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Dielectric Behavior and Electric Strength of Polymer Films in Varying Thermal Conditions for 50 Hz to 1 MHz Frequency Range

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Abstract: **Dielectric behavior and electric strength of polymer films are dependent on various factors. In this paper, experimental study is presented on the dielectric behavior of polymer films under high frequency voltages and thermal stresses. The ac electric breakdown strength of thin polymer films as a function of sample thickness with the sphere-plane electrode configuration was investigated at various temperatures. The electric strength of the polymer film is reduced with increasing thickness of the film and temperature. The relative permittivity of polyester under thermal stress decreases with increasing frequency, especially at high frequencies and low temperatures. At low frequencies, the loss factor of polyester is very low. At high frequencies and in high temperatures it increases rapidly.**

INTRODUCTION

The study of dielectric behavior and electric strength of polymer films under high frequency voltages and thermal stresses has become very important with the operating stress increases in electric power apparatus such as power cables and capacitors. In practice thermal and voltage stress usually are applied simultaneously. From a practical point of view, the application of data from a single stress may not be related or may include errors in reference to real conditions. Because of this fact, research on dielectric properties is concentrated now on multiple stress conditions [1-4].

In the study of insulating materials, the knowledge of the different components often gives the opportunity to predict their dielectric behavior. Electric breakdown in polymers, which is an important limiting phenomenon has been subject to numerous investigations during the years. The mechanisms for electric breakdown in solids have been extensively studied and reviewed [5-10].

The aim of this study is to observe the influence of temperature and frequency on dielectric properties of polymer films. The experimental procedure and the experimental results are described below.

EXPERIMENTAL

The material used for this study is polyester film. The films used as the samples were 0.012, 0.023, 0.036, 0.050, 0.100 and 0.200 mm thicknesses. Film thicknesses were measured with a film thickness meter with the resolution of 0.001 mm. Before measurements, the samples used were conditioned in an oven at 23 ± 2°C, 50 ± 5% relative humidity for 24 hours to remove moisture, release internal mechanical stresses and improve reproducibility of results.

In the breakdown tests, a sphere-plane electrode configuration was used. This electrode configuration has a sphere 20 mm in diameter and plane electrodes. The plane electrode was a disc of 50 mm diameter and 15 mm high with the edges rounded to a radius of 3 mm. These electrodes were arranged coaxially. During the experiments, the samples were sandwiched between the electrodes. The entire electrode setup was installed in a vessel.

For the measurements of ac electric breakdown strength of films, a 50 kV transformer was used. The test voltage was applied on the sphere electrode, while the plane electrode was grounded. All measurements were performed in air medium under the ambient pressure and humidity conditions: 100 kPa pressure, humidity of 50 to 65%. The measurements of the breakdown voltage were performed using a continuous increase in voltage at a rate of 500 V/s from 0 V until breakdown occurred. All voltage values are rms. The experiment was repeated 10 times for each film thickness, and average of ten readings was determined. The scatter in the readings was ± 5% with respect to the mean value and the readings were reproducible within that limit. The breakdown voltage was divided by the film thickness to determine the electric strength at breakdown of the film.

In tests performed in different temperatures, the Heraeus-Vötsch VM 04/100 environmental test system was used. Samples were placed in the system and the temperature was adjusted to the desired level. When that level was reached the voltage was increased until breakdown occurred. Tests were performed within the range -40 to 120°C.

In measurements of relative permittivity and loss factor within the range 50 Hz to 1 MHz as a function of film temperature, an impedance analyzer having a frequency range of 5 Hz to 13 MHz was used as a source of variable frequency. In these measurements a guard ring was employed to reduce the effects due to stray fields. Before each measurement sequence there was a preparation run which consisted of short-circuiting both surfaces of the sample and raising its temperature to desired level.

RESULTS and DISCUSSION

The experimental results and discussion have been grouped as follows.

Temperature and Thickness Dependence of Breakdown Strength

We investigated the temperature and thickness dependence of the breakdown strength of polymer films. Figure 1 shows variation of the electric strength of polyester film at nine different temperatures as a function of the film thickness.

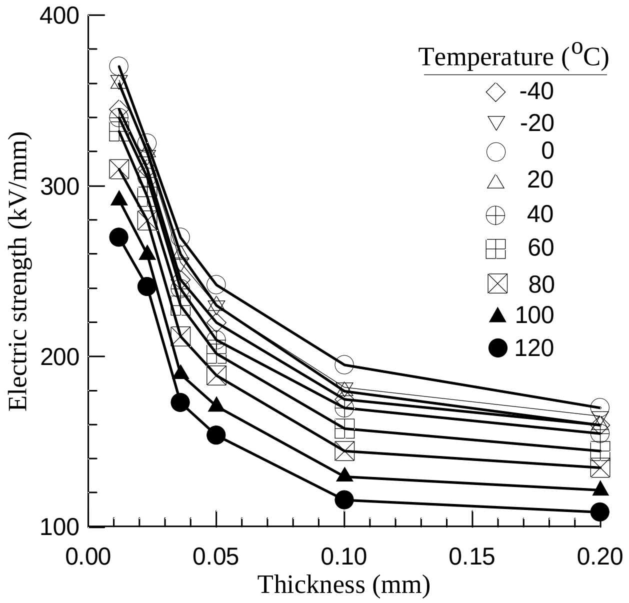

Figure 1. Variation of electric strength of polymer film with thickness in nine different temperatures.

In Figure 1, when temperature levels are -40, -20, 0, 20, 40, 60, 80, 100 and 120^{o}C, film thickness was varied from 0.012 to 0.200 mm.. As it indicates, the electric strength decreases with the increasing thickness. At different temperatures electric strength - thickness characteristics follows a similar variation. When films are particularly thin, the breakdown strength can be strongly affected by film thickness. it is clearly seen that the film thickness has noticeable effect on the electric strength of thin polymer films. The percentage decrease in the electric strength is found to be approximately 52% for the sphere-plane electrodes as thickness is increased from 0.012 mm to 0.200 mm.

The electric strength greatly decreases with the increasing temperature (Fig.1). The dielectric breakdown mechanisms of polyester films are considered to be an electronic breakdown process below room temperature and thermal breakdown above room temperature. In low temperatures the electric strength scarcely varies with temperature. On the contrary, in high temperatures the electric strength rapidly decreases with increasing temperature.

Frequency and Temperature Dependence of Permittivity and Loss Factor

In order to examine frequency dependence of loss factor and permittivity of polymer films under thermal stress measurements were made in the temperature region from -20 to 80^{o}C. The measurements were performed in the frequency range of 50 Hz - 1 MHz. In tests, polyester films having 0.036 mm thickness were used. The experimental results are given Figures 2 and 3. The relative permittivity of polyester decreases with increasing frequency (Figure 2).

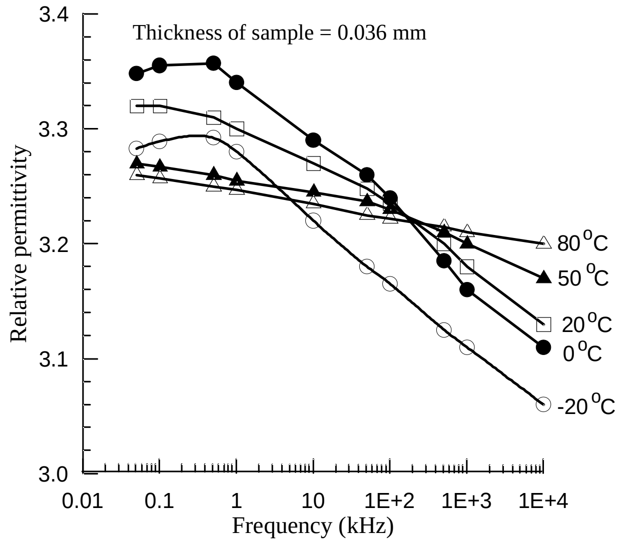

Figure 2. Variation of the relative permittivity of polyester film with frequency in five different temperatures.

The relative permittivity of polyester increases with increasing temperature. Increasing the frequency causes a shift of the permittivity and loss factor curves. At power frequencies, loss factor of polyester is very low, and it increases as the temperature increases. At high temperature, the conduction loss component due to mobile carriers becomes significant, and show a large frequency dependence.

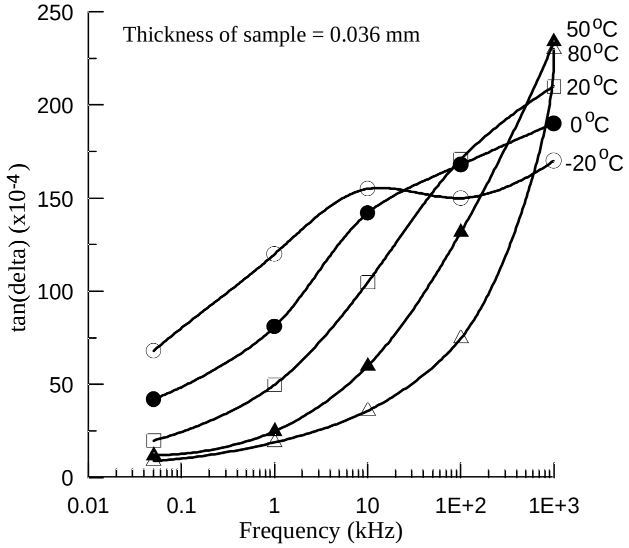

Figure 3. Variation of loss factor of polymer film with frequency in five different temperatures.

CONCLUSION

We investigated the effects of thickness, temperature and frequency on the dielectric behavior and the electric strength of thin polymer films. The experimental results clearly show the effect which thickness has on the value of the breakdown voltage and the electric strength. Generally speaking, the electric strength reduced with increasing thickness of the sample due to so-called volume effect. In other words, the electric strength of the polymer increases rapidly as the sample thickness is reduced. The relative permittivity of polyester under thermal stress decreases with increasing frequency, especially at high frequencies and low temperatures. At low frequencies, the loss factor of polyester is very low. At high frequencies and in high temperatures it increase rapidly.

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