

Experimental Investigation of the Electric Discharge Stability: Behaviour with the Air Relative Humidity

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Abstract- The stability of the DC electric discharge is very important for its use in different applications. The stability is affected by the appearance of sparks that are very dangerous and may be deadly. To avoid the sparks and to work in a stable condition we must know the parameters that have an influence on the corona discharge stability. In this paper, we investigate the effect of the relative humidity on the direct current electric discharge behaviour. The corona discharge is created between two parallel wire electrodes for aeronautical purpose. Through our experimental study we notice that corona current is not yet interesting when the humidity becomes greater than 50%. Moreover, analysis of corona inception voltage shows that this voltage increases with the relative humidity up to a certain limit after which the corona inception voltage begins to decrease as the air relative humidity increases. We note that the disruption voltage decreases when the humidity increases. Also, the domination of the "Streamer corona" discharge or "Glow corona" discharge is conditioned by the humidity span.

Keywords- *Electrodes; Inception Voltage; Corona Discharge; Disruption Voltage; Stable; Corona Current*

I. INTRODUCTION

The direct current corona electric discharge in atmospheric air is subjected to the environmental conditions such as humidity and temperature. These environmental parameters have visible consequences on the corona discharge behaviour. Due to the importance of the air relative humidity for the electric discharge, this parameter was examined for some discharge configurations. Studies in the case of positive corona discharge in a three-electrode system (point-grid-plane) [1] showed that the corona inception voltage changes with the relative humidity. Other works has been done to analyse the discharge development in the case of two-electrode systems in humid air [2-4]. The appearance or disappearance of certain corona mode as well as the transition from a corona mode to another depends on air relative humidity [1, 5]. Abdel-Salam [6] has shown experimentally that at high voltages the corona current decreases as the relative humidity increases. He explained this phenomenon by the decrease of ion mobility as a result of the ion combination with polar water molecules that become abundant when relative humidity increases.

In our paper, we will present the results obtained for several discharge configurations. For different relative humidity values, current-voltage and current density-electric field characteristics were laid out for all studied cases in order to study the humidity consequence on the current values and discharge stability. Also, we will examine the effect of the air relative humidity on the inception and disruption voltages.

II. EXPERIMENTAL SET-UP

The positive high voltage is generated by a Direct Current (DC) High Voltage Generator (HVG), providing a maximum positive voltage of 50kV and a maximum current of 12mA so a maximum electric power of 600W (Figure 1). This generator has some useful options such as the Over Current Limitation mode (OCL: this mode limits the current value to the instruction value) and the Over Current Protection mode (OCP: in this mode the generator dies out automatically when the current reaches the instruction value). The plasma actuator consists of two parallel electrodes with different widths or diameters, according to the case. The corona wire, linked to the positive high voltage, has the lower diameter and the cathode has the largest diameter. Theses electrodes are flush mounted at the surface of a dielectric support, the electric corona discharge is created at atmospheric pressure. We have studied four configurations having different geometrical forms and materials of the dielectric support: the flat plate, the cylinder, the NACA0015 profile and the NACA4412 profile. The first case is a positive presensitized epoxy plate used for printed circuits: the electrodes are two parallel printed circuits with a distance of 4cm, having a length of 20cm, width of 0.5mm and 2mm respectively for the anode and the cathode. In the second case, the electrodes are two parallel copper wires having diameters of 0.4mm and 2mm and a length of 20cm, which are diametrically opposed, encrusted and levelling on the surface of a Polyamide (PA) circular cylinder. For the third case, the electrodes are two printed circuits embedded in a surface of wood NACA0015 airfoil, they have a length of 20cm, width of 0.5mm and 2mm and the inter-electrode gap is equal to 4cm. The fourth case in this paper consists of plasma actuator at the surface of a NACA4412 airfoil; in this case the two electrodes are two parallel copper wires separated by a gap of 4cm and having diameters of 0.6mm and 2mm and lengths of 42mm and 40mm, respectively for the anode and the cathode.

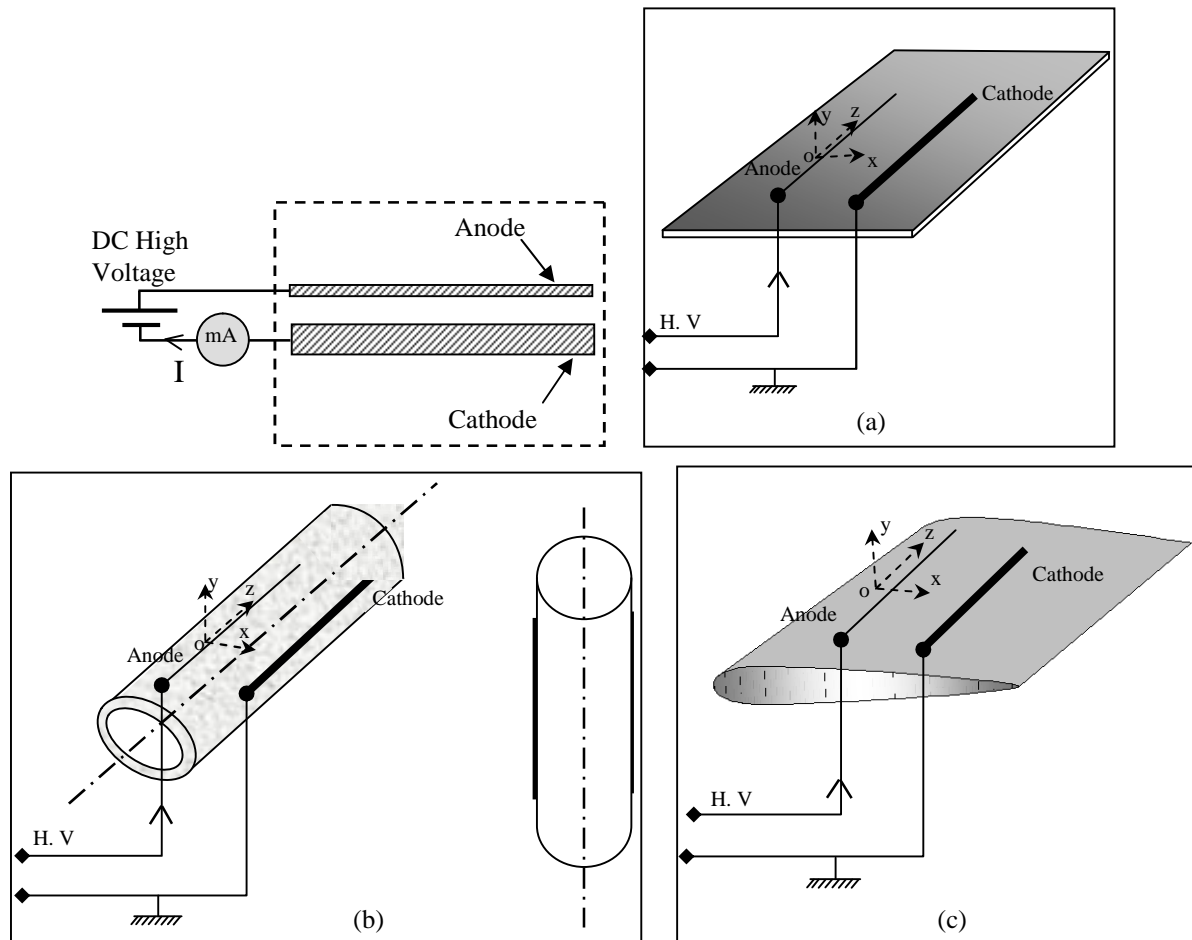


Fig. 1 Diagram of the experimental setup (a): electrodes at the surface of a flat plate, (b): electrodes at the surface of a circular cylinder, (c): electrodes at the surface of a NACA profile

III. EXPERIMENTAL RESULTS AND DISCUSSION

The results given in this paragraph correspond to different values of the ambient air relative humidity. We have collected series of measurements which are spread over a period of 3 years. We have filed and consigned statements acquired along the period of year.

A. Effect of the Humidity on the Inception

The inception voltage, also called onset voltage [7], is the voltage at which the corona current starts to appear while increasing the applied voltage progressively. This voltage depends on the air relative humidity.

Figures 2.a, 2.b, 2.c and 2.d show that at first the inception voltage increases with the humidity and then it decreases for greater values of humidity. We note a maximum inception voltage when humidity is centred between 50% and 60%, depending on the configuration. Indeed, when the relative humidity increases the thickness of the ionization zone diminishes because the coefficient of electron attachment increases with relative humidity at a rate higher than that of the ionization coefficient [6]. The photons that emitted from the primary avalanche, decay faster (due to absorption) along the thickness of the ionization layer on increasing the relative humidity, as the absorption coefficient increases significantly with the relative humidity. Therefore, less ionization takes place in the air gap and the corona inception voltage increases. However, with more increase in the relative humidity the thickness of the ionization zone becomes smaller, the photons decay very slightly and the secondary avalanches are expected to grow in slightly much higher fields nearer to the anode surface and so more ionization takes place in the air gap and the corona inception voltage begins to decrease [1].

B. Effect of the Humidity on the Disruption Voltage

The disruption voltage is the voltage at which the sparks start to appear while increasing the applied voltage progressively. So, for higher voltage the electric discharge is not stable any more. Experimental statements made for the studied configurations converge all to the same result, and the disruption voltage decreases with the air relative humidity (Figure 3). However, the voltage plateau reached in the case of the printed flat plate can be due to measurements uncertainties. Indeed, as the relative humidity increases, the disruption voltage decreases because Hermstein sheath is weakened materially by vapour

[8], and in turn this permits an earlier appearance of vigorous breakdown streamers [1].

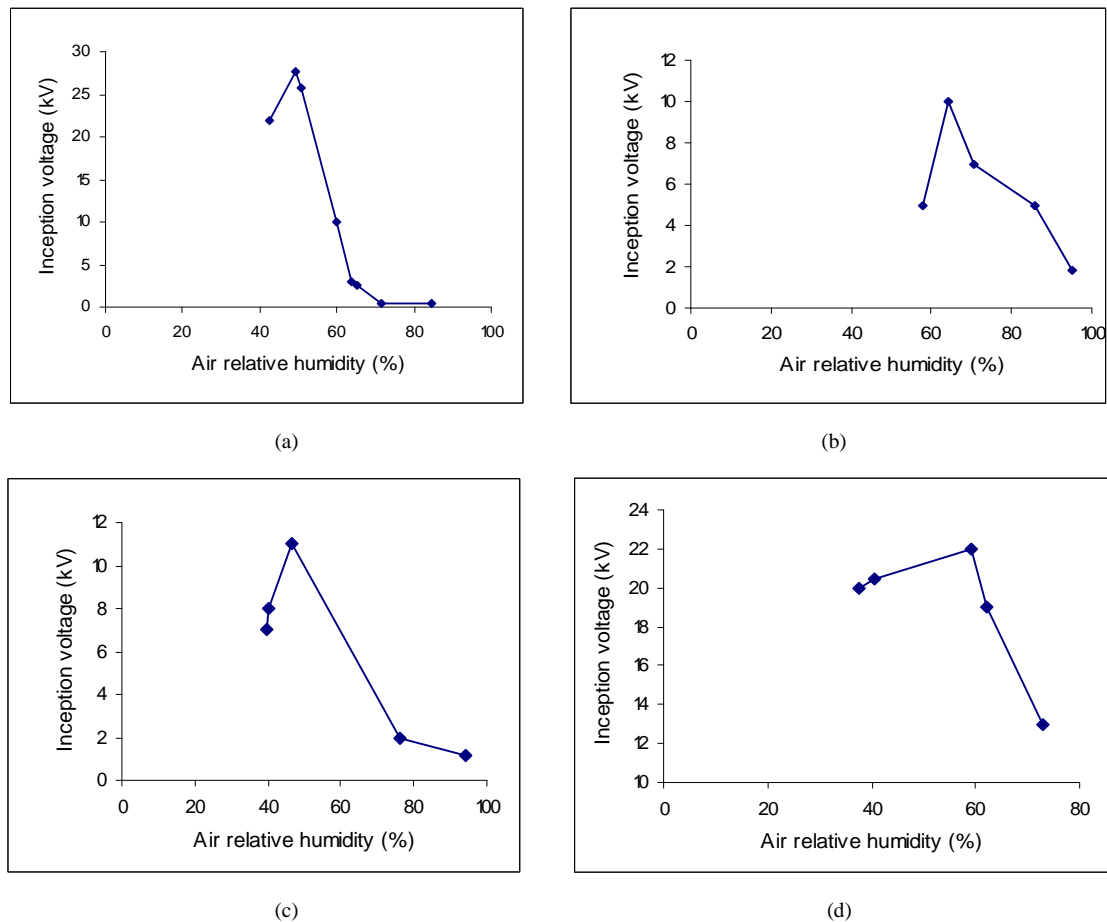


Fig.2 Inception voltage vs air relative humidity ((a): case of a printed flat plate, (b): case of a PA circular cylinder, (c): case of a NACA0015 profile, (d): case of a NACA4412 profile)

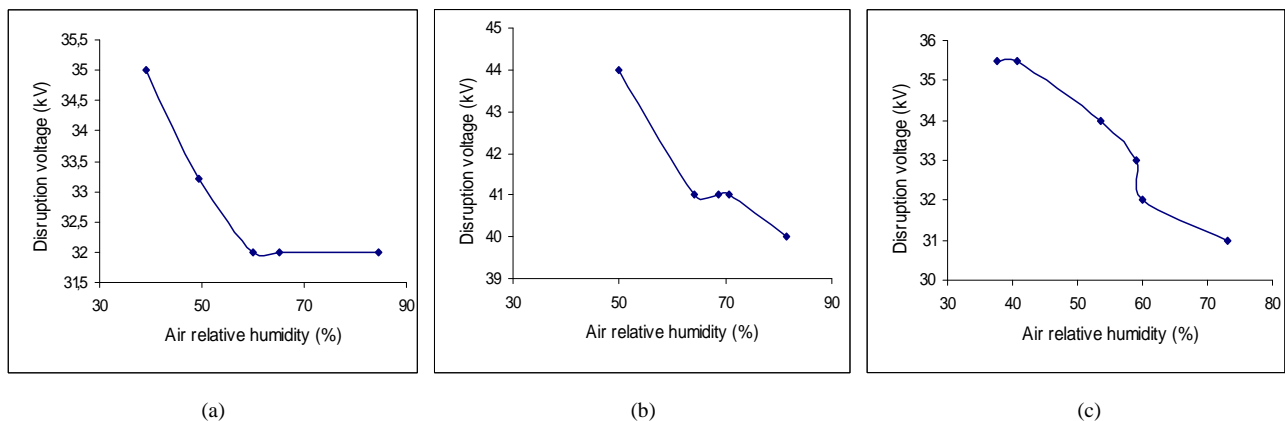


Fig. 3 Disruption voltage vs air relative humidity (a): case of a printed flat plate, (b): case of a PA circular cylinder, (c): case of a NACA4412 profile

C. Effect of the Humidity on the Corona Current

In this paragraph we present the current-voltage characteristics to see the maximum of the corona current obtained with a positive DC discharge. For the printed flat plate, humidity higher than 45% makes the current lower (Figure 4.a). Current in case of a PA cylinder is no longer important if humidity exceeds 50% (Figure 4.b). The Figure 4.c shows in case of a NACA0015, that humidity about 40% ensures high current values. The corona discharge at the surface of a NACA4412 is characterized by maximum current when the relative humidity is 43%, whereas for greater humidity it is not large any more (Figure 4.d).

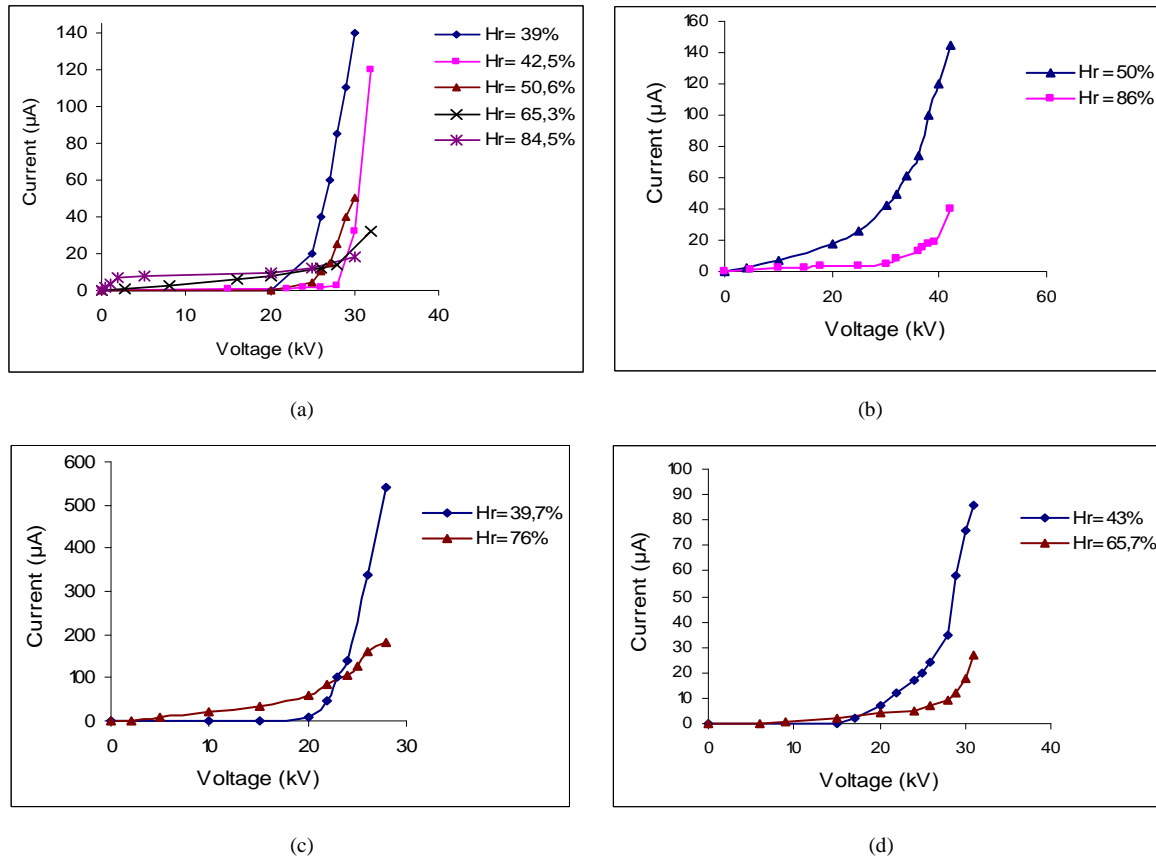
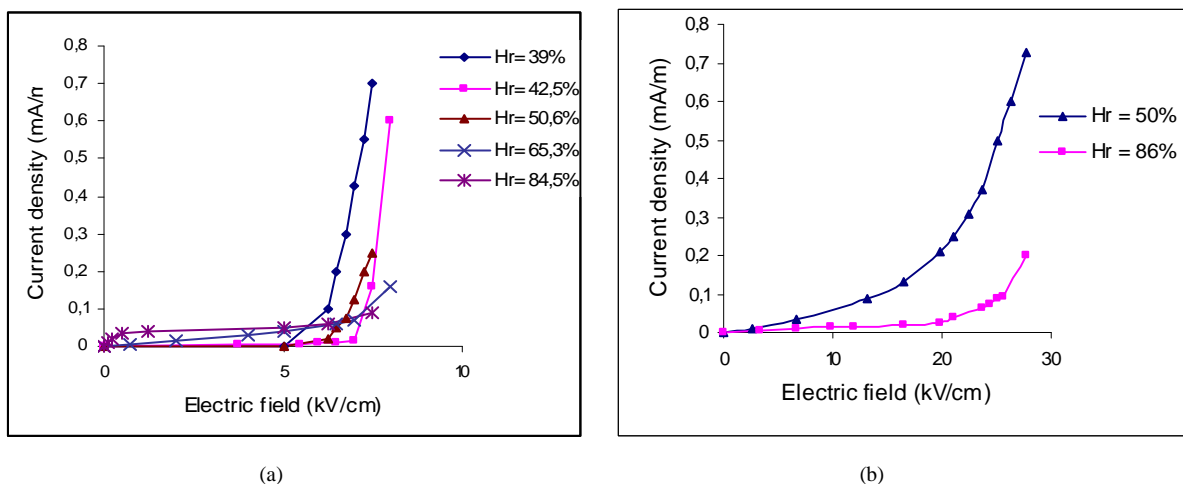


Fig. 4 Current-voltage characteristics for different relative humidity values (a): case of a printed flat plate, (b): case of a PA circular cylinder, (c): case of a NACA0015 profile, (d): case of a NACA4412 profile

D. Effect of the humidity on the discharge stability

Through the current density-electric field characteristics we can withdraw from each case the obtained maximum current density without any spark. So we can determine the obtained discharge modes based on a classification of the discharge modes as function of a current density [9]. Characteristics showed up for a printed flat plate display less important current density when the humidity increases (Figure 5.a). We can deduce that for humidity above 50% the discharge is no longer stable, so that any surface irregularity on the electrode or the insulating support may induce an electric arc. In the case of a PA cylinder, Figure 5.b shows that for humidity of 50% the discharge is "Glow corona", while for greatest humidity the discharge becomes less stable. For the NACA0015 profile, with humidity of 39.7%, DC surface corona discharge is a thin and unstable generalized "Streamer corona" mode range, the "Glow corona" mode range is larger so the discharge is more stable (Figure 5.c). When humidity is 76%, we see that "Streamer corona" mode is more stable and homogenous. The range of the "Glow corona" mode is very thin and this mode can be absent. Finally for the case of a plasma actuator at the surface of a NACA4412 profile, Figure 5.d shows that when humidity is 65.7% the discharge is limited to "spot" mode characterized by a low current. Whereas, when the humidity is lower ($H_r=43\%$), the discharge reaches the more stable "Streamer corona" mode.



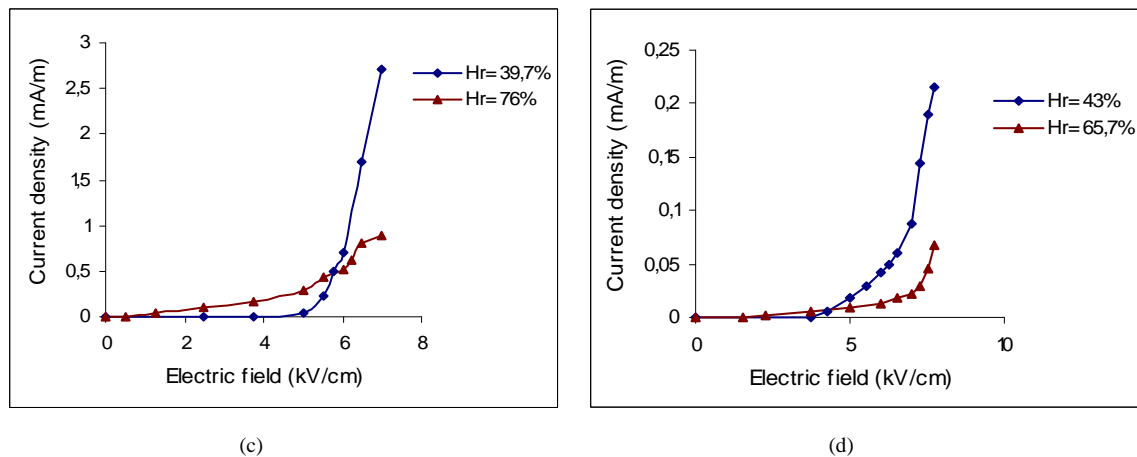


Fig. 5 Current density-electric field characteristics for different relative humidity values (a): case of a printed flat plate, (b): case of a PA circular cylinder, (c): case of a NACA0015 profile, (d): case of a NACA4412 profile

IV. CONCLUSIONS

Several conclusions may be withdrawn from the series of measurements that we made. Which appears obvious to us is that the relative humidity affects the electric discharge behaviour. In this paper we exposed results for several electric discharge configurations: printed flat plate, Polyamide (PA) circular cylinder, NACA0015 airfoil and NACA4412 airfoil. First investigated effect of the humidity was that on the inception voltage, we found that inception voltage has a maximum for a moderate humidity, between 50% and 60%. Evolution of the disruption voltage was the subject of the second effect of the humidity that showed a decrease of disruption voltage with higher relative humidity. Third effect of the humidity was on the corona current which became less significant when humidity increased. Fourth and last presented effect consisted in the current density evolution that allowed us to deduce the range of the discharge mode. We found that the "Glow corona" and "Streamer corona" modes are obtained when humidity is between 40% and 50%, so this range is most favourable because it corresponds to the most stable discharge.

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