Quantitative insights in to the fluid interactions downstream of an atmospheric pressure dielectric barrier plasma jet

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1. Introduction

Low-temperature atmospheric pressure plasma jets are dielectric barrier discharges generated in thin dielectric tubes. The gas flowing through the capillary, typically helium or argon, is ionized, and emerges into the ambient air creating a variety of reactive chemical species. The spatial separation between the region of plasma generation and reactive species creation makes the plasma jet configuration unique, facilitating a stable source of short-lived and long-lived reactive oxygen and nitrogen species (RONS) under ambient conditions (Figure 1). Understanding the complex interaction between the discharge and the background gas is the key to understanding the RONS chemistry arriving at a downstream sample.

Recently, considerable progress has been made in understanding the complex fluid interaction at play in a plasma jet configuration. Many studies have demonstrated dramatic changes to the structure of the flowing gas, which initiate turbulent fluctuations; both gas heating and electro-hydrodynamic forces have been cited as possible mechanisms behind these observations [1, 2, 3].

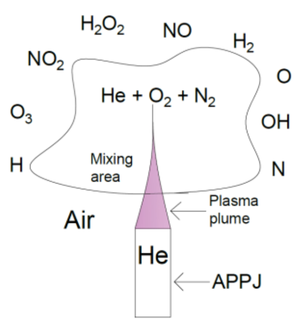

Figure 1: Schematic representation of the plasma chemistry of a helium atmospheric pressure plasma jet in air

2. Experimental methods

Particle image velocimetry (Figure 2) was used to study quantitatively the behaviour of the complex fluid interactions at the edge of an ignited low temperature atmospheric pressure plasma jet (Figure 3). The PIV box was filled with gas seeding, and a laser sheet illuminates the particles at a 90 degree angle with respect to a high speed camera. The synchronisation between the camera and the lasers allows a time-resolved detection of particle positions, a cross-correlation method calculates the particle movements.

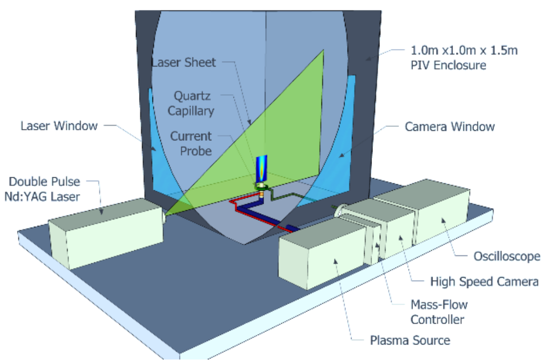

Figure 3: Depiction of experimental arrangement used to capture Particle mage Velocimetry measurements

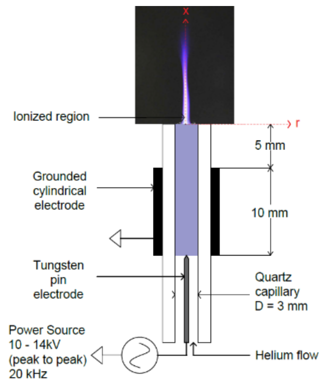

Figure 2: Schematic representation of the experimental set up of the low temperature atmospheric pressure plasma plume device.

3. Results

a. Plasma jet averaged velocity field

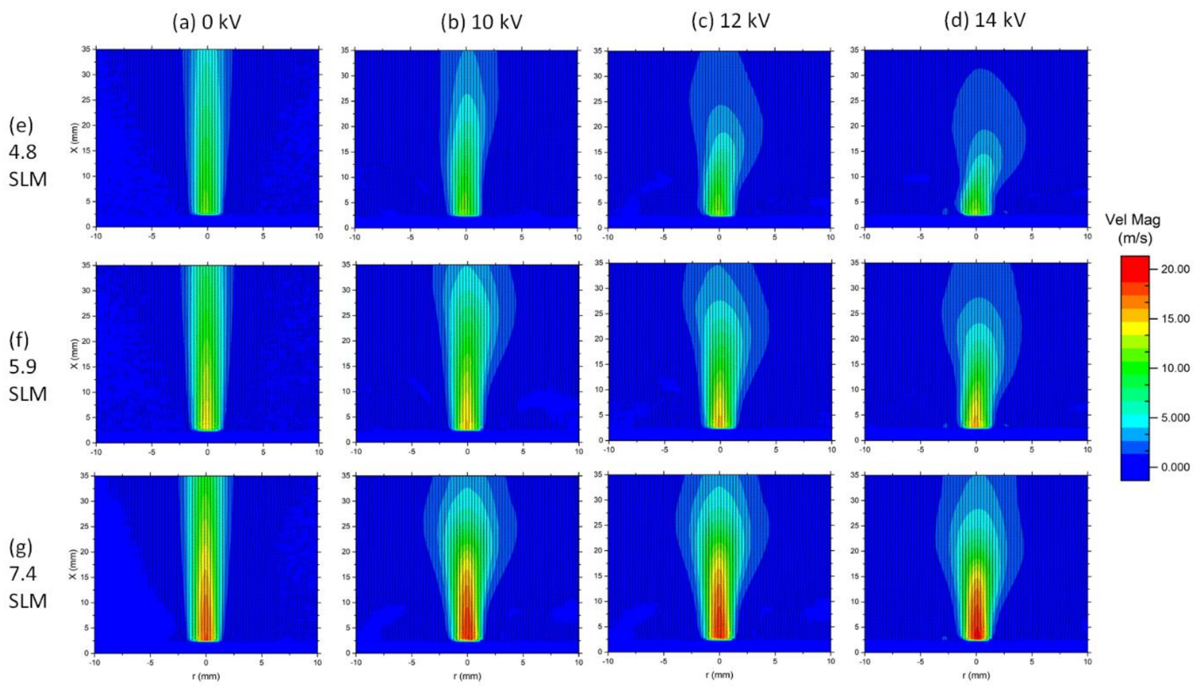

Figure 4: Averaged velocity vector maps of a helium atmospheric pressure plasma jet measured with PIV for flowrates of (e) 4.8, (f) 5.9 and (g) 7.4 SLM. The jet was studied without plasma (a) and with applied voltages of (b) 10, (c) 12 and (d) 14 kV.

The averaged velocity field of the flowing gas on Fig 4 shows that the applied voltage has little to no impact on the velocity of the flowing gas but influences the length of the laminar section and the radius of the turbulent structure. Augmenting the flowrate increases the laminar section and the velocity.

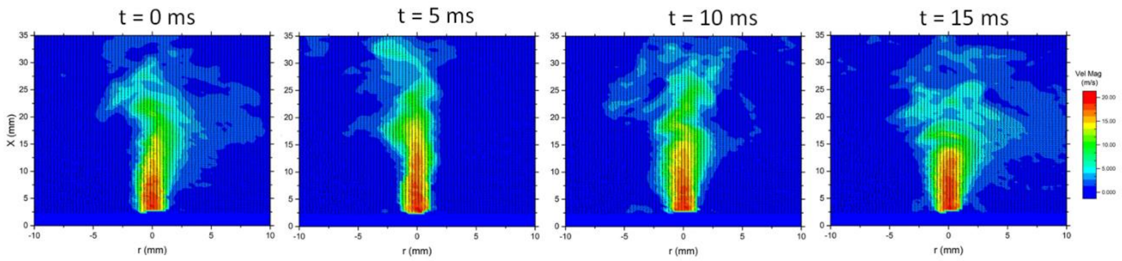

Figure 5: Time-resolved velocity vector maps of a helium atmospheric pressure plasma jet measured with PIV for a flowrates of 7.4 SLM and an applied voltage of 14 kV with a delay of 5 ms between two images.

The time-resolved turbulent behaviour of the flowing gas under the influence plasma discharge. The averaged velocity fields (Figure 4) are axisymmetric whereas the time-resolved velocity fields (Figure 5) reveal fluctuations in turbulent flows.

b. Reynolds shear stresses

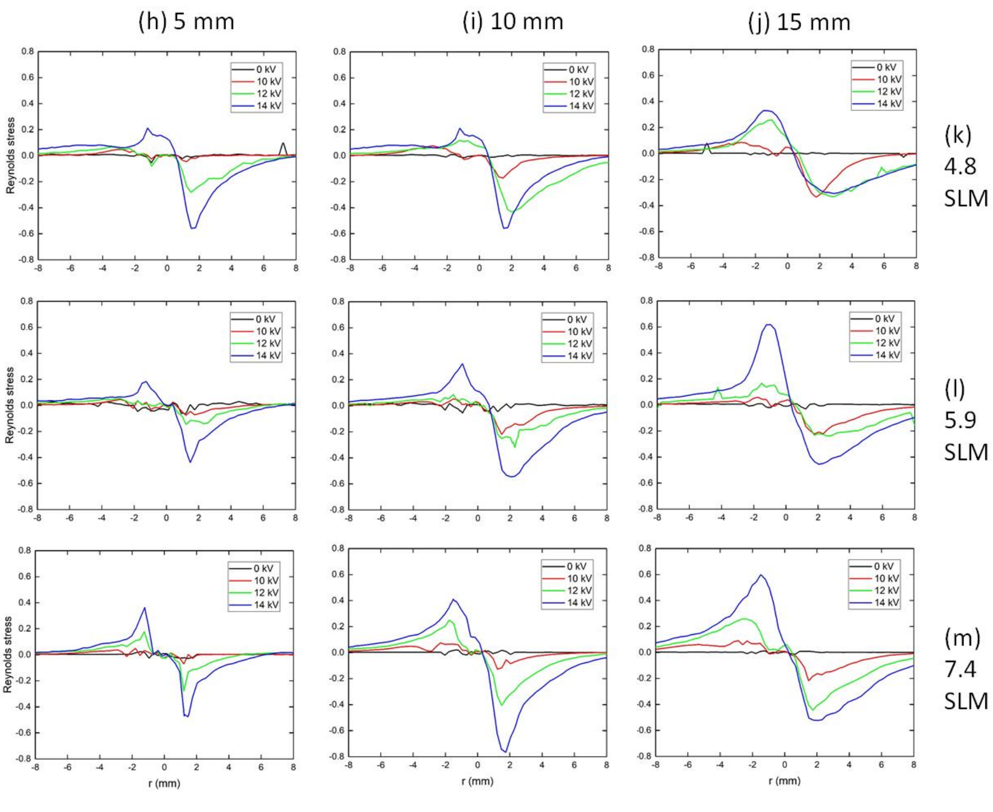

Figure 6: Reynolds shear stress calculated at (h) 5, (i) 10 and (j) 15 mm from the tip of the tube for flowrates of (k) 4.8, (l) 5.9 and (m) 7.4 SLM and applied voltages of 0 (black), 10 (red), 12 (green) and 14 kV (blue).

Reynolds shear stresses along the turbulent plasma jet (Figure 6) depending on three parameters; the applied voltage, the flowrate and the distance from the tip of the tube. Reynolds shear stress ($\overline{u'v'}$) indicates the turbulence production in the plasma jet where (u') and (v') are respectively the streamwise and radial velocity fluctuations.

4. Conclusion

In this investigation, particle imaging velocimetry (PIV) was used to provide quantitative insights into the complex fluid interactions at the orifice of a helium plasma jet. Two parameters were studied, the flow rate (4.8, 5.9 and 7.4 SLM) and the applied voltage (0, 10, 12 and 14kVpp).

By capturing the velocity profile of both the flowing and background gas the impact of plasma generation parameters on the flow structure were identified. It was observed that key plasma parameters, such as the applied voltage, have little impact on the velocity of the flowing gas.

This finding implies that the early onset of turbulence in the plasma jet is not attributed to an increased velocity, but is more likely a consequence of a periodic perturbation to the jet shear layer introduced by the discharge. The perturbations revealed by Reynolds shear stresses can be attributed to gas heating and electrodynamic forces based on literature.

5. References

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