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DC corona surface discharge along an insulating flat plate in air: experimental results

C. Louste, E. Moreau, G. Touchard,
Laboratoire d'Etudes Aérodynamiques, University of Poitiers, FRANCE

Abstract: *A high voltage difference between two parallel wire electrodes placed close to an insulating surface may be used to produce a dc corona discharge. In this original configuration, an homogenous stable generalized glow discharge is obtained very close to the insulating surface. This discharge may be used in aerodynamics. This experimental work brings out some important parameters to control the dc corona discharge such as the insulating properties of the flat plat. Experiments show that when the two electrodes moved away from the surface, a plasma sheet is still observed at the vicinity of the surface. This paper also presents the influence on the dc corona discharge of parameters as the electrode gap and the distance between the flat plate and the electrodes.*

Introduction

The dc corona discharge generates an ionic wind force that can be used to modify characteristics of an air flow along a flat plat [1-2]. It acts on air as an electro-mechanical system usually called electroaerodynamic actuator. The main points of this process are first a kinetic energy production without moving mechanical parts, secondly a very short response time and third a local mechanical effect very close to the surface. Such discharges can be used for example in drag reduction of a circular cylinder [3].

Experiments in a wind tunnel have shown that the plasma sheet, produced between two wire electrodes, accelerate the air flow downstream the dc corona discharge [1-5]. In such experiments, a high voltage difference between two parallel wire electrodes placed close to the surface is used to produce the dc corona discharge on the surface. There is a direct relationship between current intensity (and so with the ionic wind) and the air flow velocity in the boundary layer.

Recent works led inside our laboratory have shown that in a wire to wire configuration, different corona regimes like “spot line” or “generalized glow” or “high spot” discharge can be produced. Each regime has specific electroaerodynamic effects that are studied in our laboratory according to two approaches. The first one concerns fluid mechanic effects. The second one concentrates on corona discharge regime stability and electrical power. The present study deals with the second researches.

Although such an electroaerodynamic actuator is very promising, the main inconvenient of the discharge is that electrical power and stability of a corona discharge depends accurately on geometrical and electrical configurations, and on gas properties [8] (mainly air humidity and pressure). First experiments were made on PMMA surface [1-5]. On a PMMA surface, it is difficult to obtain a stable discharge when the air relative humidity is higher than 55 % at ambient temperature. Accordingly, an overall study of fundamental parameters of the wire to wire dc corona discharge is started to increase the maximum current and so mechanical effects even if the air is at a high level of relative humidity. This paper presents the first part of this experimental study.

A first set of experiments shows that the maximum current depends on the surface properties of the flat plat. Glass and paper surfaces are presented as example. In a second time, influence of the distance between electrode and insulating surface on current intensity is measured on a glass surface. In fact, a generalized glow discharge can be produced even if the two electrodes moved away from the surface.

In a third part, the current of the discharge is studied as a function of the electrode gap.

At last, the effect of the relative humidity of air (ranged from 55 to 80%) on the current intensity is presented.

Experimental setup

Figure 1 shows the experimental setup. Two parallel wire electrodes in copper are placed on a PTFE electrode holder. The copper electrodes have a diameter of 2 mm and a length of 30 mm. The insulating plates are cut into rectangular shape having a length of 30 mm, a width of 10 mm and a thick of 5 mm.

The insulating plate is put on micrometrical gauge blocks in order to control the distance between the wire electrodes and the top surface of the insulating plate.

To ensure measurements which can be reproduced, the following experimental procedure has to be respected. First, the insulating surface and the wire electrodes are both cleaned with Heptane. After a drying time of 5 minutes, the corona discharge is established. In order to reach an electrical equilibrium, an homogenous glow discharge is kept for 20 minutes.

(1) and (2): Wire electrodes in copper, with a diameter of 2 mm and a length of 300 mm
(3) Insulating plate
(4) PTFE electrode holder (set of hachure parts)
(5) and (6) : Electric cables
(7) and (8) : Micrometrical gauge blocks

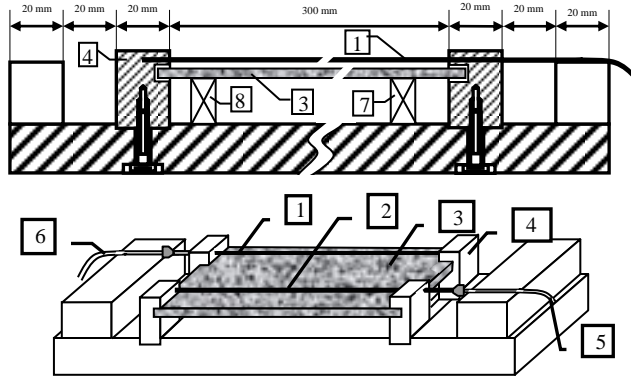


Figure 1 : Experimental setup.

In these experiments, the influence of two geometrical parameters is tested. The first one is the distance between electrodes and the top of the insulating plate (h). The second one is the electrode gap (d).

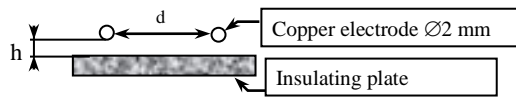


Figure 2 : Geometrical notations.

Instrumentation

The discharge is generated by applying:

- A negative high voltage ranged from -1 kV to -15kV at the cathode. This voltage is produced by a DELL DC HV power supply (-40kV, 3.75 mA)
- A positive high voltage square signal, with a frequency of 0.01 Hz and an amplitude of 20 kV, is delivered at the anode by 20/20C Trek amplifier ($\pm 20\text{kV}$, $\pm 10\text{mA}$)

Measurements of the current variations have been performed using the Trek's current monitor (DC Accuracy $\pm 10\mu\text{A}$, Output Noise $40\mu\text{A}$, Bandwidth greater than 10 kHz).

Influence of the surface material

Although corona discharges have been widely studied [5-7], the “wire to wire on insulating surface” shape has received little attention. In this configuration, current variations depend on the surface material.

Current versus time approach

Figure 3 presents the discharge current as a function of time for two different insulating materials. The anode is maintained at a constant value (-14kV). At $t=0$, a high voltage of 20 kV is applied (slow rate $=350\text{V}/\mu\text{s}$) at the cathode. In the paper case, the discharge current increases abruptly (about 1 ms) and reaches a steady state value (0.3 mA). With a glass surface, the current increases higher (0.75 mA) but more slowly than in the paper case (1s) and then decreases until reaching a constant value. On the glass surface a capacitive phenomenon can be observed.

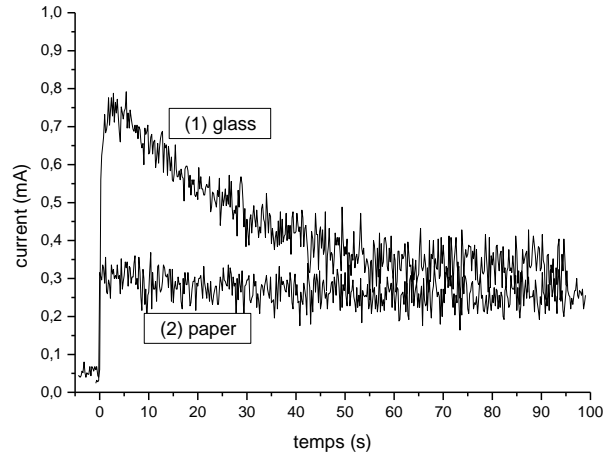


Figure 3 : Current-time curves in standard geometry (2mm diameter, $h=0.4\text{mm}$, $d=40\text{mm}$, 70% relative humidity, atmospheric pressure, potential 14kV) on glass surface (1), and on paper surface (2).

Each measured signal $i(t)$ can be expressed as a sum of two waves: a mathematical curve $C(t)$ obtained by least squares method (Figure 4), plus a “noise” signal $B(t)$ for which time average value is equal to zero (Figure 5):

$$i(t) = C(t) + B(t) \quad (1)$$

The signal $i(t)$ is fit as a first order exponential decay $C(t)$ such as :

$$C(t) = A + B \times e^{\left(\frac{-t}{\tau}\right)} \quad \langle B(t) \rangle = 0 \quad (2)$$

where τ is the time constant, B depends on the maximum current value and A represents the stabilised current value.

The capacitive effect is more important on glass surface than on paper surface ($B_p < B_g$) (Figure 3). The time constants are nearly the same ($\tau_p \cong \tau_g$) and the stabilised current value A is slightly higher with the

glass insulator ($A_g > A_p$). On the other hand, the “noise” is equivalent.

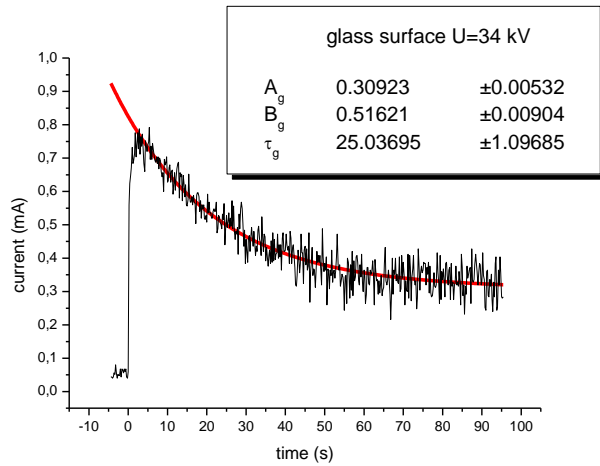


Figure 4 : Exponential fit of the current-time curve on a glass surface.

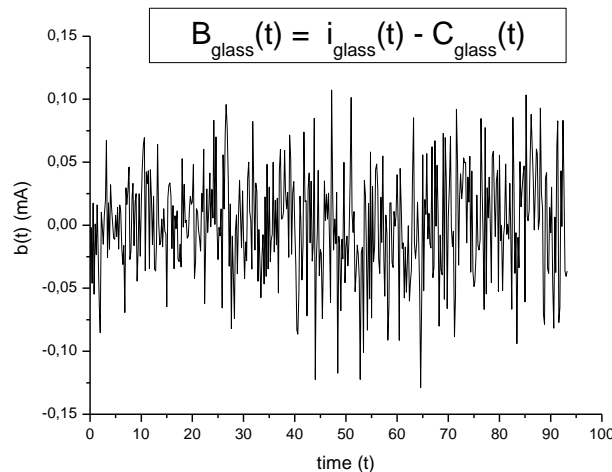


Figure 5 : “Noise” signal $B(t)$ (glass surface case).

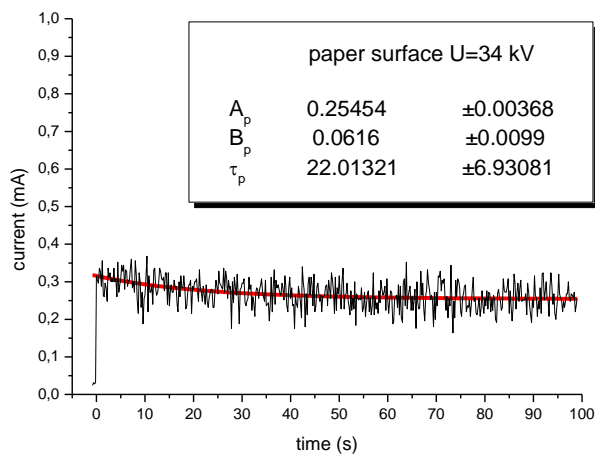


Figure 6 : Exponential fit of the current-time curve (paper surface case).

Current versus voltage study

In order to compare the two materials, these experiments have been done at various potential values.

On a glass surface, two corona discharge regimes are observed (Figure 7). In “regime I”, the discharge is concentrated in some visible spots on wires. This regime is also called “spot regime”. When the voltage is increased, a thin sheet of blue ionised air between the two electrodes may be observed very close to the surface (regime II, Figure 7). It is the generalised glow discharge regime or “plasma sheet regime”. In the generalised glow regime, the current is about six times higher than in the spot regime. A particular point C can also be noticed. It is the breakdown point.

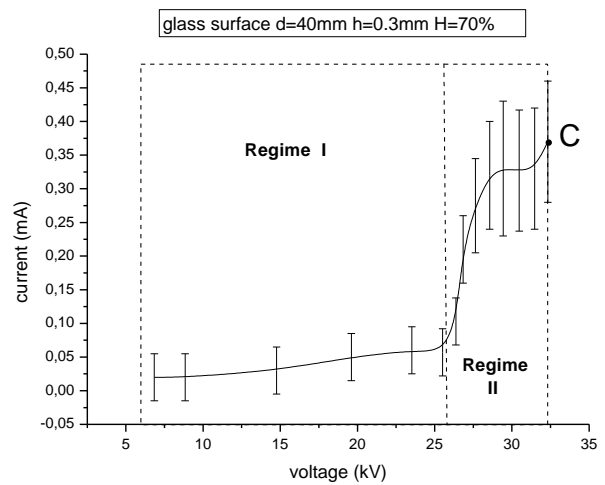


Figure 7 : Current-voltage characteristic on a glass surface in standard geometry (2mm diameter, $d=40\text{mm}$, $h=0.4\text{mm}$, atmospheric pressure, 70% of relative humidity).

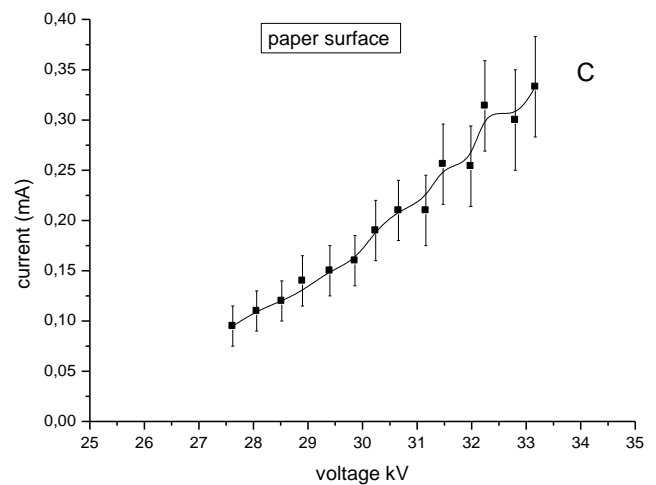


Figure 8 : Current-voltage characteristic on a paper surface in standard geometry (2mm diameter, $d=40\text{mm}$, $h=0.4\text{mm}$, atmospheric pressure, 70% of relative humidity).

On the paper surface, the two regimes and the breakdown point may be observed too, but the current increases nearly linearly with the applied voltage (Figure 8).

Other materials have been tested like PVC, Teflon, but no discharge was observed in these experimental conditions (probably because these materials are very hydrophobic).

Influence of the geometrical arrangements of electrodes

The glass seems to be more practical for electroaerodynamic experiments. Then, the glass was used in all of the next experiments.

The current variations seem to be independent of the distance between the electrodes and the top of the insulating surface as long as this distance remains smaller than 0.3 mm (Figure 9). For distances higher than 0.3 millimetres, the current decreases rapidly when the distance (h) increases.

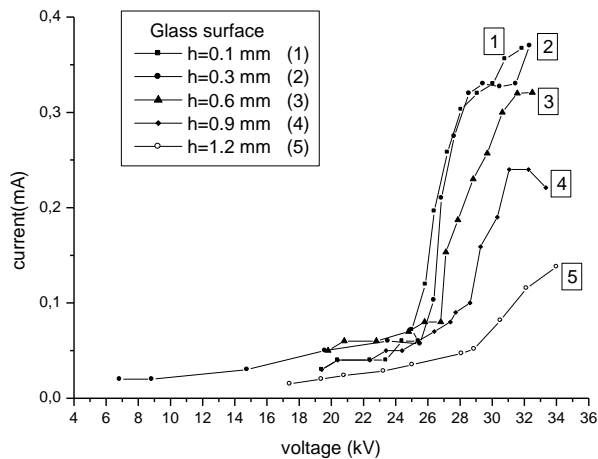


Figure 9 : Current-voltage curves at various values of electrode – surface distances (h), on a glass surface in standard geometry (2mm diameter, d=40mm, atmospheric pressure, 70% of relative humidity).

As a rule, the onset potential of the plasma sheet increases linearly with the electrode gap. The Figure 10 shows that the maximum current value is increases when the electrode gap gets wider.

The relative humidity influence

Humidity of air act to increase the current intensity of the discharge on glass (Figure 11). The current is two times more important with a 80% of relative humidity than with 55% and the general comportment seems to be linear.

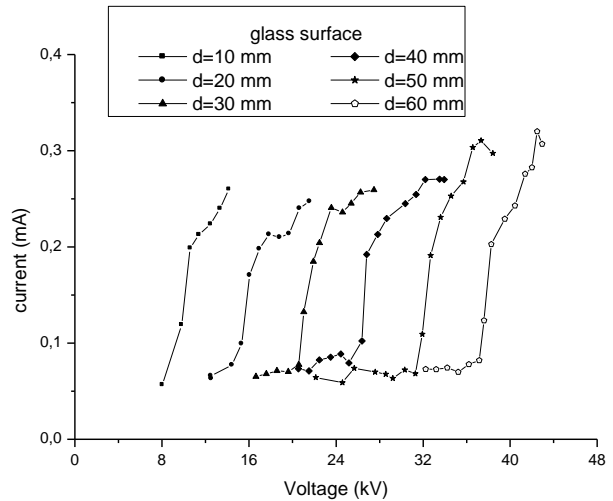


Figure 10 : Current-voltage curves at various values of electrode gap (d), on a glass surface in standard geometry (2mm diameter, h=0.4mm, atmospheric pressure, 60% of relative humidity).

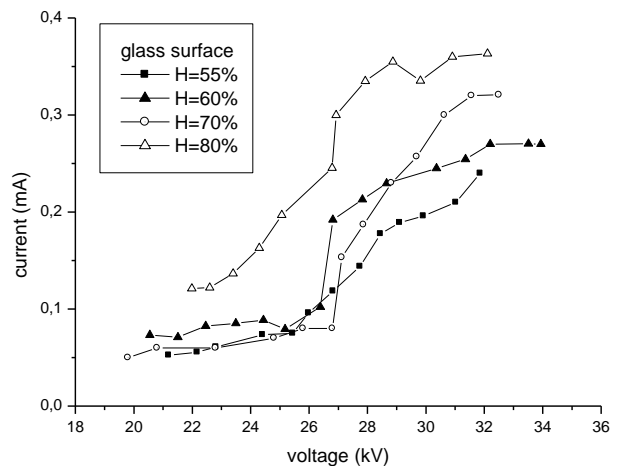


Figure 11 : Current-voltage curves at various values of relative humidity , on a glass surface in standard geometry (2mm diameter, h=0.4mm, gap d=40mm,atmospheric pressure).

Conclusion

The two aims of this study were to obtain an increase of the discharge current and a stable discharge even with a high level of relative humidity. As it has previously been observed, the surface material and the relative humidity have a great influence on the current intensity of a dc surface corona discharge. Stable discharges have been obtained until 80% of relative humidity of air on a glass surface. This work has shown that the current intensity should be increased by a geometrical optimization too. Very stable plasma sheets

have been obtained but no “high spot type” regime could be produced.

This is the first part of a more complete experimental study. Then, in the near future, many geometrical parameters will be tested. Others insulating material will be tried in order to increase the current intensity.

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Author address: Christophe LOUSTE, Laboratoire d'Etudes Aérodynamiques, Electrofluidodynamic group, University of Poitiers, Téléport 2, Bd Curie, BP 30179, 86962 Futuroscope. E mail: Christophe.Louste@lea.univ-poitiers.fr