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LETTER TO THE EDITOR

The effect of organic additives on the breakdown strength of transformer oil

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Abstract. The breakdown voltage of degassed and gas-saturated transformer oil has been measured as a function of concentration of organic additives known to affect the breakdown strength of the oil. By using a wide range of additive concentrations, it is shown that the existence of optimum concentrations in the breakdown voltage against concentration characteristics which have hitherto been reported is in fact only one phase of a more complex relationship between breakdown voltage and additive concentration. The characteristics are markedly affected by the presence of gases dissolved in the oil.

We report here some new results on the effect which the addition of varying concentrations of organic additives has on the breakdown strength of degassed transformer oil (British Standards Institution 1959) and transformer oil saturated with hydrogen, nitrogen and oxygen. It is well known that the addition of aromatics to insulating oils improves their gassing properties (Berberich 1938, Blodgett and Barlett 1961, Clarke and Reynolds 1963), and a number of workers (Ruhle 1941, Booth and Johnson 1954, Angerer 1965) have reported that small concentrations of aromatic additives improve their electric strength. Results so far have indicated that there exists an optimum concentration that gives a maximum increase in the breakdown strength of an oil. A recent study by Zaky and Megahed (1972) on the effect of additives on the gassing characteristics of transformer oil has shown that the same optimum concentration of additives which gives a maximum increase in breakdown voltage (Angerer 1965) also gives maximum gas absorption or minimum gas evolution; in particular, the optimum concentrations were found to be independent of the gas phase used. The fact that Clarke and Reynolds (1963) found a continuous reduction in the gassing tendencies of mineral oils with increasing concentrations of aromatic additives, over a wide range of additive concentrations, suggested that if in fact there exists a correlation between the gassing tendency of a mineral oil and its electric strength, then there must exist an additive concentration, above the optimum, for which the strength increases with increasing concentrations. The present results indicate that this is so.

Breakdown tests were performed on degassed transformer oil samples under a few torr hydrostatic pressure, and on oil samples saturated (after degassing) with H_2, N_2 and O_2 and under a hydrostatic pressure of 1 atm. The oil was passed through a 1 μm porosity sintered glass filter, thoroughly degassed in a magnetically stirred vessel, and introduced into the test cell via a 0·3 μm Millipore filter. Spherical 5 mm diameter hard chrome-plated electrodes were used in all tests. A stress conditioning similar to that used by Angerer (1965) was adopted, and each breakdown voltage reported is the mean of 14 breakdowns; stabilized direct voltage was used in all tests. The additives used were benzophenone $(C_6H_5)_2C{=}O$, naphthalene $(C_{10}H_8)$, quinoline (C_9H_7N) and tetralin $(C_{10}H_{12})$, with molar concentrations ranging from 4×10^{-4} to 0·4. It should be pointed out that although it was once thought that the greater the aromatic content of an oil the poorer its resistance to oxidation, this is not necessarily so (Sloat *et al* 1967); in effect it has been shown by Melchiore and Mills (1967) that, in the absence of nitrogen and sulphur impurities, aromatics in an oil improve its thermal oxidation stability.

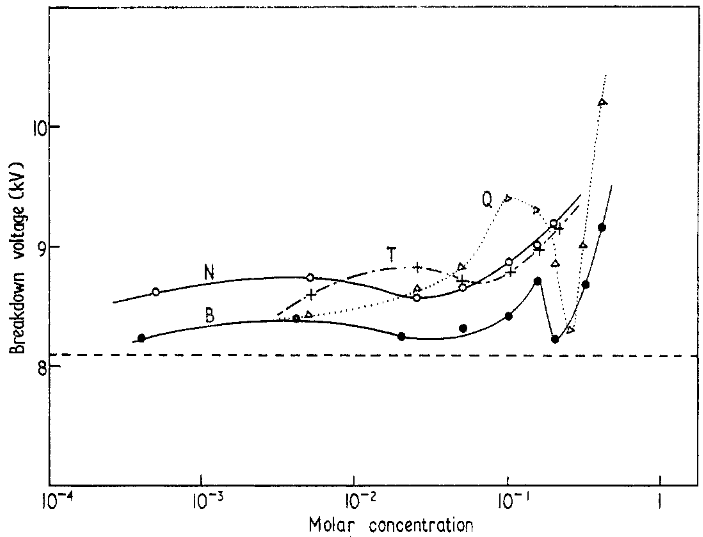

Figure 1. Breakdown voltage against additive concentration characteristics for degassed transformer oil: B, benzophenone; N, naphthalene; Q, quinoline; T, tetralin. The gap was 125 μm. Tests were carried out at a few torr hydrostatic pressure. The broken horizontal line indicates the breakdown voltage of plain oil.

Figure 1 shows the relationship between additive concentrations and breakdown voltage for degassed transformer oil at a few torr hydrostatic pressure. With benzophenone as additive the breakdown strength showed a maximum for a molar concentration of 4×10^{-3}, corresponding almost exactly to that obtained by Angerer for the same additive ($4{\cdot}59\times10^{-4}$ mol/100 g oil). However, with increasing concentrations there was a second sharper maximum at 0·15 molar followed by a sharp minimum at 0·25 molar; thereafter there was a continuous increase in the breakdown voltage with increasing concentrations.

Figure 2 shows the effect of dissolved gases on the breakdown voltage of transformer oil with varying concentrations of quinoline. Although a detailed analysis of the results will be reported later, two facts are worth noting: firstly, that the additive concentrations giving maximum or minimum breakdown voltages do not vary with the type of dissolved gas; and secondly, that although with hydrogen and nitrogen in solution the addition of quinoline has an overall beneficial effect, in the presence of oxygen the quinoline, especially in small concentrations, has a markedly harmful effect—in particular the

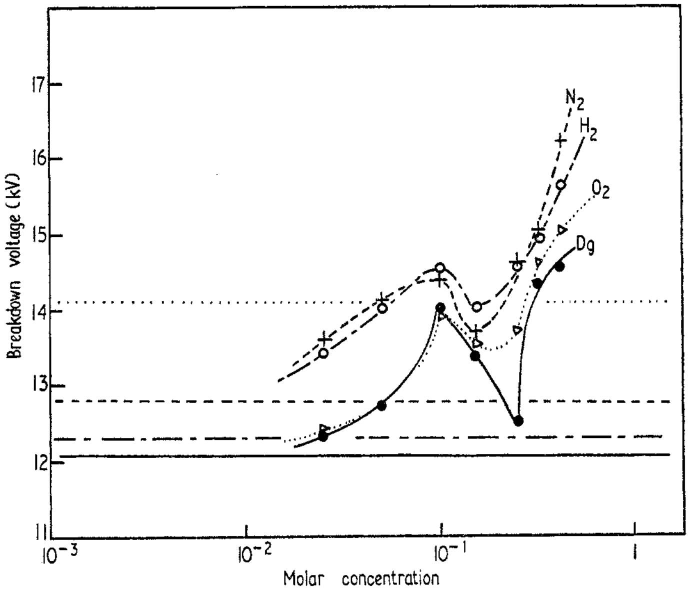

Figure 2. The effect of dissolved gases on the breakdown voltage of transformer oil with varying concentrations of quinoline: Dg, degassed oil. The gap was 200 μm. All tests were carried out at 1 atm hydrostatic pressure, and the oil saturated with gas. The horizontal lines indicate the breakdown voltage of plain gas-saturated oil.

characteristic indicates that the breakdown voltage will have to rise by about 2 kV as the molar concentration drops from the weakest experimental value to zero.

The authors are now investigating the effect of a wide range of concentrations of the above additives on the gassing properties of transformer oil, and preliminary results indicate a parallelism between the breakdown voltage against concentration characteristics and the gas evolution against concentration characteristics.

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