Investigations of an atmospheric plasma jet for different surface treatments/activations -First results

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The Lab for Plasma Technology owns, among others, two non-thermal, atmospheric plasma systems (Relyon Plasma PB, Regensburg Germany and Plasmatreat RD1004, Steinhagen Germany), which shall be qualified for the large-scale decontamination of surfaces contaminated with different bacteria. In order to achieve this, we first have to assess which reactive species are produced by the plasma sources as well as the impact of the sources on various bacteria (Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa and Candida albicans). In particular, the emitted dose of UV-C radiation by the sources has to be determined with an appropriate measuring camera system. The next step of our work will be to evaluate the modes of action of the different plasma components. In this paper, we describe – after a short introduction regarding the characteristics and the decontaminating effect of non-thermal plasmas – the setup and startup of the first plasma jet generator (RD1004). Beyond that, we report on initial results our Lab has produced with this plasma source so far.

1. Introduction

In recent years non-thermal plasma sources have increasingly prevailed due to their antimicrobial activity being used for decontamination, sterilization and cleaning of contaminated surfaces and equipment. Especially for heat sensitive substrates, cold plasmas are unrivalled. Examples include the sterilization of medical equipment (e.g. stents, scalpels and surgical instruments) [1, 2], the decontamination of biological and chemical warfare agents [3, 4] and the deactivation of various bacteria [5, 6, 7, 8].

Based on their operating pressure non-thermal plasmas are divided into the groups of atmospheric pressure plasmas and low-pressure plasmas. The latter need a closed vacuum chamber, for that reason these techniques are expensive and can only run as batch processes. In addition, low-pressure plasmas are only suitable for no vacuum-sensitive substrates and the size of the objects to be treated is limited. Atmospheric pressure plasmas can be categorized into one of the following discharge types: corona discharges, glow discharges and arc discharges [9]. Low-pressure plasmas are classified into corona discharges, DC glow discharges, high frequency discharges and microwave frequency discharges [10]. Non-thermal atmospheric plasma sources, such as plasma jets, plasma needles and micro plasmas produce just a small diameter beam of approximately 1 mm. In order to use these sources for large-scale decontamination usually several sources are connected in series, as described in [11] and [12].

Cold atmospheric pressure plasmas (CAPP) are a subcategory of non-thermal plasmas and are mainly used for medical applications, e.g. treatment of chronical wounds and skin diseases without damaging the ambient healthy tissue [13, 14, 15]. The most important reactive species in CAPP`s, regarding their antimicrobial impact, are the reactive oxygen and nitrogen species (ROS and RNS) [16, 17]. On the contrary the UV radiation produced does not yield a significant influence on the inactivation of bacteria, as UV doses of several mW*s/cm^2 are required, which cold atmospheric pressure plasmas do not provide [16]. In low-pressure plasmas the UV radiation is the most crucial component for deactivation processes [18, 19].

In order to detect single plasma ingredients, like radicals, atomic and molecular species, several spectroscopic methods come into consideration, e.g. emission and absorption spectroscopy [20], Raman spectroscopy [21] and mass spectroscopy [19]. In addition, phase-contrast and fluorescence microscopy [21], gas detection systems [17], UV photometer [16] as well as numerical simulations [16, 22, 23] are appropriate methods to analyse plasma components.

2. Experimental Setups

The first measurements were carried out on a plasmatreat Openair® facility (Plasmatreat GmbH, Steinhagen Germany) during atmospheric pressure with FG 5001 power supply and RD1004 (with a standard nozzle 22818) plasma jet. The gas used in these experiments is pure air. The spray parameters (two different parameters) are listed in *Table 1*.

Table 1: RD1004 atmospheric plasma jet parameter

	Parameter_01	***Parameter_02***
voltage	256 V	280 V
current (resulting)	10,1 A	14,5 A
frequency	19 kHz	23 kHz
plasma cycle time	50 %	100 %
gas jet pressure (air)	500 mbar	500 mbar

The principle setup is consists of an inner electrode and a grounded rotating outer electrode The inner electrode is coupled to a stepped high-frequency pulse current power supply with an high voltage transformer. The pulse current supply produces with an integrated AC/DC converter, modern IGBT's coupled with the high voltage transformer produced the necessary discharge/arc. Furthermore the plasma jet parameter are controlled and monitored with the power supply (rotating velocity, gas jet pressure etc.). The complete setup and working function of the plasma jet are shown in *Figure 1*.

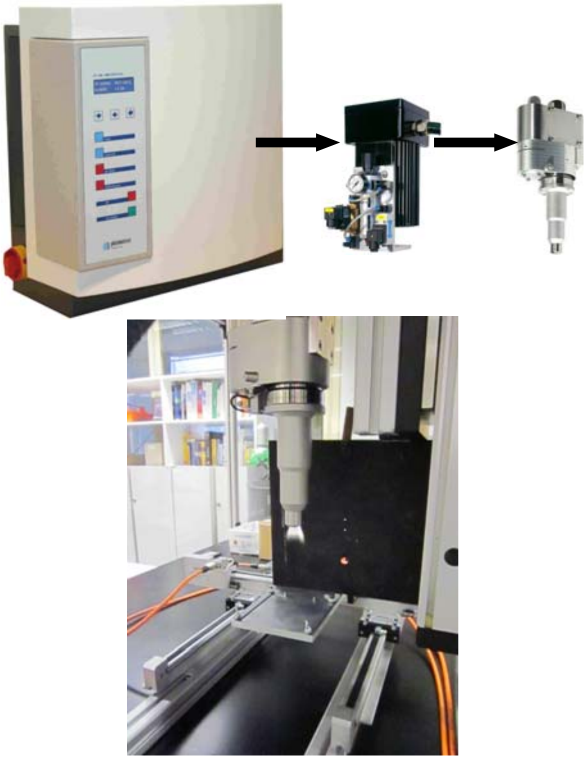

Figure 1: top: principle main tools of the atmospheric RD1004 plasma jet generator (power supply, high voltage transformer, RD1004 plasma jet torch), bottom: complete experimental setup (RD1004 plasma jet generator and positioning system for surface treatments/activations)

3. Investigations of atmospheric RD1004 plasma jet-first results

The plasma jet geometry, the gas composition and the gas temperature must be measured to understand the characteristics of the process plasma for the impact of the surface and treatment applications. Cold processing plasmas are generally in a non-equilibrium in which the electron temperature is significantly higher than the gas temperature with ion and gas temperatures close to room temperature. In most research work [24-27] spectroscopic measurements are commonly used tools for characterizing plasmas and for better understanding of physical and chemical processes. From these first results and with future spectroscopic measurements and absolute determination of the UV emission and the behavior of constituent species can be analyzed and the resulting temperature distribution can be calculated. In this study, we have performed UV-camera (pco.ultraviolet) investigations along the plasma jet plume. The investigation setup is depicted in *Figure 2*.

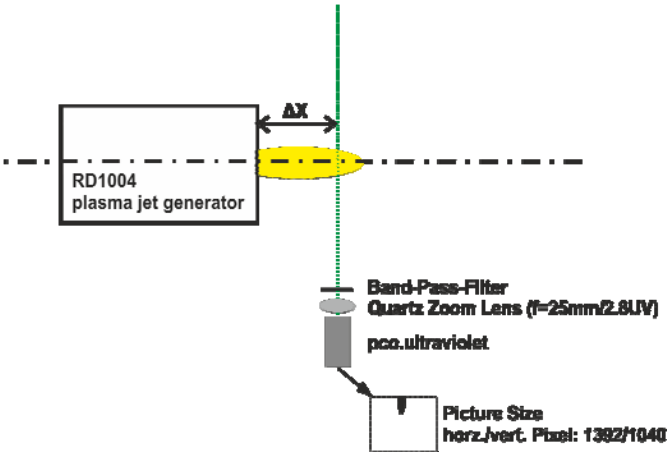

Figure 2: investigation setup for determination of the RD1004 plasma jet generator with UV-camera (pco.ultraviolet)

A UV-camera system with a resolution of 1392 x 1040 pixel, and 14 bit dynamic range was used to investigate the plasma emission in a spectral range from 190 nm - 1100 nm. Additional band pass filters (220 nm FWHM = 90 nm, 308 nm FWHM = 50 nm, 360 nm FWHM = 40 nm, 442 nm FWHM = 10 nm and 532 nm FWHM = 10 nm) completed the spectrally selective setup. The band pass filters may also allow the detection of different gas species which may lead to possible treatment applications. Here the main focus of the research work was to find out the interaction between the adjustable source parameters (voltage, current, frequency, plasma cycle time, gas jet pressure and gas composition) and the plasma jet geometry. In a first step the complete imaging setup was adjusted and calibrated, In *Figure 3* the used calibration image is shown, with a vertical resolution of 1040 pixel = 87 mm (1 pixel = 83,654 µm).

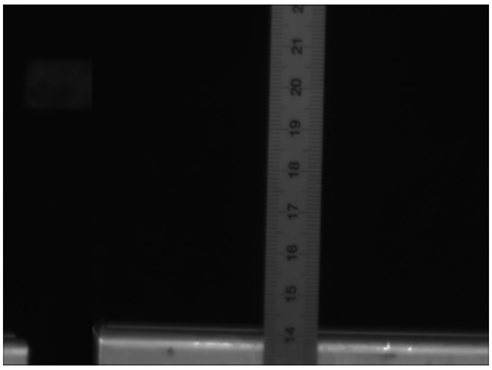

Figure 3: calibration image (1 Pixel = 83,654 µm) for measurement and determination of the RD1004 plasma jet

The second imaging step is based on the projection of a 3d body (plasma jet) into a 2d picture (depending on detection direction). The imaging software, which determines the geometry of the plasma jet, consists of 4 parts (1. image improvement and noise filtering; 2. image measurement and image of the plasma jet calculation; 3. comparison, interpretation and with the calibration lamp in the future the calculation of the temperature distribution; 4. presentation and calculation of plasma jet sizes/shapes). This software is used for different plasma jet parameters and camera-adjustments.

In low-pressure plasmas the UV radiation is the most crucial component for decontamination of surfaces and surface treatments/activations. In *Figure 4 – Figure 6* images of the UV emission for different plasma jet parameters and variations of band pass filters are presented. .

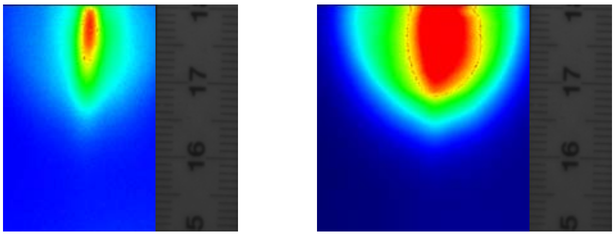

Figure 4: image processing false colour presentation (direct behind the RD1004 torch) determined with camera pco.ultraviolet exposure time 10 s and equal band pass filter 220 nm FWHM 90nm, left: parameter_01, right: parameter_02

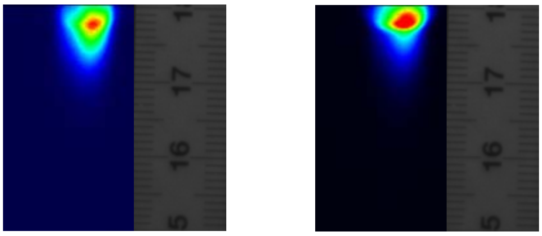

Figure 5: image processing false colour presentation (direct behind the RD1004 torch) determined with camera pco.ultraviolet exposure time 1 s and equal band pass filter 360 nm FWHM 40 nm, left: parameter_01, right: parameter_02

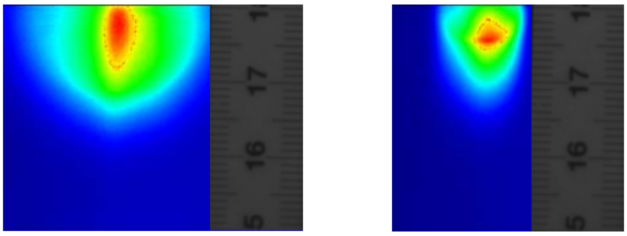

Figure 6: image processing false colour presentation (direct behind the RD1004 torch) determined with camera pco.ultraviolet exposure time 5 s, different band pass filter and equal plasma parameter_02, left: band pass filter 220 nm FWHM 90nm, right: band pass filter 308 nm FWHM 50 nm

Using this kind of setup the absolute emission of UV radiation from various sources can be evaluated with high spatial resolution. The emissivity at certain wavelengths in dependence of the source parameters can be quantitatively determined and thus be used to provide a tailored emission profile for the application in question.

4. Summary and Outlook

The first camera determinations (pco.ultraviolet) with additional different band pass filters (in the range of UV-lines) allow a forecast of plasma jet geometry and UV radiation intensity as a function of source settings. These radiation characteristics will have to be investigated with respect to possible decontamination demands. In the presentation these results will be compared for various thermal and non-thermal sources and predictions will be made as to how these sources are suitable for large area applications. The influence of plasma instabilities on radiation characteristics will be presented as well as the use of this analysis tool for gas species investigation.

5. References

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