Electrical Discharge in Liquid Dielectrics.

By

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I. Introduction.

Many liquid insulators are used in electrical engineering, as, for instance, transformer oil, switch oil, or impregnating materials for fibrous insulating matter in cables. The mechanism, however, of electrical discharge or electrical breakdown in these liquids, has as yet, never been explained with exactness.

II. A. Nikuradse's Theory.

A few years ago one of the authors of the present study(1) measured the current-voltage curve as far as the breakdown voltage in the liquid, and attempted to explain the phenomena of the electrical breakdown. He was, however, unable to arrive at a complete explanation.

A. Nikuradse(2) subsequently found that the current-voltage curve is not changed by a reduction in atmospheric pressure, but the breakdown voltage is reduced, i.e. the breakdown sometimes occurs on the lower slopes of the current-voltage curve. He(3) expressed the current-voltage curve by the following equation :

$$I = I_0 e^{\alpha\delta} \quad \ldots\ldots\ldots\ldots (1)$$

where I = Current

I_0 = Saturation current

α = Ionization constant

δ = Distance between electrodes

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(1) Y. Toriyama, Archiv. f. Elekt. 1927. Bd. 19.
(2) A. Nikuradse, Archiv. f. Elekt. 1931. Bd. 25.
(3) A. Nikuradse, Ann. d. Phys. 1932. Bd. 13.

The ionization constant, α was represented by the following equation.

$$\alpha = C(E-E_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where C = Constant

E_0 = Constant

E = Mean electric field intensity

If the electric field intensity E reaches a certain value, the current I increases abruptly resulting in a breakdown. Nikuradse(1) concluded from the experiment mentioned above, that there are two kinds of electric breakdown in liquid, i.e., the first is the direct breakdown of liquid, being expressed by the equations (1) and (2), and is called "Ionization breakdown (Ionizierungsdurchschlag)"; the second is the breakdown in liquid under low atmospheric pressure, and is caused by the gas adsorbed on the electrodes and absorbed in the liquid. This latter type he called, "Non-ionization breakdown (Nichtionizierungsdurchschlag)", but it is not a thermal phenomenon, as asserted by Edler.(2) Rather, it is due to the breakdown of the combined dielectrics, i.e. ionization by collision occurs at first in the adsorbed gas film, and then the molecules of the liquid are ionized.

III. Study of Electric Breakdown by Means of Dust Figures.

The authors(3) have been studying dust figures in liquid dielectrics for several years, and have used these figures for the investigation of breakdown phenomena of liquid insulators. There are two kinds of dust figures in liquid; the one is twig-like, as illustrated in Fig. 1, while the other is leaf-like, as shown in Fig. 2. The former is obtained by applying impulse voltage, and the latter by direct current voltage. These figures are obtained as follows:— the sheet of insulator and the electrodes are immersed in the liquid, and the

(1) A. Nikuradse, E. u. M. 1932. Heft 34.
(2) H. Edler, Arch. f. Elekt. 1931. Bd. 25.
(3) Y. Toriyama, Phys. Review. Vol. 27, No. 5, 1931.

voltage is applied. Then when the sheet is removed from the liquid, an electric charge will remain on its surface. By sprinkling a fine powder containing a mixture of red lead and resin on the sheet, and then carefully washing it in gasoline, a clear dust figure is produced. The positive figure appears yellowish white, because of the resin, while the negative figure is reddish owing to the red lead.

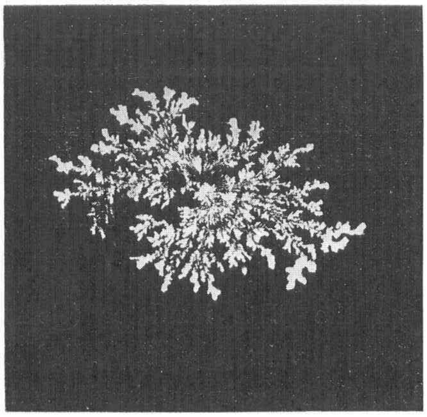

Fig. 1. Positive Dust Figure on Window Glass in Transformer Oil. Impulse Voltage 39.5 kV. max. R.H. 47% T. 21°C

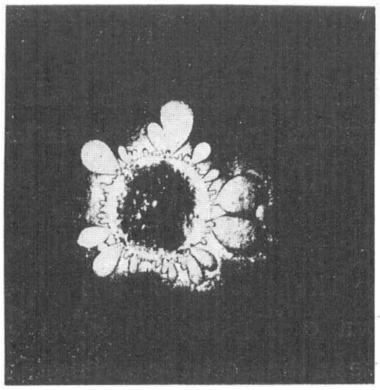

Fig. 2. Negative Dust Figure on Window Glass in Transformer Oil. D.C. Voltage 28 kV. R.H. 43% T. 18°C

When A. C. voltage is applied, the twig-like and small leaf-like figures are produced as shown in Fig. 3. In the case of pulsating voltage, the leaf-like is produced so far as the applied intensity of voltage is rather low, but the twig-like figure sometimes appears for rather high voltage. An example of such a figure is shown in Fig. 4.

The current-voltage curve in liquid dielectrics was measured when applying D. C. voltage, and at the same time dust figures were obtained. The current increases linearly with the voltage so long as the voltage is low, but abruptly from a certain intensity of voltage. Dust figures such as shown in Fig. 2 are produced above this critical voltage.

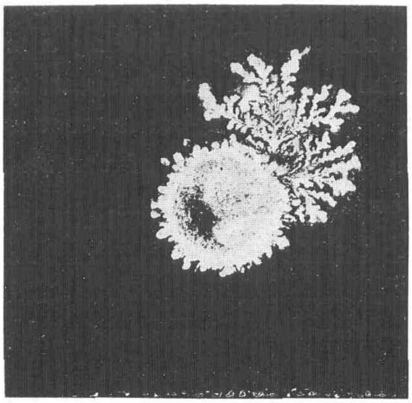

Fig. 3. Dust Figure on Window Glass in Petroleum.
A.C. Voltage 31.5 kV. max.
R.H. 42% T. 21°C

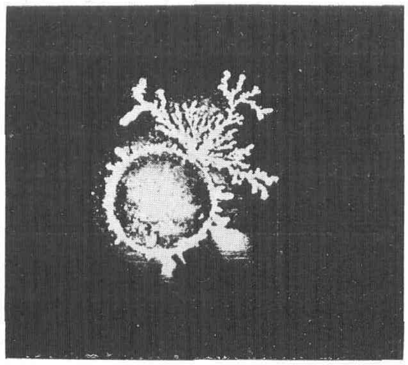

Fig. 4. Positive Dust Figure on Window Glass in Petroleum.
Pulsating Voltage 24.5 k.V.
R.H. 55% T. 20°C

The electrodes E E were set on the plate insulator (cleaned ebonite or glass) as shown in Fig. 5, and voltage was applied between the electrodes. A series of dust figures were obtained through a gradual increase in the intensity of the voltage. In the case of impulse voltage, the positive figure appears at first, and then positive and negative figures, such as shown in Fig. 6, are produced for the higher intensity of the voltage. When the two figures intersect the breakdown takes place. The streamers in liquids are more conductive than those in gases.

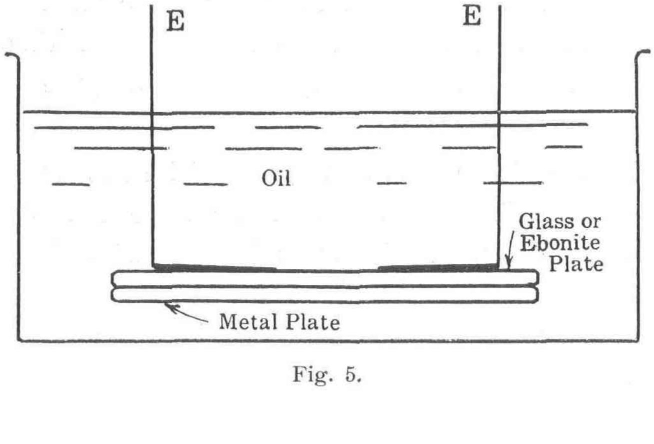

Fig. 5.

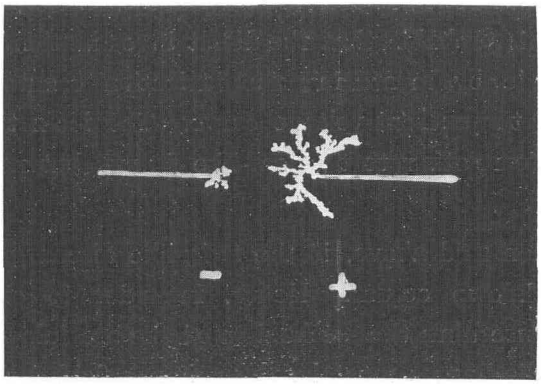

Fig. 6. Dust Figure on Window Glass in Petroleum.
Impulse Voltage 38.5 kV. max.
R.H. 48% T. 18°C

In the case of D. C. voltage the breakdown does not take place even if the leaf-like figures intersect. An example of such a case is shown in Fig. 7. When the spark-over occured clear dust figures could not be obtained, but twig-like traces of sparks were recognized, so it seems reasonable to suppose, the breakdown is not caused by the leaf-like figure but by the twig-like one. In the case of A. C.

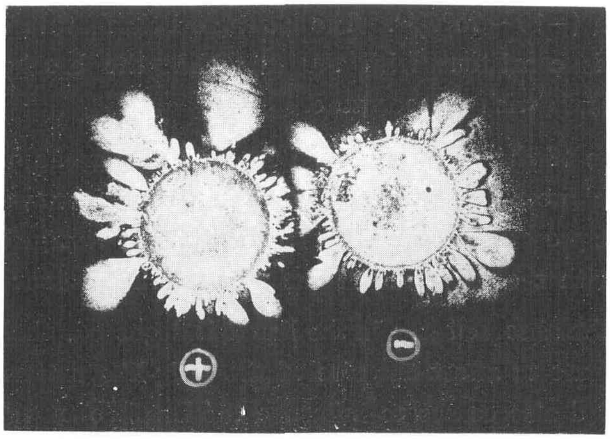

Fig. 7. Dust Figure on Pyrex Glass in Petroleum.
Pulsating Voltage 40.5 kV.
R.H. 57% T. 19°C

voltage, when the twig-like figures intersect, the spark-over takes place. It seems probable that the direct investigation for breakdown cannot be made by measuring the ionization constant α which is deduced from the current-voltage curve. The ionization constant α has an intimate relation to the leaf-like figure, but not to the twig-like one.

As has been said above, if the twig-like discharges intersect, a complete breakdown occurs. Hence, in order to obtain accurate information concerning the mechanism of the breakdown phenomena, the twig-like discharges must be the primary field for investigation. To this end impulse coronas in liquid dielectrics are being studied in the authors' laboratory, and they hope to publish some of their results in the near future.

To establish the fact that the twig-like discharge rather than the leaf-like pattern is the direct cause of breakdown, several experiments were conducted. For instance the effects of temperature or atmospheric pressure on the size of the figures were measured. The radius of the leaf-like figure was found to increase with the increasing temperature of the liquid insulator ($0 \sim 60°C$), but that of the twig-like pattern formed by impulse or A. C. voltage, decreased with temperature ($-10 \sim 70°C$)[(1)]. The characteristic feature of the twig-like figure is consistent with the fact that the breakdown of the liquid increases with temperature.

The size of the leaf-like figure does not change according to the atmospheric pressure, but the twig-like figure increases when the atmospheric pressure is reduced. The breakdown voltage of the liquid decreases with the reduction of the atmospheric pressure.

When the absorbed gas in the liquid is degassed, the atmospheric pressure ceases to affect the size of the twig-like pattern (as shown in Fig. 8) and also ceases to influence the breakdown voltage of the liquid.

(1) Y. Toriyama, Phys. Review. Vol. 37, No. 5, 1931.

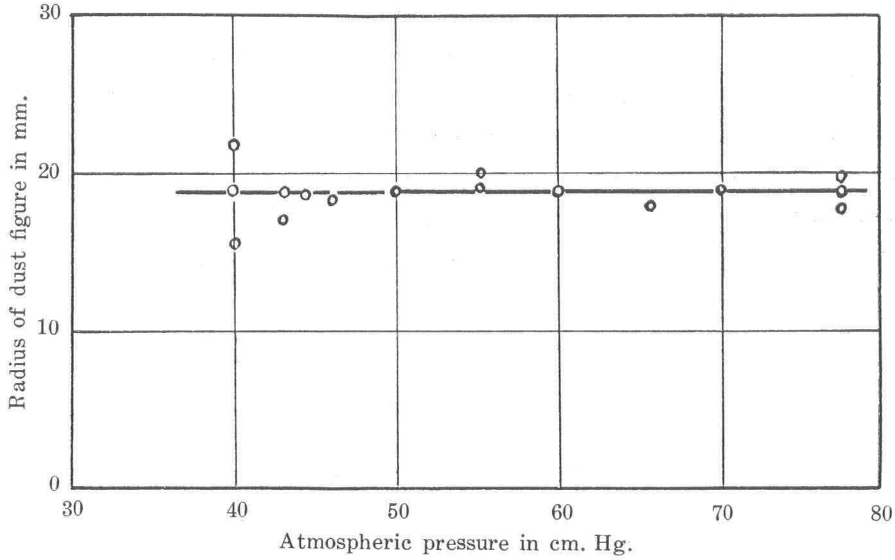

Fig. 8.

The leaf-like figure was ordinarily produced by applying D. C. voltage, but when the atmospheric pressure was reduced and sufficient intensity of voltage applied, occasionally a twig-like figure, such as shown in Fig. 9, was produced.

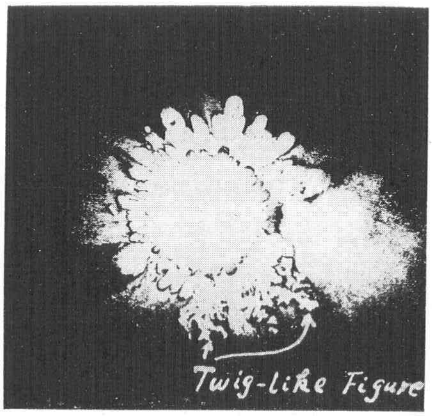

Fig. 9. Positive Dust Figure on Window Glass in Transformer Oil.
D.C. Voltage 49.2 kV.
Atmospheric Pressure 60 cm. Hg.
R.H. 43% T. 18°C

In the case of pulsating voltage, the twig-like figure was rarely produced, except when the atmospheric pressure was reduced, when it occurred frequently. An example of such a pattern is found in Fig. 10. When the liquid dielectric and the insulator sheet were degassed, twig-like patterns were produced by pulsating voltage with difficulty.

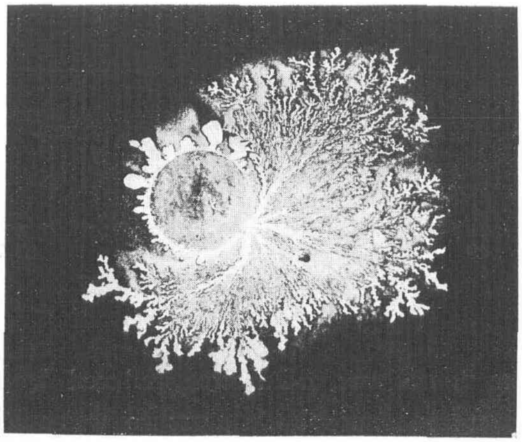

Fig. 10. Positive Dust Figure on Window Glass in Transformer Oil.
Pulsating Voltage 28 kV.
Atmospheric Pressure 30 cm. Hg.
R.H. 43% T. 18°C

It seems, therefore, to be a fair presumption that there is an intimate relation between the breakdown phenomenon and the twig-like discharge, but not so with the leaf-like pattern. The twig-like discharge may be due to the local breakdown of the liquid, and also to electronic phenomena. The leaf-like figure may have no direct relation to breakdown and be an ionic phenomenon.

IV. Conclusion.

Study of these experiments may fairly lead to the conclusion that there are not two kinds of breakdown as A. Nikuradse asserts, but only one. In the case of oil which has not been degassed, the twig-like discharge easily takes place under low atmospheric pressure. We now know, however, that the mechanism of breakdown is not different from that under higher atmospheric pressure. The breakdown of the liquid is caused by the twig-like discharge, and the breakdown voltage depends upon whether the twig-like discharge can or cannot take place easily. The gas adsorbed on the surface of the electrodes and absorbed in the liquid acts as an agent in making easy the twig-like discharge.