"DIFFUSION" ELECTRODES FOR INVESTIGATION OF THE BREAKDOWN OF LIQUID DIELECTRICS

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A method which excludes the effect of electrode microinhomogeneities on the breakdown of a liquid is proposed. The method consists in forming at the surface of each electrode a transitional layer with a conductivity which gradually decreases with increasing depth in the liquid.

The breakdown of a liquid in fairly narrow gaps usually begins at the surface of one of the electrodes (see [1], for instance). The reason for this appears to be the presence of various kinds of microinhomogeneities on the electrode surface, which lead to local intensification of the electric field. Hence, the threshold electric fields obtained in experiments do not characterize the liquid itself, but the processes occurring at the liquid–electrode surface.

We suggest that the influence of electrode effects on liquid breakdown can be eliminated by creating at the surface of each electrode a transitional layer with a conductivity that decreases gradually with depth in the liquid by, for instance, applying to the electrode surface a thin film of substance whose solution in the liquid makes the latter conducting.* In the course of time the conductivity profile becomes Gaussian due to diffusion of this substance into the liquid, which ensures a gradual transition between the conducting and nonconducting media. The diffusion time τ_D (i.e., the time between the start of solution and the start of the breakdown of the conducting layer) must be chosen so that the effective thickness of the conducting layer $l \sim \sqrt{2D\tau_D}$ is much greater than the height of the microinhomogeneities on the metal surface, but is much smaller than the interelectrode distance L. Budker has already indicated that the electrical strength of a liquid can be increased by the addition of an insignificant amount of impurity distributed uniformly throughout the volume of the liquid.

We make the following estimates for experiments of the type conducted in [1], where the electrical strength of water was investigated. In such experiments $L \sim 1$ cm, so that l can be made about 0.1 cm. The diffusion coefficient in water for substances of the NaCl type is $\sim 3 \cdot 10^{-6}$ cm^2/sec, so that $\tau_D \sim l^2/2D \sim 10^3$ sec. During this time convection currents should not mix the liquid; i.e., their velocity v will satisfy the condition $v \lesssim l/\tau_D \sim 10^{-4}$ cm/sec. Since the kinematic viscosity of water $\nu = 10^{-2}$ cm^2/sec, we can evaluate the decay time of convective movements as $\tau_\nu \sim L^2/\nu \sim 100$ sec. This means that the impurity will not enter the water until approximately 10 min after the discharge gap is filled with water.

In a gravitational field convection currents can be created by the Rayleigh–Taylor instability due to the difference between the density of the solution and that of the pure liquid. To prevent this effect the substances dissolved in the liquid must be chosen so that the density of the solution at the upper electrode is greater than that at the lower electrode.

The electrode boundary layers can be destroyed by ponderomotive forces arising when the electric field is applied. The destruction time satisfies the inequality $\tau_* \geqslant l\,(8\pi\rho/E^2)^{1/2}$, where ρ is the density of the liquid. For water with E as high as $\sim 10^6$ V/cm this estimate gives $\tau_* \sim 10^{-4}$ sec, whereas the time for streamer development (if a streamer is formed at all), according to the data of [1], does not exceed 10^{-6} sec; i.e., the ponderomotive effect is of no importance in the investigation of the electrical strength of water.

*An impurity can actually be introduced into the electrode boundary layer by other methods.

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To obtain the electrotechnical characteristics of the considered system we find its response to a "steplike" voltage pulse

$$U(t) = \begin{cases} 0, & t < 0 \\ U_0, & t > 0 \end{cases}$$

In the case of flat electrodes the corresponding problem is represented by the system of equations

$$\frac{\partial}{\partial t}\rho(x, t) + \frac{\partial}{\partial x}\sigma(x) E(x, t) = 0$$

$$\frac{\partial}{\partial x}\varepsilon E(x, t) = 4\pi\rho, \quad \int_0^L E(x, t)\, dx = -U(t)$$

$$\sigma(x) = \sigma_0 \left\{ \exp\left(-\frac{x^2}{l^2}\right) + \exp\left[-\frac{(x-L)^2}{l^2}\right] \right\}$$

where ε is the dielectric constant of the liquid, σ is its conductivity, and ρ is the charge density. The conductivity is assumed to be independent of time (since the breakdown time is much less than the diffusion time). It can be shown that if $L \gg l$ the density of the current through the coatings $j \equiv \sigma_0 E(0, t)$ is given by the formula

$$j = -\frac{U_0\sigma_0}{L}\left[e^{-\gamma t} + \frac{2l}{L}\int_0^\infty d\xi \frac{\exp(-\gamma t e^{-\xi^2}) - \exp(-\gamma t)}{\exp \xi^2 - 1}\right]$$

where $\gamma = 4\pi\sigma_0/\varepsilon$. When $\gamma t \gg 1$,

$$j \simeq -\frac{\sigma_0 U_0}{L}\frac{l}{L}\frac{1}{\gamma t}\frac{1}{\sqrt{\ln \gamma t}}$$

The origin of this slowly (nonexponentially) decreasing part of the current is the gradual movement of the layer where the space charge is concentrated into the depth of the liquid. In time $t \gg \gamma^{-1}$ the layer moves through a distance $\sim l\sqrt{\ln \gamma t}$ from the electrode surface.

Besides problems associated with the investigation of the electrical strength of liquids, diffusion electrodes may also be useful in high-voltage energy storage devices with a liquid dielectric.

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LITERATURE CITED

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