Programme title: Biophysical Chemistry

Mode of study: full-time

Topic title: Bioinformatics and biophysical characterization of local structures from genomic sequences of nucleic acids

Supervisor: prof. Mgr. Václav Brázda, Ph.D.

Description: Current bioinformatics approaches allow efficient nucleic acid analysis to study the presence of local structures in complete genomes. In particular, the presence of inverted repeats and G-quadruplex forming sequences has emerged as an important regulatory aspect in fundamental biological processes including transcription regulation. This topic will use bioinformatic approaches to identify the sequences required for the formation of these local structures and further characterize these sequences using biophysical methods to determine whether and under what conditions local structures are formed. The formatting, stability and localization of these structures will be studied using CD spectroscopy, fluorescence and microscopy methods. Collaboration with a foreign institute is anticipated.

Topic title: Engagement of hydrogen bonding in pharmaceutical retention by humic substances and by selected soil mineral phases

Supervisor: prof. Ing. Martina Klučáková, Ph.D.

Description: Investigation of mechanism of binding of studied drugs with humic substances (as representatives of soil organic matter) and mineral soil constituents, evaluation of effect of hydrogen bonds.

Topic title: Mobility/interactions of pharmaceuticals - comparison of behaviour of zwitterions and neutral drugs

Supervisor: prof. Ing. Martina Klučáková, Ph.D.

Description: Study on hydrogels, experiments addressing the mobility of the selected compounds in the presence of humic material as the sorbing phase could be done. The experiments would cover a range of pH such as 4 to 8 as being the most relevant pH range in soils and waters. As humic material, one could use one of the IHSS materials which are well characterized.

Topic title: Development and Biophysical Characterization of 3D Bacterial Cellulose-Based Structures

Supervisor: prof. Ing. Adriána Kovalčík, Ph.D.

Description: The aim of this doctoral thesis is the development of three-dimensional bacterial cellulose (BC) structures, with a focus on scaffolds of various 3D geometries (e.g., tubular, disc-shaped, and other geometric configurations), and their systematic biophysical characterization. The research will focus on the optimization of cultivation conditions for the formation of 3D BC in modified cultivation vessels and bioreactor systems, including control of oxygen supply, nutrient transport, and the reproducibility of the shape and dimensions of the resulting structures.

Subsequently, the mechanical properties of the prepared structures (strength, elasticity, and resistance to deformation), transport-related parameters (permeability, diffusion behavior, and water retention capacity), and surface characteristics relevant to interactions with microorganisms or cells will be evaluated.

The thesis will also investigate the potential for functional modification of BC scaffolds, for example through the immobilization of probiotic yeasts as a model functional component within the 3D cellulose matrix, and the assessment of their stability and interactions with the BC structure. The results of this work may contribute to the design of novel 3D cellulose-based materials and to the development of preparation and characterization methodologies for applications in biomedicine, food technology, and bioengineering.

Topic title: Characterization of microwave discharges for plasma therapies

Supervisor: doc. Ing. Zdenka Kozáková, Ph.D.

Description: Applications of plasmas initiated by electrical discharges became a hot topic in medicine during the last decade. A broad spectrum of therapeutic applications is possible by such tool, namely blood coagulation, tissue ablation, living tissue surface microbial decontamination and support of wound healing including chronical wounds. Different plasma systems, mainly high frequency operating plasma jets, were developed across the world. These systems commonly do not allow interaction of the treated surface with the active discharge because this zone is inside the applicator and thus, interaction is limited to an effluent of plasma activated gas, only. In contrary to these systems, our microwave sustained plasma system allows direct interaction of the active plasma zone with the treated surface which leads to much higher treatment efficiency (i.e., shorter treatment times) and therefore, it is beneficial for patients as well as doctors. Before the real application, it is necessary to complete detailed plasma sources diagnostics in order to optimize the treatment parameters.

The PhD study will focus on this issue. The optical emission spectrometry will be used for the plasma characterization (composition of radiating species, neutral gas and excitation temperatures) in spatial resolution. The presence of active species at the surface will be determined by colorimetric methods using selective reagents fixed in agar. To confirm these basic results, the sterilization effect of plasma will be studied using selected non-pathogenic bacteria and yeasts. The microwave applicator construction, gas flow, applied power, duty cycle and shielding gas composition will be the main studied parameters. As the final goal, construction of a prototype of the microwave plasma source for therapeutical purposes with optimized parameters is expected. This point will be solved under collaboration with our industrial partners.

Topic title: Study of intracellular changes in microbial cells by non-thermal plasma

Supervisor: doc. Ing. Zdenka Kozáková, Ph.D.

Specialist supervisor: prof. Mgr. Václav Brázda, Ph.D.

Description: A study of non-thermal plasma effects generated at atmospheric pressure (CAP) on microorganisms represents a fast developing field of physical chemistry and biological sciences. Plasma generates a complex mixture of reactive species (RONS), electromagnetic fields, UV/VUV photons and other physical-chemical factors which might significantly influence living systems. This work will be focused on detailed understanding of non-thermal plasma effects on microbial cells. It will observe changes in cell structures, functions of organelles connected in oxidative stress regulation, and biochemical as well as genetic mechanisms that might contribute to microbial resistance.

Experimental part will include a study of non-thermal plasma interactions with microbial cells and analyses of its effects via modern methods of molecular biology, analytical and immunochemical techniques such as flow cytometry, optical and electron microscopy, protein analysis or genetic mutations. Attention will be paid to changes in oxidative stress regulation, intracellular processes related to apoptosis and stress paths, creation and function of cellular vesicles and other morphological or genetic responses to the plasma treatment.

The aim of the work will be a complex evaluation of biochemical, intracellular and morphological changes induced by the plasma treatment and thus, a contribution to deeper understanding of mechanisms of plasma effects on microorganisms, including its potential to influence creation of resistant phenotypes.

Topic title: New catanionic complexes for the formulation of vesicular carrier systems

Supervisor: doc. Ing. Filip Mravec, Ph.D.

Description: Complexes of oppositely charged amphiphilic substances, which are able to formulate vesicles in aqueous solutions, appear to be an interesting and progressive replacement for standard phospholipids and liposomes formulated from them. The choice of the number and length of chains, the type of hydrophilic groups and different relative representation of amphiphilic substances indicate high variability in the formulation of new types of carrier systems and modeling of their physicochemical properties.

The aim of this topic is the preparation and physicochemical characterization of membrane carrier systems, where the basic catanion-active complex contains three hydrophobic chains. The system can be formulated from a two-chain cationic or anionic surfactant with the counterions left or removed and the membrane supplemented with stabilizing agents such as fatty acids or cholesterol. The description of the size, stability and membrane properties of vesicular systems formulated from such complexes when the temperature, pH or ionic strength of the environment changes will be decisive.

The main characterization methods will be, in addition to dynamic and electrophoretic light scattering, also fluorescence techniques, whether in the form of stationary, time-resolved or microscopic. These techniques enable full physicochemical characterization of vesicular systems and will be crucial for further research including, for example, nebulization of vesicular solutions for possible inhalation administration of biologically active substances.

In the first phase of the work, including preparation and characterization, close cooperation is expected with Prof. Chien-Hsiang Chang from National Cheng Kung University (Tainan, Taiwan), with whom there is a long-term collaboration on the topic of catanionic systems. In the possible application phase, cooperation is expected with the group of Assoc. Prof. František Lízal (FSI, BUT), which has nebulization techniques at its disposal, with which there is more than a decade of cooperation.

Topic title: A physico-chemical contribution to discussion on soil organic matter

Supervisor: prof. Ing. Miloslav Pekař, Ph.D.

Description: Soil organic matter, in a narrower sense, humic substances, has been subject of research for several centuries. Nevertheless, questions on its formation or character still have not been resolved. The traditional polymer theory seems to be replaced in the last two decades by supramolecular views, lately claims on the non-existence of the humic substances have become rampant, looking at the soil organic matter as a complex mixture of products at various degrees of the decomposition of decaying original plant or animal matter. Further, it can contain also metabolic products of the soil microorganisms.

After additional but in-depth literature search, the PhD study will be focused on one of or both following partial goals. 1) Thermodynamics and kinetics of the soil metabolic reactions with special regard to the synthesis of polyketides and their potential incorporation into the principal structural unit of the soil organic matter. 2) Heat effects of the formation of soil organo-mineral complex and of the soil microbial life. Results will be evaluated also from the point of view of the current discussion on the origin, character, and stability of soil organic matter.

Topic title: Tailoring Biochar as the Carrier of Soil Bacteria: Structural Determinants of Colonisation, Viability, and Controlled Release of PGPR

Supervisor: prof. Ing. Miloslav Pekař, Ph.D.

Specialist supervisor: Ing. Michal Kalina, Ph.D.

Description: The PhD thesis will be focused on understanding the mechanisms of colonisation of the porous structure of biochar by plant growth–promoting rhizobacteria (PGPR) and on the development of advanced biochar–PGPR carriers with high stability and driven controlled release of microorganisms. The first part will address the relationship between the material characteristics of biochar (ultrastructure, surface chemistry, porosity, wettability) and the ability of bacteria to form biofilms, colonise the pore system, and survive within it. These findings will be used for the design and optimisation of protective strategies, including the use of additives, hydrogel matrices, and drying procedures, aimed at enhancing PGPR resistance during formulation and storage. The second part will focus on the characterisation of the mechanical and transport properties of the prepared carriers and on the study of the release dynamics of bacterial cells and bioactive metabolites under soil-simulating conditions. The outcome of the work will be a comprehensive model linking biochar material parameters, PGPR colonisation mechanisms, and the functional stability of the carrier, enabling the design of an effective bioinoculant for sustainable agronomic solutions.

Topic title: Optical micromanipulations applied in biophysics and chemistry

Supervisor: prof. Ing. Miloslav Pekař, Ph.D.

Specialist supervisor: Ing. Jiří Smilek, Ph.D.

Description: The thesis will involve measuring material characteristics using so-called optical tweezers. We will focus on the study of both biological and material samples. The method is suitable for measuring the rheological properties of gels, measuring force interactions between micro-objects, and for the targeted modification of materials. Through a suitable combination of optical tweezers with spectroscopic techniques, it is also possible to measure the localized molecular composition of materials. The work will primarily utilize techniques such as Raman and infrared spectroscopy. It will also include the design and fabrication of microfluidic chips necessary for the experiments, followed by the analysis of the measured data combined with machine learning.

Topic title: Rhizobacteria: Impacts on Soil Microbiome Dynamics, Physicochemical Properties and Agronomic Productivity

Supervisor: doc. Ing. Petr Sedláček, Ph.D.

Specialist supervisor: Ing. Michal Kalina, Ph.D.

Description: The dissertation will provide a comprehensive evaluation of soil conditioners enriched with plant growth–promoting rhizobacteria (PGPR) and their effects on soil microbiome dynamics, soil physicochemical properties, and agronomic performance. Using multi-cycle cultivation experiments, the study will track how different biologically active conditioners influence soil enzyme activities, microbial community composition, and functional microbial traits (including PGP effects), as well as organic matter transformation and humification processes. In parallel, changes in key physical and chemical soil parameters—pH, water regime, nutrient availability, organic carbon content, and related indicators—will be quantified alongside the growth and productivity of model plants. The overarching goal is to integrate soil, microbial, and plant responses to develop a conceptual model describing how PGPR-based conditioners function in soil systems, with particular emphasis on their applicability in sustainable agriculture.

Topic title: Beyond conventional hydrogels: Architectured hybrid polymer networks with tunable responsiveness for advanced biomedical applications

Supervisor: doc. Ing. Petr Sedláček, Ph.D.

Specialist supervisor: Ing. Jiří Smilek, Ph.D.

Description: Hydrogels are widely used in biomedical applications due to their high water content and biocompatibility, yet their functionality is often limited by insufficient mechanical performance and lack of adaptability to dynamic biological environments. This PhD project aims to overcome these constraints by developing hybrid polymer networks with controlled composition and architecture that combine chemically crosslinked and physically interpenetrated polymer networks.

The research will focus on hybrid systems based on photopolymerized chemical networks from biocompatible acrylic monomers such as poly(ethylene glycol) diacrylate (PEG-DA) and 2-hydroxyethyl methacrylate (HEMA), integrated with semi- or fully interpenetrating physical networks. Special attention will be given to the incorporation of biomedically relevant hydrophobic polymers, such as polyhydroxyalkanoates (PHAs), into the hydrogel structure using solvent-exchange strategies. This approach is expected to enhance mechanical properties and introduce additional functionalities while maintaining the advantageous characteristics of hydrophilic networks.

A central objective of the project is to engineer stimuli-responsive behavior through systematic variation of network composition and architecture. Functional co-monomers and tailored physical networks will be employed to induce controlled changes in swelling, mechanical, and transport properties in response to pH, temperature, and electric potential. Furthermore, the integration of these responsive hybrid materials with advanced additive manufacturing and 4D printing techniques will enable programmable shape-shifting and time-dependent functionality. Overall, this project seeks to extend the capabilities of conventional hydrogels and establish a versatile materials platform for advanced biomedical applications.