STREAMER INITIATION IN LIQUID HYDROCARBONS

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INTRODUCTION

Electrical breakdown in liquid hydrocarbons is preceeded by the development of streamers [1-3]. Their growth can be studied using optical techniques [4-6]. In earlier studies, the primary interest was in streamer propagation rather than streamer initiation. A factor contributing to this emphasis was the use of low magnification (about 0.5x to 5x) to record events in the entire interelectrode gap. To study initiation, the present authors earlier [7] acquired data using a magnification of about 30x. That work suggested that even higher magnification was necessary. Here, results are given using 93x magnification and a framing rate of 2×10^7 frames/s under divergent and convergent electric fields. At this level of magnification, it is possible to resolve distances of the order of 10 μm and, thus, some aspects of the growth of both negative and positive streamers.

EXPERIMENTAL CONDITIONS

The equipment used in this investigation [2,3] consisted of a high voltage pulser and a test cell with a needle-plane electrode system through which filtered fluid was circulated. The modification introduced for this investigation was the use of 93x magnification when photographing prebreakdown events. At this magnification, only the immediate vicinity of the needle point was visible. The liquids studied were purified toluene and isooctane [2] and a technical grade of white oil, Marcol 70 [8], from Exxon Company USA. This paraffinic oil has been used in other published breakdown studies [4,7].

RESULTS

Typical negative streamers are shown in Fig. 1(a). From photographs of this type, one can measure the approximate streamer growth rate. The data provide approximate information because the photograph is a two-dimensional projection of the three-dimensional motion. The average measured values for the growth rates are given in Table 1.

Table 1: Rates of Initial Growth

Fluid	Growth Rate (cm/s)
Isooctane	$(2.6 \pm 0.4) \times 10^4$
Toluene	$(2.5 \pm 0.6) \times 10^4$
Marcol 70	$(2.0 \pm 0.2) \times 10^4$

The uncertainties included in Table 1 represent only the variations in the measured data and not the accuracy of the measurement. In each fluid, the initial growth was a thin pencil-like structure which subsequently branched into a tree-like structure. The resulting shape has been recorded in earlier photographs [9].

Positive and negative streamers generally have different shapes. Comparing the photographs in Fig. 1(a) and 1(b), shows that the positive streamer develops into a large filamentary structure whereas, at comparable times, the negative streamer is smaller and bushier. The toluene photograph in Fig. 1(b) presents rare, but possibly interesting, phenomena. In frame 2, a dark spot appears to develop to the upper left of the anode. This spot grows until the contact with the electrode can be resolved in frame 5. This photograph is of interest in that it could be evidence that the positive streamer initiates in the fluid and propagates to the point electrode before crossing the gap. It should be emphasized, however, that only a few of the few hundred photographs taken suggested that the streamer initiated in the fluid. In the remainder, the initiation could not be resolved.

In Fig. 2(a), one photograph shows a streamer which stopped growing and the other, taken under similar conditions, shows a streamer growing normally. In Fig. 2(b), streamers which stop growing disappear in less than 0.5 μs.

DISCUSSION AND CONCLUSIONS

Above some level of applied voltage, a streamer develops [3]. This localized development suggests that, at particular sites on the cathode surface, favorable conditions for electron emission exist [10,11]. The pencil-like structures in Fig. 1(a) are postulated to be lower density regions [11] in which the electrons would have a longer free path than in the bulk fluid. The dynamic models required to characterize the streamer growth have not been developed, but insight into the possible processes has been gained using static approximations [12]. If it is assumed that the streamer is a conductor with a radius of about 5 μm, the electric field at the tip can be calculated [10]. For an applied voltage of 50 kV, the field could be as high as 15 MV/cm, although shielding by adjacent structures and/or space charge would reduce the field strength. At this value, field ionization is probably negligible [14] but electron-induced dissociation and ionization require a smaller electric field and may contribute to the streamer growth.

A different picture prevails for positive streamers. If it is assumed that the positive streamers are also initiated by electrons [11], they would be extracted from the liquid and collected by the point anode. This assumption is strengthened by the photograph in Fig. 1(b) which appears to show streamer initiation in the bulk fluid. The problem remains, however, as to why such events occur only rarely. Again dynamic models would be necessary to predict the probability of a particular macroscopic observation from atomic-level processes. It is obvious, however, that for a streamer to be resolved, it must initiate sufficiently far from the electrode and it must propagate sufficiently slowly that photography is possible. Toluene has a larger electron affinity than either isooctane or Marcol 70, and a larger electron affinity may increase the possibility of the initiation event occurring farther from the electrode.

The photographs in Fig. 2 underscore the complexity of the streamer initiation process. Under nominally identical conditions, a streamer may grow then disappear, may grow to bridge the gap, or may grow to a

certain length then persist. It is plausible to assume that the streamers stopped in Fig 2(b) because of a reduced electric field strength due to shielding from nearby streamers and/or a limited electron supply. This assumption does not, however, explain the persistence of the stopped streamer in Fig. 2(a) and the disappearance of the stopped streamers in Fig. 2(b).

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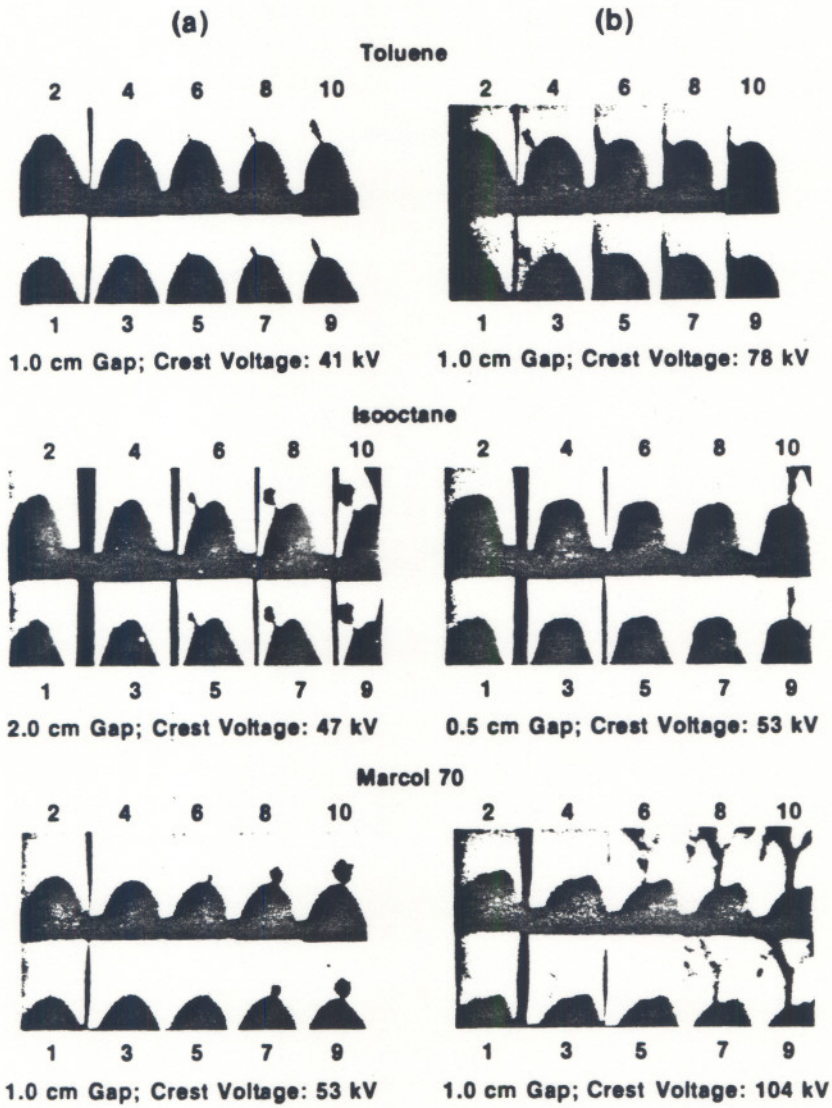

Fig. 1 Photographs of streamer initiation in toluene, isooctane, and Marcol 70. The photographs in column (a) were taken with the point electrode having a negative potential with respect to the plane electrode. Those in column (b) were taken with the opposite polarity. The numbers at the edges of the photographs indicate the framing sequence.

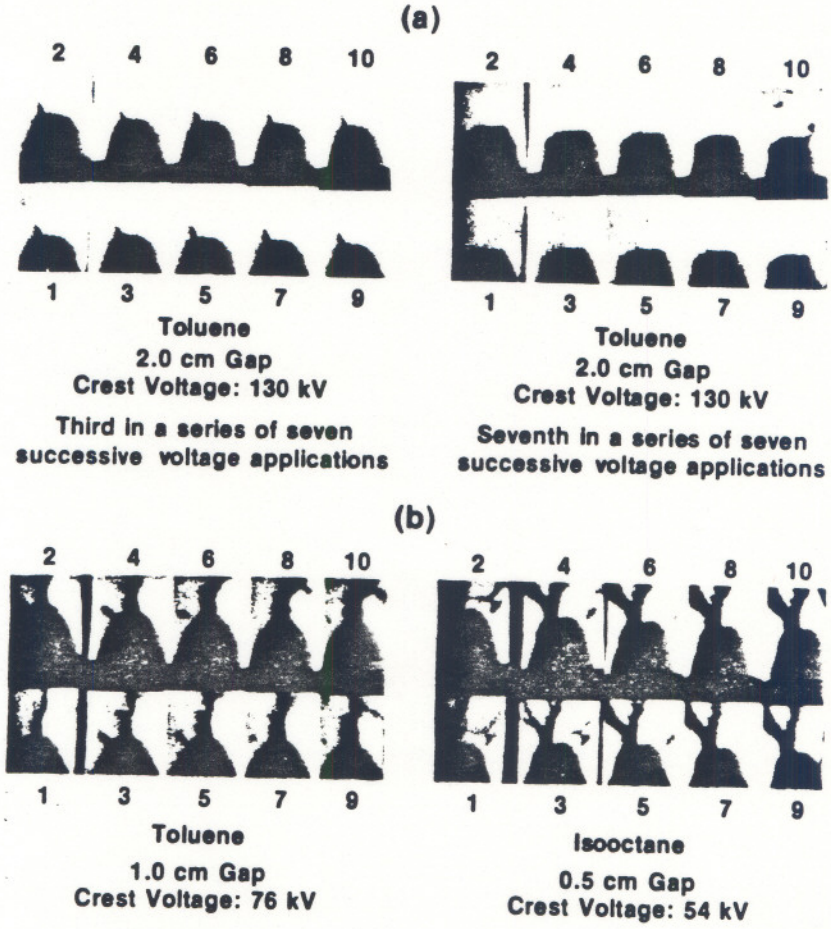

Fig. 2 Streamer behavior under positive polarity. The photographs in (a) show that under the same conditions a streamer can either grow rapidly or can persist at approximately the same size. Those in (b) show that streamer branches which stop growing can rapidly disappear. The numbers at the edges of the photographs indicate the framing sequence.