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Solvation of Gaseous H_2O_2, HNO_2, NO_2, NO, and O_3 into Water Aerosol and Electrospray

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Plasma–liquid interactions have become of high-rank interest and importance in many applications because they produce reactive oxygen and nitrogen species (RONS) which are delivered into liquids [1]. Electrospray (ES)/Aerosol of liquids is one of the efficient ways to accelerate the transport of RONS into water by producing droplets of liquid in the sub-micrometer dimensions with a large surface-area-to-volume ratio [2]. The solubility of the gas species in liquids, e.g., water under the equilibrium conditions is given by Henry's law solubility coefficient (K_H) where the achieved concentration for each species dissolved is significantly different [3,4].

This work presents an investigation of the transport mechanism of gaseous RONS: H_2O_2, HNO_2, NO_2, NO, and O_3 generated by several external sources separately into water microdroplets. Deionized water microdroplets are produced in two ways. First: charged microdroplets with different sizes (~20-300 μm) during ES produced by the positive dc high voltage applied on the needle electrode. Second: non-charging microdroplets using the atomizer compressor nebulizer to produce mist/aerosol of water microdroplets with the same sizes (~5 μm).

During the ES process, the solvation of the gaseous H_2O_2, HNO_2, NO_2, NO, and O_3 into water is enhanced by increasing the applied voltage which increases gas-water interface surface area [5]. H_2O_2 was solvated in water with 4 orders of magnitude more efficiently than O_3, despite the 7 orders of magnitude larger Henry's law coefficient. This is because of the insufficient amount of gaseous H_2O_2 which is completely depleted from the gas [6]. HNO_2 is solvated into the water as a dominant source of NO_2^- with 3 orders of magnitude higher than O_3, which corresponds well with Henry's law coefficient [7]. NO_2 is solvated in water also making aqueous NO_2^-, with 2 orders of magnitude higher efficacy than O_3 despite similar Henry's law coefficients due to the quick diffusion of NO_2^- into the volume. NO also seems better soluble than predicted, especially at higher voltages where a weak corona discharge is ignited: OH radicals are generated and interact with NO to produce the highly soluble HNO_2. In the nebulizer results, the solvation of H_2O_2, NO, and O_3 is higher than that found in ES due to the larger surface-area-to-volume ratio obtained during the mist/aerosol. While the solvation of HNO_2 and NO_2 as NO_2^- is limited because they also ionize to NO_3^- once entering water, where NO_3^- was found higher than NO_2^- in the collected water which makes it saturated. Based on the obtained results, the solubility of gaseous species is not determined purely by Henry's law. These results can lead to a better understanding of the transport mechanism of gaseous RONS generated by plasma into water and will enable optimization of plasma–liquid interaction systems.

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