PROBABILITY DISTRIBUTION OF THE BREAKDOWN ELECTRIC FIELDS OF POLYMER DIELECTRICS

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The probability distribution is derived for the breakdown electric field of polymers, treated as inhomogeneous dielectrics. The extremal distribution and the Weibull distribution are shown to be particular cases of the result found. The experimental results found with low-pressure polyethylene and polyethylene, Styroflex, and polyethylene terephthalate films are consistent with the theoretical probability distribution found for the breakdown electric field.

Any real dielectric actually contains structural discontinuities, vacancies, dislocations, radicals, etc. [1]. Local fields arise near these defects, locally reducing the breakdown field.

An evaluation of the breakdown field intensity of a dielectric must of course take the defect distribution into account. We will use several assumptions in deriving the probability distribution for the breakdown electric field:

1. The dielectric breaks down when a field intensity \( E_M \) equal to the dielectric strength of the dielectric is established in any part of the dielectric.
2. The defect distribution in the dielectric is described by random-mixture laws.
3. The defects in the dielectric are spherical and uniform in size.

Using these assumptions, we can show (Appendix 1) that the breakdown field is governed by the probability distribution of defects in the dielectric in the electric-field direction; the corresponding probability distribution function is

\[
Q(y) = e^{-\frac{dS}{\rho S}} e^{-\frac{dS}{\rho S}} y^{\frac{dS}{\rho S}}
\]

(1)

where \( Q(y) \) is the distribution function of the largest member of the sample; \( d \) is the thickness of the dielectric; \( S \) is the electrode area; \( v_0 \) is the elementary volume of the dielectric; and \( p \) is the defect concentration.

Replacing the spherical homogeneities arranged side by side by an ellipsoid of revolution, and solving Eq. (1) for \( y \), where

\[
y = \frac{0.482}{\ln \left( \frac{1 - \frac{1}{E}}{1 - \frac{E}{E_M}} \right)}
\]

(2)

we can show (Appendix 2) that the probability that breakdown does not occur at a given average field intensity \( E \) is
The extremal distribution [2] and the Weibull distribution [3] are particular cases of Eq. (3). Setting

\[ \varphi(E) = 0.82 \ln \ln \frac{1 - \frac{1}{\nu}}{1 - \frac{E}{E_M}} - \frac{0.482 \ln \frac{0.65}{P^{0.3}}} {\left( \ln \frac{1 - \frac{1}{\nu}}{1 - \frac{E}{E_M}} \right)^{0.52}}, \]

we have

\[ P(E) = \exp \left[ - \frac{dS}{0.482 \nu_0} \exp \varphi(E) \right]. \]

Expanding \( \varphi(E) \) in a Taylor series in powers of \( E \) or in powers of \( \ln E \), and taking into account only the first two terms in the series, we find

\[ P(E) = \exp \left[ - \exp \left( \beta + E \right) \right], \]

\[ P(E) = \exp \left( - K E^B \right), \]

where

\[ \alpha = \varphi'(E_i) = \frac{1}{E_M - E_i} \left[ \frac{0.82}{\ln \frac{1 - \frac{1}{\nu}}{1 - \frac{E}{E_M}}} + \frac{0.395 \ln \frac{0.65}{P^{0.3}}} {\left( \ln \frac{1 - \frac{1}{\nu}}{1 - \frac{E}{E_M}} \right)^{0.52}} \right], \]

\[ \beta = \frac{\varphi(E_i)}{\varphi'(E_i)} - 1, \]

\[ B = \frac{dS}{0.482 \nu_0} \exp \left\{ \varphi(E_i) - (\ln E_i) \frac{d \varphi(E)}{d (\ln E)} \right\} \bigg|_{E = E_i}, \quad K = \frac{d \varphi(E)}{d (\ln E)} \bigg|_{E = E_i}. \]

This analysis has thus shown that Eq. (3) is a more general probability distribution.

We studied the dc breakdown field of low-pressure (P = 40) polyethylene and films of polyethylene, Styroflex, and polyethylene terephthalate. The experimental results were analyzed on the basis of Eqs. (3), (6), and (7) and plotted on probability paper (Figs. 1-4) [4].

The distributions of breakdown fields for these polymers shown in Figs. 1 and 2 were found from Eq. (3) with \( \nu = \infty \) and \( E_M = (1.1-1.2)E_{br max} \).

We see from Figs. 1 and 2 that the distributions conform well to straight lines; when plotted on full exponential paper (Fig. 3), the results also conform to straight lines. When plotted on Weibull-law probability paper (Fig. 4), on the other hand, the breakdown-field distributions are significantly nonlinear at low \( E \), except for the case of low-pressure polyethylene.

The agreement between the experimental results and the various types of distributions was determined on the basis of the Pearson criterion [5].

Tables 1 and 2 show the results of the agreement checks, along with the parameters of the distribution laws determined from Figs. 1-4 on the basis of Eqs. (3), (6), and (7).