PHYSICS

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1963

SovietRxiv

Abstract

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DEVELOPMENT OF AN ELECTRIC DISCHARGE IN AQUEOUS ELECTROLYTES

(Presented by Academician M. A. Leontovich on 17 VII 1962)

Experimental method. In (^{1}) it was established that the character of a "high-voltage" discharge depends mainly on the specific "low-voltage" electrical conductivity of the solution, and not on its chemical composition. Therefore, in the present work only aqueous solutions of common salt were used, with specific low-voltage electrical conductivity from $0.6 \cdot 10^{-5}$ to 0.2 $\Omega^{-1} \cdot \text{cm}^{-1}$. This electrical conductivity was measured with an R-38 bridge with an Kh-38 cell. The discharge occurred between electrodes placed in a 10-liter polyvinyl-chloride vessel with an observation window, through which the luminous phenomena were photographed. The electrical circuit of the experiments coincides with the circuit indicated in (^{1}), but in the present work the high-voltage electrode was the end of the core, 1.3 mm in diameter, of an RK-3 cable. The grounded electrode included the flat end of an M6 bolt, as well as some metal structural parts of the apparatus. A pulse voltage of up to 16 kV was applied to the discharge gap from a capacitor with capacitance from 0.25 to 10 F through an air trigatron. The current shunt and voltage divider were connected to a DESO-1 oscilloscope by means of 2-meter lengths of RK-47 cable.

View of a brush discharge in the region of intermediate electrolyte concentrations. Interelectrode distance $l = 15$ mm, $C = 0.25$ μF. $U = 12.5$ kV

Fig. 1. View of a brush discharge in the region of intermediate electrolyte concentrations. Interelectrode distance $l = 15$ mm, $C = 0.25$ μF.
$U = 12.5$ kV

The study of the rate of development of the discharge was carried out by the method of the "incomplete discharge" (^{2}). Each photograph of an incomplete discharge was accompanied by photographing the corresponding oscillograms of the voltage and discharge current. The rate of development of the discharge was determined as the ratio—

a change in the radial dimensions of the photographed glow with the duration of the voltage pulse applied to the discharge gap.

Three characteristic ranges of specific electrical conductivities, manifested in high-voltage discharges, can be distinguished:

1. The range of high concentrations with low-voltage specific electrical conductivities from $2 \cdot 10^{-1}$ to $1 \cdot 10^{-1}$ $\Omega^{-1} \cdot \text{cm}^{-1}$. Breakdown proper is not observed even with small discharge gaps (of the order of 1 mm), although the current reaches very high values (7-10 thousand A). At the tip, independently of its polarity, a limited glow appears, resembling a corona discharge in air.

Rate of development of brush glow at different electrical conductivities. $U = 12.5$ kV, $C = 0.25$ μF, $l = 5$ mm. A –range of low concentrations; B –range of medium concentrations; CD –asymptote.

Fig. 2. Rate of development of brush glow at different electrical conductivities. $U = 12.5$ kV, $C = 0.25$ μF, $l = 5$ mm. A –range of low concentrations; B –range of medium concentrations; CD –asymptote.

2. The range of medium concentrations with electrical conductivities from 10^{-1} to 10^{-3} $\Omega^{-1} \cdot \text{cm}^{-1}$. The corona glow turns into a brush glow, which begins to develop slowly at the tip, independently of its polarity, immediately after the application of a high-voltage pulse. Characteristic of this range is a spark discharge in several parallel channels. The spark discharge occurs when one or, more often, several branches of the brush glow simultaneously grow to the opposite electrode (Fig. 1). At voltages below 7 kV (field strength at the electrode about 110 kV), the brush discharge has the appearance of hoarfrost.
3. The range of low concentrations with specific electrical conductivities from 10^{-3} to $0.6 \cdot 10^{-5}$ $\Omega^{-1} \cdot \text{cm}^{-1}$. The brush glow begins to develop immediately after the voltage pulse is applied, and after some time (“statistical delay time”) the phenomenon ends in an almost instantaneous spark, while the rate of development of the branches of the brush glow decreases as the conductivity of the liquid decreases. Here the brush form of discharge is not the determining one, and the spark can jump while the brush is still undeveloped. As a rule, the discharge occurs through a single spark channel.

Variation of breakdown voltages as a function of the length of the discharge gap at different electrical conductivities of the electrolyte ($\Omega^{-1} \cdot \text{cm}^{-1}$): 1 –0.012; 2 –0.006; 3 –0.003; 4 –0.0015; 5 –0.0010; 6 –0.00053; 7 –0.00026; 8 –0.00013; 9 –0.00006; a –medium electrical conductivities; b –low electrical conductivities.

Fig. 3. Variation of breakdown voltages as a function of the length of the discharge gap at different electrical conductivities of the electrolyte ($\Omega^{-1} \cdot \text{cm}^{-1}$): 1 –0.012; 2 –0.006; 3 –0.003; 4 –0.0015; 5 –0.0010; 6 –0.00053; 7 –0.00026; 8 –0.00013; 9 –0.00006; a –medium electrical conductivities; b –low electrical conductivities.

Summary of results. On the basis of measurements of the photographed discharges and the corresponding oscillograms, numbering in all about 2000, empirical regularities were noted that relate to the case of a positive tip and are summarized in Table 1. All numerical data in this table have an accuracy of the order of 15%.

Formula (1) of this table was obtained from the straight-line asymptote CD, shown in Fig. 2. The results depicted there were obtained by the method of incomplete discharge with a positive tip. With a negative charge on the tip, the velocities obtained are an order of magnitude lower. As the interelectrode gap increases, the rate of discharge development decreases only slightly.

Table 1

	Specific electrical conductivities σ $(\Omega^{-1}\cdot\mathrm{cm}^{-1})$	Specific electrical conductivities σ $(\Omega^{-1}\cdot\mathrm{cm}^{-1})$
	low, $6\cdot 10^{-6} < \sigma < 10^{-3}$	medium, $10^{-3} < \sigma < 10^{-1}$
1. Propagation velocity of the branches of the bush-like discharge ($C = 0.25\,\mu$F)	$\frac{v^2}{\sigma} = A\,\frac{\Omega\cdot\mathrm{cm}^{-3}}{\mu\mathrm{sec}^2} \quad (1)$ $U = 12.5$ kV; $A = 25$ for $l = 5$ mm, $A = 13$ for $l = 20$ mm	$v^2 = 10.6\,\frac{U-U_0}{U_0}\lg\frac{\sigma}{\sigma_0}\,\frac{\mathrm{mm}^2}{\mu\mathrm{sec}} \quad (2)$ for $U > 7$ kV Here $U_0 = 7$ kV, $\sigma_0 = 10^{-3}\Omega^{-1}\cdot\mathrm{cm}^{-1}$ $\frac{v}{U} = 8\cdot 10^{-3}\,\frac{\mathrm{mm}}{\mu\mathrm{sec}\cdot\mathrm{kV}} \quad (3)$ for $U < 7$ kV
2. Duration of pre-spark phenomena	$\frac{\tau}{l^2} = 0.1\,\frac{\mu\mathrm{sec}}{\mathrm{mm}^2} \quad (4)$	$\frac{\tau}{l} = 0.5\,\frac{\mu\mathrm{sec}}{\mathrm{mm}} \quad (5)$
3. Relation between breakdown voltage and the length of the spark gap	$U = U_0\left(\frac{\sigma_1}{\sigma}\right)^m + lE\lg\frac{\sigma_2}{\sigma} \quad (6)$ for $C = 10\ \mu$F $U_0 = 0.37$ kV, $E = 0.55$ kV/cm, $\sigma_1 = 10^{-3}\Omega^{-1}\cdot\mathrm{cm}^{-1}$, $\sigma_2 = 2.0\ \Omega^{-1}\cdot\mathrm{cm}^{-1}$, $m = 0.6$	$l = l_0\,[C(U-U_0)]^m\lg\frac{\sigma_0}{\sigma} \quad (7)$ for $C \le 0.5\ \mu$F $m = 0.37$, $l_0 = 9$ mm $\sigma_0 = 0.1\ \Omega^{-1}\cdot\mathrm{cm}^{-1}$ $U_0 = 7$ kV

Formula (6) was obtained from Fig. 3. The plots were recorded with a large capacitance ($C = 10\,\mu$F) in order to eliminate the dependence of the breakdown voltages on the duration of the voltage pulse applied to the arrester. In this case the time constant of the discharge circuit is considerably greater than the time required for breakdown of the selected gaps. It is seen that, in the region of low conductivities, a clear dependence of the breakdown voltages is observed both on the length of the interelectrode gap and on the conductivity of the solution. In this region the properties of the liquid in its bulk are predominantly manifested. In the region of medium concentrations the breakdown voltages are almost independent both of the gap length and of the conductivity of the solution. Here the properties of the liquid in the near-electrode layer play the decisive role (for example, electrolytic gas evolution).

Dependence between the maximum length of the discharge gap broken down at a given voltage and the electrical conductivity of the electrolyte. 1—$U = 10$ kV, $C = 0.25\,\mu$F; 2—$U = 10$ kV, $C = 0.5\,\mu$F; 3—$U = 13$ kV, $C = 0.25\,\mu$F.

Fig. 4. Dependence between the maximum length of the discharge gap broken down at a given voltage and the electrical conductivity of the electrolyte.
1—$U = 10$ kV, $C = 0.25\,\mu$F; 2—$U = 10$ kV, $C = 0.5\,\mu$F; 3—$U = 13$ kV, $C = 0.25\,\mu$F.

The inadequacy of theoretical ideas does not yet make it possible to propose an interpretation of the observed phenomena.

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Received
13 VII 1962

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Note: Figure translations are in progress. See original paper for figures.

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