Controlling aqueous phase reactive chemical species generated by air surface micro-discharge

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It is well established that atmospheric pressure air plasmas generate a wide variety of reactive oxygen and nitrogen species (RONS) in gas phase. For biological and medical applications, aqueous-phase chemical reactions and mass transfer are also thought to play crucial roles because cells and tissues to be treated are mostly immersed in or contact with aqueous solution.

Several recent reports demonstrated that plasma-treated water or other solution has antimicrobial activities [1-5]. In our recent report [4], we showed that plasma-activated water (PAW) maintains the sterilization activity at least for 7 days after PAW generation. Interestingly, the concentration of chemical species in plasma-treated water shows surprisingly dynamic behavior during the 7-day period. This is a clear indication that gas/aqueous-phase reactions and mass transfer is quite important. A challenge is to find a way to precisely control the plasma chemistry and to identify RONS stored in plasma-treated liquid medium.

In this study, we focus on aqueous-phase RONS generated by surface microdischarge (SMD) in air [6]. 150 μl of phosphate buffered saline (PBS) with E. coli K12 was added to a small glass vial (15 mm in diameter and 45 mm in height), covered by the SMD device, and treated for 0.5-5 minutes. After plasma treatment, suspension were plated on agar and incubated overnight, after which colonies were counted to determine the number of viable cells. Hydrogen peroxide was measured with an electrochemical probe. Nitrite and nitrate were quantified using UV absorbance spectroscopy. Our results showed that RONS stored in plasma-treated PBS shows three different modes, depending on power consumed in plasma. At high power density (> 0.2 W/cm^2) nitrite was dominant, while nitrate became dominant over nitrite around 0.1 W/cm^2. When power decreased further (< 0.05 W/cm^2), nitrite and nitrate concentration monotonically decreased. However, the inactivation rate was highest at the low power mode and the antimicrobial efficacy significantly dropped when the power density was higher than 0.1 [W/cm^2]. Our gas-phase spectroscopic measurement suggests that ozone plays a key role at the low power mode. These results clearly show that air plasma chemistry is quite dynamic and that RONS can be modulated by carefully controlling discharge conditions.

References

[1] Ikawa S, et al., Plasma Process. Polym. (2010), **7**, 33.
[2] Oehmigen K et al., Plasma Process. Polym. (2010), **7**, 250.
[3] Kamgang-Youbi G, et al., Appl. Environ. Microbiol. (2007), **73**, 4791.
[4] Traylor M, et al., J. Phys. D. (2011), **44**, 472001.
[5] J. Julak, et al., Physica Medica (in print).
[6] Morfill G E, et al., New J. Phys. (2009), **11**, 115019.