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A Study of the Temperature and Moisture Dependent Dielectric Properties of Oil-Impregnated Pressboard

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1 Introduction

The dielectric properties of pressboard depend on the temperature and on the amount of water contained in the cellulose [1, 2]. It is important to monitor the moisture content of the pressboard used as insulation in high-power transformers, because its conductivity determines the rate of static charge relaxation and is thus an important factor in static electrification phenomena.

The *dielectric spectrum* of a material is a representation of its complex permittivity as a function of frequency. The real component of the complex permittivity gives the dielectric constant while the imaginary component determines the power dissipation (loss) in the material.

Once it is known how the dielectric spectrum of oil-impregnated pressboard varies with temperature and moisture, it will be possible to measure the moisture content in a sample by taking a frequency scan and comparing the results to the known calibration mapping. In this paper we present dielectric spectra for oil-impregnated pressboard samples of two different moisture contents at five temperatures.

2 Instrumentation

The dielectric spectrum of pressboard is measured with the help of a parallel-plate sensor. The sensor is essentially a lossy capacitor, with the two plates in physical contact with the test sample. Its structure is shown in figure 1 and its equivalent circuit representation is that of a resistor and capacitor in parallel. A driving AC potential with a magnitude of 1V is applied to one of the plates. The other plate is loaded with a known impedance to ground that is in series with the test sample. The magnitude and the phase of the potential at the second plate are measured with respect to the driven potential and this information is used to determine the resistive and the capacitive components of the impedance of the test cell.

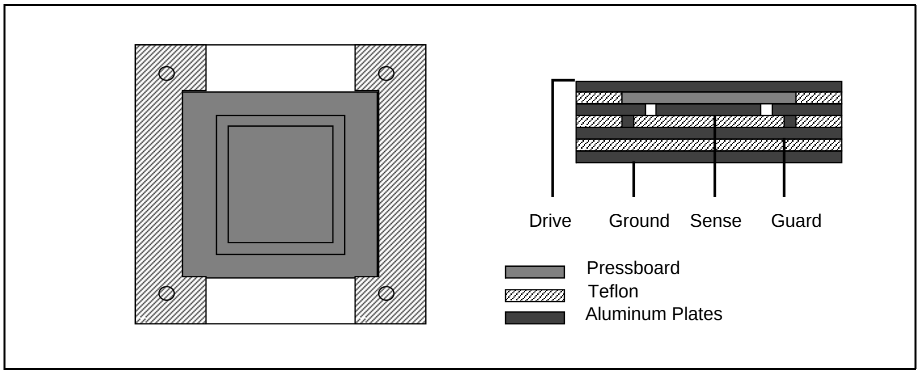

Figure 1: Structure of the parallel-plate sensor used to measure the dielectric properties of pressboard.

Let $Z_T = R_T + 1/j\omega C_T$ be the unknown test impedance and $Z_L = R_L + 1/j\omega C_L$ be the known load impedance. Then the measured potential across the load impedance can be expressed as a voltage divider relation:

$$V_{OUT} = \frac{Z_L}{Z_T + Z_L} V_{IN}$$

and from this we obtain expressions for R_T and C_T as functions of the magnitude M and the phase angle φ of the response:

$$\begin{aligned} \frac{1}{R_T} &= \frac{(M\cos\varphi - M^2)(1/R_L) - M\sin\varphi\,(C_L\omega)}{1 + M^2 - 2M\cos\varphi} \\ C_T &= \frac{M\sin\varphi\,(1/R_L\omega) + (M\cos\varphi - M^2)C_L}{1 + M^2 + 2M\cos\varphi} \end{aligned}$$

The complex permittivity data of the pressboard normalized with respect to ϵ_0 can then be expressed in terms of the measured impedances:

$$\frac{\epsilon^*}{\epsilon_0} = \frac{\epsilon'}{\epsilon_0} - j\frac{\epsilon''}{\epsilon_0} = \frac{\epsilon}{\epsilon_0} - j\frac{\sigma}{\omega\epsilon_0} = \frac{C_T}{C_{AIR}} - j\frac{1}{R_T C_{AIR}\omega}$$

where C_{AIR} is the capacitance of the test capacitor in air.

3 Experimental Results

The temperature range examined was 30°C to 70°C. The sample shown in figure 2 is relatively dry, with a moisture content of 1%. Figure 3 shows a sample of higher humidity, 3%. All data presented in this paper is taken with samples of 40 mil thick EHV-Weidmann HI-VAL pressboard. The oil used for impregnating the pressboard is Shell Diala A transformer oil.

The moisture content of the pressboard samples is measured twice, immediately before and after the frequency scans are made. A Mitsubishi VA-05 Vaporizer is used together with the Mitsubishi CA-05 Moisture Meter.

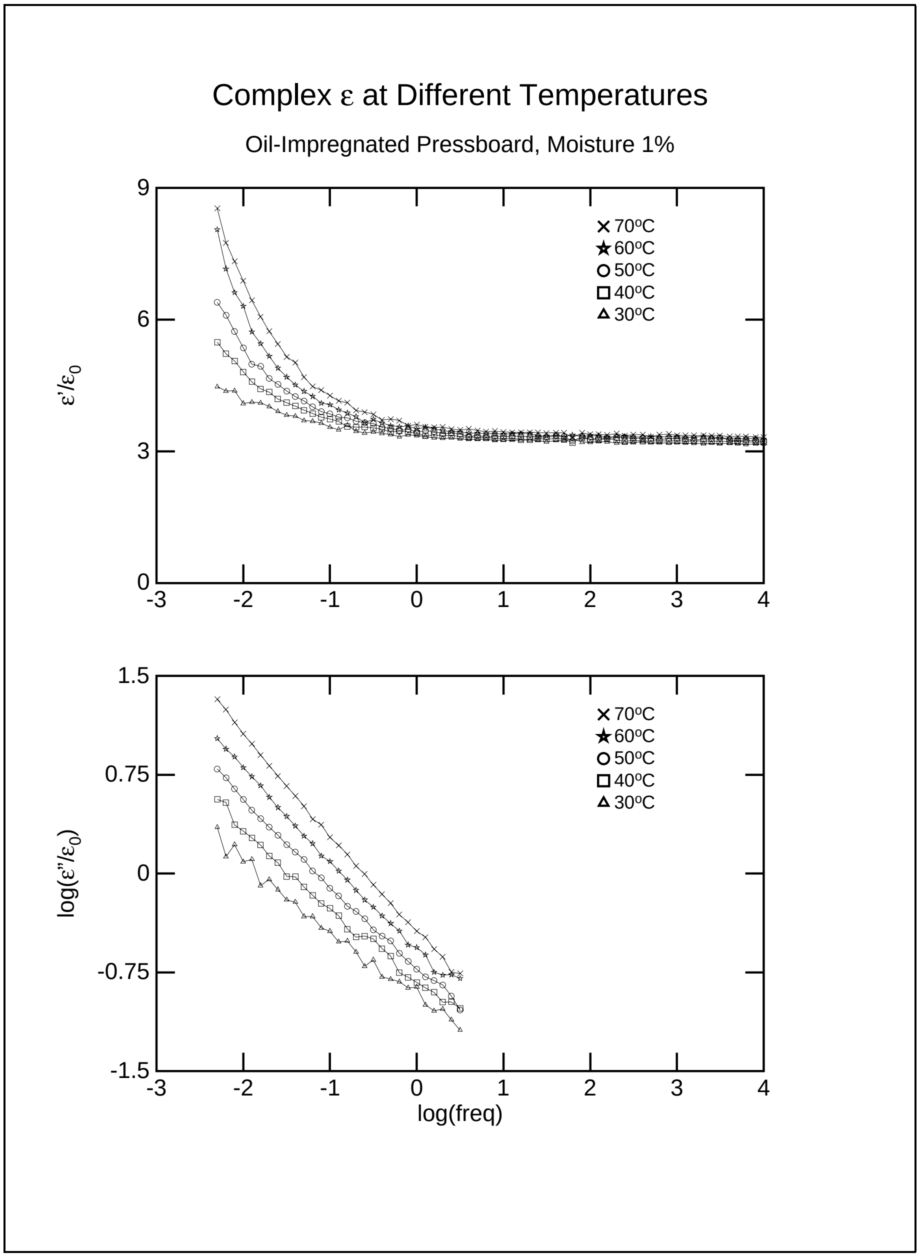

Figure 2: Family of dielectric spectra of EHV-Weidmann HI-VAL pressboard impregnated with Shell Diala A transformer oil with a moisture content of 1% at five different temperatures.

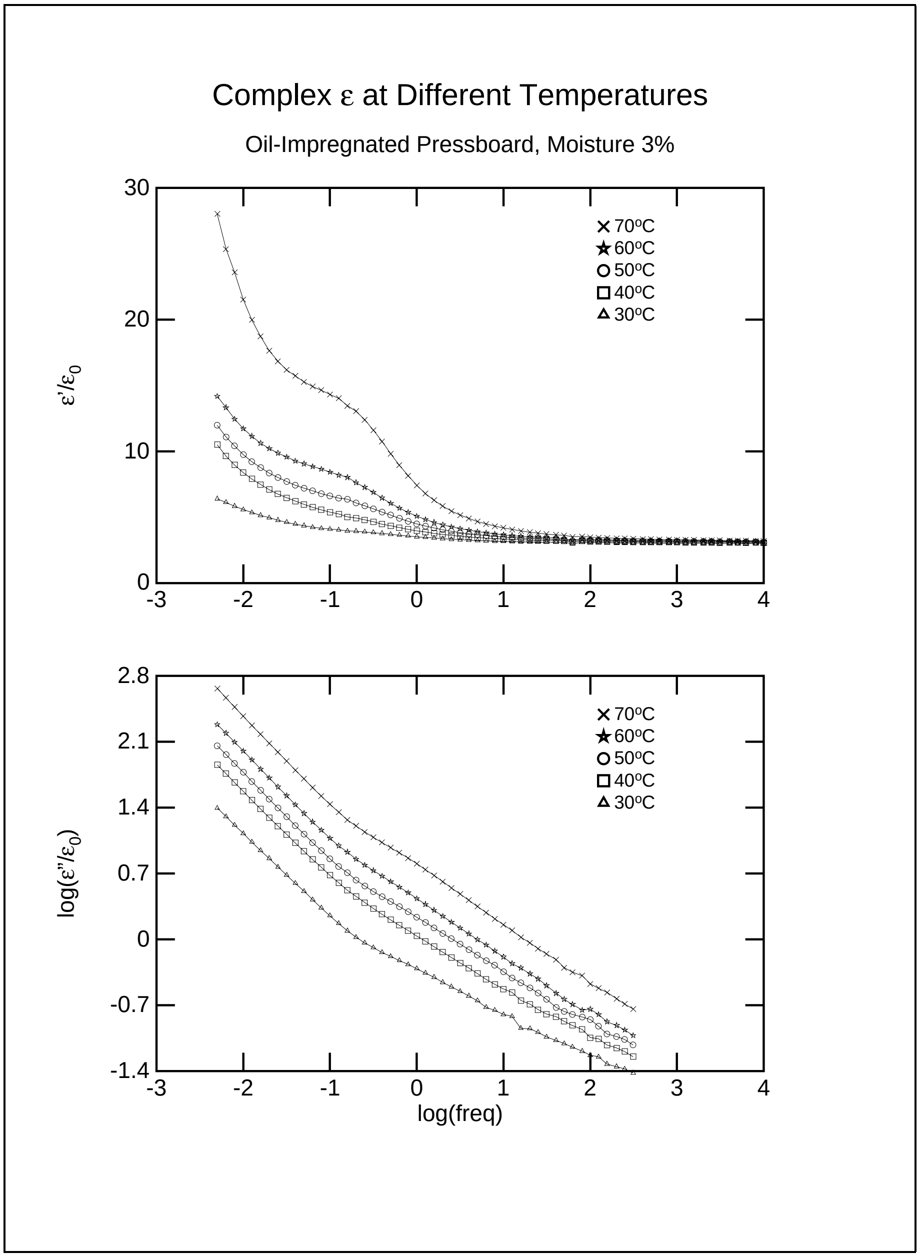

Figure 3: Family of dielectric spectra of EHV-Weidmann HI-VAL pressboard impregnated with Shell Diala A transformer oil with a moisture content of 3% at five different temperatures.

After oil-impregnation, we allow the samples to rest for a few days, to let the moisture redistribute itself across the thickness of the pressboard. This is necessary because during the impregnation process the surfaces of the sample are exposed to relatively wetter oil and may acquire a different moisture content than the bulk. The transient associated with this conditioning process has a time constant of about 30 hours.

In an ohmic material ϵ and σ are independent of the frequency or amplitude of the applied electric field and a plot of $\log(\epsilon''/\epsilon_0)$ versus ω has a slope of -1. In a dispersive material, when ϵ'' is plotted against frequency on a log-log scale, it can be characterized by one or more loss peaks. The magnitude of the slope at which these peaks are approached on either side is between 0 and 1 for most materials [3, pp. 163–200]. For every loss peak in the ϵ'' spectrum, there is an associated elevation in the ϵ' spectrum [3, pp. 47–52].

One loss peak is visible in figure 2, which is approached on the right, but its maximum occurs at frequencies below our range. The curves in figure 2 can be shifted in frequency to obtain a temperature universal spectrum, as shown in figure 4. The median temperature, 50°C, is chosen as the reference. The origins of the other plots are shifted horizontally by the amount shown in the figure to make the curves overlap. No vertical shift is needed. Both the ϵ' and the ϵ'' plots are shifted by the same amount. This indicates that the temperature dependence of dry pressboard may be represented by one curve.

The dielectric spectra of the wet sample in figure 3 cannot be shifted to create such a universal curve. This is so because at this higher humidity a qualitatively different kind of behavior is observed. Two superimposed loss peaks are visible. The lower-magnitude peak, occurring at a higher frequency is almost fully absorbed by the other peak and is difficult to see on the ϵ'' plot, where it only causes a change in the slope. However, it is clearly visible in the ϵ' plot, where the curve flattens out for a short interval. The second peak described above is not visible for the drier sample, either because it occurs at frequencies below the range of our equipment, or because a higher quantity of water in the cellulose exists in a different band state.

It is also possible to map the family of curves in figure 2 onto those in figure 3 by shifting the latter -1.5 units of logarithmic frequency. In order to create the full universal spectrum for different moisture content, more data is required.

References

[1] B. Nettelblad, *Effect of Moisture Content on the Dielectric Properties of Cellulose*, NORD-IS 92, Paper 8.9.

[2] U. Gäfvert, B. Nettelblad, *Measurement Techniques for Dielectric Response Characterization at Low Frequencies*, NORD-IS 92, Paper 7.1.

[3] A. K. Jonscher, *Dielectric Relaxation in Solids,* Chelsea Dielectrics Press, London, 1983.

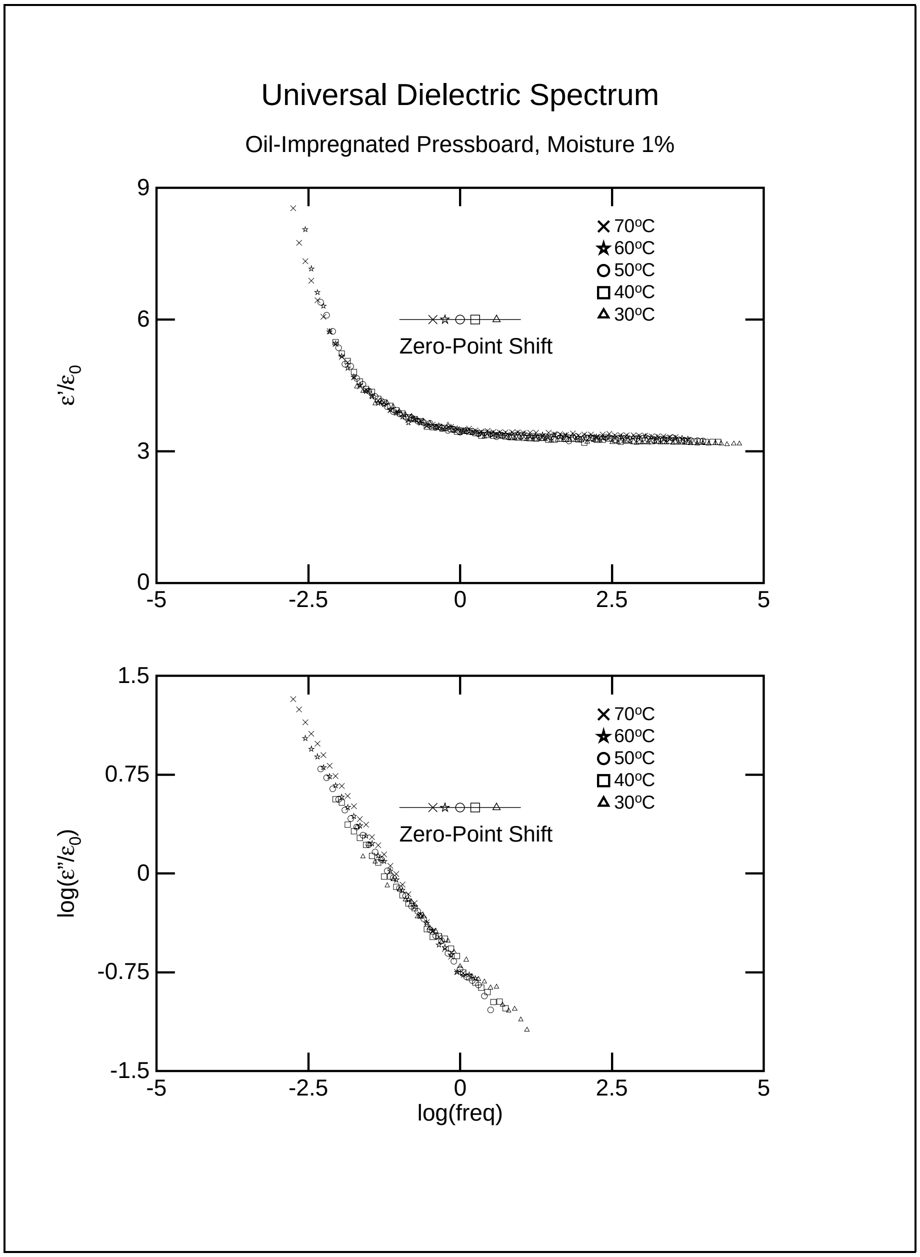

Figure 4: A universal dielectric temperature spectrum of EHV-Weidmann HI-VAL pressboard impregnated with Shell Diala A transformer oil with a moisture content of 1%.