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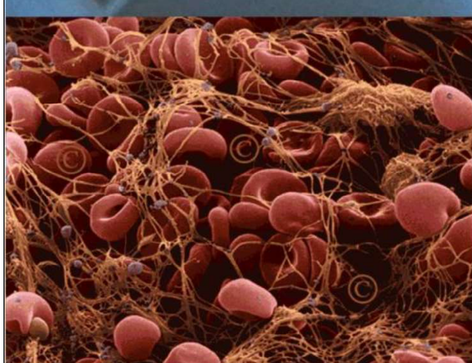

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Dominant effects of RONS in air plasma biomedical treatments and the roles of electric field and radiation

Zdenko Machala

Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovakia

Cold atmospheric pressure plasmas operating in contact with water and biological media induce antimicrobial or antitumor effects and represent a great potential for applications in biomedicine, food technologies and agriculture. In direct plasma treatments, aqueous solutions, bacteria or eukaryotic cells, tissues/seeds/plants are exposed to the (typically pulsed) electric field, short and long-lived radicals and reactive species, UV-vis radiation, and in some cases also shock waves or heating. In indirect treatments, they are only subjected to the medium or long-lived chemical species, especially reactive oxygen and nitrogen species (RONS). Plasma activated water/media (PAW/PAM), despite carrying only these long-lived species, often perform strong antibacterial or anticancer effects for hours or days post plasma activation. The need of understanding, control and tunability of the chemical and biomedical effects of direct plasma or PAW/PAM treatments is emerging [1].

By comparing two non-thermal air plasma sources: streamer corona and transient spark, interacting with water in open and closed reactors and by enhancing the plasma-liquid interaction by water electrospray through these discharges or by induced gas flow by ionic wind towards the liquid, we demonstrate that the plasma gaseous products strongly depend on the discharge regime, its deposited power and gas flow conditions. Streamer corona leads dominantly to the formation of ozone and hydrogen peroxide, while more energetic transient spark leads to nitrogen oxides and hydrogen peroxide. The gaseous products then determine the chemical properties of the PAW and the dominant aqueous RONS. Production of hydrogen peroxide depends on water evaporation and hydroxyl radical formation that is determined by the discharge power. Transient spark produces higher concentrations of gaseous and aqueous RONS and induces stronger antibacterial effects than streamer corona; however, the RONS production rates per Joule of deposited energy are comparable for both studied discharge regimes. The net production rate per Joule of gaseous nitrogen oxides strongly correlates with that of aqueous nitrites and nitrates. Antibacterial effects of the PAW tested on E. coli bacteria are mainly determined by the aqueous RONS: in the lower power streamer corona mainly by the dissolved ozone and hydrogen peroxide, in the higher power transient spark by the combination of hydrogen peroxide, nitrite and acidic pH, while in transient spark in the closed reactor by acidified nitrites.

Nevertheless, a significant difference in antibacterial effects between direct plasma application to suspended bacteria and the indirect effect of PAW indicate that besides RONS chemistry, electric field and perhaps UV radiation play certain roles. Preliminary results with bacteria exposed to PAW and PAW combined with pulsed electric field confirm this hypothesis. Even UVA radiation emitted from the discharge seems to co-operate with the nitrite chemistry and enhance the antibacterial effects of PAW.

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[1] Z. Machala, B. Tarabová, D. Sersenová, M. Janda, K. Hensel: J Phys. D: Appl. Phys. 52, 034002 (2019).