Nanyang Technological University – Jagiellonian University

Joint Research Seminar

Jagiellonian University, Faculty of Chemistry

Krakow, 27 July 2026

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

JAGIELLONIAN UNIVERSITY IN KRAKÓW

Seminar Program

9:00-9:15 *Welcome and Opening Remarks*

9.15-9.30 NTU and JU Presentations

9.30-11.00 Nanyang Technological University (NTU) Session

9.30-10.00 Prof. Teik Thye Lim, *Bridging heterogeneous catalysis and membrane separation: A synergistic integration to intensify micropollutant elimination*

10.00-10.30 Prof. Xunchang Fei, *Singapore's sustainable waste management*

10.30-11.00 Prof. Grzegorz Lisak, *Beyond waste volume reduction: Integrating advanced thermochemical pathways, resource reclamation, and real-time assessment*

11.00-11.30 *Coffee break*

11.30-13.30 Jagiellonian University Session

11.30-12.00 Dr. Karolina Tarach, Prof. Kinga Góra-Marek, *Catalytic transformation of plastics on zeolites - toward feedstock recycling*

12.00-12.30 Prof. Ewa Kowalska, Dr. Marcin Kobielusz, *Environmental applications of photocatalysis and research methods for photoactive materials' characterization*

12.30-13.00 Prof. Piotr Pietrzyk, Prof. Lucjan Chmielarz, Prof. Agnieszka Węgrzyn, Dr. Tetiana Tatarchuk, *Advanced oxidation processes for water treatment - examples of fundamental investigations, materials and applications*

13.00-15.00 *Lunch*

15.30 *Jagiellonian University Museum Collegium Maius*

Location: Jagiellonian University, Faculty of Chemistry, Gronostajowa 2, room: A1-01

Bridging Heterogeneous Catalysis and Membrane Separation: A Synergistic Integration to Intensify Micropollutant Elimination

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In the quest for high-quality reclaimed water through advanced wastewater treatment, the removal of recalcitrant micropollutants (MPs) stands as a formidable challenge. Wastewater hosts a spectrum of biorefractory MPs, ranging from industrial additives to pharmaceuticals, presenting a barrier to effective elimination through conventional methods. Advanced oxidation processes (AOPs) emerge as a promising solution, leveraging the on-demand generation of reactive oxygen species (ROS) that are capable of degrading and even mineralization of most MPs. Heterogeneous catalysis, the most explored AOPs, activates diverse oxidants to produce ROS. Despite substantial strides in research and innovation, practical applications of heterogeneous catalysis in water treatment still face multiple challenges including catalyst recovery, catalyst agglomeration and overall low efficiency due to mass transfer limitations. Membrane separation is an integral process in advanced water treatment, but membrane fouling is its main hurdle for wide applications. Addressing the dual challenges posed by heterogeneous catalysis and membrane separation, a burgeoning area of interest involves synergistic integration of catalytic oxidation and membrane separation in a hybrid system. This novel paradigm employs a catalytic ceramic membrane (CCM) as a reactor, intensifying MP degradation via space confined catalysis while offering a stable support for nanocatalysts. This presentation elucidates the landscape of advanced water treatment, delineates the role of heterogeneous catalysis in ROS generation, summarizes commercial applications of ceramic membranes, details the fabrication of catalytic ceramic membranes (CCM), and delves into the hybrid oxidation-separation process with CCM. The discussion encompasses a process evaluation framework and outlines the prospects for practical applications, fostering a comprehensive understanding of this innovative treatment solution for advanced water reclamation in the context of MPs removal.

Singapore's sustainable waste management

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Constrained by extreme land scarcity, Singapore has constructed an integrated, circular-oriented sustainable waste management framework guided by the 2019 Zero Waste Masterplan and Singapore Green Plan 2030, aiming to extend the service life of Semakau Landfill beyond 2035. The country adopts a multi-tiered system following recycling, incineration, and residual waste disposal. Safe and sustainable reuse of residual waste in Singapore is a promising solution but remains in its early stage and calls for further scientific research and practical development. We will present the methodologies, results, and regulatory implications of our two ongoing projects supported by the National Environment Agency of Singapore. Specifically, the first project focuses on developing localized environmental standards for safe and sustainable reuse of residual waste, and the second project focuses on characterization and treatment of landfilled residual waste in Semakau Landfill.

Beyond Waste Volume Reduction: Integrating Advanced Thermochemical Pathways, Resource Reclamation, and Real-Time Assessment

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Traditional waste management focuses primarily on reducing the volume of waste sent to landfills, treating municipal and industrial residues as costly liabilities. This research presents a practical approach to shift toward a sustainable, resource-recovery model using advanced thermochemical conversion. By upgrading standard processing methods, municipal solid waste, plastics, biomass, and sewage sludge are turned into valuable materials and energy. The research bridges engineering and real-world application across three areas. First, it improves standard Waste-to-Energy systems by adding secondary resource recovery and carbon dioxide capture. Second, it designs specific chemical breakdown pathways to handle highly mixed, complex waste streams. Third, it implements real-time sensing technologies to immediately test and validate the safety of the raw waste and the final, recycled products. Ultimately, this work thrives to replace simple disposal with a scalable resource extraction and emissions reduction.

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Catalytic Transformation of Plastics on Zeolites - Toward Feedstock Recycling

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Information on the molecular pathways involved in catalytic polyolefin cracking is crucial for improving chemical recycling processes. In this work, the cracking of polypropylene (PP) and low-density polyethylene (LDPE) over zeolites was examined using an integrated operando approach that combined FTIR spectroscopy, chemometric analysis (2D COS and MCR-ALS), and thermogravimetric analysis (TGA).

Operando FTIR enabled real-time monitoring of hydrocarbon species confined within zeolite micropores, providing direct insight into polymer activation, intermediate formation, and catalyst deactivation. 2D COS improved spectral resolution and clarified the sequence of transformations from aliphatic polymer fragments through olefinic intermediates to aromatic compounds and coke precursors. MCR-ALS further resolved overlapping spectra into pure-component profiles and concentration trends, allowing identification of the main reaction stages, including polymer degradation, transient olefin accumulation, and formation of condensed aromatic species. Comparative analysis showed that PP undergoes faster conversion with enhanced production of branched olefins and aromatic compounds, whereas LDPE follows a slower pathway dominated by linear hydrocarbon intermediates.

The combined spectroscopic analyses demonstrated that Brønsted acid sites in zeolites promote carbenium-ion chemistry, β-scission, oligomerization, cyclisation, and aromatization, ultimately governing product distribution and coke formation. Independent TGA measurements quantified polymer conversion and carbonaceous residue accumulation, linking spectroscopic observations with catalyst deactivation. Correlating FTIR, 2D COS, MCR-ALS, and TGA data highlights the key role of zeolite micropore confinement in controlling the lifetime and reactivity of polyolefin-derived species. This integrated analytical approach provides mechanistic insight into zeolite-catalyzed polyolefin cracking and supports the development of more selective and coke-resistant catalysts for chemical recycling.

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Environmental Applications of Photocatalysis and Research Methods for Photoactive Materials' Characterization

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Our research focuses on the design, synthesis, and characterisation of heterogeneous photocatalysts for environmental- and energy-related applications. A major aspect of our work is the development of advanced photocatalytic materials with enhanced light-harvesting capabilities, including photonic crystals and plasmonic materials based on noble metals exhibiting localized surface plasmon resonance (LSPR). In parallel, we investigate strategies to improve charge separation and transfer in photocatalysts. These include the fabrication of facet-engineered semiconductor crystals, heterojunctions, and other architectures designed to enhance photocatalytic efficiency.

A key strength of our groups is the investigation of the fundamental mechanisms governing photocatalytic processes. To this end, we employ a broad range of advanced characterization techniques, including photoelectrochemical and spectroelectrochemical methods, as well as time-resolved spectroscopic techniques, to elucidate charge carrier dynamics and reaction pathways.

The photocatalysts developed in our laboratories are evaluated in a variety of photo(electro)catalytic applications. Our environmental research includes the degradation of emerging contaminants, particularly pharmaceutical compounds in water and microorganisms using advanced oxidation processes driven by various photocatalysts. At the same time, we explore light-driven reduction reactions, including carbon dioxide conversion, photocatalytic hydrogen production, nitrogen reduction, and the selective transformation of organic compounds into value-added chemicals.

Through the combination of advanced material design, mechanistic studies, and application-oriented research, our goal is to develop highly efficient photocatalysts that contribute to sustainable environmental remediation and solar energy conversion.

References

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Advanced Oxidation Processes for Water Treatment - Examples of Fundamental Investigations, Materials and Applications

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The Faculty of Chemistry at the Jagiellonian University has developed a distinctive research profile in advanced oxidation processes (AOPs) characterized by fundamental mechanistic understanding of catalytic oxidation, advanced catalyst design for reactive oxygen species (ROS) generation (catalytic and photocatalytic), strong expertise in heterogeneous catalysis, integration of spectroscopy with catalytic studies, applications to model and environmentally relevant pollutants, and high-quality materials chemistry supporting environmental catalysis. In our studies, we focus on connecting catalyst electronic structure, ROS chemistry, and reaction mechanisms to enable the rational development of next-generation catalytic oxidation systems, rather than focusing solely on treatment performance.

In particular, contributions to understanding how H_2O_2 is activated on non-redox oxide catalysts and Fenton-like materials, revealing electroprotic and redox mechanisms responsible for the formation of hydroxyl radicals, superoxide radicals, and peroxide intermediates, have been recently published [1]. Other systems studied include titanium-containing zeolites, TiO_2-based photocatalysts, and other heterogeneous catalysts that efficiently activate H_2O_2 for the highly selective oxidation of organic sulfides under mild reaction conditions [2]. These studies are relevant not only to the synthesis of valuable fine chemicals but also to the oxidative desulfurization of petroleum-derived fuels, providing environmentally friendly alternatives to conventional sulfur-removal technologies. Heterogeneous Fenton- and photo-Fenton-like advanced oxidation processes based on iron oxide-modified clays, TiO_2-supported catalysts, and pillared clay materials capable of activating hydrogen peroxide under dark and illuminated conditions to generate reactive oxygen species have been tested for the degradation of pharmaceuticals, endocrine-disrupting compounds, phenols, and other persistent organic pollutants [3]. Finally, magnetic oxide nanomaterials for environmental remediation, water purification, and accelerated degradation of organic contaminants and microbial pathogens have been investigated. As an example, spinel ferrite catalysts (including $CoFe_2O_4$, Ni–Co ferrites, Cu-substituted magnetite, and multicomponent ferrites) for Fenton-like reactions have recently been studied [4].

References

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