7th Central European Symposium on Plasma Chemistry
Sveti Martin na Muri, Croatia,
3-7 September 2017.

Scientific Program & Book of abstracts

ISBN: 978-953-7666-16-3

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Edited by Slobodan Milošević and Nikša Krstulović

Published by Institute of Physics, Zagreb

Printed by LDK-PROMET d.o.o. Zagreb

ISBN: 978-953-7666-16-3

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Plasma activated water: plasma-induced gas-phase and liquid-phase chemistry and applications in biomedicine and food processing

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Water and aqueous solutions treated by cold atmospheric plasmas – so called plasma activated water (PAW) demonstrate antimicrobial or cytotoxic effects that are of great interest for many applications in biomedicine and food processing. Nonequilibrium air plasmas generate various radicals, ions, and reactive molecules commonly called reactive oxygen and nitrogen species (RONS: OH, H_2O_2, NO, NO_2, O_3, O_2^-). They are transported from the gas phase through the plasma-liquid interface and may induce formation of secondary RONS in the liquid water, such as H_2O_2, nitrites/nitrates NO_2^-/NO_3^-, peroxynitrites/peroxynitrous acid $ONOO^-$/ONOOH, superoxide O_2^-, or OH.

The PAW bio-relevant effects can be enhanced by the efficient mass transfer of plasma-generated RONS into the water, e.g. when air discharges are combined with water electrospray. PAW antimicrobial activity normally decays in a few hours. The fast freezing can preserves it for days and weeks, as tested on various bacteria and yeasts.

The detection of RONS in the PAW is challenging due to the chemical instability of the detected RONS, or possible cross-reactivities of the analytical methods. We tested diagnostic methods for PAW, such as colorimetric detection of H_2O_2, NO_2^- and NO_3^-, fluorescence spectroscopy of $ONOO^-$ and OH, and indirect O_2^- detection using superoxide dismutase. We showed that established indigo blue assay of dissolved O_3 might be misleading in PAW.

The discharge regime and gas/liquid characteristics determine the PAW composition and the consequent bio-relevant effects. In low power air corona discharges, water electrospray increased O_3 production in both gas and liquid, which enhanced the biocidal effect. When the discharge regime transits to higher power transient spark, gaseous NO_x are dominantly formed, leading to significant NO_2^- and NO_3^- in the PAW and practically no O_3, and the bactericidal action mainly due to the synergy of H_2O_2, NO_2^- and acidic milieu (via ONOOH).

Preliminary results on cold plasma pasteurization of apple juice extending its shelf life up to 4 weeks without changes of its nutrient values demonstrate new potentials in food industry.

Supported by Slovak Research and Development Agency APVV-0134-12 and COST Action TD1208.