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I. Introduction

Handbook values for materials' dielectric breakdown strength of necessity come from accelerated test methods. DC Voltage ramp rates for dielectric strength tests values are recommended to as high as 500 V/s [1]. When designing applications of dielectric materials, one can either assume the large differences frequently observed between test and application conditions are of negligible consequence or rely on extrapolation using standard empirical models [2]. However useful empirical models may be, physical models allow for greater conceptual understanding of the problem at hand. Empirical models are also less amenable to extensions to unknown materials.

In previous studies, we have proposed models of the ramp rate dependence of breakdown together with some preliminary data and practical considerations [3, 4]. The current study compares two standard empirical models and two proposed physical models to series of DC breakdown tests in four polymeric insulators—namely, Kapton E and Kapton HN (polyimide, PI), biaxially oriented polypropylene (BOPP), and low-density polyethylene (LDPE).

II. Empirical Models

The simplest assumption is that a material's breakdown electric field strength, F_{BD}, does not vary significantly with voltage ramp rate [2]. If valid; it follows that the results of (reasonably) accelerated tests will be appropriate for any application. Explicitly this is

$$F_{BD} = F_{BD_0} \qquad (1)$$

The standard three parameter model for the ramp rate dependence of breakdown is [2]:

$$F_{BD} \approx \left(\frac{\partial F}{\partial T}\right)^{a/a+b} \text{ or } \; F_{BD} = c\left(\frac{\partial F}{\partial T}\right)^{a/a+b} \qquad (2)$$

In some cases b may be at least an order of magnitude larger than a, which is often close to unity; this essentially reduces (2) to (1).

III. Physics Models

Dielectric breakdown is driven by the spatial and energetic distribution of defects in a material. The simplest mean field theory assumes only a single average defect energy and defect density, [5]. Assuming that the probability of breakdown, P_{BD}, scales linearly with ramp rate and defining r_0 to be 1 (thereby defining ramp rate units) one can arrive at the following simplified model [4]:

$$F_{BD}(r) \approx F_{BD}(r_0)\sqrt{1.1346\ln\left(r+\sqrt{1+r^2}\right)} \qquad (3)$$

Relaxing the former assumption requires numerical solutions of the following [3]:

$$P_{BD} = 1 - \prod_{j=1}^{V/\Delta V}\left[1 - \alpha\Delta t \sinh\left[\beta(j\Delta V)^2\right]\right] \qquad (4)$$

Where ΔV and Δt are the voltage and time step increments.

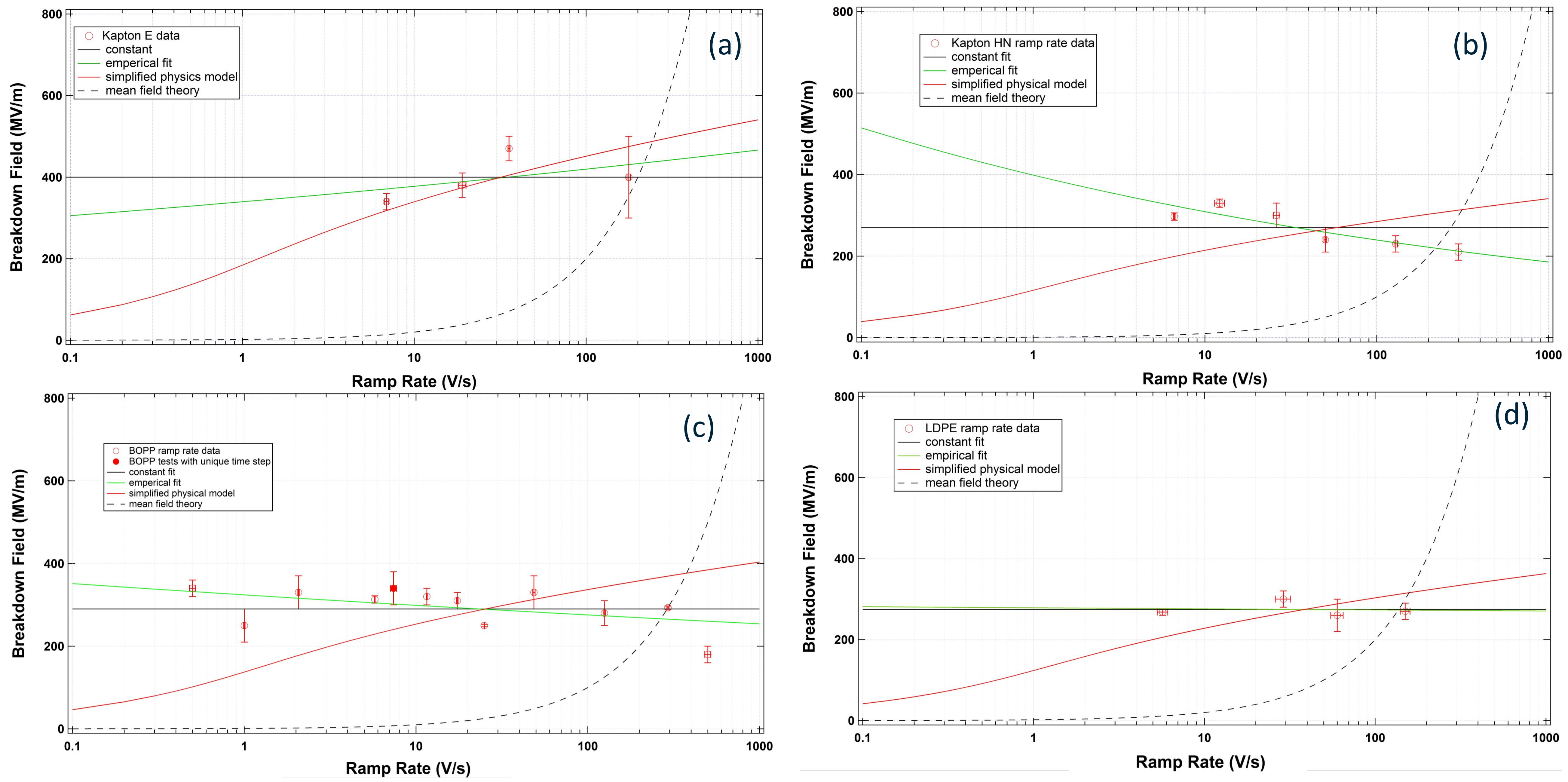

Figure 1 – Average dielectric breakdown field versus voltage ramp rate, together with empirical and physical theoretical fits (1) through (4). Error bars correspond to the standard deviation of the means of repeated measurements. (a) 22 voltage step-to-breakdown tests on Kapton E at four ramp rates. (b) 90 tests on Kapton HN at six ramp rates. (c) 139 tests on BOPP at twelve ramp rates. (d) 126 tests on LDPE at four ramp rates, with most of these data at 5.7 V/s.

IV. Conclusions

Given the success of the simplified physical model (3) with preliminary tests in Kapton E, it was surprising that data of Kapton HN, BOPP, or LDPE did not agree with (3).

The failure of the (3) and (4) likely shows that the assumptions made in their formation are not valid for these tests. In previous work with static voltage endurance time to breakdown tests, theory derived from these same assumptions matched data quite well [3]. The results of the current study for three of the four materials tested favor the model that breakdown is constant with respect to voltage ramp rate.

More testing, especially at slower ramp rates (the most time consuming tests), would be helpful in testing the voltage ramp rate dependence of breakdown. Tests of similar ramp rates using different voltage steps and corresponding time increments would investigate the dependence of ΔV and Δt in the physics based models. Also, better physical models, perhaps considering a dynamic defect density of states, are needed to describe the behavior observed.

References

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