CHARACTERIZATION OF AN ATMOSPHERIC DBD PLASMA JET WITH OPTICAL EMISSION AND MASS SPECTROMETERS

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ABSTRACT

The present study reports a characterization of a cold plasma jet at atmospheric pressure. It is obtained from a Dielectric Barrier Discharge (DBD). The final aim is to create a soft ionization source which coupled with a Time Of Flight Mass Spectrometer (TOF-MS) permits the detection of species of an analyte present on a surface or injected in the gas flow. In this work a comparison between Neon and Helium plasma jet will be presented, the lengths of the jets and the spatial distributions of the species excited by the plasmas in open air will be investigated.

1. INTRODUCTION

In recent years cold plasma sources at atmospheric pressure have tempted many research groups [1-2]. They don't need expensive vacuum equipment and their low temperature and particular properties make it a useful tool in various fields as biomedicine, nanomaterial synthesis, material surface modification and analytical chemistry. This work belongs to the last one. The aim is direct analysis of analytes. Desorption and ionization abilities of the plasma source coupled to a mass spectrometer allow high sensibility and selectivity for chemical analysis. There exists two domains: atmospheric pressure ionization mass spectrometry (API-MS), this technique needs a preliminary sample preparation, and ambient desorption/ionization mass spectrometry (ADI-MS) which needs any preparation of the sample before its analysis.

Among the atmospheric pressure plasma sources, dielectric barrier discharge sources (DBD) have been investigated [3]. A soft ionization can be obtained allowing the preservation of the analyte integrity [4]. The fragmentation must be avoided otherwise the molecules of interest risk to be difficult to identify [5]. Some configuration of DBD allows the creation of a plasma jet (plasma plume) extending beyond the end of the source in open space [6]. The jet can be directly pointed toward the surface to be analyzed.

In this work in order to characterize our plasma source recently developed, a comparison between Neon and Helium as gas discharge will be performed. The experimental results about the jet length and the spatial distribution of excited species along the plume as a function of flow rate and applied voltage will be investigated.

2. EXPERIMENTAL SETUP

The DBD plasma source apparatus is shown on the figure 1. It consists of two parts: the first one is a cylindrical chamber and the second one is a slightly conic capillary tube. Each part is surrounded by an external conductive electrode. The originality of this source is its asymmetric geometry.

The source is powered by a square alternative voltage of some tens of kHz. The supply (A2e Technologies) can vary the frequency from 10 kHz to 100 kHz and the applied voltage in a range from 0 kV to 3 kV. The working gases are Neon and Helium. They are fed by a flow controller (Bronkhorst High Tech). The flow rate can vary in a range from 0.1 to 21.2 $L.min^{-1}$. The electrical measurements are achieved with a Tektronix TDS7104 digital phosphor oscilloscope coupled with a Tektronix P5210, 50 MHz Active Differential Probe for voltage measurements and a Pearson current monitor 6585, 250 MHz for current measurements. The optical measurements are performed with two Optical Emission Spectrometers (OES):

- Avantes (2048-2) spectrometer with two fibers: one from 188 to 714 nm and the other one from 639-1099 nm.
- Ocean Optics (USB 4000) spectrometer operating in the spectral range 350-950 nm.

The length of the plasma is achieved by treating pictures obtained with a photo camera (Konica Minolta Dimage A2).

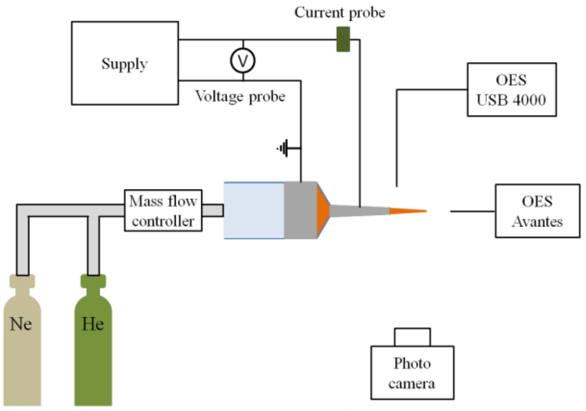

Figure 1: Experimental setup of DBD plasma jet.

3. RESULTS WITH NEON AND HELIUM AS DISCHARGE GAS

The discharge is ignited between the two electrodes near the input of the capillary tube. A plasma jet is blown out from the capillary termination. The influence of different parameters is studied for the two gases and they are compared between them. The influence of the flow rate and the injected power has been investigated. In this study the flow rate of Neon varies in a range from 1.1 $L.min^{-1}$ to 3.4 $L.min^{-1}$ and the voltage in a range from 900 V to 1700 V and for Helium the flow rate varies from 1.1 $L.min^{-1}$ to 5.6 $L.min^{-1}$ and the applied voltage from 2000 V to 2700 V. These applied voltages have been chosen in a way to have several voltages above the breakdown voltage.

3.1. PLASMA JETS

Neon is ignited at lower applied voltage than Helium, 900 V against 2000 V. However the injected power for Neon is much higher, it is from 4 W (900 V) to 18 W (1700V) and from 2.5 W (2000 V) to 5 W (2700 V) for Helium. As shown on the figure 2 the plasma jet has the same shape for the two gases; they look like a slender needle. For a fixed flow rate the length of the jets increases with injected power (figure 3).

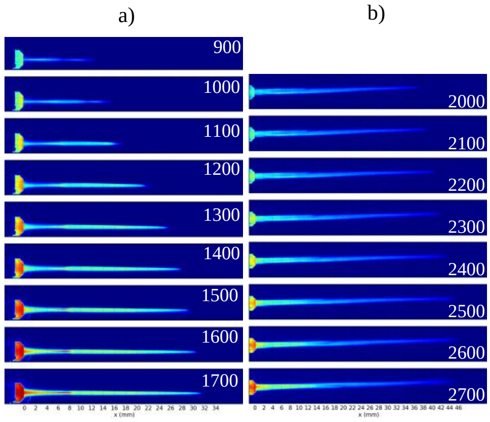

Figure 2: plasma jets for Neon a) and Helium b) as a function of the applied voltage at their own optimal flow, respectively 2.3 $L.min^{-1}$ and 4.5 $L.min^{-1}$

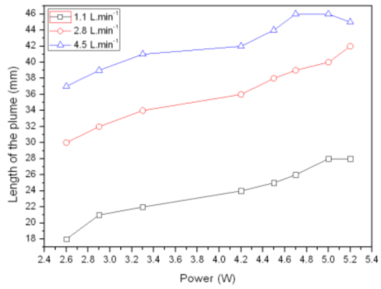

Figure 3: Length of the He plasma jet in air as function of the injected power for different flow rate

The plume obtained with Neon is shorter than that obtained with Helium. The length of the plumes increases with the flow rate until an optimal flow and decreases after it (figures 4a and 4b). The optimal flow rate is lower for Neon, respectively 2.3 $L.min^{-1}$ and 4.5 $L.min^{-1}$ for Ne and He. When the flow is too high, the length of the plume decreases fast due to gas perturbations.

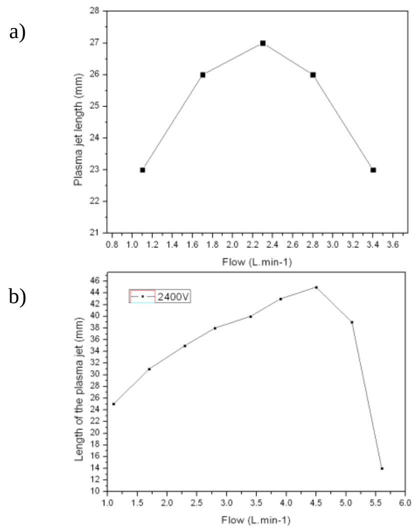

Figure 4: length of the plasma plume as function of the flow rate for Neon a) and for Helium b).

3.2. EXCITED SPECIES

For the optical measurements two optical emission spectrometers are used. The Avantes spectrometer is placed in front of the end of the capillary termination with the aim to observe the excited species.

For Neon the lines of Ne, O, and H are observed and in smaller amount OH and N_2 are also detected as shown in figures 5a and 5b. With Helium as discharge gas same species are observed with emission lines of N_2^+ (figure 5c).

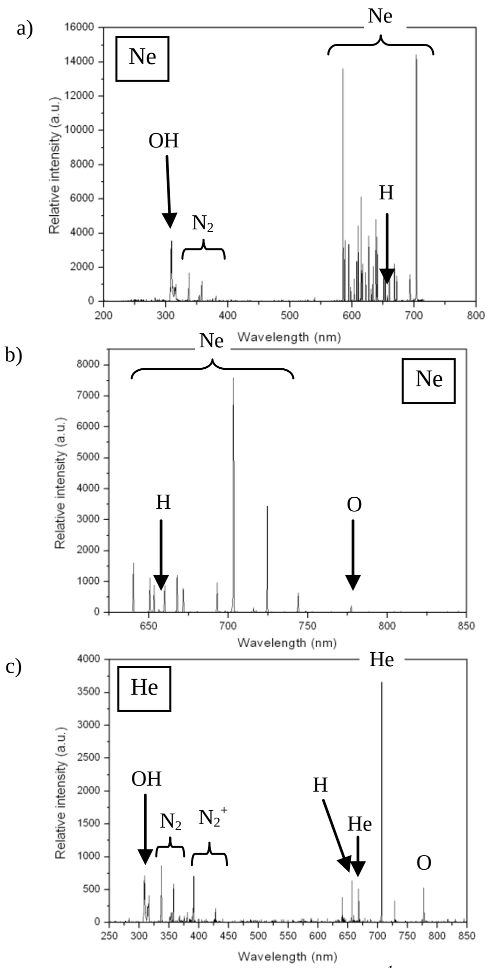

Figure 5: front spectrum: a) Neon at 1.2 L.min^{-1}, 1700V, acquired with 500 ms integration time in a range from 250 nm to 714 nm, b) Neon at 1.2 L.min^{-1}, 1700V, acquired with 15 ms integration time in a range from 639 nm to 850 nm, c) Helium at 3.2 L.min^{-1}, 2300V, 200 ms integration time in a range from 250 nm to 850 nm.

The Ocean Optics spectrometer is placed on the side of the plasma jet and moving along the plume with the aim to investigate spatial distribution of the excited species. From the capillary tube to the end of the jet a lateral spectrum is recorded at each millimeter.

The spatial distribution along the plasma jet of Ne is performed for the lines 585 nm, 640 nm and 703 nm of Ne, 656 nm for H and 777 for O, the OH and N_2 lines cannot be observed in good conditions with the Ocean optics spectrometer. Along the jet of He the lines 706 nm of He, 391 nm for N_2^+ and 380 nm for N_2 add to the lines of O and H already followed.

On figure 6a and 6b, it can be observed that the lines of Ne, He, H and O are more intense close to the capillary and their intensities decrease with distance, while the lines of N_2 and N_2^+, observed in the case with He, are maximum about 5 mm after the beginning of the jet in open air. On figure 6 the intensity of N_2 is increased by a factor 4 to be easiest to observe. The intensity of N_2^+ decreases faster than the intensity of N_2 along the jet.

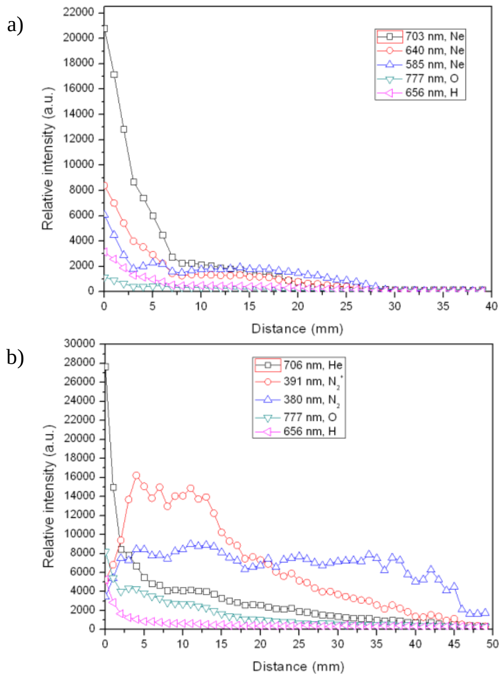

Figure 6: spatial distribution of excited species along the plasma jet for Neon a) at 1400V and 1.6 L.min^{-1} and for Helium b) at 2400V and 3.2 L.min^{-1}.

The influence of applied voltage and flow rate is studied. On figure 7, the spatial distribution of N_2^+ is plotted at different voltage (a) and at different flow rate (b). We can observe that the intensity increases with the applied voltage and the zone of N_2^+ presence becomes broader and is shifted with increasing the voltage. The same results are observed when the flow varies until the optimal flow rate and then when the flow is too high the length of the plasma plume decrease and the area of interest is shortened. For the other species the reactive zone becomes broader too and the maximum of intensity becomes higher.

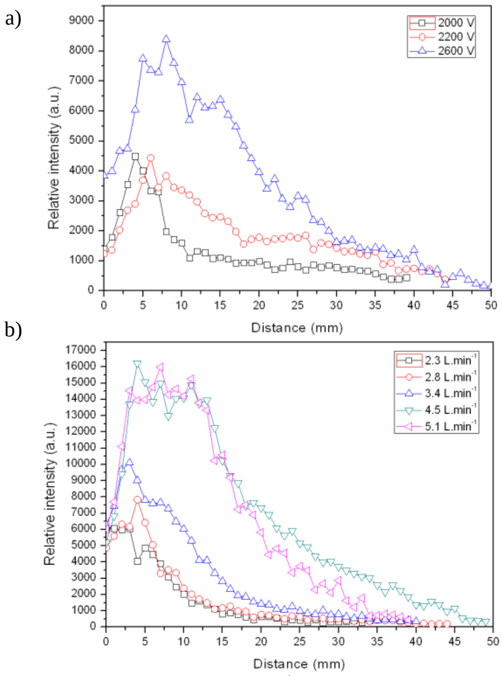

Figure 7: spatial distribution of N_2^+ as a function of a) the applied voltage (at fixed flow rate) and b) the flow rate (at fixed applied voltage)

4. CONCLUSION

Optical measurements have been presented to characterize our plasma source. The length of the plume is influenced by the applied voltage, the flow rate and the discharge gas. The variations of the excited species line intensities have been plotted as a function of the distance from the source exit according to the applied voltage and the flow rate. For Neon and Helium their ability to ionize or excite the species of the open air was illustrated. There are more excited species with Helium in the ambient air region.

The characterization by a mass spectrometer of this source with Helium as gas discharge will be more investigated with the aim to optimize the creation of reactive species.

5. ACKNOWLEDGMENT

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