



# Ambient humidity has minor influence on OH emission of an atmospheric pressure argon plasma jet than feed gas humidity

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## Research Background

Since several years atmospheric pressure plasmas are investigated for biomedical applications due to their highly reactive species production at modest gas temperatures. Large achievements were accomplished by using these plasma sources for decontamination purposes, in wound treatment and even for the inhibition of cancer cells [1]. In order to understand the complex interaction mechanisms between the plasma and the treated biological material several research groups worldwide do basic research in the young field of plasma medicine. From the application point of view not only the active agents but also the influence of different ambient conditions must be studied. This is since from location to location temperature, pressure and humidity level can change drastically. In this report we focus on the influence of ambient humidity since variety plasma chemical reactions are drastically influenced by the presence of water molecules. In previous studies we found that small amounts of humidity inside the active zone of an radio-frequency driven atmospheric pressure argon plasma jet (figure 1) have large effects on the generation of active species in the gas phase like hydroxyl radicals (OH) and hydrogen peroxide ( $H_2O_2$ ) but also drastically influence the viability of plasma treated human skin cells [2, 3]. When the feed gas humidity concentration is changed from dry feed gas condition to several hundred parts per million (ppm) the cell viability decreases by 50 %.

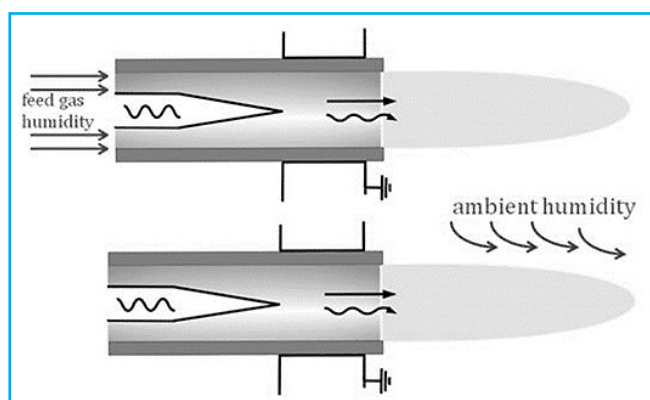


Figure 1: Schematic of the radio-frequency driven atmospheric plasma jet displaying different sources of humidity. [4]

## Application Note

The open question was whether the ambient humidity has a similarly relevant effect. Therefore, the plasma jet was operated with a shielding gas device [5], which provides a defined gas shield around the effluent. Using humidified air as shielding gas mimics a humidified ambient air condition.

One important species to monitor in the context of humidity variation is OH. It is mainly created by dissociation of  $H_2O$  by collisions with energetic particles (e.g. electrons, metastable argon atoms). When excited OH(A) relaxes to the ground state characteristic bands are observed in the spectral range between 308 nm and 313 nm (figure 2). The aim of the study is to compare the space resolved OH emission intensity for the three cases that (1) no humidity is artificially added neither to the feed gas or the shielding gas, (2) water is admixed to the feed gas and the jet is operated under dry ambient conditions and (3) that dry feed gas and humidified ambient conditions are used. Together with other techniques like laser induced fluorescence spectroscopy (LIF) and Fourier transformed infrared spectroscopy (FTIR) conclusions on the importance of ambient humidity can be drawn [5].

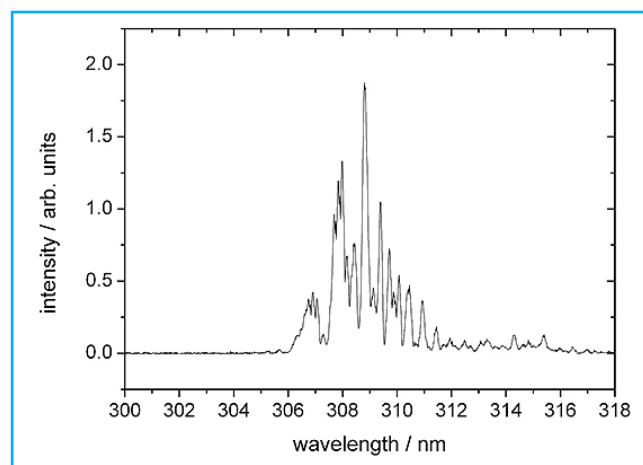
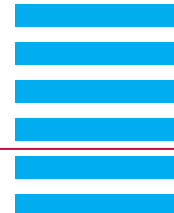


Figure 2: Optical emission spectrum of OH(A-X) for humidified feed gas condition at position  $r = 0$  and  $z = 4$  mm.

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## Application Note

### Space resolved OES: devices

The emission spectrum of relaxing excited OH produced by the plasma jet was detected space resolved with an imaging spectrograph (Shamrock SR-500i-A, grating 2400 l/mm blazed at 300 nm, focal length 500 mm). The plasma jet was imaged by a set of lenses onto the entrance slit of the spectrometer. By means of a stepping motor (Thorlabs, LNR50K3/M) the plasma jet was moved precisely in radial direction. The spectrograph was equipped with a Newton EMCCD-Detector (DU971P-UVB) sensitive in the UV spectral range. This back illuminated detector with 1600 x 400 pixels was used to detect the small intensities emitted from the plasma jet. At every jet position each row of the camera's two dimensional array represents the emission spectrum of a different axial position of the plasma. Thus, 400 axial positions with a spatial resolution of 70  $\mu\text{m}$  were obtained and spectrally analyzed in a single shot. The radial spatial resolution was determined by the step size of the stepping motor and was set to 100  $\mu\text{m}$ . A radial range of  $\pm 2$  mm around the jet nozzle center was scanned.

Due to the small emission intensity the camera gain was set to the maximum value. This enabled us to use a rather short exposure time of 2 s and to perform 10 accumulations at every radial jet position. A complete spatial scan of the jets emission took about 20 minutes. The complete measurement system (spectrograph, EMCCD detector and stepping motor) was controlled by a self-developed Python code which uses the software development kits provided by Andor and Thorlabs.

### Space resolved OES: results

Figure 3 shows the spatial intensity distribution integrated from 308-313 nm of excited OH-emission for the three investigated humidity admixture cases. The intensities are normalized on the maximum value of figure 3c. The center of the jet nozzle is located at zero radial position. A slight asymmetry of the intensity signal is observed, which originates from the pin type high voltage driven electrode and the fact that the core discharge tends to ignite on one side in the nozzle tube. In axial direction z, intensities are not plotted from the jet nozzle position at z = 0 but from 2.5 mm, which is the end of the glass made shielding gas nozzle.

In case of dry feed gas and dry shielding gas condition (a) the lowest signal intensity was measured. Although, theoretically no OH emission should be visible for dry condition a small signal is detected up to an axial nozzle distance of 6 mm. This remaining signal probably originates from humidity residues in the gas pipe channel. By increasing the humidity level in the shielding gas to 10,000 ppm and using dry feed gas at the same time, the signal of figure 3b is obtained. The intensity is higher than for the dry case in figure 3a and emission is detected up to an axial distance of 8.5 mm.

Figure 3c shows the OH emission for dry shielding gas and humidified feed gas (humidity concentration 490 ppm). Although the humidity concentration is by a factor of 20 lower than for the case in figure 3b, the most intense signal was obtained for this case. This emphasizes the importance of feed gas humidity in the excitation process of OH and indicates that ambient humidity plays a minor role at least for the generation of OH emission. Topic related studies on the different impact of feed gas and shielding gas humidity on cell viability also show that although the humidity concentration in the shielding gas is by far higher than in the feed gas a significantly smaller effect on human keratinocyte viability was found.

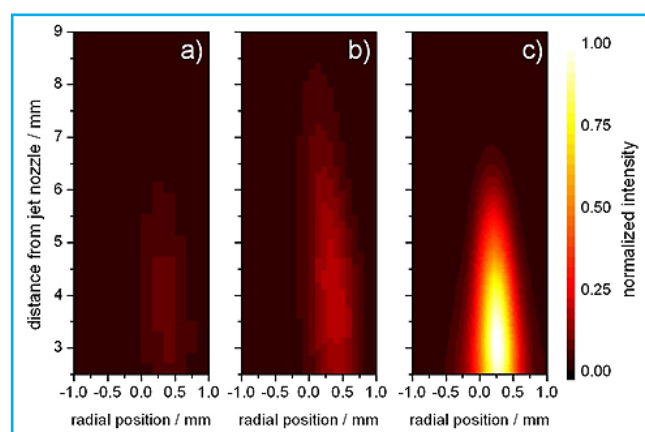


Figure 3: Spatial intensity profiles for a) dry condition (humidity concentration < 20 ppm), b) dry feed gas and humidified shielding gas air (10,000 ppm) and c) feed gas humidity (490 ppm).

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## Application Note

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### Literature

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