STUDIES IN THE ELECTRICAL INSULATION OF NATURAL AND SYNTHETIC MATERIALS

Part I.—Breakdown Voltage and Variation of Specific Conductance for Paper, Wood and Jutoid* of Various Water Contents

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Measurements of electrical specific conductance have been made on various samples of paper, wood and Jutoid (bituminous composition on a jute base) at various applied fields up to breakdown. The effect of absorbed moisture has been studied. The conductance at small fields apparently shows a quadratic dependence on water content from zero up to about 2% by weight of water.

1. Introduction

In a previous communication,[1] some measurements of insulation resistances were made at various voltages on samples of insulating varnishes and Jutoid, and it was shown that the curves for resistance against applied voltage (in kilovolts) could be linearly extrapolated to a value equal to:

$$\frac{\text{Breakdown voltage}}{(0.88 \pm 0.05)}$$

It was, therefore, considered worthwhile to extend these investigations to other natural and synthetic materials with a view to analyzing the mechanism of electrical conduction and breakdown. The present communication gives some experimental results on samples of paper, wood and Jutoid, both dry and wet.

The apparatus used is straightforward and has been described before,[1] but the results now obtained are plotted as (i) specific resistance versus applied field strength, which leaves the shape of the curve unaltered, and (ii) specific conductance versus applied field strength, which form is likely to be more useful for interpreting the mechanism of electrical conduction. The temperature and humidity were also recorded for each set of observations, and from these the vapour pressure of water was calculated. In some cases, the weight of water absorbed by the sample was directly measured.

2. Results with Paper and Wood

Curves for specific resistance versus applied field in kilovolts cm. for a sample of Karnaphuli typing paper folded four times is shown in Fig. 1(a), while Figs. 1(b) and 1(c) show the corresponding results for samples of "deodar" wood measured at pressures of water vapour of about 15 mm. and 29 mm. as noted against the two graphs, the last figure (Fig. 1(c)) having been

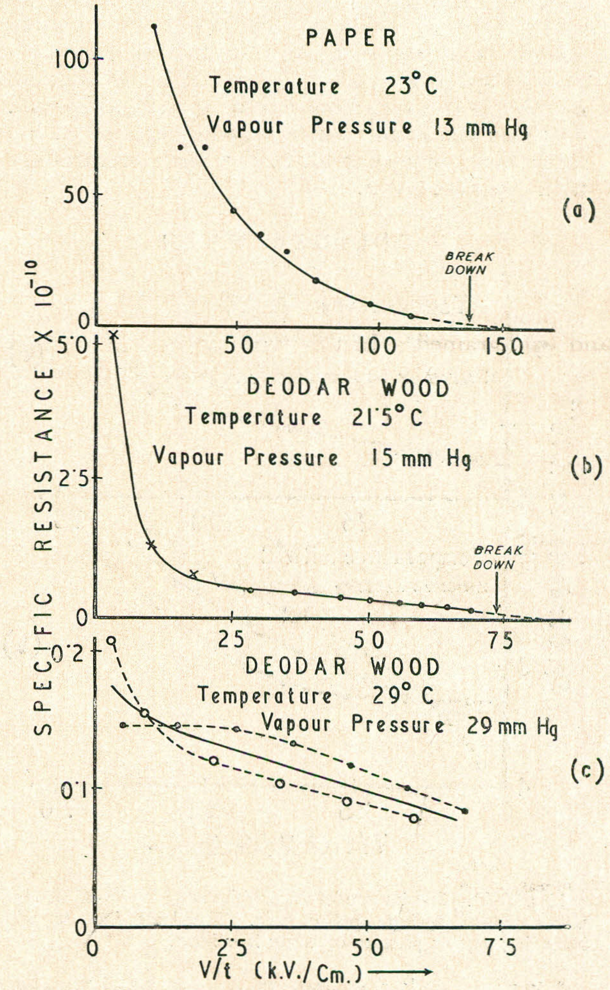


Fig. 1(a-c).—Variation of specific resistance of paper and wood samples with applied field. The crosses in Fig. 1(b) indicate means of pairs of readings, while the solid and hollow circles in Fig. 1(c) are measured values for two samples of "deodar" wood.

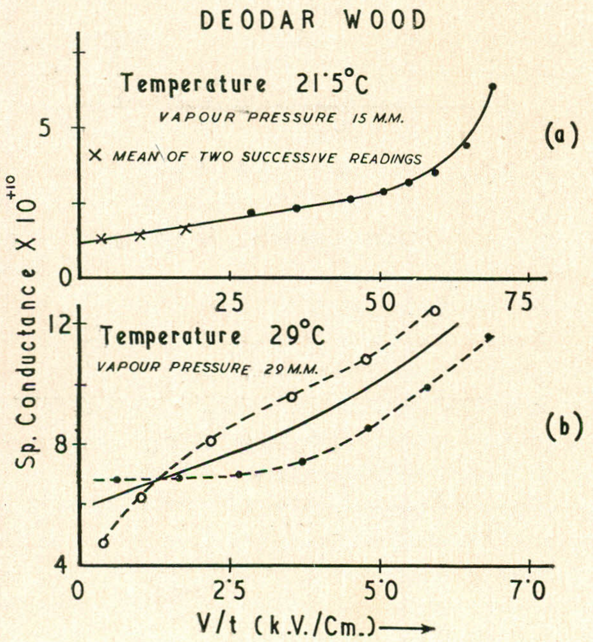
* A bituminous, jute-based, waterproof material developed at the Central Laboratories, P.C.S.I.R., Karachi (Pakistan Patent No. 109344, September 8, 1958).

got by testing on a 4 kv. set-up to examine the initial part of the graph. It is seen that, apart from a matter of scale, the three graphs are generally similar to those previously obtained[1] for Jutoid and insulating varnishes. Moreover, the breakdown voltage approximately equals:

$$(0.90 \pm 0.05) \times \text{linearly extrapolated value for } R = 0,$$

as against (0.88 ± 0.05) previously obtained.

The important effect of water content (as indicated by vapour pressure of water) can be seen by comparing Figs. 1(b) and 1(c). Its significance is brought out better by plotting specific conductance against applied field strength as in Figs. 2(a) and 2(b), which show that an increase of vapour pressure from 15 mm. to 29 mm. increases the conductance several fold and at the same time somewhat alters the form of variation with applied field.



Figs. 2(a-b).—Specific conductance of the two samples of "deodar" wood plotted against applied field. The large increase with increasing vapour pressure of water is evident.

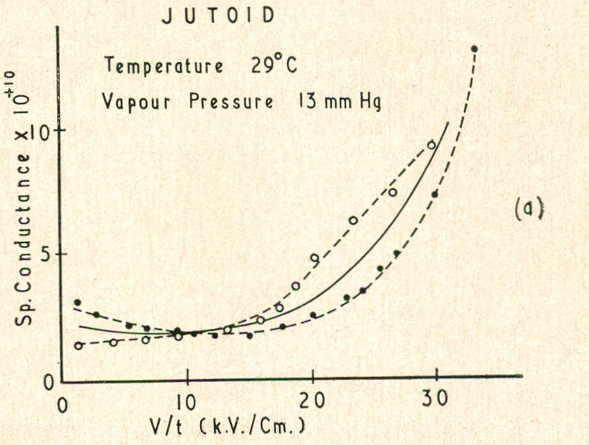


Fig. 3(a).—Variation of specific conductance with applied field for two Jutoid samples (solid and hollow circles), together with the mean (solid line) for the pair of samples.

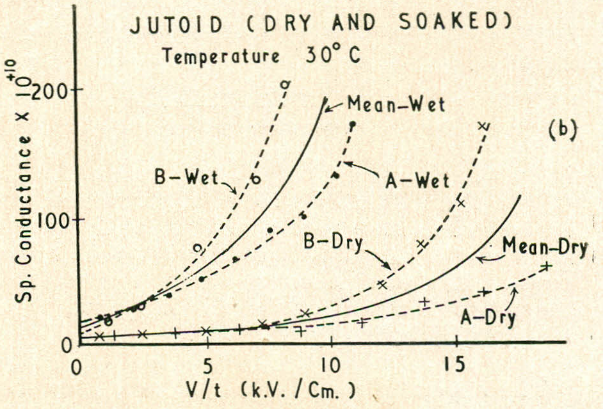


Fig. 3(b).—Variation of specific conductance with applied field for two samples A and B of Jutoid, measured when (i) dry and (ii) soaked in water. The mean curves for dry and soaked samples are shown by the solid lines.

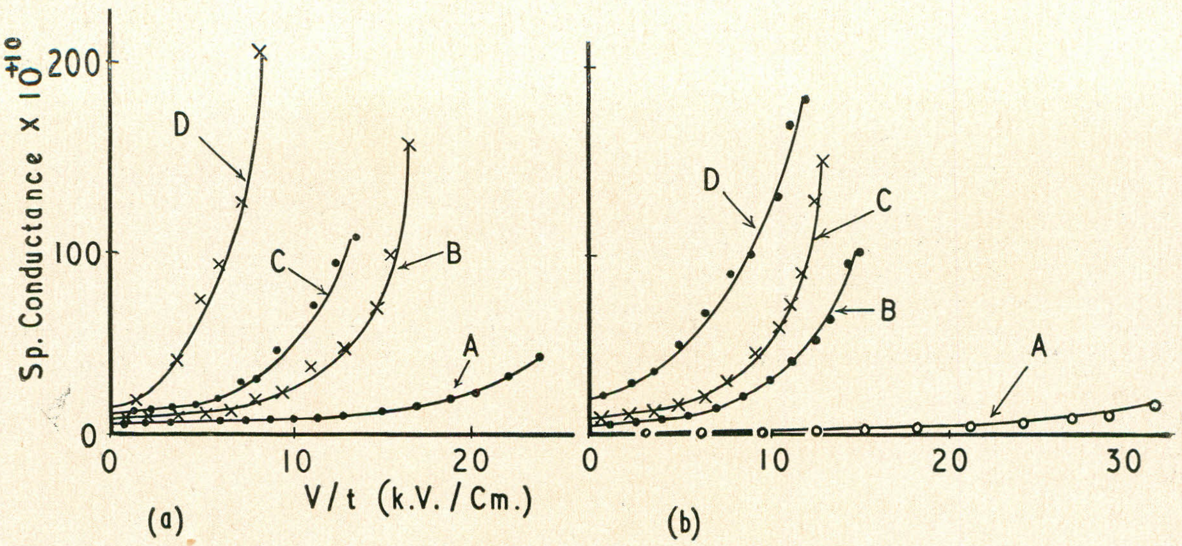
3. Measurement with Dry and Wet Jutoid

In order to study these effects further, a series of measurements were carried out on dry and wet Jutoid (a jute-based bituminous composition) saturated with water. Fig. 3(a) shows plots of specific conductance versus applied field for two dry specimens from one type of Jutoid, and indicates an acceptable degree of reproducibility. Two more samples were saturated by immersing in water for four to five hours, after which the surface was dried with filter paper and then electrical testing carried out. The results obtained for these samples, both in dry and soaked conditions, are plotted in Fig. 3(b) together with the means for the pair of samples. These graphs indicate that the nature of the variation of conductivity with applied field is essentially the same before and after soaking.

4. Effect of Time of Soaking of Jutoid

In order to study the effects of soaking time of Jutoid on electrical conductivity, a number of experiments were performed by taking Jutoid samples and immersing them in water for periods

JUTOID (SOAKED)



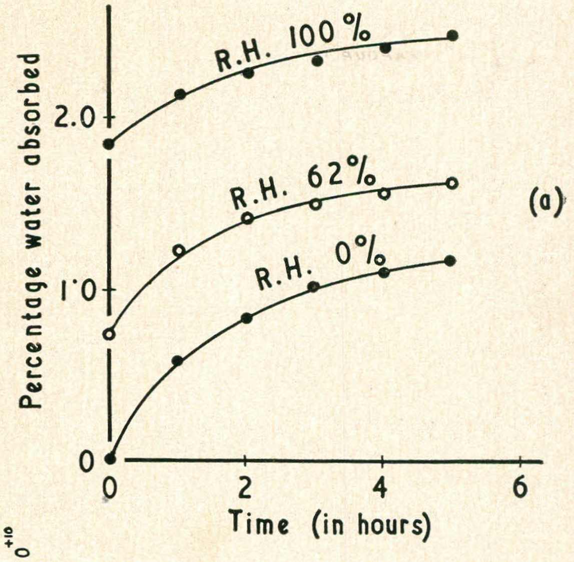
Figs. 4(a–b).—Specific conductance as a function of applied field for two Jutoid samples soaked for various periods ranging from 1 to 5 hours.

a) A: As received; with 0.6% water content.
B: Soaked for two hours; 1.15% water content.
C: Soaked for $3\frac{1}{2}$ hours; 1.36% water content.
D: Soaked for 5 hours; 1.5% water content.

b) A: Desiccated dry sample.
B: As received; with 1.4% water content.
C: Soaked for one hour; 1.78% water content.
D: Soaked for 4 hours; 2.18% water content.

ranging from one to five hours. In each case, the surface was dried with filter paper before carrying out electrical tests. Fig. 4(a) shows the variation of specific conductivity with applied field for Jutoid samples (originally in equilibrium at relative humidity of 45%) soaked for 2, $3\frac{1}{2}$ and 5 hours, respectively. A plot for dry Jutoid of the same type is also included in the figure for the sake of comparision. Figure 4(b) shows the results of another such experiment, in which the samples (originally in equilibrium at relative humidity of 85%) were soaked in water for zero, one and four hours, respectively, and a fourth graph for a completely desiccated sample is also included. The weight of absorbed water was measured for some of these samples under different conditions, with the results shown in Fig. 5(a).

Figure 5(b) shows the dependence of the specific conductance upon percentage water absorbed for



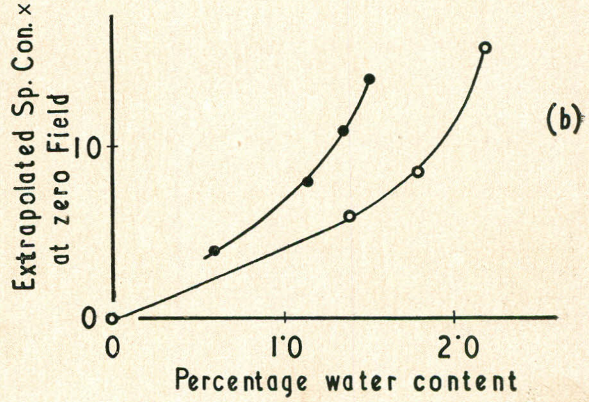


Fig. 5(a).—Percentage water absorbed against soaking time for Jutoid originally kept at various relative humidities.

Fig. 5(b).—Dependence of specific conductance (for small applied fields) upon percentage water content for the two Jutoid samples. The solid circles correspond to the sample of Fig. 4(a) while the hollow circles correspond to Fig. 4(b).

very small applied field. These graphs pass through the origin within the limits of experimental error, and seem to be linear only for very small percentages of moisture in the Jutoid. The differences between the plotted points for the two sets of samples are probably attributable to small changes in composition of different batches of the Jutoid.

5. Conclusion

It thus follows that the electrical conductance (at small applied fields) is at first nearly proportional to the absorbed water. However, the actual process does not appear to be a simple one because the dependence on water content is actually more nearly quadratic when the full range of water contents is examined (Fig. 5(b)). Similarly, the voltage dependence of the specific conductance for any one sample is far from linear and appears to be exponential for medium to high fields. This, however, is to be expected if the conduction and breakdown process is any way similar to the cascade ionization processes that occur in gaseous discharges.

Further experiments on the elucidation of these phenomena are being conducted on wood and a variety of materials.

Reference

1. S.N. Ahmad and M.M. Qurashi, Pakistan J. Sci. Ind. Research, **4**, 49 (1961).