Liquid-Phase Chemical Reactions Induced By Low-Temperature Atmospheric-Pressure Plasmas Relevant For Plasma Medicine

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Low-temperature, non-cauterizing plasmas are considered to be effective means for medical treatment and material processing for medical applications, including sterilization of material surfaces [1]. When a living tissue is exposed to a low-temperature atmospheric-pressure plasma (APP), there is almost always a liquid layer, such as blood or lymph, that separates the gas plasma from the tissue. The goal of this research is to understand the generation and transport of chemically reactive species in water facing an APP and identify the key chemical species and reactions affecting biological systems. In this presentation, after a brief review on biological/medical application of APPs, numerical simulation results on liquid-phase ROS/RNS generation and transport will be presented and compared with experimental data on cell proliferation affected by plasma exposure.

Numerical simulations employed in this study are both zero-dimensional (i.e., global) chemical reaction simulation [2] and one-dimensional reaction-diffusion simulation for 37 species and 111 chemical reactions in water exposed to an APP. Under typical simulation conditions used in this study, the liquid is pure water (pH=7) with dissolved oxygen and nitrogen in equilibrium with air at 1 atm. The gas phase species generated by plasma discharge are assumed to be in steady state and to enter water at their thermal velocities. The outward flux of chemical species from water to gas phase is determined from Henry's law.

To understand elementary reactions in the liquid, we typically consider the cases where only a few reactive species enter the liquid with given fluxes. For example, it has been found that, when OH radicals and NO molecules in the gas phase enter pure water, they generate a variety of ROS/RNS in the liquid phase [2]. One-dimensional simulation results also indicate that, under the same conditions, OH radicals supplied to water by the plasma are confined to a very thin layer near the gas-liquid boundary due to their high-rate reactions whereas highly stable species such as H_2O_2 diffuse into water.

The simulation results, combined with cell viability experiments by plasma exposure, have shown that cell viability in the culture medium is strongly affected by long-time exposure of the cells to less reactive (and therefore relatively long-lived) molecules such as hydrogen peroxide H_2O_2 than cell interactions with highly reactive species such as OH radicals.

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[1] S. Ikawa, K. Kitano, and S. Hamaguchi, Plasma Process. Polym. 7 (2010) 33–42.
[2] S. Hamaguchi, AIP Conf. Proc. 1542 Eighth International Conference on Atomic and Molecular Data and Their Applications ICAMDATA-2012 (ed. by John D. Gillaspy, Wolfgang L. Wiese, and Yuri A. Podpaly) (2013) 214-222.