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# Mechanism of Negative Corona Pulses in CO<sub>2</sub> - SF<sub>6</sub> Mixtures

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## Abstract

Current waveforms of first negative corona pulses have been measured in CO<sub>2</sub>-SF<sub>6</sub> mixtures over a pressure range extending from 6.65 kPa to 50 kPa and various overvoltages. Effects of changing cathode secondary electron emission were studied using a copper cathode coated by CuI and graphite. The results indicate a positive-streamer discharge mechanism and important role of field emission processes at pressure above 30 kPa.

## 1. Introduction

Mixtures of SF<sub>6</sub> with other less expensive gases such as air, N<sub>2</sub> and CO<sub>2</sub> are extensively investigated as a cheaper and environmentally attractive option to pure SF<sub>6</sub>. Also, comparing to pure SF<sub>6</sub>, there are indications of the superior dielectric characteristics of these mixtures in non-uniform field conditions and in the case of projection-initiated breakdown. Since in these conditions the breakdown criteria often can be interpreted as the negative corona-onset voltage [1,2,3], it is apparent that a better understanding of the negative corona mechanism in SF<sub>6</sub> and the SF<sub>6</sub> containing mixtures can help to optimize their insulation performance.

In a recent series of papers [4,5] it has been concluded that in air-SF<sub>6</sub> and N<sub>2</sub>-SF<sub>6</sub> mixtures containing less than approximately 10 % of SF<sub>6</sub> the negative corona pulse is associated with the formation of a cathode-directed streamer-like ionizing wave in the immediate vicinity of the cathode [6]. However, in the mixtures containing more than 10 % of SF<sub>6</sub> the ionizing wave was quenched and, consequently, the discharge was governed by the Townsend ionization mechanism fed by cathode  $\gamma_p$ -emission processes. This work is now being extended to study the negative corona pulse mechanism in CO<sub>2</sub>-SF<sub>6</sub> mixtures.

## 2. Experimental results and discussion

The point-to-plane electrode system consisted of a hyperbolically capped Cu-cathode with a value of tip curvature radius of 0.1 mm situated 12 mm from a planar stainless steel anode. The experimental set-up and procedure were similar to those given in Refs. [4,5]. To clarify the role of  $\gamma_p$ -emission processes, copper iodide and graphite, which have exceptionally high and exceptionally low photoelectric yields, respectively, were used as alternative cathode surface materials to copper [4,5,7,8].

Figure 1 shows the first corona current pulses measured in CO<sub>2</sub>-SF<sub>6</sub> at a pressure of 6.65 kPa for the SF<sub>6</sub> percentage varied from 0% to 30%. From Fig.1 it is apparent that increasing the SF<sub>6</sub> content a more significant reduction in the step height on the pulse leading edge than in the pulse maximum was observed, which is in contrast to the observed discharge behaviour in SF<sub>6</sub> with N<sub>2</sub> and air mixtures [4,5].

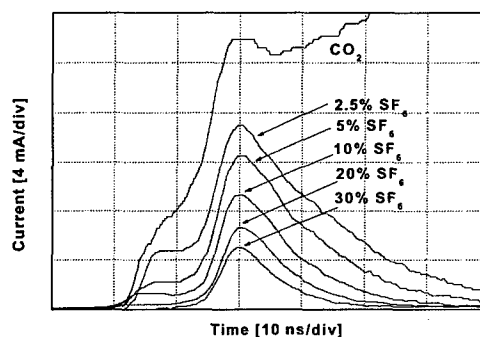


Fig. 1: Current pulse waveforms taken for various SF<sub>6</sub> admixtures at a gap voltage value of 3 kV and a pressure of 6.65 kPa.

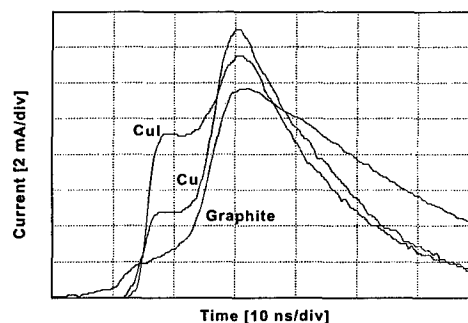


Fig. 2: First negative corona pulses measured using the Cu-cathode, the CuI-cathode and the graphite-coated cathode for CO<sub>2</sub> at a pressure of 6.7 kPa with 2.5% SF<sub>6</sub> at gap voltage value of 3 kV.

Figure 2 compares the first corona pulses measured at a pressure of 6.7 kPa using the copper cathode, CuI-coated cathode, and graphite-coated cathode for 2.5% of SF<sub>6</sub>. The observed sensitivity of the step height and relative insensitivity of the pulse maximum to the changing the cathode  $\gamma_p$ -emission, which are identical with the discharge behaviour observed in SF<sub>6</sub>-air and SF<sub>6</sub>-N<sub>2</sub> mixtures [4,5], are also in a good agreement with the above mentioned streamer-based hypothesis for the discharge mechanism [6].

The first corona current pulses measured in CO<sub>2</sub>-SF<sub>6</sub> at a pressure of 50 kPa for SF<sub>6</sub> content varied from 0% to 30% are shown in Figs. 3(a)-(b).

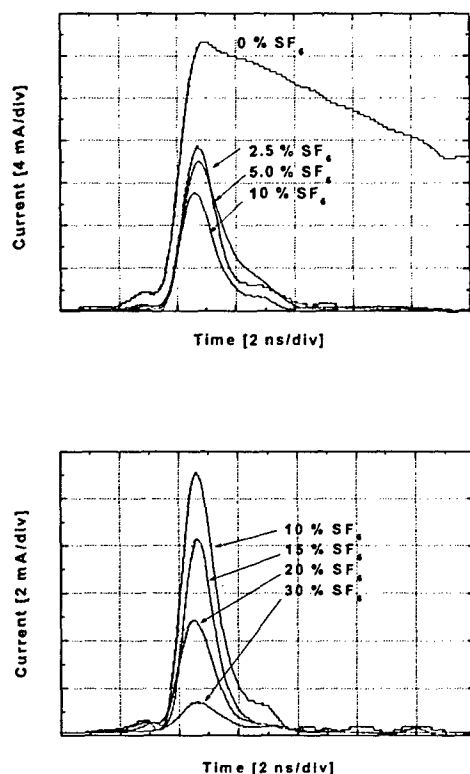


Fig. 3: Current pulse waveforms taken at a gap voltage value of 5 kV and a pressure of 50 kPa for  $\text{SF}_6$  admixtures (a) 0%-10%; (b) 10%-30%.

At a pressure of 50 kPa the step on the pulse leading edge in pure  $\text{CO}_2$  is less discernible than at 6.67 kPa apparently due to an increased collisional quenching of photon-emitting excited states and absorption of photons in the gas. The decrease may also be due to increased electron attachment near the cathode surface [9].

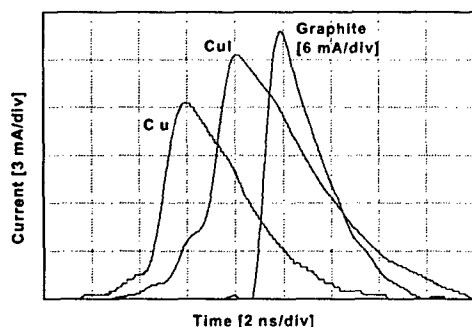


Fig. 4: First negative corona pulses measured using the Cu-cathode, CuI-coated cathode, and graphite-coated cathode at a pressure of 50 kPa in  $\text{CO}_2 + 2.5\% \text{SF}_6$ , and at gap voltage value of 5.5 kV.

Figure 4 exemplifies the effects of changing of the cathode  $\gamma_p$  - emission using 2.5% of  $\text{SF}_6$  and gap voltage of 5.5 kV, where the step on the pulse leading edge was

clearly seen. In a close correspondence with the results shown in Fig. 2 and with the streamer-based hypothesis the graphite coating led to a dramatic reduction of the step on leading edge, while the CuI coating led to a well pronounced increase of the step. However, in a contrast to the results measured at a reduced pressure of 6.65 kPa, at 50 kPa the graphite coating resulted in a marked increase of the pulse magnitude. The observed effect of the graphite cathode coating observed at higher gas pressures is the same as that studied in more detail in work [5] for the discharge in  $\text{N}_2\text{-SF}_6$  mixtures. On this base, and in line with the recent studies of other authors [10-12], we hypothesize that this effect can be an indication that with increasing gas pressure and consequently increasing gap voltage the field emission becomes to play an important role in the discharge mechanism.

### 3. Conclusions

The above results interpreted in terms of the streamer-based hypothesis suggest that the effect of adding  $\text{SF}_6$  to  $\text{CO}_2$  was primarily to quench the Townsend multiavalanche ionization processes, while the effect on the positive streamer ionization processes was much less pronounced. This is in contrast to our results obtained in similar experimental conditions in air- $\text{SF}_6$  and  $\text{N}_2\text{-SF}_6$  mixtures [4,5], where the observed effect was opposite. One may therefore speculate that the stronger streamer quenching in  $\text{N}_2\text{-SF}_6$  mixtures, and the resulting more efficient corona stabilization effects can be responsible for higher dc breakdown voltages measured at pressures less than 0.2 MPa in  $\text{N}_2\text{-SF}_6$  mixtures, comparing to those measured in  $\text{CO}_2\text{-SF}_6$  mixtures [13].

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