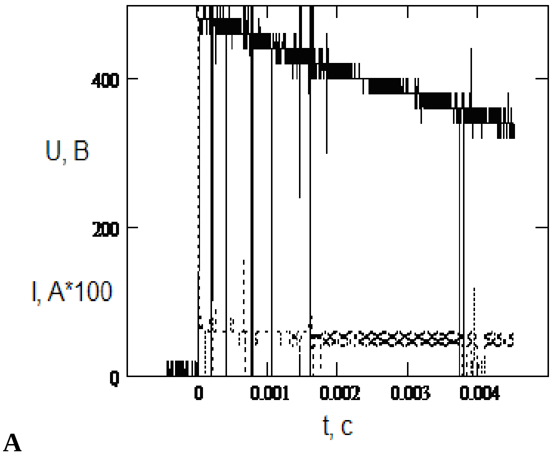
The gathering of gaseous products of sonoplasma discharge was performed using water check and was analyzed using a standard gas chromatograph.

A morphology of the structure of formed precipitate was studied using a scanning electron microscope CAM SCAN S2, and the study of particle size distribution was performed by small-angle X-ray scattering. Measurements of scattering intensity were conducted using a diffractometer "AMUR-K". The device was provided with a one-coordinate position-sensitive detector OD2 for a specific radiation wavelength λ equal to 0.1542 nm (CuKα line of a fine-focus tube BSV-29 with a copper anode and a monochromator made of pyrolytic graphite) and a collimation Kratki system. The cross section of X-rays was 0.2 x 8 mm, and the region of scattering angles corresponded to the range of the values of the scalar of wave vector $0.1 < s < 5.0$ nm-1 ($s = 4\pi \sin\theta/\lambda$, 2θ - scattering angle). The samples of the particles under study were placed into cuvettes with walls made of 20 μm film of polyethylene terephthalate. The cuvette thickness (0.3 - 0.5 mm) was not constant, therefore absolute calibration of measurements was not conducted. Experimental data were normalized for the intensity of a falling beam, after that a collimation distortion correction was made. To compensate for scattering from the cuvette walls, air and residual intensity of primary beam, the empty cuvette scattering was subtracted from the sample scattering data. Measurements were conducted according to the certified procedure approved for the device "AMUR-K" [4].

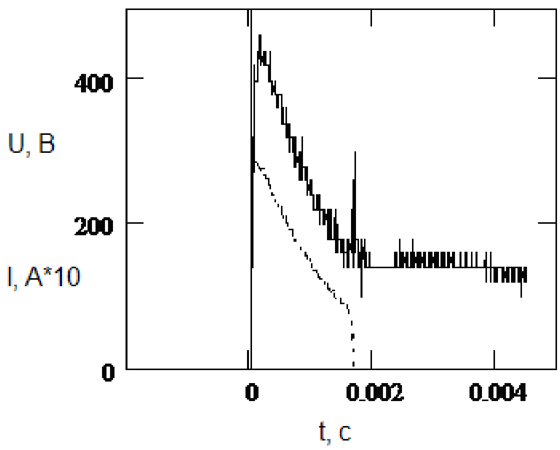
III. RESULTS AND DISCUSSION

Experiments on the initiation of discharge in liquid in an ultrasonic field were performed as follows. First, ultrasonic vibrations with an intensity sufficient for the development of cavitation in the interelectrode space were excited in liquid. Then, a discharger commutating capacitor C2 to the primary winding of a step-up pulse transformer was switched on. A voltage pulse arising on the secondary winding caused the breakdown of the interelectrode gap in a reaction chamber, which was picked up by the discharge of capacitor C1 charged to voltage 400 – 800 V. At the parameters of a scheme presented in the Fig. 2, the duration of discharge was several milliseconds. Varying the value of resistance R1 and charging voltage of capacitor C1, the duration of discharge glow can be changed in a wide range. The source of charging voltage of capacitor C1 enabled discharge pulses with a frequency of up to 1 Hz to be periodically repeated. Such a scheme is convenient for the study of discharge volt-ampere characteristics and the determination of breakdown current and the energy of discharge initiation.

Typical oscillograms of current and voltage during the discharge of capacitor C1 onto the discharge gap with steel electrodes 50 mm in diameter and the gap between the electrodes 5 - 10 mm filled with predeionized water are given in the Fig. 3. Oscillograms in the Fig. 3A show the features of the discharge of capacitor C1 precharged up to a voltage of about 500 V in the absence of cavitation in liquid. The discharge current does not exceed 1 A, glow is absent, the resistance of discharge gap is about 200 Ohm, and the density of discharge current is not more than 0.05 A/cm2.



A



B

Fig. 3. Oscillograms of electrode voltage (upper curve) and discharge current (lower curve) in liquid (water). A – in the absence of cavitation, B – under cavitation.

A character of the discharge of capacitor C1 changes fundamentally under conditions of the development of ultrasonic cavitation in liquid (Fig. 3B). In this case, the resistance of discharge gap is about 15 ohm at the beginning of discharge and smoothly increases up to 20 ohm at the moment preceding the break of current. In the interelectrode space, quite intense glow arises (Fig. 5), whose duration corresponds to the time of current pulse to the moment of its break (in Fig. 3A about 2 ms). Voltage fluctuations at discharge gap are observed in voltage oscillogram.

The break of discharge current is accompanied by a short voltage pulse.

Fig. 4. Photograph of plasma discharge implemented in water.

In the next step the oscillograms of electrode voltage and discharge current were studied when one of the electrodes is made in the form of a rod 2 mm in diameter, at that discharge occurs between the rod end and the flat surface of an ultrasonic radiator. In this case, arc discharge with a falling characteristic arises, where glow is localized near the rod electrode end, the current density at the rod electrode end being 200-500 A/cm2 , and the discharge gap resistance changing in the range 5-10 Ohm. The phase trajectory of discharge in a cavitating liquid in coordinates V and I reflects a volt-ampere characteristic of discharge when voltage at discharge electrodes is decreased during the discharge of capacitor C1. It is seen that in the range from 160 to 450 V, volt-ampere characteristic has a rising character, current increasing from 7 to 27 A. The density of discharge current is 0.35 – 1.4 A/cm^2.

It should be noted that in this mode of arc discharge, switching on an ultrasonic generator does not lead to noticeable changes in characteristic values of arc voltage and current, as well as in the form of volt-ampere characteristic of the discharge gap. Only a change in the spectrum of voltage fluctuations occurs: when ultrasound is switched on, the intensity of low-frequency part of voltage noise spectrum decreases, and the intensity of high-frequency part of spectrum increases.

Thus, the conducted experiments show that in liquids in a high-intensity ultrasonic field that exceeds the cavitation threshold, a specific form of electric discharge can exist, which is characterized by volumetric glow throughout the space between the electrodes and rising volt-ampere characteristic that is inherent to abnormal glow discharge in gas [1].

IV. CONCLUSIONS

A new form of electric discharge in polar liquids under conditions of ultrasonic cavitation – volumetric quasistationary plasma discharge having a rising volt-ampere characteristic was revealed. A possible mechanism of the initiation of plasma discharge as a consequence of the breakdown of gas-phase microchannels formed by cavitation bubbles at the stage of their growth was analyzed. In plasma discharge, chemical conversations in liquid, in which it develops, are implemented. In hydrocarbon liquid phase, the alteration of chemical composition of liquid phase with the formation of compounds with lower molecular mass, hydrogen-containing fuel gas and nanosized particles of solid phase (carbon) takes place [5-7].

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