Porous Organic Materials in Action: The design of COFs and COPs in the Energy application

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Porous organic materials are driving innovation in membrane science, enabling the design of advanced functional membranes with tunable properties. Among these, covalent organic frameworks (COFs) and covalent organic polymers (COPs) offer modular synthesis, adjustable pore sizes, and structural versatility for precise control of ion and molecule transport. This presentation will first introduce the chemistry and design principles of COFs and COPs, focusing on strategies for achieving high surface area and selective transport, including the integration of functional groups such as sulfonic acids and the tailoring of hydrogen bonding and imine-linkages. The main emphasis will be on energy applications, highlighting our recent work on polybenzimidazole membranes doped with sulfonic acid-functionalized COFs and COPs for vanadium redox flow batteries. These hybrid membranes exhibit enhanced coulombic and energy efficiency through optimized ion selectivity and minimized vanadium ion crossover, demonstrating the impact of rational pore and interface engineering in next-generation electrochemical membrane systems.

Natural Nitrogen-Doped Nano-Graphene from Palm Kernel Shell via Ball Milling Mechano-Synthesis: Synthesis, Functionalization, and Structural Characterization

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The synthesis of high-quality graphene using biomass as a carbon precursor offers a sustainable pathway toward eco-friendly advanced materials. This study investigates the pivotal role of mechanical milling in transforming palm kernel shell (PKS)-derived carbon from micron-scale to nanometer-sized graphene while enhancing its structural order. Graphene was synthesized via a single-step carbonization of PKS at 500 °C for 90 minutes, followed by mechanical ball milling for durations ranging from 0 to 5 hours. This simplified thermal route significantly minimizes the need for hazardous chemical reagents typically required in graphene synthesis. The effects of milling duration on particle size distribution, crystallinity, and defect density were examined using Raman spectroscopy, X-ray diffraction (XRD), high-resolution transmission electron microscopy (HRTEM), and particle size analysis. Raman spectra revealed that prolonged milling decreased the defect density and promoted graphitic ordering, evidenced by a progressive reduction in the ID/IG ratio and the emergence of 2D-band features characteristic of few-layer graphene. XRD analysis further confirmed improved crystallinity with extended milling, while particle size measurements demonstrated a marked reduction from the micrometer scale (0-hour sample) to uniform nanoscale dimensions (5-hour sample). HRTEM images clearly showed well-defined layered graphene structures with interplanar spacing consistent with graphitic carbon, confirming the successful formation of nanoscale graphene sheets. These findings highlight the critical role of milling duration in optimizing the structural and morphological uniformity of biomass-derived graphene, establishing a scalable and sustainable route for producing high-quality few-layer graphene suitable for advanced applications in energy storage, catalysis, and multifunctional nanocomposites.

Researches on materials and membranes for green society in Gyeongsang National University

Sang Yong, Nam

Gyeongsang National University

At Gyeongsang National University, we are advancing research on innovative materials and membranes that contribute to a sustainable green society. Our work primarily focuses on developing high-performance separation membranes for water treatment, which enhance purification efficiency and sustainability. In the realm of gas separation, we are creating advanced membranes for efficient hydrogen and carbon dioxide separation, aiming to optimize energy use and reduce environmental impact. Additionally, we are pioneering electrolyte membranes for hydrogen fuel cells and electrolysis, which promise to improve energy conversion and storage capabilities. These research efforts have led to significant improvements in membrane selectivity, permeability, and durability, positioning our developments at the forefront of sustainable technology solutions. By integrating these advanced materials into practical applications, we aim to address critical energy and environmental challenges, thereby contributing to the global pursuit of a greener future.

Polymer Nanofiltration Membranes for High-Temperature Separation

Ling-Shu Wan

Zhejiang University

Polymer nanofiltration membranes have been widely used in many fields such as water treatment, food, and medicine industries. In some fields such as some food and textile industries, separation of solutions above 70 °C is required. However, the upper limit working temperature of the commercial polymeric nanofiltration membranes is typically 45~55 °C, which makes liquid cooling a necessary process before membrane separation. Extra energy is consumed during the heat exchange process for liquids which need to be re-heated. To meet the increasing demand, it is of great significance for the development of thermally stable nanofiltration membranes. This talk focuses on polymer nanofiltration membranes for high-temperature separations. Some strategies are proposed to improve the thermal stability of the nanofiltration membranes, which include the choice of thermally stable ultrafiltration substrate membranes, the design of monomers for interfacial polymerization, and the modulation of the interfacial polymerization process. The thermal stability and the high-temperature separation performance of the prepared nanofiltration membranes will be discussed.

Nanostructures and electrochemical functions of redox-active liquid crystalline thin films based on perylene bisimide moiety

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,
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We synthesized liquid crystalline perylene bisimide derivatives bearing triethylene oxide chains and cyclotetrasiloxane rings. These liquid crystals exhibited columnar phase in which ion-conductive sublayer and electron transporting π-stacks were segregated on a nanometer scale. The thin films of the compounds could be insolubilized by an exposure on acid vapors. The thin films underwent interstitial doping to exhibit anisotropic electric conductivity. We also synthesized liquid crystalline perylene bisimide derivatives bearing crown ether moieties. Nanosegregated structures were formed in the thin films during a spin-coating process. The nanostructures could be modulated by complexation with alkaline metal salts. Under a few conditions, ion- and electron-transporting channels were segregated on a nanometer scale separately. In organic electrolyte solutions, the thin films exhibited reversible electrochromism. The thin films of the liquid crystals worked as a mixed conductor.

Layer-by-layer nanofiltration membranes for removal of micropollutants

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Water-based assembly of Layer-by-Layer (LBL) nanofiltration membranes has emerged as a new type of green, high-performance separation material, and outperformed conventional interfacial polymerization membranes for some applications. However, the understanding of how to create highly selective LBL nanofiltration membranes is still in its infancy. The interaction of the LBL coating layer with the substrate is largely unknown. It remains unclear how the assembly of polycations and polyanions impacts the separation properties of nanofiltration membranes. The reaction of the LBL coating to external hydraulic pressure and chemicals requires further investigation. This presentation outlines our recent discoveries regarding the unique behavior of LBL nanofiltration membranes for micropollutant removal. New mechanisms and hypotheses will be proposed, and perspectives for future develc Presentation discussed.

Interface Engineering for Stable Lithium-Metal and Anode-Free Batteries: From Asymmetric Membranes to Surface Coatings

Wei-Fan Kuan

Chang Gung University

The advancement of lithium-metal and anode-free lithium-metal batteries is essential for realizing next-generation energy storage systems with high energy density. However, their practical implementation is impeded by challenges such as dendritic lithium growth, unstable electrodeposition, and limited cycling stability. In this presentation, we highlight two complementary interface engineering strategies developed in our group to address these issues. First, an asymmetrically porous polyvinylidene fluoride (PVDF) membrane is designed to regulate lithium-ion flux and suppress dendrite formation, facilitated by the formation of β-phase PVDF. This porous membrane also serves as a scaffold for constructing solid polymer electrolytes with enhanced ionic conductivity. Second, a β-phase-enriched PVDF coating is applied to copper current collectors, promoting uniform lithium nucleation and reversible plating/stripping, thereby improving the cycling stability of anode-free configurations. These approaches highlight the importance of interfacial structure and chemistry in enabling safe, stable, and high-performance lithium-metal battery technologies.

Evaluations of Cell Performances for Zn-CO2 Batteries using Bifunctional Honeycomb-like ZnS/CusS and S-doped NiO/Co3O4 Electrocatalysts on Ni-foams as Gas Cathodes

Cheng, Kong-Wei

Chang Gung University

Renewable energy applied in industrial activity is limited due to its unstable energy output and new storage system has to be developed to meet industrial requirements. Zn-CO2 energy storage system is an interesting battery for further application. In this study, plate-like (O-Cu-S)x/(O-Zn-S)y MOF was prepared using solvothermal method at temperature of 100°C for 72 hours and then were annealed at 650°C for 1 hour to obtain ZnS/CuxS electrocatalysts with high surface area. Powders of S-doped NiO/Co3O4 catalysts were also obtained using co-precipitation of NiO/Co3O4 samples under sulfurization process. These S-doping NiO/Co3O4 sample combined with ZnS/CuxS electrocatalyst attached onto graphene oxide were coated onto Ni-foams as gas-cathode in Zn-CO2 battery for further tests.

Electrocatalyst using ZnS/CuxS : S-doped NiO/Co3O4 ratio of 3:1 on gas-cathode in our homemade Zn-CO2 battery showed the best electrochemical performance, which exhibited the lowest charge/discharge voltage difference value of 0.7-0.8 V at constant charge/discharge current density of 5 mA/cm2 and the product converted from CO2 reduction reaction was examined as formic acid. Using electrochemical impedance spectra of samples, high carrier concentration and low charge transfer resistance of the electrocatalyst on gas-cathode made it have the best electrochemical performance and stability in electrolyte.

Sustainable Environmental Technology research at Victoria University

Mikel Duke

Victoria University

Victoria University is developing advanced membrane technologies to support Australian water industry strategies aiming to increase use of recycled water for agriculture, urban water supply and environmental flows. Additionally, climate change heightens risks of water supply disruptions from cyanobacteria blooms, initiating membrane solutions to also be explored. Recent research focuses on nanofiltration to remove and recover emerging contaminants often found industrial and treated wastewaters to enable their reuse, such as herbicides, pesticides, antibiotics, and pharmaceuticals. Additionally, photocatalytic membrane reactors (PMRs) using MoS_2/Fe_2O_3/Graphene Oxide-coated PVDF membranes and light-transmitting PMRs with titania photocatalysts show promising anti-fouling and contaminant removal and mineralization (complete destruction) capabilities under ideal conditions. Collaborative work with Kobe University has recently improved this PMR concept. Current efforts explore real-world water matrix applications to address reaction inhibition and maintain contaminant destruction. Industry partnerships are also investigating membranes for harvesting cyanobacterial bloom biomass for bioenergy and using PMRs to eliminate cyanotoxins, aligning with sustainable water management goals.

Surface-Modified PVDF Membranes with Antifouling Polymers for Improved Microalgae Filtration

Irish Valerie B. Maggay

Chung Yuan Christian University

The efficiency of microalgae harvesting by microfiltration is often hindered by severe membrane biofouling, mainly due to the release of extracellular polymeric substances (EPS) during operation. In this study, polyvinylidene fluoride (PVDF) membranes were modified with antifouling polymers to establish a stable hydration layer that suppresses foulant adhesion and improves filtration stability. The modified membranes exhibited markedly higher water flux, enhanced flux recovery, and reduced protein and algal deposition compared with pristine PVDF. Characterization confirmed limited EPS accumulation on the surface, while long-term stability tests demonstrated negligible leaching of the modification layer and sustained antifouling performance. These results demonstrate a straightforward and scalable strategy to mitigate biofouling in membrane-based microalgae harvesting processes.

Resource recovery from wastewater using membrane technology for a circular economy

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Increasing population growth and rapid urbanisation is placing increasing pressure on existing water infrastrucuture and agricultural food productivity to meet future supply and demand. The World Bank predicts that by 2050, the global population will be nine billion, placing a 50% increase in agricultural food productivity and 15% increase in water withdrawals. With these fertilise shortages, there is a strong market driver for bioavailable nutrients through a renewable approach. Decentralising the treatment of our wastes is especially interesting as it has the potential of making an industry, notoriously thirsts in energy, water and raw materials, a net producer. It was also demonstrated that the integration of source-separation of urine, faeces and greywater would help to achieve this goal, while also opening new opportunities for building a more flexible and resilient urban wastewater network. Urine valorisation is attractive due to its low volume, high nitrogen (N) and phosphorus (P) concentrations (80% of N and 50% of P inputs into sewers), and relative ease of collection and storage. As such, it has often proven to be a suitable raw material from the production of fertiliser, energy and water (this last one mainly on board of the International Space Station). However, conventional technologies often struggle in dealing with urine alkalinity, high NH3 and dissolved organic carbon concentration (i.e. 5 to 10 g.L-1) and high salinity (i.e. 4 to 9%). That is why, the strong chemical resistance, small footprint, tuneable selectivity and versatility in the operation of processes makes them an ideal technology to extract value from human urine. As such, this presentation will cover four main research themes from the ARC Research Hub for Nutrients in a Circular Economy (ARC NiCE Hub) in terms of economic, commercial, environmental and societal benefits

Blocking Carboxyl Groups of Polyamide RO Membranes for Antifouling Performance during Industrial Wastewater Treatment

Yunxia Hu

Tiangong University

Reverse osmosis (RO) membranes used for industrial wastewater treatment last only months, not years like in seawater desalination, greatly increasing maintenance costs. Carboxyl groups in polyamide (PA) RO membranes are key contributors to fouling and scaling, hindering sustainable operation. To address this, we developed surface engineering and interfacial polymerization (IP) tailoring methods to block carboxyl group generation and enhance antifouling performance. Grafting short aliphatic/aromatic amines onto PA via layer-by-layer IP effectively suppressed carboxyl groups in RO membranes, significantly improving membrane fouling resistance against small organic foulants. Tailoring IP with surfactants produced carboxyl-free PA, substantially enhancing fouling/scaling resistance during coking wastewater treatment. Both experimental results and molecular dynamics simulations confirm that avoiding carboxyl group formation and preventing foulant penetration into the PA are essential for improving membrane fouling resistance. Our work offers new insights into molecular structure engineering of PA, advancing RO membrane durability against small charged foulants during industrial wastewater treatment.

Catalytic membrane reactors for treatment of emerging pollutants

King Lun YEUNG

Hong Kong University of Science and Technology

This study explores the use of catalytic membrane reactors for the treatment of emerging pollutants, specifically focusing on a tubular zeolite membrane coated with catalysts. The reactor facilitates the simultaneous reaction and degradation of pollutants such as phthalates, diclofenac, and caffeine into harmless byproducts. Various membrane reactor configurations were evaluated to optimize performance, allowing for efficient separation and recovery of clean water through pervaporation. The findings demonstrate the effectiveness of this approach in mitigating environmental contaminants, highlighting its potential for sustainable water treatment solutions and addressing the growing concern of emerging pollutants in wastewater.

Resource Recovery and Biovalorization in Membrane Photobioreactors for Agro-Industrial Wastewater Treatment

Helen Julian

Institut Teknologi Bandung

This study explores the use of a membrane photobioreactor (MPBR) with Spirulina platensis for palm oil mill effluent (POME) treatment, biomass production, and biovalorization, with nanofiltration (NF) incorporated as part of the treatment scheme. The effects of aeration and hydraulic retention time on biomass growth, metabolite formation, and nutrient removal were evaluated. The MPBR successfully reduced organic and nutrient loads while producing microalgal biomass enriched with lipids and β-carotene. In the next stage, NF was investigated in two configurations: (i) as a replacement for ultrafiltration (UF) inside the MPBR to improve selective retention and reduce fouling, and (ii) as a polishing step following MPBR-UF to further lower residual contaminants and enhance permeate quality. The combined approach demonstrates the potential of integrating biological treatment, membrane separation, and resource recovery. Overall, MPBR coupled with NF offers a promising pathway for sustainable POME management, enabling simultaneous wastewater remediation and the generation of valuable bioproducts.

Virus filtration challenges for validation of virus clearance

S Ranil Wickramasinghe

University of Arkansas

Virus filtration is routinely used to validate virus clearance in the manufacture of biopharmaceuticals. Minute virus of mice (MVM) a model parvovirus 18-22 nm in size, is used in virus clearance studies. Virus filters are run in dead end mode. They are designed to achieve 4 or more log (10,000 fold) virus clearance in the permeate relative to the feed. In addition, more than 95% product recovery is required. Virus filtration occurs toward the end of the purification train thus fouling of virus filters is due to product related foulants consisting of irreversible and reversible aggregates.
Here we have investigated the use of pretreatment (by size exclusion and membrane adsorbers) in order to minimize membrane fouling which leads to a decrease in flux, reduced productivity and altered membrane rejection properties of the virus filter. We show that hydrophobic interaction membrane adsorbers are the most effective at removing product related foulants.

The effects of solvent on the mechanisms and pathways for the biomass conversion to levulinic acid

Xianghong QIAN

University of Arkansas

Levulinic acid is one of the critical platform chemicals for the conversion of lignocellulosic biomass to biofuels and bio-based products. However, current conversion technology is not yet commercially viable due to the high production cost and low yield. We have developed a patented technology for converting lignocellulosic biomass into levulinic acid in one step at mild conditions with high conversion and high yield. Our unique catalyst consists of two polymer chains acting synergistically to hydrolyze the biomass and convert the hydrolyzed sugars to levulinic acid. However, the product yield is strongly dependent on the solvent and solvent mixtures. Here the effect of solvent on mechanisms of levulinic acid production is elucidated using cellulose substrate. MALDI-MS combined with GC-MS was used to determine all the intermediate- and side- products. Moreover, the kinetics of the levulinic acid production and activation energies for the conversion are determined at different solvent medium and solvent mixtures.

Fabrication of High-Performance Polyether Sulfone-Based Membranes and Their Application

Ya-kai Lin

Tsinghua University

This study focuses on the development of high-performance polyether sulfone (PSf)-based membranes for advanced separation applications. Three distinct membrane configurations were designed and fabricated. First, PSf loose nanofiltration (NF) membranes were prepared via a hybrid-induced phase separation (HIPS) method, demonstrating high efficiency in dye/salt separation for textile wastewater treatment. Second, TMA/VBC-g-PSf loose NF membranes were synthesized through a UV-initiated grafting technique, which significantly improved selectivity and performance in dye and salt fractionation. Third, a PA-PSf NF membrane was constructed by integrating the HIPS method with interfacial polymerization (IP), specifically tailored for drinking water purification. This membrane exhibited excellent removal efficiency toward trace antibiotics, addressing a critical challenge in water safety assurance. Collectively, this work presents a series of versatile and effective PSf-based membrane strategies applicable to both industrial dye recovery and the production of high-quality drinking water.

The sustainable vision of membrane preparation

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The use of green solvents as substitutes for traditional solvents is the trend of the future for the preparation of polymeric membranes as well as Mixed Matrix Membranes (MMMs). [1] In this regard, during the last years, different solvents, with more benign properties, have been introduced. Among them, Dimethyl isosorbide that is a bioderived-green solvent was used, for the first time, for the preparation of polyether sulfone (PES) and polyvinyl difluoride (PVDF) flat-sheet membranes [2]. Membranes have been prepared by varying different parameters including polymer concentration and evaporation time before coagulation. This solvent was used to produce MMMs membranes for catalytic membrane application. In the second of the work, for the first time the deep eutectic solvents (DES) were explored as novel alternative solvents for preparation of membranes thanks to their favourable green properties [3]. The results confirmed the possibility to obtain membrane with DES as a solvent tailoring the pore size and morphology for Microfiltration (MF) and Ultrafiltration(UF) applications.

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Polymers of intrinsic microporosity (PIMs) applications in gas-separation membranes

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Polymers of Intrinsic Microporosity (PIMs) have attracted growing interest owing to their rigid and contorted macromolecular architectures, which generate substantial internal free volume and interconnected microporous networks. These structural features enable exceptionally fast and selective molecular transport, making PIMs excellent candidates for advanced gas separation [1,2] and liquid separation membranes. [3] Beyond their traditional use in separation technologies, recent research has highlighted the potential of PIMs in electrochemical energy devices. [4,5]. This presentation will further explore various classes of PIMs known for their that exhibit an excellent combination of permeability and permselectivity. Besides their integration into gas separation processes, particular emphasis will be placed on the design of ion conductive membranes, achieved through post-synthetic chemical modification. The discussion will underline how tailored functionalization strategies can expand the applicability of PIM-based materials in next-generation membrane technologies.

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Machine learning-driven design and optimization of MOF mixed matrix membrane towards He separation

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The application of machine learning (ML) techniques in the field of membrane separation is still in its initial stage. For MOF mixed matrix membrane (MMM), two critical challenges persist: (i) constructing reliable structure-performance datasets of MMMs; (ii) developing descriptors that effectively correlate with MMM interfacial properties. To address these challenges, we performed high-throughput grand canonical Monte Carlo (GCMC) and molecular dynamics (MD) simulations to compute reliable structural and performance features of thousands of MOF fillers. These computed data were integrated with experimental data of polymer membranes to construct MMM big datasets. We introduced interfacial interaction energy (Eint) as a quantitative metric to characterize the MOF-polymer interface. Comprehensive data-driven model interpretation analyses identified key functional groups that is beneficial to the enhancement of interfacial stability. Eint serves as a robust interfacial descriptor to evaluate MMM separation performance and guide MMM design.

Pharmaceutical Waste Management: Advanced Oxidation and Membrane Technology

Haipeng Zhu

Nanjin Tech University

Pharmaceuticals with low biodegradability and high hydrophilicity have been frequently detected in industrial and drinking water streams, thus it is of high significance to explore effective pharmaceutical waste's resource recovery and discharge throughout the drug production and treatment processes, therefore to comply with active pharmaceutical ingredients (API)'s discharge limits. Singapore Membrane Consortium (SG MEM) has gathered valuable problem statements from the leading pharmaceutical industry players, which are related to separation of ingredients from liquid waste, zero liquid discharge, water reuse, protein separation, replacement and reduction of solvent consumption, as well as modular waste treatment systems. To address the current challenges of pharmaceutical discharge and to achieve the useful ingredients' recycling, SG MEM is collaborating with Pharma Innovation Programme Singapore (PIPS), the innovation partner (i.e., IPI Singapore) and the solution provider members from the SG MEM ecosystem to investigate the efficient pharmaceutical waste management techniques. The advanced oxidation processes (AOP) have emerged as a 'polishing' step to be applied to remove recalcitrant COD before proceeding with the tertiary treatment. In addition, integrating AOP with specific downstream membrane technology can potentially increase the pharmaceutical wastewater biodegradability. The updated findings of the AOP with various membrane types are showcased in this poster of the SG MEM discovery series in 2024 to enhance the environmental awareness and provide the insights of potential waste management to the pharmaceutical industry end-users.

Recent research activities at Membrane Center of Kobe University

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Research Center for Membrane and Film Technology,
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As the first and only-one university-driven membrane research center in Japan, the Center for Membrane and Film Technology (MaFTech Center) of Kobe University was established in 2007. In 2015, the integrated membrane research building (6000m^2) finished its construction and started its operation. Currently we are collaborating with more than 80 industrial companies, as well as partnering 17 academic membrane research centers overseas.

In this presentation, MaFTech center's recent research related to CO_2 separation membrane will be introduced. An ion-gel-based TFC membrane by forming a thin ion-gel layer containing a highly CO_2-soluble ionic liquid on a loosely cross-linked polydimethylsiloxane (PDMS) gutter layer was developed. The cross-linking degree of the gutter layer was decreased by adjusting the molar ratio of vinyl-terminated polydimethylsiloxane and methylhydrosiloxane-dimethylsiloxane copolymers to increase the gas permeability. The CO_2 permeability of the loosely cross-linked PDMS gutter layer reached about 10,000barrer. The ion-gel layer with highly CO_2-soluble1-ethyl-3-methylimidazolium tricyanomethanide ([Emim][C(CN)$_3$]) was prepared by physical cross-linking of a Pebax1657 network. The physical cross-linking enabled the formation of a thin ion-gel layer on the gutter layer by a simple spin-coating and drying process. The CO_2 permeance and CO_2/N_2 permselectivity of the TFC membrane with the thinnest ion-gel layer were 1156 GPU and 22 at 50°C, respectively, meeting the required separation performance for capturing CO_2 from flue gases emitted by coal-fired power plants.

In my presentation, I also introduce the COF membrane results for CO_2 separation. COF was prepared at the interface of water and oil and was located on the porous support. The obtained membrane performances will be mentioned.

Plenary Lecture（Online）

Membrane design with nano and sub-nano selectivity

Suzana Nunes

King Abdullah University of Science and Technology

The lecture will discuss recent advances on polymeric membranes for applications in the chemical and pharmaceutical industry, crude oil fractionation, and water sector. Examples of strategies will include interfacial polymerization, copolymer self-assembly and advanced methods of membrane morphology characterization.