Ozone mapping the kINPen-MED plasma jet

S. Kelly[1*], G. S. Gogna[1], R. Monaghan[2] and S. Daniels[1]

[1]*National Centre for Plasma Science and Technology, Dublin City University, Dublin 9, Ireland*
[2]*NuWave Sensors, Innovation Campus, Glasnevin, Dublin 11, Ireland*
* *email: sean.kelly@dcu.ie*

Spatial mapping of the ozone concentration in the plume of the kINPen-MED® plasma jet was carried out using a heated metal oxide ozone sensor (NuWave MO35). A honeycomb optical breadboard was used to position the sensor accurately at points in the plane of the jet effluent. Operating with an argon carrier gas ozone values of 240-11 ppb are found to extend 500 mm from the nozzle encompassing a radius of 20 mm. For jet operation with compressed air larger ozone values of 1100-15 ppb were found to extend 500 mm from the nozzle within a radius of 20 mm.

1. Introduction

Ozone is well known for its sterilisation, anti-bacterial and bio-active properties. It is currently of particular research interest due to its central role in promising bio-medical applications of low temperature atmospheric pressure plasmas [2]. Direct measurement of ozone concentrations in the jet plume and surrounds is of particular interest in characterising dosage, a key requirement for advancement of bio-medical applications. Ozone measurements also provide insight into the behaviour of other reactive species such as NO which shares a competitive chemistry and is strongly correlated to O_3 concentrations [5, 6]. Recent reports on atmospheric pressure argon and air plasma jets [8, 5, 6] have discussed the ozone density in close proximity to the plasma nozzle (< 40 mm). In this report we explore the spatial variation in ozone concentration in the "far" region (25 - 500 mm) for these jets.

The kINPen-MED® [1] is a commercially available plasma jet designed for use in medical applications such as wound healing and sterilisation [3]. This low temperature corona source consists of a pin and plate geometry enclosed in a ceramic shower head for plasma generation. The pin electrode is biased at a ~MHz frequency (~1 MHz) with voltage amplitudes of the order of 2 - 6 kV [1, 3]. The power source is pulsed at a ~kHz frequency to limit gas heating. In this report the device is operated with compressed air and bottled Argon (99.999 % purity).

The NuWave MO35 sensor [4] is a commercially available ozone sensor based on heated metal oxide sensor (HMOS) technology. This probing method exploits the sensitivity of heated metal oxides (TiO_2) to ozone by correlating changes in the metal oxide electrical resistance in the presence of ozone [7, 4]. The MO35 uses an internal temperature sensor and microcontroller to correct the measured ozone levels in real-time. Data is output in parts per billion (ppb) increments each second. The maximum concentration detectable by the NuWave MO35 sensor is 2000 ppb [4].

2. Method

The kINPen-MED® and NuWave MO35 sensor were laid out on a honeycomb structured optical breadboard as shown in figure 1. The kINPen-MED was aligned horizontally using an x-y positioning stage. The sensor head (diameter ~8 mm) is aligned with the jet nozzle at fixed positions on the breadboard using the optical post and feet accesories.

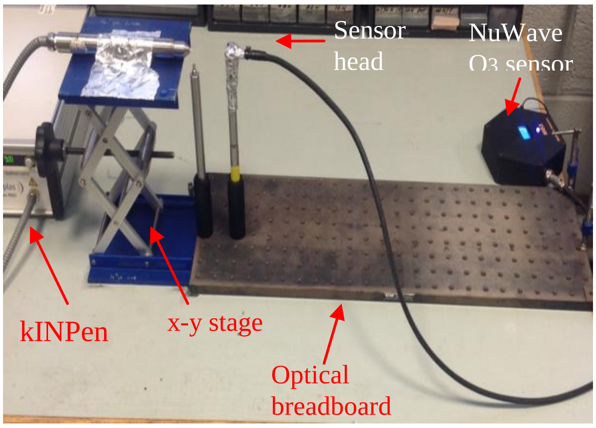

Fig. 1 - KINPen-MED and NuWave MO3 sensor aligned with an optical breadboard

This novel steup allows accurate and repeatable measurement of reactive species (ozone) in the central plane of a plasma jet plume using small sensors of this type. An ozone map is formed by positioning the sensor head at the numerous bore holes on the optical breadboard (25 mm separation). Finer readings are then taken by offseting the plasma jet position relative to the breadboard bore holes within 5-20 mm and repeating the measurement. Steady state readings during jet operation were reached after ~1 minute. Sensor data is taken as an average over ~30-60 seconds of data capture. The error is caluclated from the standard deviation of this data.

3. Results

Ozone (O_3) sensor measurements for operation of the kINPen-MED® with an Argon carrier gas using a 5 slpm gas inlet flow are shown in figure 2 and figure 3. Background (ambient) ozone values of ~11 ppb were recorded. Results in figure 2 display a diffuse ozone distribution around the plasma jet. Peak O_3 values of 238 ppb occur in the vicinity of the nozzle (x = 25 mm) and encompass a radius of ~5 mm. Downstream ozone values of ~30 ppb, well above the background density, are found to occur at x = 500 mm and encompass a radius of ~25 mm surrounding the nozzle.

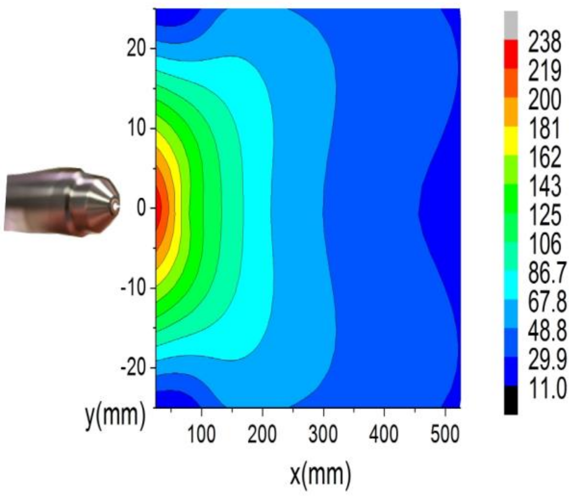

Fig. 2: Ozone density (ppb) in the horizontal plane of plasma jet plume (25 - 500 mm): Argon (5 slpm inlet)

The spatial variation of ozone concentration in figure 2 displays (approximately) a semi-circular pattern with an expanding radius of ozone diffusing from the nozzle. Ozone measurements along the central axis of the jet plume (y=0 (see figure 2)) are shown in figure 3. The O_3 concentration drops from 238 ± 19.8 ppb to 128 ± 2.2 ppb between x = 25 and x = 100 mm away from the nozzle. At 200 mm ozone values of 72 ± 2.8 ppb are recorded and at 525 mm this drops to 27 ± 2 ppb. This trend displays an exponential decay towards background ozone levels (~ 11 ppb) in the far region downstream of the device nozzle. Ozone diffusion profiles shown in figures 2 & 3 illustrate that ozone is relatively stable in the environs of the jet compared to other reactive oxygen species (ROS) such as atomic oxygen (O) which are typically consumed in the vicinity of the plasma jet nozzle.

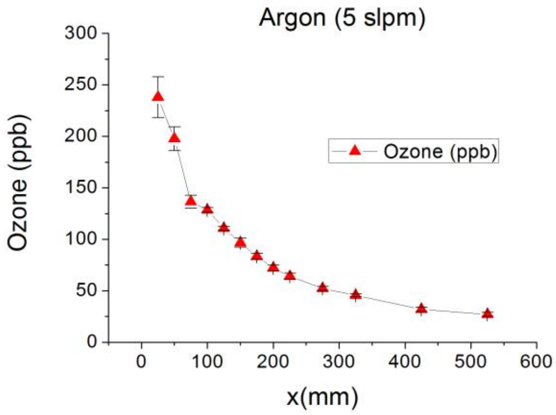

Fig. 3 - Ozone density (ppb) along the central axis (y = 0 (see figure 2)): Argon (5 slpm inlet)

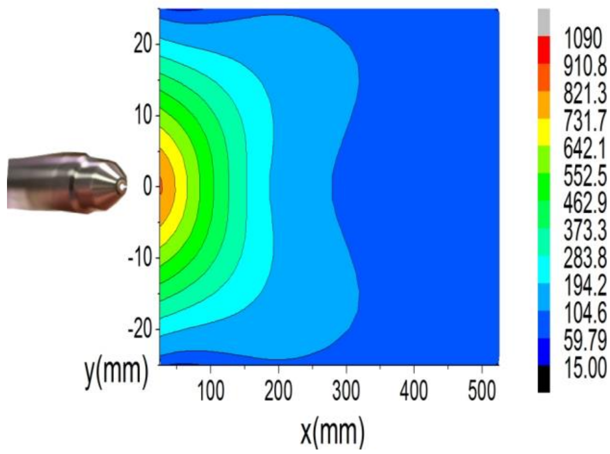

Fig. 4 Ozone density (ppb) in the horizontal plane of plasma jet plume (25 - 500 mm): Air (5 slpm inlet)

Figure 4 shows the Ozone (O_3) sensor measurements for operation with air as the carrier gas (5 slpm). Air is captured from the surrounding environment via a compressor (Clarke WizAir) and feed to the KINPen-MED. Figure 4 shows a diffuse ozone pattern similar to argon shown above (see figures 2 and 3) but with significantly larger ozone concentrations. Figure 5 shows the equivalent ozone density along the horizontal axis (y = 0). At x = 25 mm the O_3 concentration is 1088 ± 187 ppb which is approximately 5 times that of the equivalent argon value (see figure 3). A similar exponential decay with increasing distance from the nozzle to argon operation is found for air. Ozone values at x= 125 mm, 225 mm and 525 mm were (respectively) 378 ± 26.7, 129 ± 3.8 and 64 ± 2.4 here (see figure 5).

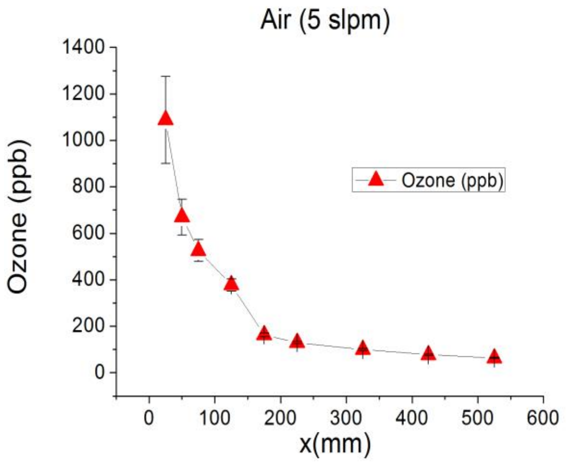

Fig. 5 - Ozone density (ppb) along the central axis (y = 0 (see figure 4)): Air (5 slpm inlet)

4. Conclusions

Spatial mapping of the ozone concentration in the plume of the kINPen-MED® plasma jet was carried out using a commercial heated metal oxide ozone sensor (NuWave MO35). Results show a diffuse O_3 pattern around the plasma plume for both argon and air carrier gases. For both operating gases the O_3 concentration is found to decay exponentially along the central axis of the plasma plume with concentrations exceeding background levels at over 500 mm downstream and within a 25 mm radius of the nozzle. Peak ozone density recorded for argon operation ranged from 27-238 ppb along the central axis of the plume. Two dimensional ozone values of 240-11 ppb are found to extend 500 mm from the nozzle encompassing a radius of 20 mm. Operation with compressed air lead to significantly larger ozone values ranging from 64-1088 ppb along the central axis. Two dimensional ozone values of 1100-15 ppb were found to extend 500 mm from the nozzle within a radius of 20 mm.

Acknowledgements

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