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LETTER TO THE EDITOR

Effect of polarity and gap length on the breakdown characteristics of mineral oil for non-uniform fields

A A Zaky†, A Nosseir†, I Y Megahed‡ and C Evangelou‡
† Faculty of Engineering, University of Riyadh, POB 800, Saudi Arabia
‡ Faculty of Engineering, University of Alexandria, Egypt

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Abstract. The direct breakdown voltage of degassed transformer oil has been measured as a function of gap length using point–sphere electrodes, for both polarities of the point. Although changing the material of the sphere electrode altered the magnitude of the breakdown voltage for both point polarities, the critical gap length at which the breakdown voltage was the same for both polarities remained unchanged. This critical gap length was markedly reduced by the presence of dissolved oxygen.

So far there have been no extensive studies on the dependence of the breakdown voltage of liquid insulants on the polarity and gap length for non-uniform field electrode geometries. For point–sphere electrodes there is a definite polarity effect; for large gaps the breakdown voltage is higher for a negative point polarity (Eldine and Tropper 1956) whereas for small gaps a negative point gives a lower breakdown voltage (Lewis 1953). These results indicate the presence of a critical gap length at which the breakdown voltage is the same for both polarities of the point electrode. This critical gap length corresponds to a crossover point in the superposed breakdown voltage against gap length characteristics for both point polarities. Although the results obtained by Angerer (1965) for degassed transformer oil did not show a crossover point for the gap range used, extrapolation of the characteristics indicated that a crossover point would occur at a gap length of about 300 μm. With aromatic additives in the degassed liquid the characteristics showed a crossover point at much smaller gaps; the actual length depended on the type of additive.

The work reported here gives the results of an investigation of the effect of polarity and gap length on the breakdown voltage of mineral oil using point–sphere electrodes. The results confirm the existence of a critical gap length and show that for degassed oil, this gap length is independent of the electrode material used for the sphere.

Breakdown tests were performed on degassed transformer oil samples (BS 148 : 1959) and on oil samples saturated (after degassing) with oxygen under a hydrostatic pressure of 1 atm. The oil was filtered through a 0·3 μm Millipore filter. A nickel-plated steel sewing needle of tip radius 25 μm was used as the point electrode; the 5 mm diameter sphere electrodes were either stainless steel or aluminium. The electrodes were mechanically polished to a mirror finish and the aluminium electrodes were then etched. The electrodes were mounted horizontally in the test cell. Direct voltages and a diverter circuit were used in all tests. Each breakdown voltage reported was the mean of 20

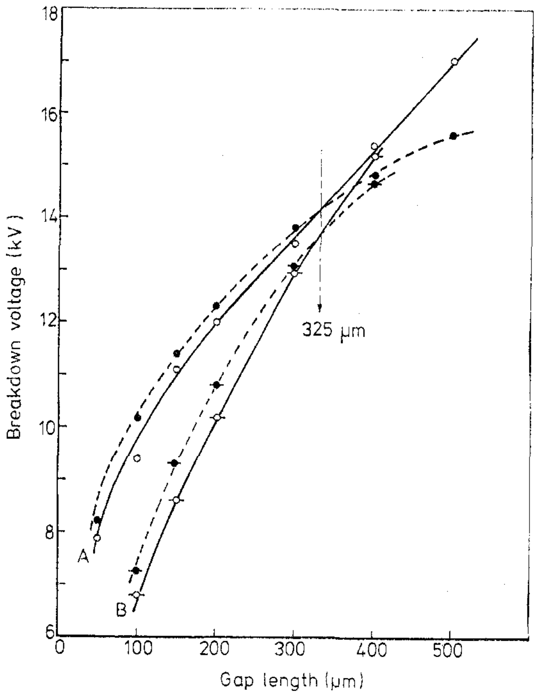

Figure 1. Breakdown voltage against gap length characteristics for degassed oil. A, etched aluminium sphere; B, stainless steel sphere. --- point positive; —— point negative.

breakdowns and the coefficient of variation varied between 5 and 11 %. New electrodes and fresh liquid samples were used for each gap setting.

Figure 1 shows the breakdown voltage against gap length characteristics for degassed oil obtained using both aluminium and stainless steel spheres, for the two polarities of the point. For a given sphere electrode both characteristics show a crossover point. Although a change in the material of the sphere electrode altered the breakdown level for both point polarities, the critical gap length of about 325 μm, corresponding to the crossover point, remained unchanged. This value is in excellent agreement with that obtained from an extrapolation of Angerer's results for degassed oil using a nickel sphere electrode. In view of the fact that measurements of the breakdown voltage in liquid dielectrics are difficult to reproduce, the consistency of the value obtained for the critical gap length is striking. This length thus seems to be an inherent property of the type of liquid tested.

With a point–sphere electrode geometry, breakdown is always preceded by the onset of corona and bubble formation at the point electrode (Singh *et al* 1972, Shammas *et al* 1974, Takahashi and Ohtsuka 1975). Moreover, corona may also form at local asperities on the surface of the sphere electrode. For large gaps, corona from the point electrode will not bridge the entire gap and breakdown will be triggered by a back streamer travelling from the sphere electrode towards the corona region at the point electrode (Fiebig 1969). Such a back streamer is more readily initiated from a sphere cathode due to the presence of local high emissivity sites at which the field is enhanced by the presence of a positive space charge. This would account for the lower breakdown voltages obtained for a positive point polarity at large gaps. For small gaps, the extent of the point corona is such that it will bridge the entire gap. Since the corona inception voltage is lower for a negative point than for a positive one (Takahashi and Ohtsuka 1975), the breakdown voltage for a negative point will be lower than that for a positive one. This would explain the presence of a crossover point in the breakdown voltage against gap length characteristics. Such a crossover point corresponds to a critical gap length at which the extent of corona propagation from the point electrode is just sufficient to bridge the gap.

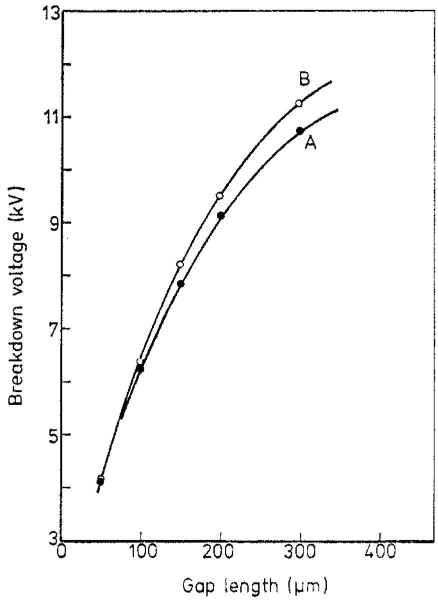

Figure 2. Breakdown voltage against gap length characteristics for oil saturated with oxygen using a stainless steel sphere. A, point positive; B, point negative.

Factors affecting the extent of corona propagation, e.g. additives or dissolved gases, should affect the critical gap length. This is confirmed by the present results obtained for oil saturated with oxygen, as shown in figure 2. Here there is a marked reduction in the critical gap length to about 50 μm which is attributed to the well-known quenching properties of oxygen.

A more detailed interpretation of these and other results will be reported separately.

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