The interaction of non-thermal atmospheric pressure plasma with liquid

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Abstract: A pin-water geometry is used to study the gas phase properties of a non-thermal atmospheric pressure plasma in interaction with water. The accent is on the comparison of the AC- and the pulse-driven discharges. Properties like electrical characteristics, gas temperature distribution, electron densities and their development over time are discussed.

Keywords: Atmospheric pressure non-thermal plasma, plasma-liquid interaction

1. Introduction

Plasma-water interactions hold interest of scientists in the last years mostly due to the potential applications of plasmas in contact with water. In medicine using plasma-treated liquid is simpler than applying plasma directly on the patient's body and even in the direct plasma-tissue interaction there is always a liquid layer covering the tissue. For agriculture plasma-water interactions are being studied and upscaled either for green fertilizer production or to produce liquid for disinfecting plants, thus keeping them healthier. Here efficiency is key, bringing the need for detailed understanding of the manner in which the liquid is "activated" and the energy spent in this process. There are also numerous applications involving cleaning water from either chemicals or microorganisms. Here high throughput is of interest, thus necessitating the development of reactors capable of treating high volume of liquid; next to engineering the plasma well, these reactors require careful consideration of transport phenomena. All those applications require careful engineering, however the knowledge of basic plasma-liquid interaction is key for the development of systems that do not only work, but also bring about desired results.

The study of the interface in plasma-water interactions is currently of great interest, but also poses quite a challenge. The interface is difficult to access for the available diagnostics methods, even more so time-resolved. This is why there is quite some research focusing on the gas and the liquid phase close to the interface during plasma-water interaction.

This is a study of the plasma in the gas phase, during plasma-water interaction. The study is done in a simple setup that is optically accessible. It is not a setup that is efficient in the production of plasma-treated liquids, however it is representative of plasma-water interactions at kHz frequencies. The focus is on the comparison of AC- and pulse-driven discharges interacting with water. Electrical characteristics, gas temperatures and electron densities are determined for a range of parameters and their development over time is discussed.

2. Experimental setup

The setup consists of a pin-water arrangement, where the pin is on high voltage, up to 5 mm above the water surface. The water container is a standard Petri dish 88 mm in diameter. There is a grounded electrode at the bottom of the Petri dish.

The high voltage is supplied either as sinusoidal AC signal at 30 kHz with 6 kV amplitude or as pulses of variable length, typically 6 kV amplitude and 2 us length. Both polarities were used.

Measurements were done on water samples at room temperature or pre-heated to approximately 70 degrees C.

Optical emission spectroscopy was performed, as well as Raman scattering, for the determination of gas temperatures. Electron densities were measured using Stark broadening.

3. Results and conclusions

The work covers the comparison of AC and pulsed discharges in contact with water and the development of basic plasma properties over time.

Non-thermal atmospheric pressure plasmas are very sensitive to their environment. Especially in the situation where the plasma interacts with a substrate that changes properties over time, it is of importance to be able to characterize the interaction as a function of time. In the case of this setup, the AC and the pulsed-driven discharge interact with the water in a fundamentally different way, where in one the water acts as a (lossy) dielectric, in the other one as a conductor. The fundamental difference between them is the interaction time of the plasma and the water. The consequence are quite different results when using AC- or pulse-driven discharges. The AC-driven discharge interacting with water stabilizes its properties in a matter of minutes, while the pulsed-driven discharge, in both polarities, shows fast rising power dissipation over the period of approximately 15 minutes, after which the power supply cannot sustain the discharge any longer. All other properties change fast in the same time interval, including gas temperature and electron density. The properties of the treated water change in the same time interval.

The initial temperature of the water, although it varied on a relatively small scale compared to typical temperatures of gaseous species, had a large impact on the properties of the discharge, as well as its development over time. The pre-heated water caused the gas temperatures as well as electron densities to rise at a significantly higher rate. The underlying mechanism is still unclear and is currently under investigation.