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## AC Creepage discharges in SF<sub>6</sub>, Co<sub>2</sub>, N<sub>2</sub>, and SF<sub>6</sub>-CO<sub>2</sub> and SF<sub>6</sub>-N<sub>2</sub> mixtures

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# AC CREEPAGE DISCHARGES IN SF<sub>6</sub>, CO<sub>2</sub>, N<sub>2</sub> AND SF<sub>6</sub>-CO<sub>2</sub> AND SF<sub>6</sub>-N<sub>2</sub> MIXTURES

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**Abstract:** This paper deals with the experimental study of creepage discharges propagating over insulators made of different materials namely Glass, Epoxy resin and Bakelite, under AC voltage. The mainly investigated parameters are the morphology of discharges and their stopping lengths  $L_f$  versus the voltage magnitude, the type and thickness of insulator, the type of gas/gaseous mixture and pressure. The gases and mixtures we considered are N<sub>2</sub>, SF<sub>6</sub>, CO<sub>2</sub>, SF<sub>6</sub>-N<sub>2</sub> and SF<sub>6</sub>-CO<sub>2</sub>. It's shown that  $L_f$  increases quasi-linearly with the voltage; it decreases when the thickness is increased and/or the dielectric constant of insulator decreases, thus indicating the important role of electric field and capacitive effects in the propagation mechanism. On the other hand, the increase of SF<sub>6</sub> content in SF<sub>6</sub>-CO<sub>2</sub> and SF<sub>6</sub>-N<sub>2</sub> mixture leads to a significant decrease of the length of discharges.

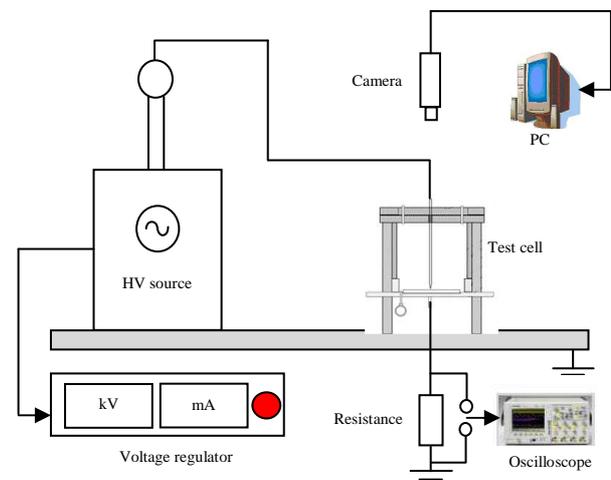
## 1 INTRODUCTION

From insulation viewpoint, the triple junction constitutes the weakest point in any high voltage equipment (bushings, insulators, switchgears, gas insulating lines, gas circuit breaker ...). Indeed, when the applied voltage, and then the electric field, reaches a critical value, partial discharges can be initiated in the vicinity of this region. The increase of the voltage leads these PDs to develop and to transform in surface discharges (creeping discharges) that propagate over the insulators up to flashover. This results in partial or total deterioration of the insulation system requiring the repair of equipments or even their replacement. To avoid such situations, the designers of high voltage apparatus have to know the characteristics of these discharges and their evolution depending on the type of insulator and gas as well as their physical and geometrical properties, the electrodes geometry and the voltage wave form as well as its amplitude and time application. Thus, the knowledge of the optical and electrical parameters of these discharges is of great interest for industrial applications. In previous papers, we investigated the characteristics of these discharges when propagating over insulators made of epoxy resin, glass and polytetrafluoroethylene (PTFE) filled with different kinds of micro- mineral fillers, immersed in gas or gaseous mixtures, under standard lightning impulse voltage (1.2/50  $\mu$ s) [1-7].

This paper deals with the characterization of this type of discharges but under AC voltage, using a point-plane electrode arrangement. We mainly investigate their morphology and their stopping length against the voltage magnitude, the type of insulator and its thickness, the type of gas/gas mixture and its pressure.

## 2 EXPERIMENTAL SETUP

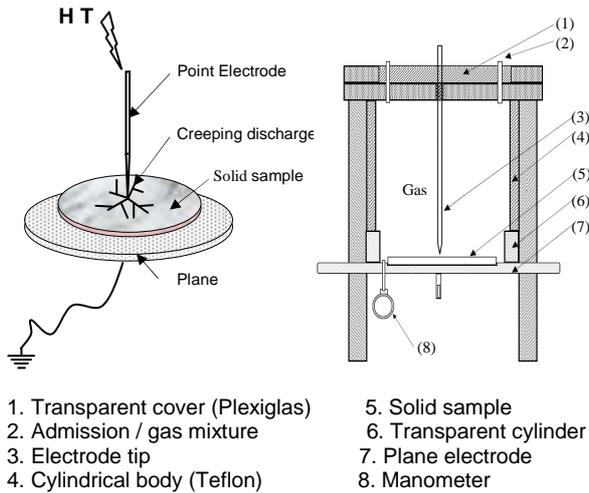
The experimental arrangement is similar to that we used in previous work (figure 1) [6, 7], except the voltage supply which is here a 50 kV/50 Hz transformer. For the continuity, we recall here its main features.



**Figure 1:** Scheme of experimental setup

The test cell containing the considered insulating structure (solid/gas or mixture) and a point-plane electrode arrangement consists of a cylindrical core of 90 mm high and 110 mm inner diameter, and two flats and circular covers (Figure 2); the upper cover was of PMMA (transparent material) enabling to visualize the discharges and to support the sharp electrode; the lower one which constitutes also the plane electrode is a circular plate of 250 mm diameter and 15 mm thickness, was of brass. The point electrode was made of tungsten, the radius tip of which is 10  $\mu$ m. The cylindrical core of the test cell consists of two screwed parts: an upper part of 60 mm high made

of Teflon and a bottom part issued from Plexiglas of 30 mm high enabling to control the contact between the point electrode and the solid insulator. The solid insulating samples are discs of 100 mm diameter and 2 to 10 mm thickness. Three types of solid insulating samples were tested: Glass, Epoxy resin and Bakelite. The gases and mixtures we considered are  $N_2$ ,  $CO_2$ ,  $SF_6$ ,  $SF_6-N_2$  and  $SF_6-CO_2$ . The solid samples are changed each time we observe traces on their surface and the radius of curvature of electrode point is checked before and after testing.



**Figure 2:** Scheme of the test cell

A system of taps associated to two manometers enables to fill the test cell and to control the pressure. When the gases are mixed, the gas with the lower partial pressure ( $SF_6$ ) is first admitted into the test cell and then the higher partial ( $N_2$ ,  $CO_2$ ) is admitted after the pressure of  $SF_6$  is stabilized.

A CCD camera (SONY XC-HR58 type, high SVGA resolution (767x580 pixels)) connected to a high performance video card (Meteor-II/Multi-Channel) is used to capture the integral light image of discharges. Thanks to this optical system, one can measure the maximum extension of discharge  $L_f$  directly on the computer screen. For a given voltage, the considered value of  $L_f$  is the average of ten tests.

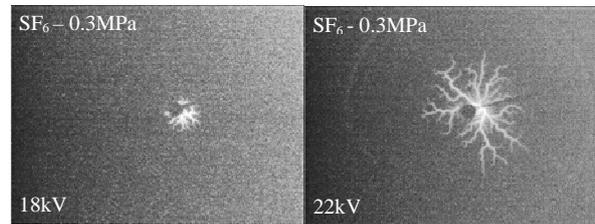
### 3 EXPERIMENTAL RESULTS

As observed under lightning impulse voltage, the shape and stopping length of discharges depend on the type and thickness of the insulator, the nature and pressure of the gas (or gas mixture), and the amplitude of applied voltage.

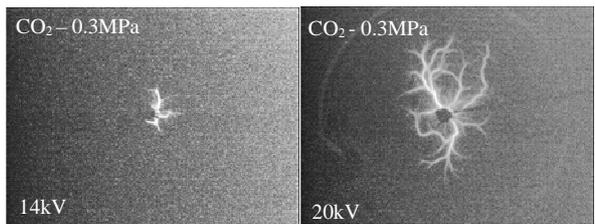
#### 3.1 Influence of the amplitude of voltage, the type of gas and its pressure

For given solid and gas pressure, the length of the discharge channels increases with the amplitude of

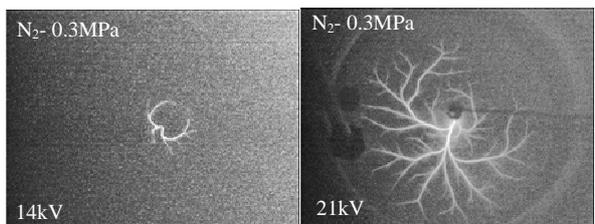
applied voltage (Figure 3) and decrease when the gas pressure is increased (Figures 4). For a given gas pressure, the increase of stopping lengths of creeping discharges  $L_f$  is quasi-linear with the voltage (Figures 5 to 7).



(a)

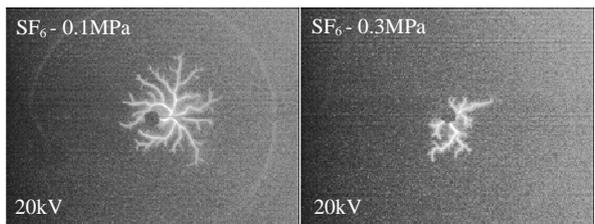


(b)

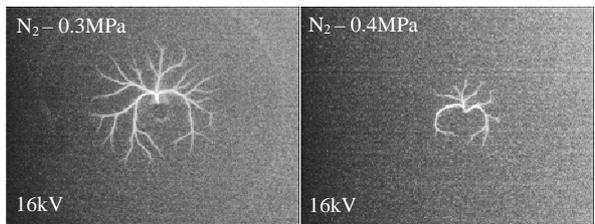


(c)

**Figure 3:** Influence of the voltage magnitude on creeping discharges propagating over different insulators of 2 mm thickness, immersed in different gases at 0.3 MPa: (a) Glass in  $SF_6$ ; (b) Glass in  $CO_2$ ; and (c) epoxy resin in  $N_2$ .



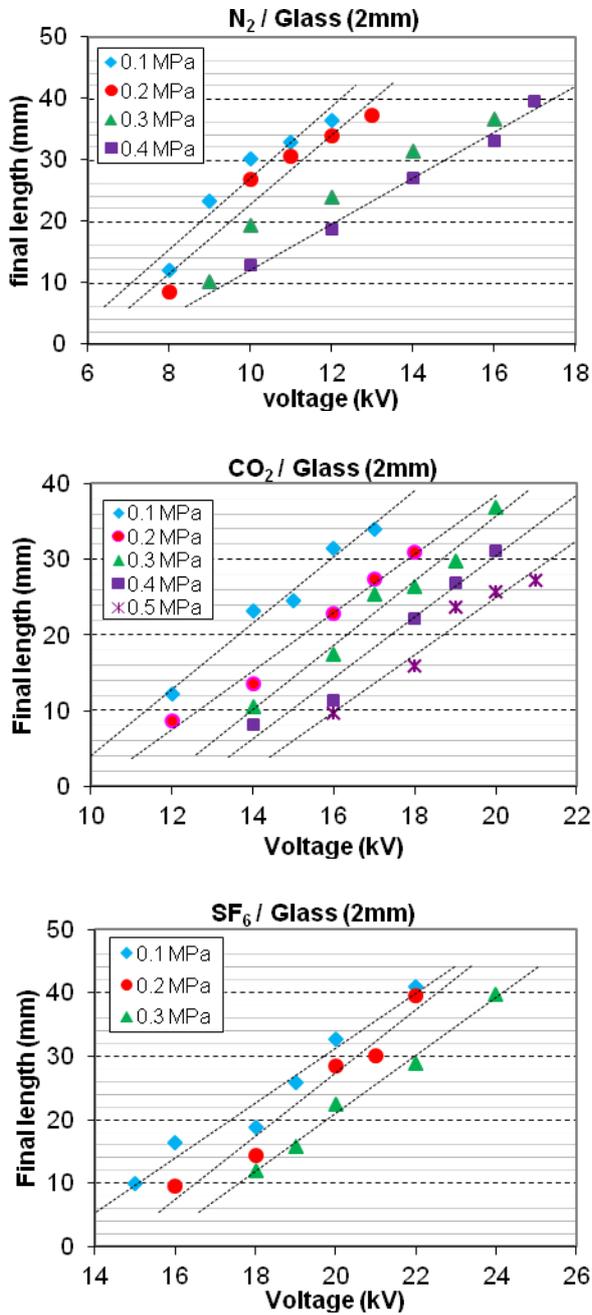
(a)



(b)

**Figure 4:** Influence of pressure on creeping discharges propagating at: (a) Glass/  $SF_6$  and (b) Epoxy resin/ $N_2$  interfaces;  $e=2mm$ .

For a given pressure and voltage,  $L_f$  is longer with  $\text{CO}_2$  and  $\text{N}_2$  than with  $\text{SF}_6$  ( $L_f(\text{N}_2) < L_f(\text{CO}_2) < L_f(\text{SF}_6)$ ) whatever the type of insulator. Similar results have been obtained under standard lightning impulse voltage with insulators made of glass and resin epoxy [1, 3, 5, 6].

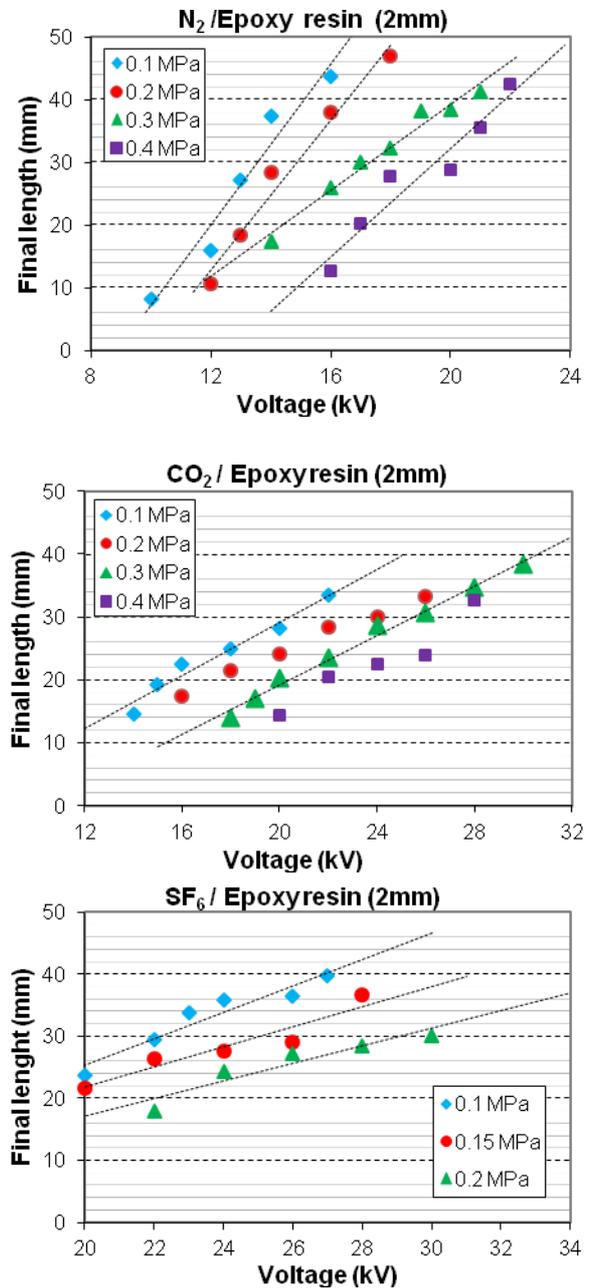


**Figure 5:** Stopping length of creeping discharges over glass sample vs. the voltage for different pressures of the investigated gases,  $e= 2\text{mm}$ .

### 3.2 Influence of the nature and the thickness of solid insulating

The thickness and the nature of solid insulating sample also influence the shape and final length  $L_f$  of discharges. Figure 8 gives an example of discharges propagating at  $\text{SF}_6/\text{glass}$  and  $\text{SF}_6/\text{Bakelite}$  interfaces for different thicknesses of insulators. The total density of branches depends

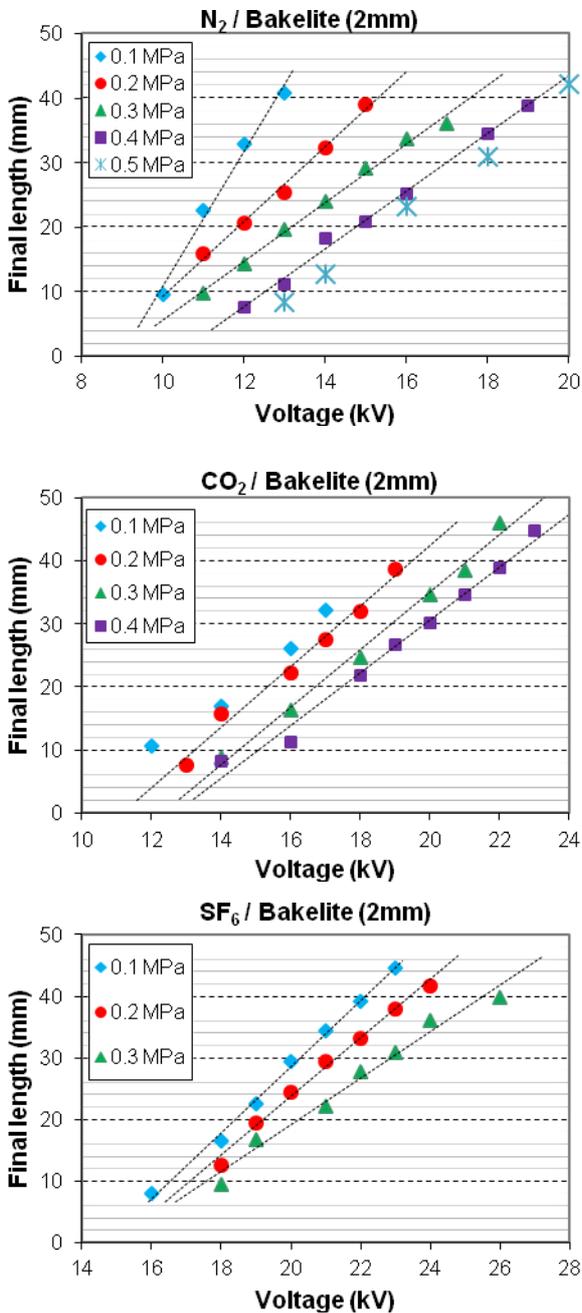
strongly on the thickness of insulator; it decreases when the thickness increases. On the other hand, for a given voltage,  $L_f$  is higher with Bakelite ( $\epsilon_r = 4.8$ ) and Glass ( $\epsilon_r = 5$ ) samples than with Epoxy samples ( $\epsilon_r = 3.5$ ). This is due to the electric field at the point which is more important as the difference of the permittivity between the solid insulating sample and gas is high.



**Figure 6:** Stopping length of creeping discharges over Epoxy resin sample vs. the voltage for different pressures of the investigated gases,  $e= 2\text{mm}$ .

On the other hand, when the thickness of insulator increases then the capacitance of the system consisting of the insulator inserted between the electrodes decreases,  $L_f$  decreases (Figures 9 and 10).

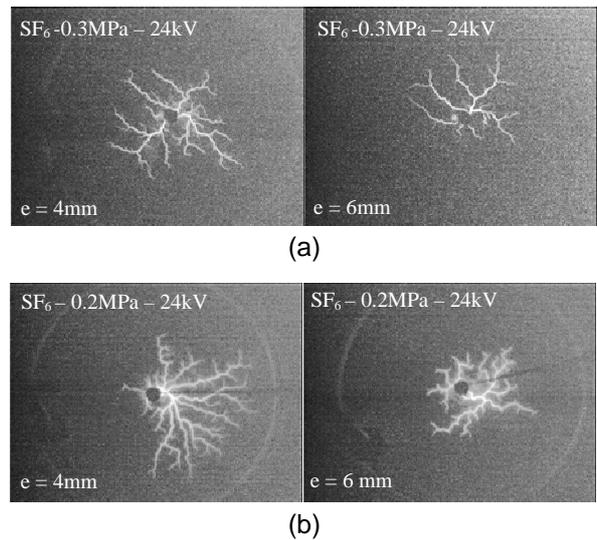
The above observations (influence of the thickness of solid and its dielectric constant) indicate the important role of the capacitive effects and the electric field on the propagation mechanism. This phenomenon has been also observed with solid/gas interface under lightning impulse [1-7] as well as with solid/liquid interfaces [8, 9]



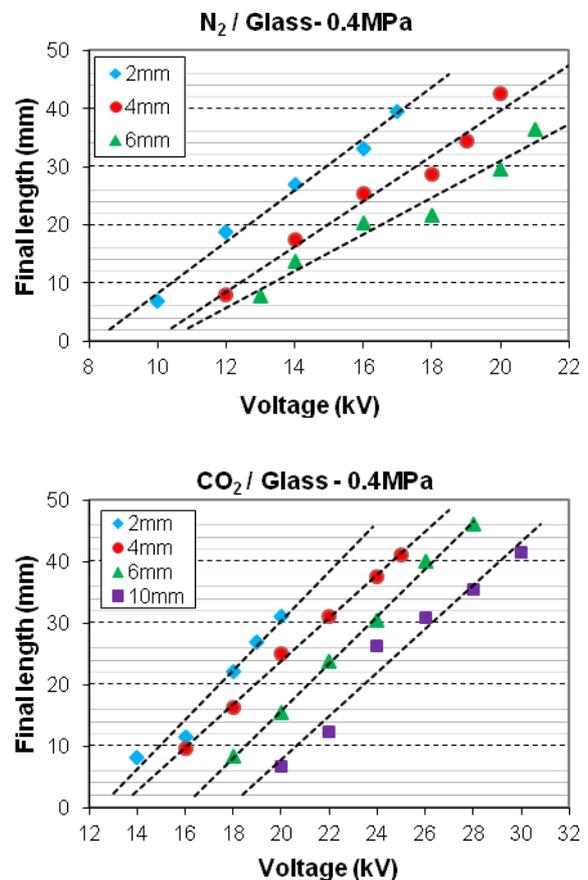
**Figure 7:** Stopping length of creeping discharges over Epoxy resin sample vs. the voltage for different pressures of investigated gases,  $e = 2\text{mm}$ .

### 3.3 Influence of $\text{SF}_6$ content

The addition of small amount of  $\text{SF}_6$  to  $\text{CO}_2$  or  $\text{N}_2$  reduces the discharge branches (Figures 11 and 12). For each gas mixtures, the stopping length of discharges also increases quasi-linearly with the voltage.

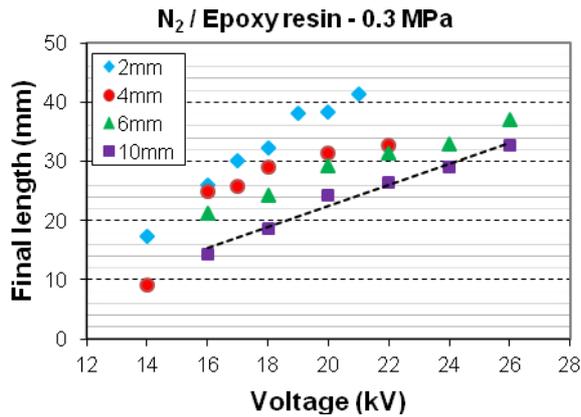
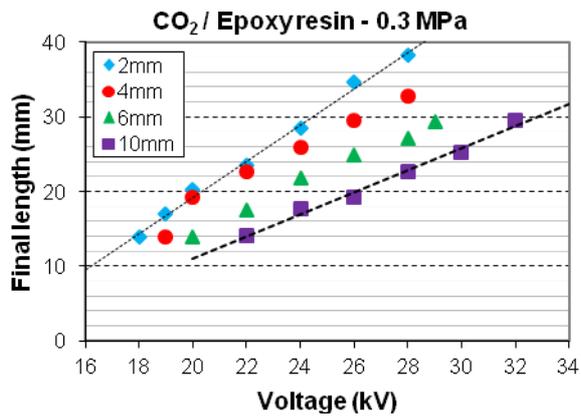


**Figure 8:** Influence of thickness of insulator on creeping discharges propagating over: Bakelite/ $\text{SF}_6$  interface (a); and glass/ $\text{SF}_6$  interface (b).

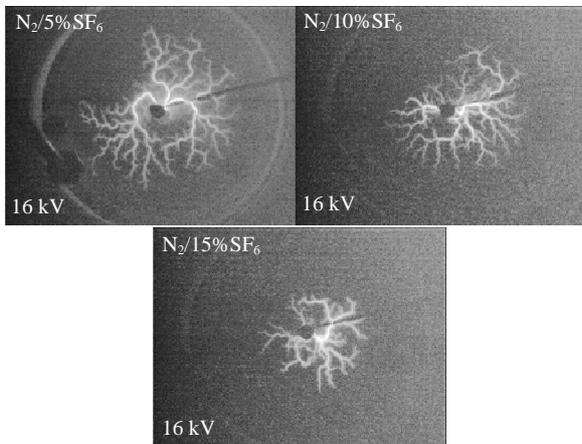


**Figure 9:** Stopping length of creeping discharges over glass sample vs. the voltage and thickness of insulator for different pressures in  $\text{N}_2$  and  $\text{CO}_2$ .

Figures 13 and 14 show examples of evolution of  $L_f$  vs. the voltage for glass immersed in  $\text{SF}_6/\text{N}_2$  and  $\text{SF}_6/\text{CO}_2$  mixtures for different concentrations of  $\text{SF}_6$ .



**Figure 10:** Stopping length of creeping discharges over glass sample vs. the voltage and thickness of insulator in  $N_2$  and  $CO_2$ , for different pressures.

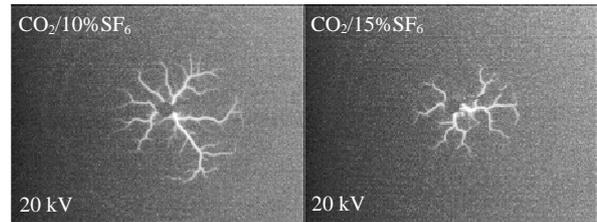


**Figure 11:** Influence of  $SF_6$  content in  $N_2$  at 0.2MPa on creeping discharges propagating over glass.

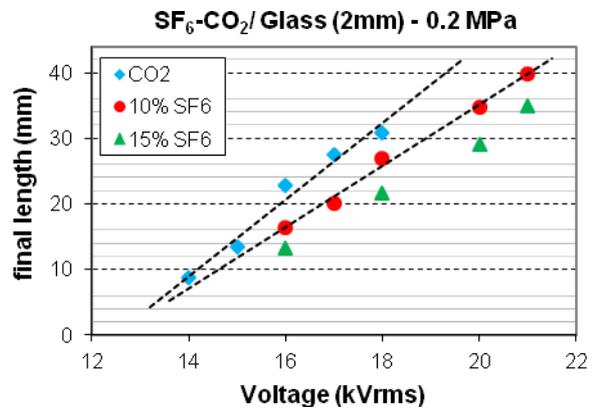
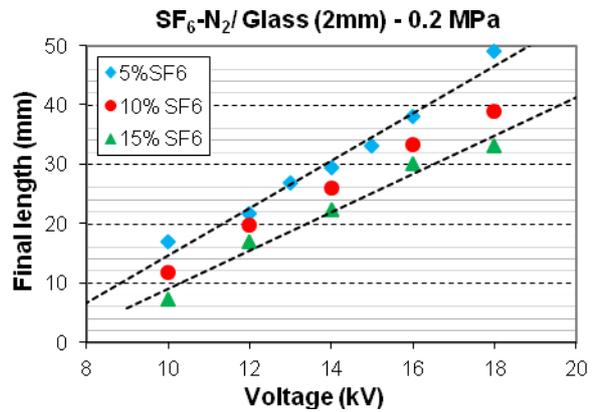
#### 4 CONCLUSION

The results we got in this work are similar to those obtained under lightning impulse voltage. Indeed, the morphology and stopping length  $L_f$  of discharges propagating over a solid insulator (Glass, Bakelite and Epoxy resin) immersed in various gases and mixtures ( $SF_6$ ,  $N_2$ ,  $CO_2$ ,  $SF_6-N_2$  and  $SF_6-CO_2$ ) submitted to AC voltage, depend on the amplitude of the voltage, the type and the thickness of solid insulator, the nature and pressure of gas as well as the concentration of

various elements constituting the mixtures. For a given interface solid/gas (mixture), we showed that  $L_f$  increases quasi-linearly with the applied voltage and reduces when the pressure of gas increases.

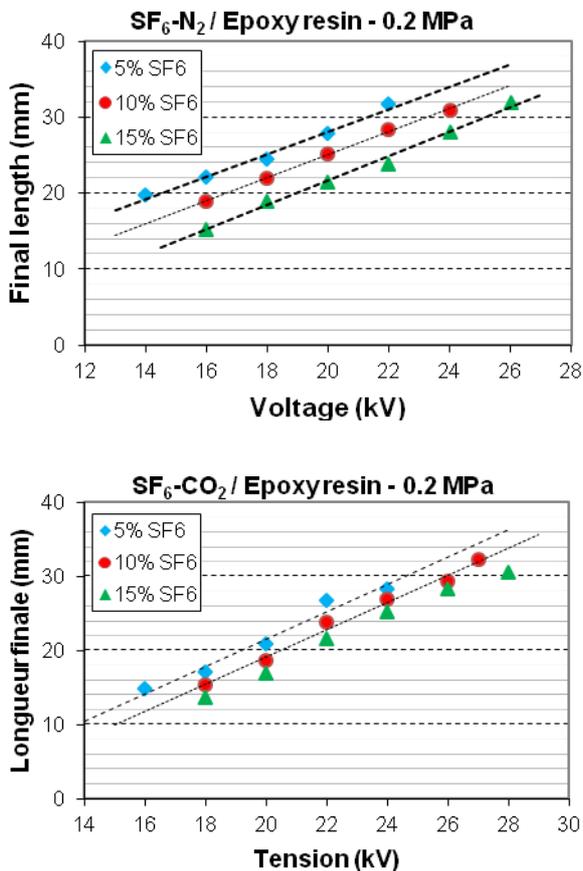


**Figure 12:** Influence of  $SF_6$  content in  $CO_2$  at 0.2MPa on creeping discharges propagating over glass.



**Figure 13:** Stopping length of creeping discharges over glass immersed in  $SF_6/CO_2$  and  $SF_6/N_2$  mixtures at 0.2MPa versus the voltage.

For a given applied voltage and gas pressure,  $L_f$  is longer with  $CO_2$  and  $N_2$  than with  $SF_6$  ( $L_f(N_2) < L_f(CO_2) < L_f(SF_6)$ ); it decreases when the thickness is increased and/or the dielectric constant of insulator is decreased indicating thus the important role of capacitive effect and the electric field in the propagation mechanism. On the other hand, the addition of small content of  $SF_6$  reduces  $L_f$ , indicating the role of electronegative gas.



**Figure 14:** Final length of creeping discharges over epoxy resin immersed in SF<sub>6</sub>/N<sub>2</sub> and SF<sub>6</sub>/CO<sub>2</sub> mixtures at 0.2 MPa versus the voltage.

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