Bratislava Brno

The 11th Seminar on New Trends in Plasma Physics

Čejkovice, Czech Republic
October 24th, 2024

BOOK OF ABSTRACTS

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Book of Abstracts: The 11th Seminar on New Trends in Plasma Physics
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Free-radical rich amine plasma polymer thin films for bioapplications

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Plasma polymerization of thin film coatings is an effective method for modifying synthetic materials that lack optimal bioapplication properties [1]. Amine plasma polymers (PPs) capable of stable binding with biomolecules [2] and enhanced cell adhesion [3] are suitable for designing biomaterials. Their properties can be tuned concerning the surface charge (from strongly positive to slightly negative) and reactivity for covalent bond formation [4]. The presence of free radicals can explain part of their properties. Therefore, it is essential to investigate their formation for different plasma polymerization conditions, namely radio frequency power absorbed by the discharge in the deposition gas mixture (argon and cyclopropylamine vapors). Electron paramagnetic resonance revealed a significant concentration of free radicals for higher power, attributed to the higher ion energy flux towards the growing PP film. The concentration of free radicals in PPs decreased exponentially over time due to their recombination at the surface or even in the bulk, as they can diffuse through the material. Nevertheless, even after three months, the spin density in PPs remained at 60% of the initial concentration. The amount and kinetics of radicals in the amine PPs and their other chemical properties were correlated to the cell-surface interactions and kinetics of protein immobilization determined by measurements with quartz crystal microbalance sensors.

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The investigation of the effect of plasma on polymer substrates

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Polymeric materials hold significant value across a variety of fields because of their adaptable properties and broad range of applications. Their flexibility makes them suitable for area such as medicine, electronics, automotive, and packaging, where they provide advantages such as resilience, versatility, and cost-effectiveness. Scientists and engineers consistently investigate these materials to improve their functionality, develop new products, and address the changing demands of technological advancement and sustainable solutions [1]. Our contribution investigates how atmospheric pressure plasma sources producing low-temperature plasma affect the surface properties of a range of polymer substrates. In our experiment, three polymer types - Polyamide 6 (PA6 or Nylon 6), Polypropylene (PP), and Polycarbonate (PC) were selected as representative materials. These polymers were subjected to plasma treatment using a diffuse coplanar surface barrier discharge (DCSBD) operated at the previously optimized conditions (input power = 400 W, distance from ceramic = 0.3 mm) in the ambient air at different exposure times, specifically 1, 3, 5, and 10 seconds. By analyzing the impact of plasma exposure at different time intervals, the study aimed to reveal trends in how plasma treatment duration affects the surface properties of each polymer type. Fourier Transform Infrared (FTIR) spectroscopy was employed to examine the chemical changes of the polymer surfaces post-treatment, providing insights into modifications at the molecular level. Additionally, WCA measurements were used to determine the changes in surface wettability, thereby indicating the plasma's effect on surface energy. Future work will extent this investigation to include additional plasma sources, namely Multi-hollow Surface Dielectric Barrier Discharge (MSDBD) [2] and the Piezoelectric Brush PZ3 [3], in order to explore how different plasma configurations and sources ca have different effects on polymer surfaces. This continued research aims to build a comprehensive understanding of how various plasma conditions can be optimized to achieve desired surface modifications in polymeric materials, potentially enhancing their functionality in various industrial applications.

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Acknowledgments

This work was supported by the Slovak Grant Agency No. 1/0688/22.

Electron induced fluorescence of formamide

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Understanding the composition of extraterrestrial bodies provides valuable insights into the origins of life and opens exciting possibilities for the future, including the search for extraterrestrial life and the potential colonization of other planets. Emission spectroscopy is particularly valuable in space exploration, as it enables remote analysis of planetary atmospheres, cometary comas, and nebulas irradiated mainly by nearby stars. Formamide, the simplest amide, is an interesting system to study due to its C=O double bond and C-N peptide bond. Its diverse chemistry includes functional groups and chemical bonds found in key biomolecules, making it a candidate as a potential precursor to life, many biochemical studies propose it likely played a crucial role in the context of the origin of life on our planet. The emission spectrum following electron impact on formamide is studied in a crossed-beam experiment. The spectrum is measured at 50eV within the wavelengths of 280 - 1030 nm, and the width of the slits was set to 100, 200 and 300 μm to achieve optimal ratio of signal intensity and resolution.

Acknowledgment

This work was supported by the Slovak Research and Development Agency under the Contracts no. SK-PL-23-0050, APVV-19-0386 and APVV-23-0522, Slovak grant agency VEGA under projects nr. 1/0489/21 and 1/0553/22. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871149.

Plasma-modified polycaprolactone nanofibers for immobilization of lignin nano and microparticles

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Lignin, one of the most abundant biopolymers, is a heterogenous crosslinked phenolic polymer industrially yielded during a kraft process of wood as a waste product of papermaking. Its antibacterial, antioxidant, and anti-inflammatory properties make it a potential agent for wound healing. To take advantage of higher surface area over the bulk material, lignin was prepared in the form of nano/microparticles of different sizes (15, 50, 300, and 1000 nm) using the solvent shifting method in this work. As a next step, lignin particles need to be applied to carrier material as which synthetic electrospun polycaprolactone (PCL) nanofibers were chosen due to their biodegradability, similarity to the extracellular matrix, and the possibility to control their porous structure. To mediate the immobilization of lignin particles and improve the biocompatibility of the resulting composite textile by introducing polar functional groups on the surface, various plasma modification techniques were applied. These included a short-lived oxygen treatment and the permanent deposition of amine or carboxyl plasma polymer (PP) thin films. All plasma modifications were carried out in low-pressure capacitively coupled radiofrequency discharge. The effectiveness of different immobilization approaches was evaluated based on the visual detection of particles (scanning electron microscopy) and by comparing the chemical composition (X-ray photoelectron spectroscopy) of PCL nanofibers before and after lignin immobilization. Coating by amine PPs proved to be the most successful method, working effectively for all particle sizes. Simultaneously, we sought lignin concentrations in suspension that are not harmful to cells (on the model example of fibroblasts and keratinocytes) but can act as antimicrobials (specifically tested against *Escherichia coli*).

Acknowledgment

The work was supported by M-Era.net LIGN4WOUND (TAČR TH71020007) and GAČR-RFBR 21-12132J projects. CzechNanoLab (LM2023051) and NanoEnviCz (LM2023066) projects funded by MEYS CR are gratefully acknowledged for the financial support of the measurements and sample fabrication.

The innate immune response controlled by the chemical composition of aminated surfaces

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The immune response, which is affected by many characteristics of the material, plays a critical role in determining the acceptance of material within the surrounding tissue [1]. To promote even more positive reactions to biomaterial, modification is needed. Deposition of thin films of plasma polymers is a relatively simple method to modify surface properties, without affecting the substrate. Plasma polymers (PPs) containing carboxyl (–COOH) and primary amino (–NH_2) groups are often proposed for bioapplications. Studies by Lenka Zajíčková showed that nitrogen-containing PPs can successfully coat non-planar substrates such as tissue culture plate (TCP) or polycaprolactone nanofibers (PCL NFs) [2], leading to improved biocompatibility [3]. Amine-PPs increased the adhesion of cells, but interestingly it was valid only for non-endothelial cells and not for endothelial ones [4], [5].

This study aims to characterize the effect of surface composition of amine PPs on the immune reaction of neutrophil-like dHL-60 cells and macrophage-like dTHP-1 cells. For dHL-60 cell, it was observed that the higher presence of nitrogen functionalities leads to greater pro-inflammatory response, as the production of pro-inflammatory cytokines was increased. On the other hand, amine PPs partially reduced the pro-inflammatory response of dTHP-1 cells. On PCL NFs, it was confirmed that the presence of the pores had a positive effect on reducing inflammatory response. Besides the chemical composition, the stability of the amine PPs plays an important role in the immune response.

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Study of direct and indirect plasma application on onion seeding bulbs

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Nowadays, agriculture is based on conventional methods that involve the application of pesticides, agricultural chemicals and fertilisers. These include chemical protection of plants against rot, fungal diseases or moulds. Treatments may also result in stimulating root growth, improving stress tolerance or promoting faster growth. These substances have a negative effect on nature and human health, so more environmentally friendly methods are being sought. One new direction of research is the use of low-temperature plasma in agriculture, known as "plasma agriculture".[1] This approach focuses on using plasma to treat seeds, plants, food or water to increase agricultural production while maintaining food quality and safety. Plasma can be characterised as the fourth state of matter. It is a liquid mixture of neutral atoms, ions and free electrons. Over the last few decades, cold plasma, generated under atmospheric pressure, has become a subject of intense interest for the scientific community and industrial applications.[2]

The thesis deals with the analysis of fragrances in onions treated with plasma before planting. The treatment was carried out to see if it would improve onion growth while maintaining or increasing the fragrance content. The theoretical part deals with the soil and it is characterization methods, plasma, quantitative and qualitative methods for the determination of volatile substances. It contains the principles of UV-VIS spectrometry, atomic absorption spectrometry (AAS), mass spectrometry (MS) as well as tandem connection of gas chromatography with mass spectrometry (GC–MS).

The experimental part was carried out over a period of three years at 22 sites. The preparation and analysis of soil samples are described, which was also evaluated. Furthermore, the procedures for treating the bulbs with corona discharge and plasma-activated water before planting were described. In total, four treatment variants were carried out and bulbs from the fifth variant were not additionally treated. Each treatment variant was planted in four replications of ten bulbs each. Twenty selected grown onions from one site were individually converted to liquid samples and the saturated vapor was analysed by proton transfer reaction time of flight mass spectrometry (PTR–TOF–MS). Thanks to this analysis, the concentrations of volatile substances were determined. Some samples were analyzed by gas chromatography with mass spectrometer as detector to identify the compounds.

Subsequently, the data were processed and evaluated. From the results obtained, it is evident that plasma treatment can be useful for the treatment of onions in agriculture, because it confirmed harvest increase without decrease of fragrances concentrations. Thus, it is necessary to carry out experiments on a larger scale in the future.[3]

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Study plasma-chemical processes of alkanes in atmospheric pressure corona discharge by ion mobility spectrometry-mass spectrometry (IMS-MS)

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The study investigated plasma-chemical processes in a pentane-air mixture at atmospheric pressure using Ion Mobility Spectrometry (IMS) and IMS combined with mass spectrometry (IMS-MS). A Corona Discharge Reactor (CDR) facilitated the reactions, with controlled parameters like discharge current, gas composition, pentane concentration, humidity, and discharge polarity. The main products of pentane produced in the CDR were 5- hydroxy-2- pentanone, 3-pentanone, and 2-pentanone. The product formation changed with humidity as 5- hydroxy-2- pentanone main product at low humidity (0.1%) whereas ketones (3-pentanone and 2-pentanone) produced more at higher humidity (32 %). The system enabled quantitative pentane detection with a limit of detection (LOD) of 0.5 ppm_v.

Keywords: Saturated hydrocarbons, Mass spectrometry, Corona discharge, Oxidation reaction, ion formation

Acknowledgment:

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Polymeric coatings deposited from propane-butane mixture in atmospheric pressure surface dbd for protection of bacterial colonization

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Antibacterial coatings on biomedical instruments are highly valuable as they can prevent bacterial colonization on these devices. In this contribution, we deposited antibacterial polymeric thin coatings onto Teflon substrates using atmospheric pressure plasma polymerization from a propane–butane mixture. This process utilized surface dielectric barrier discharge in nitrogen at atmospheric pressure. We analyzed the chemical composition of the plasma polymerized propane–butane films using energy-dispersive X-ray spectroscopy (EDX) and Fourier-transform infrared spectroscopy (FTIR). The film surface properties were examined through scanning electron microscopy (SEM) and surface energy measurements. EDX analysis revealed that the films contained carbon, nitrogen, and oxygen from the surrounding air. FTIR analysis identified the presence of alkyl, nitrile, acetylene, imide, and amine groups. The films were hydrophilic, with water contact angles ranging from 13° to 23°. The thin film-coated samples demonstrated significant antibacterial activity against both *S. aureus* and *E. coli* strains. Furthermore, the films were cytocompatible, maintaining over 80% cell viability compared to reference polystyrene tissue, see Figure 1. We also analyzed the deposition process in order to find the compounds responsible for antibacterial properties.

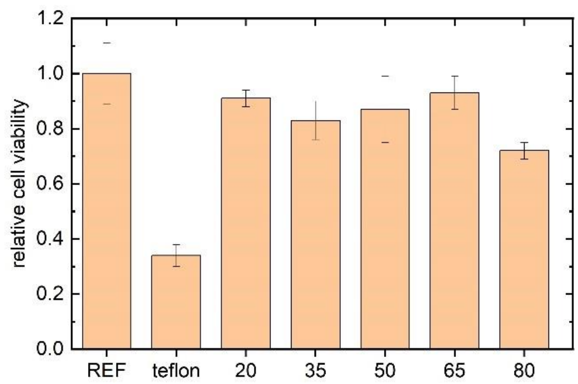

Fig.1: In vitro cytocompatibility results of tested PB films deposited at different flow rates of the monomer. REF marks tissue polystyrene, teflon marks bare substrate and the numbers are monomer flow rates in sccm.

Acknowledgement:

This research was supported by institutional support for the research organization development awarded by the Ministry of Defence of the Czech Republic.

Application of cold atmospheric pressure plasma for improvement of germination and growth parameters of radish seeds (*Raphanus sativus*)

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Application of cold atmospheric pressure plasma is promising technology in the field of agriculture and food industry for decontamination, improvement of germination, growth and physiological parameters, reduction of chemicals, increase of food safety and extending shelf-life of food products. Dielectric barrier discharges are suitable candidates for application in plasma treatment of seeds due to the low-temperature plasma generation and relatively high discharge area (compared to e.g. plasma jets). The disadvantage of DBD´s is the need of working gas or reduced pressure ensuring the diffusiveness of plasma for processing of sensitive samples:

Radish seeds (*Raphanus sativus*) are known for their fast germination and growth of plants but also for sprouting, which are popular in culinary application. We used Diffuse coplanar surface barrier discharge (DCSBD) and Multihollow surface dielectric barrier discharge (MSDBD) for treatment of radish seeds for the purpose of improvement of germination rate and growth parameters. We measured the length of roots and shoots and fresh and dry weight of seedlings grew from treated and untreated seeds. In addition, we observed the effect of plasma for inhibition of typical bacteria contaminating sprouts (*E.coli*, and members of *Salmonella* spp. and *Bacillus* spp.).

Acknowledgements:

This work was supported by the Slovak Grant Agency No. 1/0688/22 and the Slovak Research and Development Agency under the contract No. APVV-21-0147.

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Enhancing wound healing with bioprinted chitosan hydrogels treated by cold atmospheric plasma jets

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Uncontrolled bleeding in many kinds of injuries and accidents is a major factor leading to death. Severe blood loss can result in hypothermia, coagulopathy, and multiorgan failure, while bacterial infections can further complicate the recovery process [1]. Addressing this, we investigate the application of plasma treatment to improve the antibacterial characteristics of chitosan (CS) hydrogels and augment their suitability for bioprinting applications. We employ 3D bioprinting to fabricate CS hydrogel scaffolds because it can closely mimic the architecture of human tissues [2]. The 3D printing precision allows the fabrication of specific supports and improved transfer of essential nutrients, which is crucial in severe bleeding where conventional hydrogels and dressings may not be adequate [3]. Plasma activation enhances hydrogels by introducing oxygen functionalities, including reactive oxygen and nitrogen species (RONS), providing a novel approach to wound healing [4]. We investigated two approaches that use cold atmospheric pressure plasma jets (Fig. 1): (A) plasma treatment of uncrosslinked CS solutions and (B) surface modification of printed CS hydrogel scaffolds. Our initial findings suggested that the plasma-treated hydrogel scaffolds exhibit higher hydrophilicity, i.e. reduction of water contact angle. Cell viability experiments showed that plasma-treated hydrogels significantly enhanced fibroblast cell morphology and growth. Our findings indicate that plasma-treated CS hydrogels may find applications in wound dressings.

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Study of electrical discharge initiated chemical processes in prebiotic atmospheres in flowing regime

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The objective of this study is to investigate the chemical processes occurring in extraterrestrial atmospheres and the synthesis of organic compounds resulting from electrical discharges in gaseous mixtures. Specifically, this research examines the impact of water molecules on chemical reactions initiated by electrical discharges in probiotic atmospheres. This work is focused on the simulation of nitrogen atmosphere and carbon dioxide atmosphere. These gases were chosen because they represent the main components of some known atmospheres. The atmosphere of Titan, second largest moon of solar system. The most common composition of the gaseous mixture was methane (2-4 sccm) in 200 sccm of nitrogen. The second study atmosphere was atmosphere of Mars [1].

The simulations were conducted using a glow discharge in a specialized reactor at atmospheric pressure, with a flow of pure N_2 or CO_2. Measurements were performed initially in pure gas, to which water vapor was gradually introduced at flow rates of 0, 5, 10, 15, and 20 sccm. The products formed were analyzed using proton ionization mass spectrometry and a time-of-flight analyzer, detecting simple aliphatic hydrocarbons, alcohols, aldehydes, and ketones. As the amount of water vapor increased, more complex aromatic compounds were also produced. In the nitrogen-based gaseous mixture, significant products included ammonia, propane-2-ol, ethanol, and likely diethylamine. In the carbon dioxide mixture, key products included hydrogen cyanide, methenamine, and acetonitrile. In case of nitrogenous gaseous mixture, the most dominant detected gas products were ammonia, followed by hydrogen cyanide and acetonitrile. In case of carbon dioxide gaseous mixture, the most dominant detected species were ammonia or methanimine, with other additives high presents was confirmed for hydrogen cyanide or acetonitrile. Concurrently, plasma diagnostics were performed using optical emission spectroscopy [2]. The substances detected in this work agree with the available literature and also with substances detected *in situ* in Mars's and Titan's atmospheres.

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Potential Energy Surface Scans of the Carbon Monoxide's Ground State and First low-lying Excited States

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Excited electronic states of CO had been previously studied by (Dora & Tennyson, 2020) using state averaged CASSCF(10,10). In this work we examine alternative approach using SA-CASSCF(8,7) with starting orbitals obtained via NBO analysis of MP2 optimized wavefunction. Converged SA-CASSCF(Kollmar et al., 2019) wavefunctions are afterwards treated with NEVPT2(Guo et al., 2021)(Kollmar et al., 2021) . Final single point energies presented in this work consist of CASSCF energy extrapolated to complete basis set and NEVPT2 correction at aug-cc-pV5Z level. All calculations were performed using ORCA 5.0.4 (Neese et al., 2020)quantum chemistry package and NBO7(Glendening et al., 2018) program.

Although smaller active space implies meaningful description of limited number of excited states, this approach proved advantageous in several ways. Firstly we were able to obtain potential energy surface (PES) for wide range of interatomic distances from 0.85 Å up to 3.00 Å. Additionally due to the nature of state averaged calculation, crossings of electronic states with same irreducible representation and spin multiplicity lead to sharp steps in PES. Since these crossing appear primarily at higher energies, we were able to avoid most of them, thus obtaining smooth energy curves. Finally reduced computational cost made perturbation treatment possible allowing us to capture part of dynamical correlation energy as well.

For extrapolation technique we considered CBS limit of to be given by expression (Varandas, 2007):

$$E_{\infty}^{tot} = E_{\infty}^{CAS} + E_{\infty}^{dc}$$

This split of total extrapolated single point energy E_{∞}^{tot} into CAS component E_{∞}^{CAS} which captures Hartree-Fock energy and non-dynamical correlation and E_{∞}^{dc} component which corresponds to dynamical correlation is necessary due to different rates at which these components converge with respect to the cardinal number of basis set (Varandas, 2007). For E_{∞}^{CAS} we chose 3-point extrapolation scheme (Feller, 1993) :

$$E_X{}^{CAS} = E_\infty{}^{CAS} + A\exp(-\beta X)$$

Where X is hierarchical number approximately equal to the cardinality of basis set [Pansini et al.,2016], A and β are parameters to be fitted.

Correction scheme specifically proposed for dynamical correlation [Pansini et al.,2016] exists, however it contains method specific parameters, which are not available for NEVPT2, thus dynamical part of correlation was not extrapolated.

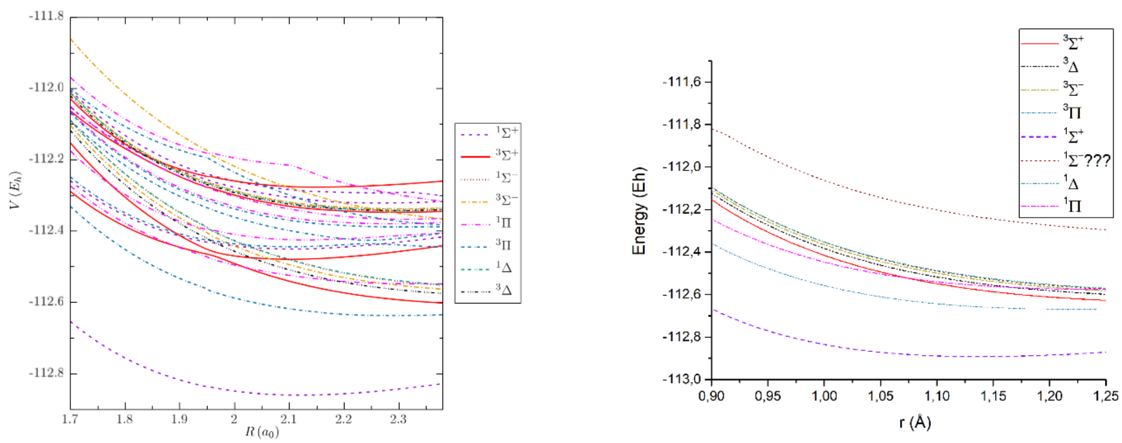

Fig. 1: Comparison of computed potential curves of CO and its excited states published by (Dora & Tennyson, 2020) and this work.

While in generally good agreement with findings of (Dora & Tennyson, 2020) we were unable to replicate some of qualitative properties of lower lying excited electronic states - most notably B $^1\Sigma^+$ and avoided crossing of two $^3\Sigma^+$ near 1.03 Å. These differences are likely due to choice of smaller active space.

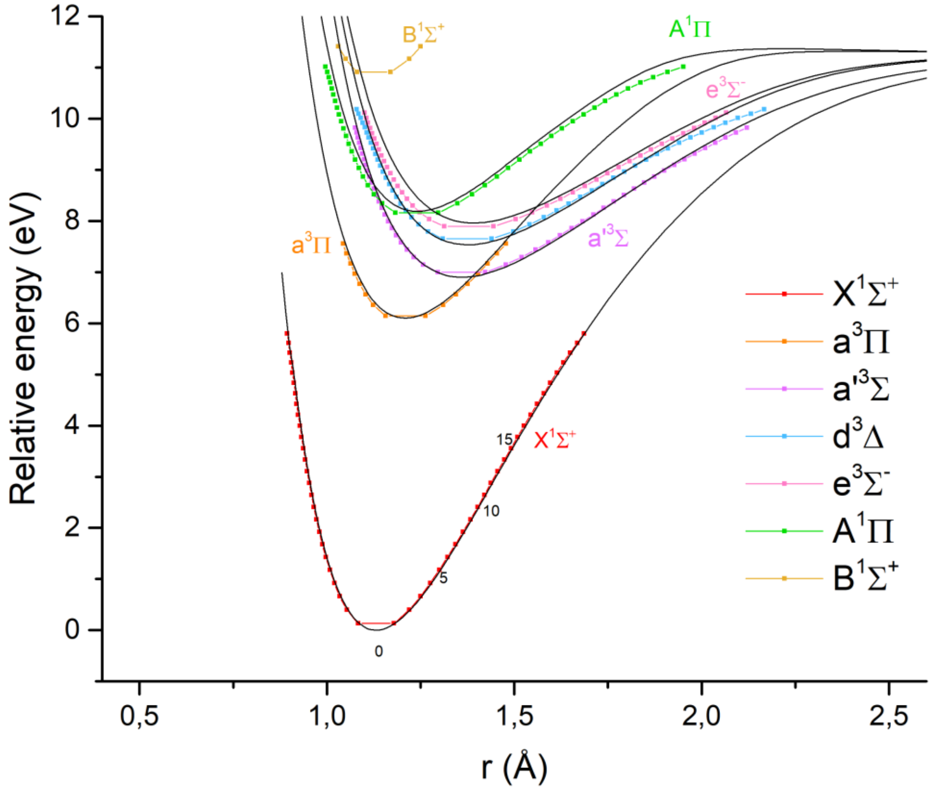

Fig.2: Comparison of selected computed excited states (solid black lines) and experimentally measured (coloured lines with nodes) (Krupenie & Weissman, 1965) potential curves.

	Computational results		Experimental results
State	This work	(Dora & Tennyson, 2020)	(Nielsen et al., 1980)
$X^1\Sigma$	0.0	0.0	0.0
$a^3\Pi$	6.39	6.43	6.32
$a'^3\Sigma^+$	8.63	8.36	8.51
$A^1\Pi$	8.67	8.97	8.51
$d^3\Delta$	9.40	9.22	9.36
$e^3\Sigma^-$	9.95	9.60	9.88
$I^1\Sigma^-$	10.04	9.95	9.88
$D^1\Delta$	10.23	10.00	10.23

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Application of Atmospheric Cold Plasma to pesticide degradation

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According to World Health Organization estimates, the global population is expected to increase by around 20 percent by 2050[1], requiring an increase in crop productivity to meet food demand, therefore the use of pesticides cannot be reduced despite their health risks, and they will continue to play a critical role in preventing crop losses by pests and diseases.

After applying pesticides to crops, some may be found in food at a residue level due to their low solubility in water and stability under environmental conditions, making them resistant to degradation. Currently, one of the challenges is to develop technologies that effectively eliminate pesticide residues without causing damage to the nutritional content of the food. Cold plasma technology is a promising tool for pesticide removal because of its ability to degrade organic molecules through reactive oxygen and nitrogen species, radicals, and UV radiation that compose the plasma.

This study aims to evaluate the degradation of chlorpyrifos using Corona Discharge (CD) and chlormequat using Plasma Activated Water (PAW). The use of chlorpyrifos has been banned in the EU since 2020, while chlormequat remains authorized as an herbicide but has recently been linked to fertility issues [2]. These pesticides were selected based on their frequent detection in recent results from the Multiannual National Control Program for pesticide residue monitoring, conducted by the European Food Safety Authority [3}. Chlorpyrifos was chosen due to its repeated occurrence in monitoring data and known risks to human health, including developmental neurotoxicity and genotoxicity [4}.

Degradation percentages and degradation products were quantified and identified using Ion Mobility Spectrometry (IMS) and Mass Spectrometry. For chlorpyrifos, 3,5,6-trichloro-2-pyridinol was the primary ion used to monitor degradation via Corona Discharge. Chlormequat degradation, achieved with Plasma Activated Water, exceeded 99%, with 2-dimethylaminoethyl was identified as the key ion for monitoring in the IMS analysis.

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Optical spectroscopy of small molecules

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Small molecules (e.g., ammonia or NOx radicals) often play a crucial role in everyday physical and chemical processes on both terrestrial and cosmic scales. One example is the characterization of exoplanets based on detecting such molecules in their atmospheres [1].

A thorough understanding of the optical spectra of these molecules and their interactions is necessary for the correct and effective analysis of absorption signals. The best way to obtain this data is through sensitive laboratory measurements, where reference spectra can be collected under known experimental conditions (as opposed to studied objects, where these data must be inferred from measurements). Our group focuses on developing both new optical detectors based on the Cavity Enhanced Absorption Spectroscopy (CEAS)[2] or the Cavity Ring-Down Spectroscopy (CRDS)[3] technologies and processing spectroscopic data to create reference databases [4]. Our most significant achievement in this field is our participation in developing a new version of the HITRAN database [5, 6], the most renowned molecular reference spectroscopy database. In the case of CEAS, our most recent focus point is the development of a detector that uses an incoherent broad-band light source to target the NOx radicals produced in plasma (Fig. 1) [7].

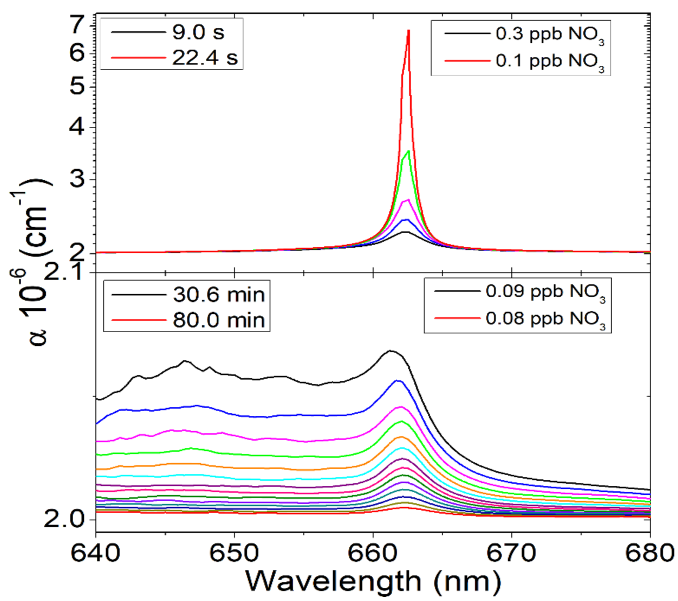

Fig.1: Comparison of time-evolution of NO_3(up) and NO_2(down) absorption spectra produced by corona discharge.

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Antenna measurement of electric field and higher harmonics in atmospheric plasma slit jet

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The electric field is one of the fundamental plasma parameters as its magnitude determines the production and energy of charged particles and, hence, the plasma gas chemistry. Despite its importance, electric fields of atmospheric pressure plasma discharges are rarely experimentally determined. The methods capable of measuring discharge electric field non-intrusively have high equipment requirements (laser-based methods) or are limited to specific plasma gas chemistries (optical emission spectroscopy-based methods). In contrast, the measurement by electro-optic sensors based on the Pockels effect is not species-specific or notably experimentally demanding. However, electro-optic sensors are typically used intrusively, in contact with plasma, which can influence the plasma parameters.

Recently, we proposed using electrical antennas to measure the semiquantitative value of a global mix of electric fields radiated by an atmospheric plasma jet. This method offers an advantage over other approaches because it is not intrusive, uses only standard equipment of electroengineering labs, and can be used for any gas feed. Furthermore, antenna measurements provide information about the excitation and intensity of higher harmonics, i.e., about the linearity of discharge behavior. In the presented study, the commercial biconical antenna BicoLOG 20300 (350 mm diameter) was applied to the electrical characterization of radio-frequency plasma slit jet (RF-PSJ) [1] working in three different gas feeds (Ar, Ar/O_2, and Ar/N_2). In all the studied conditions, the obtained frequency spectra were composed of a dominant fundamental frequency peak and a significantly weaker odd and even higher harmonics peak. Admixing molecular gas, especially nitrogen, into argon, increased the discharge nonlinearity, which was attributed to the increase in emission of secondary electrons from the RF-PSJ dielectric slit induced by the long-lived metastable species such as N_2(A). Although the values of the electric field obtained by the antenna measurements are only semiquantitative, the method exhibits high sensitivity to the changes in the RF-PSJ system. Out of the tested gas feeds, the strongest electric field was generated in the pure Ar discharge (50–140 kV/cm, depending on the applied power and Ar flow rate). The admixing of oxygen and nitrogen gas reduced the measured electric fields by 1.5 to 2.5.

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Exploring the stability of plasma polymer coatings in varied pH conditions

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The aim of this study is to understand connections between the chemical structure of plasma polymers (PP), prepared by plasma-enhanced chemical vapor deposition, PECVD, and their pH-responsive properties. In this regard, Silicon substrates were coated with amine PP and carboxyl PP. During plasma polymerization, we were able to introduce either acidic or basic functional groups, which determine the response of our coatings to the surrounding pH conditions. By tuning the deposition parameter (deposition power, power mode, precursor flow rate), we were able to control the thickness, degree of crosslinking (stability) and hydrophobicity, thereby, generating an improved surface property. Owing to the ionic functional groups in their structure, these smart polymers can undergo protonation or deprotonation which alter their solubility, conformation, surface activity, and hydrophobicity when exposed to a specific pH.

To investigate the pH sensitivity of our coatings, Silicon substrates were immersed in phosphate-buffered saline (PBS) solutions prepared at different pH (5.5, 7.4 and 8.7). We systematically evaluated process conditions and their impact on the stability of our coatings in liquids using a MIR spectroscopic ellipsometer (WOOLLAM-MIR). Surface wettability was investigated by means of contact angle measurements, surface morphology using scanning electron microscope (SEM- TESCAN LYRA3) and atomic force microscopy (AFM-ICON-SPM). Chemical and elemental composition were studied by Fourier transform infrared spectroscopy (FTIR- Vacuum FTIR Vertex70v) and X-ray photoelectron spectroscopy (XPS- KRATOS).

Deposition of polysaccharide-based coating on seed surface after plasma activation and study of the physicochemical properties

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The application of non-thermal plasma in agriculture is a rapidly developing field, as plasma has a positive effect on seed germination, seedling development and higher crop production [1]. In our study, we used diffuse coplanar surface barrier discharge (DCSBD) to activate the highly hydrophobic surface (WCA = 108.2 ± 5.8°) of pea seed (Saxon var.) to improve the adhesion of the applied polysaccharide layer with antibacterial properties. First, we optimized the plasma treatment conditions (carrier gas, exposure time) considering the improved germination parameters of pea seed and then applied the natural-based polysaccharide layer using the laboratory-scale pan coater. We found the optimal plasma treatment time at which the germination parameters of seeds and seedlings were significantly improved compared to reference seeds. In addition, the optimal exposure time was sufficient for better adhesion of the deposited polysaccharide layer to the seed surface. We performed the surface diagnosis by measuring the water contact angle (WCA) and X-ray photoelectron spectroscopy (XPS), which provided evidence for the presence of the coating on the pea surface. The resulting coating preserved the germination potential of the seed and can serve as an antibacterial protective layer in long-term seed storage. We will continue this study by considering other plasma sources with different configuration (Multihollow Surface Dielectric Barrier Discharge – MSDBD [2] and Piezoelectric Brush PZ3 [3]) to improve the germination parameters and adhesion of functional protective layers on different types of seeds that differ in size and shape (e.g. wheat, mung bean, broccoli, etc.). A very important task is to consider the synergistic effect of the active particles generated in the plasma in different configurations and treatment conditions on germination and adhesion improvement to propose the mechanism of plasma induced changes.

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Emission of carbon monoxide induced by electron impact

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Optical emission spectroscopy is used to study electron induced fluorescence of electron-molecule collisions producing excited species. These processes are abundant in many environments from laboratory and industry to atmosphere of planets and space. Carbon Monoxide (CO) is a relatively abundant molecule in the Universe, and it is an essential life-forming molecule. It is one of the dominant carbon bearing molecules in extra-terrestrial bodies such as comets or centaurs. The emission spectrum following electron impact on CO is studied in a crossed-beam experiment. The spectrum is measured at several electron energies in range from 5 to 100 eV within the wavelengths of 275 - 1030 nm. The Comet Tail system of CO^+ ($A^2\Pi$ - $X^2\Sigma^+$), few emission bands of the Baldet – Johnson system of CO^+ ($B^2\Sigma^-$ - $A^2\Pi^+$) and the emission lines of C and O in the higher wavelength region are detected. Along with the emission bands of ionized CO+, we have identified several emission bands of neutral CO.

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Application of PTR-MS for determination of compounds formed in Titan like gaseous mixtures by electrical discharges

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The Proton Transfer Quadrupole Mass Spectrometry (PTR-QMS) was used for the determination of gaseous products formed by electrical glow discharge at atmospheric pressure operating in nitrogen-methane gas mixtures related to the Titan's atmosphere. The main detected nitrile compounds were molecular structures containing nitrile groups (–CN), amino groups ($–NH_2$, –NH–, and –N<), and/or imino groups (–C=N–), namely HCN, CH_3CN and C_2H_5CN in current experiments. Hydrazine, methanimine, methyldiazene, ethylamine, cyclohexadiene, pyrazineacetylene, ethylene, propyne and propene were identified as minor compounds. The peaks at masses 21 and 37 are not listed there because they correspond to D_2HO^+, and H_3O^+ - H_2O ions originating in the ionization source. Small amounts of hydrocarbons like acetylene, ethylene, propyne, propene, 2-butene and cyclohexadiene were detected. Observation of these species is in agreement with our previous experiments [1, 2]. The major products are nitrile compounds. Hydrogen cyanide HCN (protonated mass = 28) and acetonitrile CH_3CN (protonated mass = 42) were the two major products but also other nitrile compounds like methanimine, methylamine, hydrazine, ethenamine, methyldiazene, ethylamine, propiolonitrile, propenenitrile, proparylamine, 2-propanamine, butanenitrile, 4-methyl-pyrazole, 2,5-dimethl-pyrazole and nonanenitrile were detected, too. Ammonia (protonated mass is 18) was not observed because the molecular mass is lower than 21 that is the lowest limit for used PTR-MS analytical device. The yield and generation rate of nitriles are of the following relationship: HCN > CH_3CN > C_2H_5CN > C_3H_7CN > C_4H_6N > C_6H_9N > $C_9H_{17}N$. Currently, the new experiments using PTR-TOF spectrometry are running.

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A sub-atmospheric pressure discharge generated in hydrodynamic cavitation for water treatment

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We present a recently developed plasma source that uses a synergistic effect of hydrodynamical cavitation and electrical discharge in cavitating environment, called "CaviPlasma". This plasma device, see Figure 1, breaks the limits of existing plasma generators offering the industrial-scale flow rate of 1-15 m^3/h (laboratory devices) introducing peroxide-based chemistry into treated water, thus keeping the pH practically unchanged (within 0.5 pH difference margin).

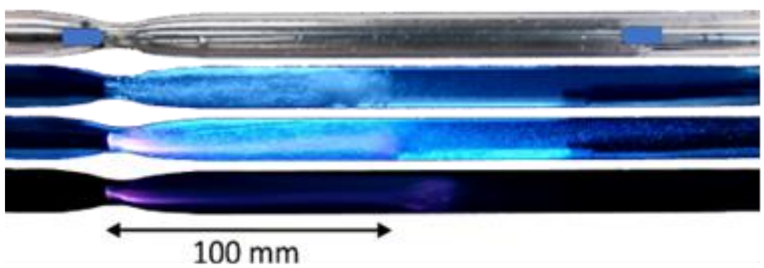

Fig.1: Experimental device.

We have achieved the peroxide concentration higher than 10 mg/l per one water passage through the CaviPlasma and peroxide yield of G(H_2O_2) = 9.5 g/kWh, which ranks CaviPlasma to high efficiency plasma sources. The effects of CaviPlasma water treatment were proven on the study of the successful remediation of cyanobacteria and algae from water, inactivation of pathogens collected from hospital environment surfaces or inactivation of the main rainbow trout pathogenic bacteria.

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