PRESSURE EFFECTS ON PARTIAL DISCHARGES IN HEXANE UNDER DC VOLTAGE *

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ABSTRACT

The pressure dependence of partial discharges (PD) has been experimentally investigated at a needle electrode in hexane from subatmospheric pressure (near hexane vapor pressure) to several atmospheres. Each PD produces a phase transition in the liquid near the needle which is photographed in synchronism with a characteristic pattern of current pulses. An image preserving optical delay allows photography to commence just before or at inception of the discharge. Individual current pulses comprising a characteristic pattern are resolved. The *cathode event* consists of a short pressure-insensitive inception phase, a pressure-sensitive growth at a decreasing rate, and finally a detachment and dissipation, sometimes with noticeable contraction before detachment; increased pressure reduces the growth rate and lifetime. The accompanying characteristic current pulse pattern always ceases during the growth of the PD. For the *anode event*, less extensive data similarly show slowing of growth with increased pressure and a (different) characteristic current pulse pattern.

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INTRODUCTION

Prebreakdown events in liquids have been the object of many studies because of their importance in understanding breakdown or aging characteristics, or because of their potential as a diagnostic tool. The first apparent prebreakdown event consists of an optical disturbance in the liquid accompanied by an electric current. This event has been given names such as "streamer", "low density region", or "partial discharge" (PD). The last term is used throughout this report. Optical studies generally have been confined to pulsed overvoltages in order to force prebreakdown activity at a *known and predicted* initiation time, relative to which a camera can be triggered. In this study, dc voltage is used to produce spontaneous activity, and yet the photographs and synchronized current records are begun at, or just before, the spontaneous initiation of the prebreakdown event.

This experimental study extends one by Kelley, et al. [1,2] at constant pressure. Fast, high resolution photography developed earlier [3,4] was employed to record PD growth, while low-noise, high bandwidth electronics developed by Blalock et al.[5] resolved individual current pulses in a characteristic pattern [6,7]. Before 1986 that pulse pattern had been detected as a single smooth or "stair-step" pulse , apparently due to inadequate bandwidth and noise reduction [8].

The history of study of pressure effects on prebreakdown and breakdown was given by Pace, et al. [9], who found a marked effect of pressure from 0.027 MPa (the hexane vapor pressure) to 0.30 MPa, viz. that the current pulses lasted much longer at the lower pressures. It was hence again desirable to correlate the PD growth *photographs* with current pulses as reported earlier by Kelley, et. al., [1,2], but with pressure controlled over the range from hexane vapor pressure to several atmospheres; this paper reports those results, with absolute pressures given in SI units.

EXPERIMENTAL APPARATUS

The major components of the experimental system, shown in Figure 1, are essentially the same as described in detail earlier [1,2], except that hydrostatic pressure on the liquid in the test cell was controllable, and previously it was left at one atmosphere. The major features of the system are summarized below.

To prepare the brass test cell, 99% pure hexane is introduced as received from the supplier, with visible particulate contamination. A grounded steel needle with nominal tip radius of 3 μm is made the cathode or anode by applying high voltage (approximately 14 kV) of the opposite polarity to a stainless steel 2.5-cm radius counter-electrode. The gap is approximately 4 mm.

The photographs are taken by passing the beam from a cw, adjustable intensity, 5-W argon laser through the cell, past the needle tip and into a high magnification imaging system consisting of a relay lens and magnification lens.

The magnified image traverses an image-preserving optical delay (developed earlier by Kelley and described in [10]), a Pockels cell with manual shutters to protect the image converter camera, and finally the photosensitive surface of that camera. The magnification, from the PD being photographed to its image on film, was ×49.3, including a ×2 factor in the camera.

The current pulses associated with a prebreakdown event are detected using a low-noise high-bandwidth voltage-sensitive preamplifier, amplified and then both (1) recorded on a digital storage oscilloscope and (2) used to trigger the synchronization system, thus marking the inception time. The current signal passes through the preamplifier and the oscilloscope buffer before reaching the oscilloscope (Fig. 1). This preamplifier is a slightly modified version of that described in [5] and has a 33-Ω input impedance, a 57-MHz bandwidth, and a voltage gain of 152. The oscilloscope buffer amplifier has a 1-kΩ input impedance, a 150-MHz bandwidth and a voltage gain of -2. All of the amplifiers used have 50-Ω output impedances. This system provides an overall bandwidth of approximately 45 MHz, a current-to-voltage gain of 3992 V/A and a 1.6-μA minimum detectable input current for a signal-to-noise ratio of five.

The pressure on the liquid was varied from the vapor pressure of hexane to 0.31 MPa. The pressure was reduced below one atmosphere by pumping with a mechanical pump on the closed test cell through a simple liquid trap. Pressure was increased by a simple piston connected to the closed liquid volume. During pressure changes and data acquisition the cell pressure was monitored at a separate port. No attempt was made to remove air from the hexane.

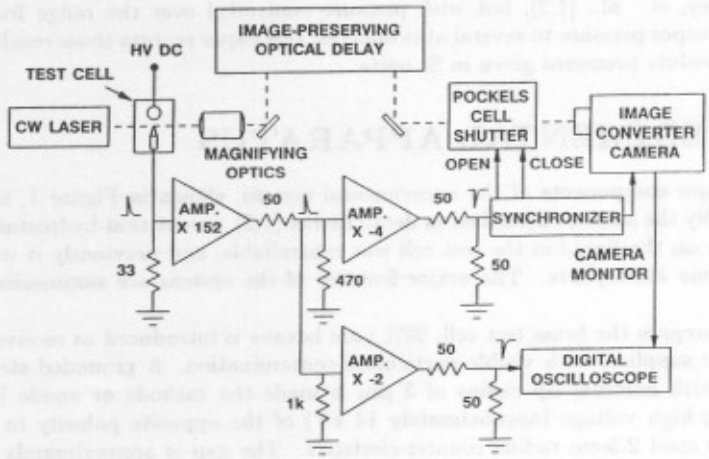

Figure 1. Diagram of experimental apparatus.

RESULTS

With the needle a *cathode*, simultaneous observations were made of the shadow of a developing PD (eight or ten frames per PD) together with the associated current pulses. The five pressures ranged from 0.027 MPa (the vapor pressure of hexane) to 0.31 MPa. With the needle an *anode*, initiation was less frequent and the film was often overexposed by light leaking through the camera. Because of this short-coming, needle anode observations were obtained only at two pressures: 0.027 and 0.10 MPa. The resulting photographs resembled those given earlier [2].

The general characteristic pattern of current pulses in a single cathode event was described previously [1,2,6,7]. The earlier study of the effect of pressure on cathode current pulses (without PD photographs) [9] showed that increased pressure decreased their durations. Figure 2 shows the durations of the current pulse pattern accompanying a cathode PD at five pressures; each point is the average of three or four observations and a vertical bar at each plotted point represents one standard deviation above and below the point. The ratio of charge in each pulse to its time after PD inception was approximately 1.9 μA, with the scatter about that value increasing with decreasing pressure. These data agree reasonably well with the measured and calculated values in the previous study of pressure effects [9]; in both, the salient characteristic is that increased pressure causes the current pulses to cease earlier.

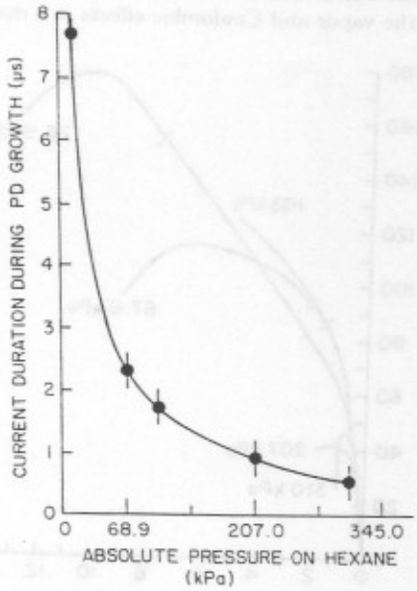

Figure 2. Duration of each current pulse pattern vs. pressure.

The photographs obtained resembled those given earlier, except that the growth varied here with pressure. The approximate length of a typical *cathode* event is given vs. time for five pressures in Figure 3. Each curve ends when the PD detaches from the cathode. Smooth growth is assumed between data points in accord with earlier streak photographs [1,2]. The current pulses accompanying each cathode event ceased *before* the growth stopped.

The observations of this study agree with those of the earlier one [1,2] *at one atmosphere* for both the cathode and anode events and accompanying current pulses, and in [2] it was suggested that the prebreakdown event was initiated by joule heating and vaporization. In transformer oil similar inhibiting effects of pressure below one atmosphere had been observed earlier [11]. The observation here that the *initial* growth is insensitive to pressure further corroborates that hypothesis. The results here also agree, as to the pressure dependence of current duration *over the same pressure range*, with the earlier study [9] of cathode current pulses without photography. That study found experimental agreement with a model that calculated growth (as a result of Coulomb expansion) and current pulses (as a result of breakdown within the PD as its potential changed with its size). The photographic observation here that the initiation is pressure sensitive in the later stage suggests that it is driven by internal pressure of some source, e.g. hot vapor or Coulomb force. The decrease in the time and spatial scales at higher pressures agrees with the scaling found in an earlier theoretical study [12] in which the growth of an ellipsoidal cavity is attributed to the internal pressure of a hot vapor. The relative importance of the vapor and Coulombic effects is a matter not resolved by these results.

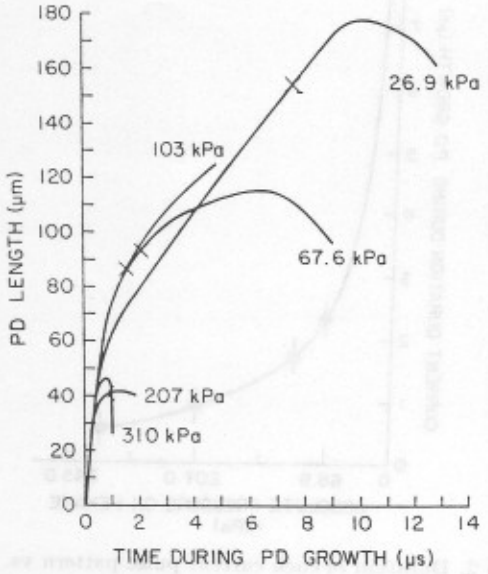

Figure 3. Length of typical cathode PD vs. time for various pressures.

Details of the modeling will accompany the report of these experimental results in a future publication. Much work remains to be done in order to understand the prebreakdown, low-density region in stressed liquid dielectrics, particularly, during the earliest inception stage. Such a fundamental understanding would be an important step in improving the breakdown and aging characteristics of liquid dielectrics.

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