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Dielectric Loss and Resistivity

Results presented at the IEE Conference on "Dielectric Materials, Measurements and Applications" (20 - 24 July, 1970) appear to suggest that it may be possible to avoid time effects due to the measuring stress in measurements of dielectric loss and resistivity of trichlorodiphenyl. Mr. Krasucki will summarise the results and open a discussion on the implication of the results to standardisation of procedures to be adopted in measurements of tanδ and resistivity of askarels.

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DIELECTRIC LOSS OF TRICHLORODIPHENYL AT ELEVATED TEMPERATURES

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Introduction Recent investigations of electrical properties of trichlorodiphenyl-impregnated polypropylene film capacitors [1] necessitated making extensive studies of the effect of polypropylene on the dielectric loss of trichlorodiphenyl. These studies were made using trichlorodiphenyl which, after purification with activated Fullers' earth, filtration and degassing, was heated in contact with polypropylene film at 95°C for 64 hours. Measurements of tan δ of the trichlorodiphenyl extracts, made in an NPL cell at 90°C and at 1 kV (r.m.s.)/mm using a Schering bridge, showed that tan δ varied from 0.005 (value obtained with the highly purified trichlorodiphenyl blank sample) to 0.5 depending on the quality of the film. It was found that, over the whole range of values considered, tan δ tended to change with time in the course of a single measurement (1-2 minutes). As these changes were considered to be a potential source of uncertainty in measurements of dielectric loss of trichlorodiphenyl, it was considered necessary to study them systematically.

Measurements of Dielectric Loss Initial measurements of tan δ of a trichlorodiphenyl extract of polypropylene were made (NPL cell, 90°C at 1 kV (r.m.s.)/mm and at 50 Hz. With the stress applied continuously to the liquid, its tan δ was found to decrease continuously with time under stress. The results of these measurements are presented in Fig. 1, curve a. Removing the stress and resting the sample at 90°C for about 16 hours resulted in an almost complete recovery of tan δ. On reapplication of the stress, tan δ again decreased continuously with time (see Fig. 1, curve b). Repetition of the process of stressing followed by a rest period, τ, the latter varying from 16 to 136 hours, gave results presented in curves c, d, e and f of Fig. 1. These results show that changes in tan δ of trichlorodiphenyl with time under stress are reversible.

The changes of tan δ with time presented in Fig. 1 were brought about by the application of the measuring stress to the liquid. It was of interest, therefore, to determine the effect of changing the magnitude of the applied electric stress on the dependence of tan δ on time. Measurements were made of tan δ of the trichlorodiphenyl sample (after its recovery from the earlier measurements) as a function of time at 50 V(r.m.s.)/mm and at 500 V (r.m.s.)/mm. The results are presented in Fig. 2 where, for comparison, curve f of Fig. 1 is also plotted. It will be seen from Fig. 2 that there was no change with time of tan δ measured at 50 V (r.m.s.)/mm and that the tan δ-time dependence at 500 V (r.m.s.)/mm was smaller than that at 1 kV (r.m.s.)/mm. These results indicate that the magnitude of the tan δ-time dependence increases with increasing stress applied to the liquid.

The tan δ-time dependences discussed so far could have been caused by changes in the resistivity of the liquid. The contribution to tan δ from the resistance of the liquid should be inversely proportional to the measuring frequency and measurements of dielectric loss of the sample used, made at frequencies between 50 Hz and 1000 Hz (low stresses), showed that the plot of tan δ against 1/frequency was a straight line. The resistance of the liquid calculated from the slope of the

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straight line was 7.9 x 10^8 ohm and that measured with a Vibron electrometer was 8 x 10^8 ohm when extrapolated to zero time. This agreement between the measured resistance and that derived from tan δ measurements suggests that dielectric loss in the trichlorodiphenyl sample used was predominantly due to the presence of free charge carriers in the liquid.

Tan δ of the trichlorodiphenyl sample used for obtaining the results presented in curve f of Fig. 1 was measured at frequencies between 200 Hz and 1000 Hz and also at 50 Hz (50 V (r.m.s.)/mm) both before and after application of the 1 kV (r.m.s.)/mm stress. The results of these measurements are presented in Fig. 3. It will be seen from the figure that the plots of tan δ against 1/frequency were straight lines and that the polar contribution to loss, given by the intercept on the ordinate, was 0.0004. Assuming that carrier mobilities do not change as a result of stressing at 1 kV (r.m.s.)/mm, the results of Fig. 3 indicate that the concentration of free charge carriers decreases with time under stress.

In order to determine whether the direct proportionality between tan δ and 1/frequency in trichlorodiphenyl is true at temperatures below 90°C and for different contamination levels in the liquid, some of the results obtained during studies of compatibility between trichloridphenyl and polypropylene film were plotted on graphs of tan δ against 1/frequency. Fig. 4 gives the dependences of tan δ of trichlorodiphenyl (contaminated to different degrees) on 1/frequency at room temperature and at 60°C. It will be seen from the figure that the dielectric loss of any given sample of trichlorodiphenyl was always inversely proportional to the frequency. These results suggest that dielectric loss of trichlorodiphenyl at room temperature and above is determined by the presence of free charge carriers in the liquid.

Discussion The results presented show that dielectric loss in trichlorodiphenyl at elevated temperatures is due to the presence of free charge carriers in the liquid and that assuming a constar mobility, the carrier concentration in the liquid decreases with time when the field applied is 500 V (r.m.s.)/mm or higher. A possible explanation for the decrease is that carriers are swept away by conducting particle impurities present in the liquid. At the stress of 1 kV (r.m.s.)/mm those conducting particles which acquire charge by coming into contact with the electrodes will move through the liquid with velocities much higher than those of free charge carriers and will thus be able to collect carriers along their paths. As on reversal of polarity the conducting particle will move back towards the electrode, where it becomes recharged, the nett effect in the course of time is expected to be the trapping of more and more carriers on the particle. As the particle velocity will decrease more rapidly than linearly with decreasing applied electric field, such a carrier trapping process is expected to be less efficient the lower the applied field.

It is felt that the results presented in this paper have a bearing on considerations of procedure to be adopted in measurements of dielectric loss and resistivity of liquids like trichlorodiphenyl. Measurements of tanδ of trichlorodiphenyl at 1 kV (r.m.s.)/mm are

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likely to be subject to uncertainty because of the presence of time effects but the magnitude of the effects decreases with decreasing stress and they appear to be absent at stresses of 50 V (r.m.s.)/mm or less. It follows therefore that, in order to avoid uncertainties due to time effects present when dielectric loss is measured at high stress, viz. stresses of 500 V (r.m.s.)/mm or more, measurements of tan δ of trichlorodiphenyl should be made at a low stress. If the available bridge is not sufficiently sensitive for making low-stress tan δ measurements at 50 Hz, then it is permissible to obtain the 50 Hz value of dielectric loss by extrapolation from a straight line plot of tan δ against 1/frequency, where the frequency ranges from 200 Hz to 1000 Hz. The intercept of this straight line on the ordinate gives the dipolar contribution to the dielectric loss and the slope of the line gives the short-time resistivity of the liquid.

Conclusions Dielectric loss of trichlorodiphenyl measured at 90°C exhibits variations with time which are caused by the application of measuring stress to the liquid and result from changes in the concentration of free carriers in the liquid. The liquid recovers its initial value of dielectric loss if the measuring stress is kept off for 16 hours.

Changes in dielectric loss of trichlorodiphenyl with time decrease in magnitude as the measuring stress is lowered and they appear to be absent at 50 V (r.m.s.)/mm. Values of dielectric loss of trichlorodiphenyl measured at frequencies between 200 Hz and 1000 Hz lie on a straight line when plotted against 1/frequency. Extrapolation to 50 Hz gives directly the 50 V (r.m.s.)/mm dielectric loss and the slope of the straight line gives the short-time resistivity of the liquid. It is recommended that, in order to avoid uncertainties due to the presence of time effects in the measurement of dielectric loss at high stress (500 V (r.m.s.)/mm and higher) and also in the measurement of resistivity, both the dielectric loss and the short-time resistivity of liquids like trichlorodiphenyl be derived from measurements of tan δ made at low stresses and at frequencies between 200 Hz and 1000 Hz.

Reference

1. Z. Krasucki and H.F. Church, ERA Report No. 5260, 1969.

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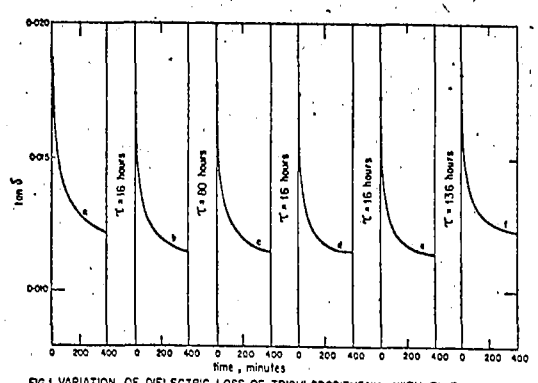

FIG.1. VARIATION OF DIELECTRIC LOSS OF TRICHLORODIPHENYL WITH TIME AT THE MEASURING STRESS OF 1 kV (r.m.s.)/mm (50Hz).
T=90°C ; τ=rest period, during which no measuring stress was applied.

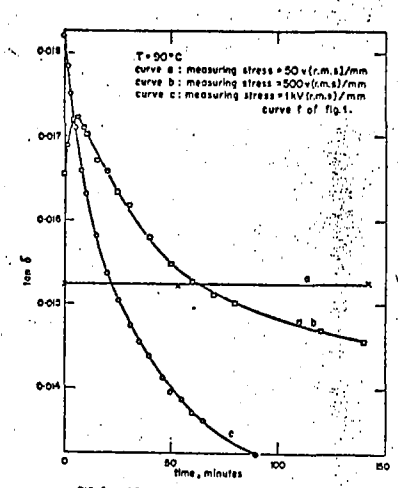

FIG. 2. VARIATION OF DIELECTRIC LOSS OF TRICHLORODIPHENYL WITH TIME.

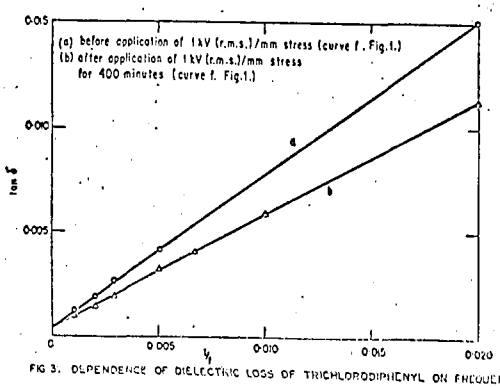

FIG 3. DEPENDENCE OF DIELECTRIC LOSS OF TRICHLORODIPHENYL ON FREQUENCY.

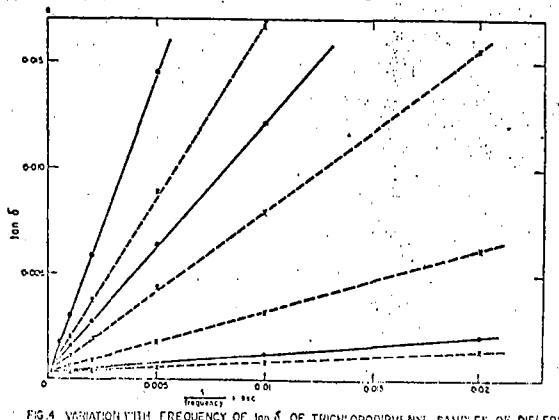

FIG.4 VARIATION WITH FREQUENCY OF tan δ OF TRICHLORODIPHENYL SAMPLES OF DIFFERENT PURITIES AND TESTED AT DIFFERENT TIMES (--x-- room temperature; —•— 60°C)

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