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15TH CONFERENCE OF ASEANIAN MEMBRANE SOCIETY

Membrane Innovations for Sustainable Solutions

19 - 21 AUGUST 2025

BERJAYA TIMES SQUARE HOTEL
KUALA LUMPUR, MALAYSIA

ABSTRACT BOOK

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Paper ID: PS1

Polymeric Nano-composite Membranes for H_2 Purification and Separation and CO_2 Capture from Flue Gas

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ABSTRACT

Clean water, clean energy, global warming and affordable healthcare are four major concerns globally resulting from clean water shortages, high fluctuations of oil prices, climate change and high costs of healthcare. Clean water and public health are also highly related, while clean energy is essential for sustainable prosperity. Among many potential solutions, advances in membrane technology are one of the most direct, effective and feasible approaches to solve these sophisticated issues. Membrane technology is a fully integrated science and engineering which consists of materials science and engineering, chemistry and chemical engineering, separation and purification phenomena, environmental science and sustainability, statistical mechanics-based molecular simulation, process and product design. In this presentation, we will introduce our efforts on membrane R&D for H_2 purification and separation, and CO_2 capture from flue gas. Various material and fabrication strategies of both dense-flat and hollow fiber membranes to enhance membrane performance will be discussed.

Keywords: *Membrane Technology, Clean Energy, H_2 Separation, Polymeric Membranes, CO_2 Capture.*

ACKNOWLEDGEMENTS

Prof. Chung would like to thank the Yushan Scholar Program supported by the Ministry of Education, Taiwan and NSTC grant of 113-2221-E-011-006 as well as Singapore NRF, A*STAR and NUS supports.

Paper ID: PS2

Ion-Conducting Membranes for Efficient Separation and Energy Applications

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ABSTRACT

Ionic transport and separation are central to various applications such as in clean energy and environment. Various types of materials such as polymers, 2D materials and advanced porous frameworks have been widely studied as advanced membranes for direct lithium extraction and fuel cells and many other applications. For instance, metal–organic frameworks (MOFs) with ordered subnanometer pores are attractive membrane materials due to their structural diversity, and tunable chemistry and functionality. Many interesting separation properties and bioinspired ion transport behavior have been discovered in MOF-based composite membranes. In addition, high-performance proton exchange membranes (PEMs) play a vital role in the efficiency of high-temperature proton exchange membrane fuel cells. For example, a novel PEM with a hyperbranched interpenetrating hydrogen bond network (HIHBN) has been recently developed by incorporating hyperbranched poly(benzyl-triptycene) (PBT) and SnP_2O_7 hydrogen bond networks. The unique structure of the hyperbranched PBT polymer with a branching point contributes to an impressive glass transition temperature exceeding 400 °C, enabling the membrane to operate at elevated temperatures (above 220 °C) in fuel cell applications. The findings highlight the potential of HIHBN PEMs for high-efficiency, durable performance in high-temperature fuel cell environments.

Paper ID: PS3

Membrane Distillation Technology: Why nanofibrous membranes?

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ABSTRACT

Compared to other separation processes, the potential of the non-isothermal membrane distillation (MD) technology lies in its ability to address the water-energy-environment nexus. It can be integrated with renewable energy sources such as solar energy or waste heat, and treat high saline solutions to saturation, enabling the treatment of brines discharged from water treatment plants. These make MD an environmentally friendly technology that seeks to achieve zero liquid discharge, water production and the recovery of valuable minerals. Generally, it contributes to at least 5 of the 17 Sustainable Development Goals (SDGs) indicated by the United Nations in the Agenda 2030. However, one of the drawbacks hindering its industrial implementation is the lack of properly engineered commercial MD membranes on the market although several types of membranes have been proposed in patents and research papers. Currently, the commercial membranes used in MD pilot plants (initially prepared for microfiltration) suffer from pore wetting, which reduces the quality of the produced water and, consequently, their lifetime. Despite the widespread knowledge of dynamic research fields of materials, membrane engineering techniques and transport phenomena, there is still a substantial information gap related to the scalability, stability and durability of MD membranes, and their resistance to harsh operating conditions. Various hydrophobic materials have been explored in MD membrane engineering, with interesting structures and functionalities for different applications. An MD membrane must be tailored for each MD configuration and for each feed solution to be treated. In this lecture, after the introduction of the current state of MD technology and its membrane engineering based on literature data analysis, bibliometric methods and machine learning, some case studies of nanofibrous-engineered MD membranes with different materials, morphological structures, hydrophobic nature and characteristics will be presented, shedding light on the advantages and drawbacks of this type of membranes with some strategies to improve their performance. These include mixed matrix, nanocomposite, surface modified, double-or-triple-layered, nature-inspired, and solar or photothermally-heated membranes, as well as recycled end-of-life membranes and discarded modules contributing to the long-awaited circular economy and sustainability in membrane science.

Keywords: *Nanostructured membrane, Mixed matrix membrane, Electrospinning, Membrane distillation, Desalination.*

Acknowledgements: The financial support of the project PID2022-138389OB-C31, funded by MCIN/AEI/10.13039/501100011033/FEDER, UE, and the grant RED2024-153562-T funded by MICIU/AEI /10.13039/501100011033, are gratefully acknowledged.

Paper ID: PS4

Recent Progresses in Membrane Preparation and Characterization

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The presentation consists of two parts, i.e. the recent progress in membrane characterization and fabrication of ultrahigh flux membrane. Membrane preparation: There has been a long debate on the presence and absence of pores in the skin layer of reverse osmosis membrane. Various advanced instrumental techniques revealed that there were sub-nanometer pores that demonstrate multiple distributions. The molecular dynamic simulation also revealed that clusters of water moved through the channels formed in the skin layer of the membrane. Membrane fabrication: Attempts are being made to fabricate ultrahigh flux reverse osmosis membranes based on carbon nanotubes, graphene and graphene oxide, aquaporin, and fluorous oligoamide nanorings. The stages in their advancement are briefly outlined and the challenges to overcome for their commercial applications are discussed.

Paper ID: PS5

Membrane Technology in Addressing Global Warming

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ABSTRACT

We are currently facing significant challenges due to greenhouse gases (GHGs), and there is a concerted global effort to address these issues. In particular, the carbon capture and utilization, a prominent GHG, is being actively researched by governments, research institutes, universities, and industries worldwide, all seeking diverse solutions. In the field of membrane technology, there is a focus on enhancing traditional gas separation membrane techniques and developing novel technologies to contribute to carbon capture, storage, and utilization (CCSU). The development and application of gas separation membrane materials in CCS (Carbon Capture and Storage) will be introduced, highlighting how they are being carried out and practically applied. In addition, as carbon dioxide emissions are an inevitable byproduct of fossil fuel use, alternative fuels are being proposed, ushering in the Hydrogen Cycle or Hydrogen Society as a new paradigm. In the Hydrogen Cycle, the role of membranes is crucial in hydrogen production and utilization. They serve as key electrolytes in hydrogen fuel cells and water electrolysis systems, facilitating ion transport. This has heightened the importance of membranes, leading to concentrated research efforts. Moreover, the integration of these new technologies with existing water treatment membrane technologies is emerging as a vital fusion field. This presentation will discuss the development trends and research in gas separation membranes within the Carbon Cycle and the development and applications of membranes in the Hydrogen Cycle.

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Paper ID: KS01

Ion Exchange Membranes Based on Block-Graft Copolymers for Fuel Cells and Water Electrolysis

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ABSTRACT

To address the environmental and economic challenges associated with perfluorinated sulfonic acids (PFSAs), we present a novel strategy for synthesizing block-graft copolymers tailored for hydrocarbon-based polymer electrolyte membranes (PEMs) used in clean energy applications such as fuel cells and water electrolysis. Our approach introduces an efficient combination of “graft-from” and “graft-onto” techniques, enabling the precise incorporation of side chains onto a main polymer backbone. This method allows for the controlled architectural design of block-graft copolymers with enhanced functional properties. Unlike conventional hydrocarbon PEMs, the membranes developed in this study were successfully integrated into a large-scale, mass-production-compatible decal transfer process for fabricating membrane electrode assemblies (MEAs). This compatibility underscores the practical scalability of our materials for industrial applications. In the field of hydrogen production, anion exchange membrane water electrolysis (AEMWE) has emerged as a promising zero-emission technology. Operating in an alkaline environment and utilizing an anion exchange membrane (AEM), AEMWE eliminates the reliance on expensive noble metal catalysts such as platinum and iridium, which are essential in proton exchange membrane water electrolysis (PEMWE). Furthermore, the dense polymer membrane and zero-gap cell configuration in AEMWE systems offer superior operational stability, making them highly suitable for accommodating the fluctuating power supply characteristic of renewable energy sources. While solution casting (SC) remains a widely adopted method for membrane fabrication, it often involves prolonged thermal and vacuum processing to achieve dense membrane structures. In contrast, our previous research introduced a simplified and rapid alternative: the nonsolvent-induced film formation (NIFF) method. This process differs from traditional nonsolvent-induced phase separation (NIPS) by exploiting the strong affinity between the polymer and the nonsolvent, which leads to the formation of a gel-like interfacial layer. This layer facilitates efficient solvent extraction while preventing nonsolvent intrusion. The resulting membranes were transparent, freestanding, and dense, demonstrating physicochemical, mechanical, and electrochemical properties—along with AEMWE performance—comparable to those of SC-derived membranes

Paper ID: KS02

Functional Nanomaterials and Thin Film Composite Membranes: Advancements & Prospects

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ABSTRACT

In recent years, Thin Film Composite (TFC) membrane technology has emerged as a pivotal solution in separation processes across various domains, including food, environmental, and water sectors. The evolution of TFC membranes is driven by innovative research and insights, encompassing material innovations, integration of nanofillers, bioinspired designs, tailored surface functionalization, pore structure optimization, and advanced process designs. Despite these advancements, challenges persist in enhancing energy efficiency, fouling resistance, resource recovery, and achieving high selectivity and permeability for specific gases, all of which are critical for sustainable energy practices and the circular economy. Addressing these challenges necessitates significant improvements in both membrane design and process engineering. Collaborative efforts among researchers, engineers, and stakeholders are essential to fully realize the potential of TFC membrane technology in tackling global challenges and fostering sustainable development.The incorporation of two-dimensional (2D) nanomaterials into TFC membranes has garnered considerable attention due to their exceptional and tunable properties. These properties include mechanical and thermal stability, abundant surface functional groups, high aspect ratios, porous structures, low density, solvent stability, and unique molecular characteristics such as polarizability, dielectric constants, dipole moments, electric charges, and van der Waals forces. The versatility of 2D nanomaterials allows for their integration into both polymeric and inorganic/metallic structures, enhancing the performance of membranes in applications like water treatment, gas separation, and energy devices. This presentation will delve into emerging insights and potential prospects of nanomaterial-based functional TFC membranes, specifically tailored for the removal of diverse cationic and anionic contaminants from wastewater.

Keywords: *Nanomaterials, Functional Groups, Thin Film Composite, Mixed Matrix Membranes, Nanofiltration Membranes*

Paper ID: KS03

Submerged Nanofiltration for Low-Energy and Advanced Drinking Water Treatment

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ABSTRACT

Nanofiltration (NF), without any conventional pre-filtration processes, is a new approach for producing high-quality drinking water. This presentation covers our recent studies examining the feasibility of direct NF treatment of surface water using submerged flat-sheet NF membrane modules. Specifically, this presentation discusses the effects of membrane type, different pre-coagulation processes, and several physical membrane cleaning methods. In general, submerged NF treatment can achieve high water quality, while the rejection of some emerging contaminants, such as perfluoroalkyl and polyfluoroalkyl substances (PFASs), pharmaceuticals, and personal care products (PPCPs), can vary considerably depending on their properties. The direct NF treatment of surface water generally results in gradual membrane fouling. However, the membrane foulant was readily removed by applying one wipe using a sponge or by applying micro nanobubbles, and the membrane permeability was fully recovered. The separation performance of the NF system remained high: total organic carbon removal remained at 80–90% on most sampling occasions. When ferric chloride-based precoagulation was applied before the submerged NF system, membrane fouling was considerably reduced. Further, we demonstrated that inline coagulation (or rapid mixing) without slow mixing using aluminium-based precoagulation can mitigate membrane fouling. Our comprehensive studies show the potential of submerged NF treatment as a low-energy and advanced treatment for drinking water.

Keywords: *Nanofiltration, Fouling, Drinking Water, PFASs, PPCPs*

Paper ID: KS04

Molecular Engineering of Advanced Polymers for High-Performance Separation

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ABSTRACT

The advancement of membrane-based separation technologies is essential for addressing critical challenges in gas purification, water desalination, and organic solvent nanofiltration (OSN). This keynote will explore the molecular engineering of advanced polymer membranes, emphasizing structure-property relationships that drive high selectivity, permeability, and stability in harsh environments. Our research focuses on the rational design of polymers of intrinsic microporosity (PIMs), polyimides, and poly(ether-ether-ketone) (PEEK) membranes. By fine-tuning polymer backbone rigidity, free volume, and functionalization, we develop membranes with superior separation performance, enhanced chemical resistance, and long-term stability. These features are critical for energy-efficient gas separation, solvent recovery, and desalination applications. A key aspect of our work is the systematic exploration of structure-property relationships in polymer membranes, enabling the design of materials with precisely controlled porosity, mechanical robustness, and selective transport properties. Additionally, PEEK-based membranes offer excellent thermal and chemical resistance, making them ideal for challenging separation processes. This talk will highlight recent advances in polymer design, focusing on the development of novel, high-performance membranes tailored for specific separation challenges. By integrating fundamental insights into polymer chemistry with performance-driven material development, our work aims to push the boundaries of molecular separations and enable next-generation membrane technologies.

Keywords: *Advanced Polymers, Polymers of Intrinsic Microporosity, Gas Separation, Water Treatment, Membranes*

Paper ID: KS05

Precise Regulation of 2D MOF Membrane Stacking Structures for Efficient Hydrogen Purification

Yanying Wei

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ABSTRACT

Two-dimensional (2D) metal-organic framework (MOF) nanosheets, with their unique structural advantages such as atomic-scale thickness and in-plane porous architecture, have emerged as ideal building blocks for constructing high-performance separation membranes. However, the inherent complexity of stacking modes during assembly—such as AA (face-to-face alignment) and AB (staggered stacking)—significantly impacts the formation of mass transport channels and ultimately dictates membrane performance. In this report, the conventional AB-stacking tendency of $[Cu_2Br(IN)_2]_n$ nanosheets can be disrupted by modulating the solvent casting temperature. This approach promoted the formation of mixed AA/AB stacking configurations, effectively reducing interlayer defects and optimizing vertical transport pathways. The resulting membrane exhibited enhanced gas separation performance, particularly for H_2/CO_2 and H_2/CH_4 mixtures. Furthermore, the ligand polarity-driven stacking engineering is found. A critical advancement lies in the precise regulation of MOF nanosheet stacking modes through ligand polarity adjustments. As demonstrated by experimental and theoretical analysis, increasing ligand polarity intensifies interlayer steric hindrance, which forced adjacent nanosheets to adopt AB-dominated stacking patterns. This phenomenon narrowed the effective stacking aperture, thereby improving molecular sieving precision. For example, CuBDC-NO_2 nanosheets with highly polar -NO_2 ligands adopted an $AB_{0.17}$ stacking mode (17% interlayer slip), achieving an ultra-small aperture of 0.372 nm. This structure selectively restricted the diffusion of larger molecules (CO_2: 0.33 nm of kinetic diameter; CH_4: 0.38 nm) while allowing rapid H_2 (0.29 nm) permeation. The optimized CuBDC-NO_2 membrane demonstrated exceptional separation performance with H_2/CO_2 selectivity of 266, H_2/CH_4 selectivity of 536, with H_2 permeance of 1325 GPU. These values surpass the Robeson upper bounds for polymeric membranes, highlighting the efficacy of stacking engineering in overcoming the permeability-selectivity trade-off. This report provides a paradigm for tailoring 2D nanosheet stacking architectures to address critical separation challenges in hydrogen purification—particularly for fossil-derived H_2 streams containing CO_2/CH_4 impurities.

Keywords: *Gas Separation, Two-Dimensional Membrane, 2D MOF Nanosheets*

Paper ID: KS06

Mechanism of Electrically Responsive Graphene-based Membranes for Simultaneous Steam and Power Generation

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ABSTRACT

Water and electricity shortages constitute a global energy crisis that cannot be ignored. The sun is an unlimited source of energy, and oceans provide abundant water and renewable energy resources. In this study, poly(vinylidene fluoride) (PVDF)/graphene solar evaporator membranes are fabricated for simultaneous freshwater production and power generation. Graphene addition transformed the PVDF crystal from the α-phase to the piezoelectric self-assembly β-phase. The resulting membrane is used to convert the mechanical energy of waves to electrical energy. The membrane has an output voltage of 2.6 V (±1.3 V) and an energy density of 2.11 Wm−2 for 1 Hz simulated waves, which are higher than values reported in the literature. The stacked graphene and polymer formed a wood-lumens-like mesoporous structure with a photothermal effect. Under one sun illumination, the water production rate is 1.2 kg m−2 h−1, and the solar-thermal energy conversion efficiency is 84%. Finally, a prototype is built to prove a single evaporator's feasibility that can simultaneously obtain freshwater and generate electricity. Thus, this membrane serves as an ocean wave power generation device that can provide all-weather energy generation, convert stored electrical energy into thermal energy at night and on cloudy days, and continuously provide safe drinking water.

Keywords: *Self-Assembling, Electrical Responsive, Graphene, Membrane separation, Piezoelectric material*

Paper ID: KS07

Antimicrobial Photocatalytic Coating for Bioaerosol Inactivation in Air Purification Applications

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ABSTRACT

Indoor air in high-risk environments such as hospitals, cleanrooms, and public transport often contains high levels of bioaerosols, including Escherichia coli and Staphylococcus aureus, which contribute to respiratory infections and cross-contamination. Conventional air filtration systems capture but do not inactivate these microorganisms, allowing viable pathogens to persist. In this study, we developed and evaluated antimicrobial photocatalytic coatings based on Cu_2O/TiO_2, Cu_2O/ZnO, and bismuth ferrite/activated carbon (BFO/AC) composites for bioaerosol inactivation under visible light. The coatings were characterized for structural, optical, and morphological properties, and their antimicrobial performance was assessed via minimum inhibitory/bactericidal concentration assays and transmission electron microscopy. Cu_2O/TiO_2 exhibited the most rapid disinfection, achieving complete inactivation of E. coli and S. aureus within 20 minutes, while BFO/AC (1:1.5) achieved 100% S. aureus inactivation in 60 minutes, significantly faster than BFO alone (120 minutes). TEM analysis confirmed severe disruption of bacterial cell membranes following photocatalytic exposure. The enhanced performance was attributed to efficient charge separation, synergistic ROS generation, and, in the case of composites, additional adsorption capacity. These findings demonstrate that engineered photocatalytic coatings can provide a chemical-free, energy-efficient, and highly effective approach for continuous bioaerosol inactivation in air purification systems, with strong potential for integration into HVAC and portable units for healthcare and public safety applications.

Keywords: Antimicrobial photocatalytic coating, Bioaerosol inactivation, Bismuth ferrite/activated carbon (BFO/AC), Visible-light photocatalysis

Paper ID: KS08

Counter-Current Cascades: A Tool to Enhance Membrane Separation Performances in Different Industrial Sectors

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ABSTRACT

In many industrial sectors, membrane performances are limited when used in single passage or arranged in multi-stage configuration. In the case of RO/NF desalination, water recovery is mainly limited by the osmotic pressure increase. In OSN (organic solvent nanofiltration), the most recent membrane technology, the lack of high selective membranes limits the development in fine chemistry, fragrance & pharmaceutical industries, etc. Membrane cascades made of several stages retreating the retentates and the permeates without any recycling as well as those involving internal recycling such as counter-current cascades (ccc) are extensively studied in this paper by the mean of simulations based on experimental data. As a first attempt, all cascade simulations were made in a continuous mode with the volume reduction ratio as main parameter for each stage (VRR_{stage} = extracted retentate flow/ stage feed flow) in close relationship with overall productivity. The simulations highlighted the great potential of cascades with internal recycling acting as a pseudo-diafiltration mode enhancing purification and recovery but without any extra solvent addition. In the case of desalination 25-34 $g.L^{-1}$ NaCl solutions, containing a model organic pollutant set at 5.10^{-4} $mol.L^{-1}$ (Tropaeolin O, 293 $g.mol^{-1}$,dye) were filtered using a SW30 spiral membrane (2540 type). The rejections of NaCl and Tropaeolin O were 99.4 and 99.6 %, at 55 bar, respectively. Simulations of counter-current cascades up to 3 stages evidenced that the water quality could be significantly enhanced decreasing the NaCl concentration in the permeate from about 250 ppm (single stage) to 5 ppm (two stages ccc) and these of the dye from 850 ppb to 11 ppb. Moreover, this same last configuration could allow to fulfil EU & WHO requirement with a degraded membrane exhibiting only 96% of NaCl rejection. In the case of a solvent free hydroformylation media of the fragrance industry, the final synthesis mixture was filtered by a PDMS membrane (Puramem flux® Evonik) using a Met-Cell cross-flow equipment (Evonik) at 40 bar. Flux and rejection of all compounds were measured. The main objective was to separate Rh species (catalyst, MW ≈ 660 $g.mol^{-1}$, 2 $mmol.L^{-1}$, to be recovered in retentate simultaneously with a P compound (102 $mmol.L^{-1}$) with P/Rh ≥ 5) and aldehyde (target product, 168 $g.mol^{-1}$, to be recovered in permeate, 4.6 $mol.L^{-1}$). The rejections were 71 %, -7% and 0% for Rh species, P and Aldehyde, respectively. For instance, the best recovery of (Rh, Aldehyde) could be (73 %, 94%) with the best discontinuous single stage while it could be (82.6%, 98.5% with 5 stages ccc) or (93.9 %, 82.8% with 4 stages ccc) among several other opportunities. The choice would depend on the economic arbitrage.

Acknowledgements: for the grants of ANR Cyrano, DN-ChimSep MSCA EU and PHC-Toubkal (23/171)

Paper ID: KS09

Development of Vapor-Induced Phase Separation Membranes for Effective Direct Contact Membrane Distillation

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ABSTRACT

Direct contact membrane distillation (DCMD) can achieve nearly 100% rejection of non-volatile contaminants, utilize “waste” heat, and treat high-salinity wastewater or water containing synthetic fluorinated pollutants. However, it still suffers from relatively low water fluxes, requires a significant thermal energy input, and is prone to membrane wetting and scaling, which can affect long-term performance. Significant improvements have been made over the past five years, focusing on adjusting membrane morphological features-such as developing re-entrant structures-and incorporating chemical modifications to enhance wetting properties. However, most approaches reported in the literature involve multiple fabrication steps, adding complexity to the process. The vapor-induced phase separation (VIPS) process is a phase-inversion technique that allows for precise control over membrane structure, particularly when using poly(vinylidene fluoride) or its copolymers, resulting in microfiltration membranes. This fabrication method enhances the polymer's intrinsic hydrophobicity, achieving very high water contact angles in air (> 150°). With proper control over pore size through VIPS process optimization, these membranes hold strong potential for DCMD applications. However, their use in desalination remains largely unexplored in the literature. Over the past few years, we developed a series of VIPS membranes for DCMD. Here, we will present these different membrane systems, with a focus on the formation process parameters, followed by an analysis of their performance. Notably, at a relatively low feed temperature (60°C) and a feed-permeate temperature difference of 35°C, these membranes achieve high fluxes (25-35 LMH), rivalling some electrospun membranes and surpassing most phase-inversion membranes under similar conditions. Additionally, we will discuss their resistance to wetting and scaling, long-term stability, and versatility in DCMD applications with various feed types.

Keywords: *VIPS Membranes, Membrane Formation, DCMD Applications*

Paper ID: KS10

High Silica Hollow Fiber Zeolite Membranes for Molecular Separation

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ABSTRACT

High silica zeolite membranes have received extensive attention in molecular separations owing to their merits of regular pore size, robust framework and excellent stability. The main challenging issues for scalable fabrication of zeolite membranes are the high cost of membranes and non-selective defects generated during high-temperature detemplation. In the past few years, we have made great efforts to address these issues and pushed forward practical application of zeolite membranes. We successfully synthesized high-quality DDR, CHA and MFI type zeolite membranes on low-cost α-Al_2O_3 hollow fibers by using industrial-grade reagents. Pure-phase DD3R zeolite membranes were prepared by using ball-milled seeds and dilute solution. Three detemplation strategies including ozonization, rapid thermal processing and ultraviolet treatments were proposed to overcome the problem of nonselective defect formation. The prepared DD3R zeolite membrane exhibited an impressive CO_2/CH_4 separation selectivity of 1172, accompanied by a CO_2 permeance of 8.9×10^{-8} mol m^{-2} s^{-1} Pa^{-1}. Now, hollow fiber DD3R zeolite membrane modules have been successfully prepared by ensemble synthesis strategy. The membrane module exhibited high selectivities for CO_2/CH_4 and H_2/CH_4 gas separation even at high feed pressure up to 4 MPaG. These strategies were extended to the preparation of SSZ-13 and MFI zeolite membranes and membrane modules. These membranes have been successfully used for separations of CO_2/CH_4, CO_2/Xe, H_2/CH_4, xylene isomers, alkane isomer (C_4-C_6) separations etc.

Keywords: *Zeolite Membrane; DD3R Zeolite; CHA Zeolite; MFI Zeolite; Molecular Separation*

Paper ID: KS11

Importance of Membrane Concentration Polarization (CP) in Brine-Staged Seawater Reverse Osmosis in Controlling Membrane Biofouling

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ABSTRACT

One of the greatest impediments to successful operation in seawater reverse osmosis (SWRO) is the presence of membrane biofouling. This type of membrane fouling results from the aggregation of individual colloidal seawater bacteria, present in the SWRO feed after pretreatment, due to excessive membrane CP at the boundary layer of the SWRO membrane surface. The membrane CP of the individual marine bacteria is dependent upon the flux and crossflow velocity at the membrane surface. Most SWRO plants have been designed as single-stage one pass in which pressure vessels contain between 6-8 membrane elements. The recoveries range from 40 to 50% with the feed-end membrane elements possessing the highest CP and brine-end membrane elements possessing the lowest CP. Membrane biofouling in SWRO always occur in the feed-end membrane elements, rather than brine-end membrane elements, even though the concentration of organics and marine bacteria are greater to the brine-end elements than to the feed-end elements. There exists a critical membrane CP in SWRO that determines the ability of individual marine bacteria to aggregate and adhere to the membrane surface. The critical CP also depends upon the type of SWRO membrane used. In order to reduce the membrane CP in single-stage SWRO and subsequent membrane biofouling potential, the only method is to reduce recoveries to below 40%. FEDCO has proposed an alternative method, utilizing its bi-turbo brine-stage design, which keeps the recoveries in both stages below 40% and attains the lowest SEC along with controlling membrane biofouling. Brine-staged SWRO facilities now in use have demonstrated that recoveries up to 70% can be attained without occurrences of any membrane biofouling.

Keywords: *Membrane Biofouling;Brine-Staged Seawater Reverse Osmosis;Bi-Turbo Technology;Critical Concentration Polarization*

Paper ID: KS12

Development of Ceramic-Based Composite Nanofiltration (Nf) Membranes Used Under Harsh Conditions

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ABSTRACT

As the demand for water and resources continues to rise, the development of novel membrane technologies capable of withstanding challenging environments has become increasingly important. Ceramic membrane is an attractive option as it has high solvent and heat resistance. However, fabricating pure ceramic nanofiltration (NF) membrane with nanoscale pore size (<2 nm) capable of effectively separating inorganic salts and small organic molecules remains both energy-intensive and costly. Polyamide/ceramic composite membrane offers a compelling solution that can be fabricated by forming an organic PA selective layer via interfacial polymerization (IP) on a ceramic substrate. This presentation reports our latest development of ceramic-based composite NF membranes used under harsh conditions. The efforts on scaling up the membrane production to raise up the technology readiness level and collaborating with industries to push the technology for commercialization are also highlighted.

Keywords: *Nanofiltration; Polyamide/Ceramic Composite Membrane; Harsh Conditions*

Paper ID: KS13

Polymeric Ionomers and their Complexes with Polyelectrolytes for Thin-Film Composite Nanofiltration Membranes

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ABSTRACT

Polyelectrolyte complexes (PECs) are a promising platform for new types of nanofiltration (NF) membranes. Usually, water-soluble polyelectrolytes are employed as building blocks. However, in a recently proposed alternative, amphiphilic polymeric ionomers as a water-insoluble film are coated on a porous support membrane and subsequently converted with an oppositely charged polyelectrolyte into the PEC; this is the basis for a simple two-step fabrication method. While the first versions of such PEC NF membranes were based on the fluorinated negatively charged ionomer Nafion, we will present here the extension of the scope to several other commercial ionomers that have originally been established for fuel cell or water electrolysis applications. Porous support membranes that enable the stable lamination of the barrier film at maximum permeance are fabricated from polyacrylonitrile (PAN), followed by surface functionalization to yield either amino groups (for coating of negatively charged ionomer) or carboxylic acid groups (for coating of cationic ionomer). The first example is the combination of the fluorine-free negatively charged pentablock copolymer Nexar (from Kraton) with polyethyleneimine (PEI) of different molecular weights. We will demonstrate that structure and separation performance of the thin-film composite (TFC) membranes depend on fabrication conditions for the first film, such as solvent system, dip-coating speed and evaporation time, as well as the molecular weight of the PEI and conditions during the second step, the immersion in the aqueous PEI solution. NF performance is comprehensively analysed, with one focus on the rejection of organic micropollutants. We will then illustrate how the modular concept can be extended to other ionomer / polyelectrolyte combinations, ultimately leading to PEC TFC NF membranes with competitive separation performance compared to established polyamide TFC membranes, but offering higher chemical stability and tunability of separation selectivity.

Keywords: *Nanofiltration; Thin-Film Composite Membrane; Polyelectrolyte Complex; Ionomer*

Paper ID: 14

Esterification Reactions in Pervaporation Membrane Reactors : Modeling and Optimisation

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ABSTRACT

The potential of pervaporation, a membrane-based separation method, to extract volatile substances like alcohols or water from liquid mixtures has attracted a lot of attention. It has several benefits when used in chemical processes, particularly in equilibrium-limited reactions like esterification. Higher conversion rates result from shifting the reaction equilibrium in favor of the creation of the desired ester through the constant removal of byproduct water or main product ester. This integration is a possible substitute for traditional methods like distillation since it increases energy efficiency, lowers the need for downstream separation, and facilitates process intensification. Water is often removed using hydrophilic membranes like polyvinyl alcohol (PVA), sodium alginate, and chitosan, whereas ester is removed using hydrophobic membranes like polydimethylsiloxane (PDMS) and certain zeolite-filled polymers. In order to develop, optimize, and scale up pervaporation-coupled esterification processes, modeling is essential. To help with process comprehension and performance prediction, a number of models have been created to mimic mass transport and membrane behavior. These consist of the Qi model, process-specific permeability model, Stefan-Maxwell model, empirical and semi-empirical models, pore-flow model, solution-diffusion model, and pseudo-change solution-diffusion model. Each model offers a unique balance between computational simplicity and physical correctness, and they differ in complexity and usefulness.The solution-diffusion model is the most popular and generally recognized of these, especially for dense polymeric membranes. It offers a dependable and simple framework for encapsulating the pervaporation-governing sorption-diffusion-desorption mechanism. In order to predict and enhance the process performance, this talk focus on solution-diffusion-based model that combines membrane mass transfer with esterification kinetics. Sensitivity analysis is also discussed the parameters that affect system performance.

Keywords: *Modeling and Simulation, Pervaporation, Esterification, Solution-diffusion, Optimization*

Paper ID: KS15

Polymeric Membranes for Future Energy Sector

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ABSTRACT

Up to 70% of OPEX in major chemical processes are associated with separation and purifications stages. The membrane separation can provide attractive alternative to the traditional separation methods to overcome this problem. Particularly, the membrane separation can play important role in hydrogen-based economy allowing extracting hydrogen from various gas streams. For instance, we recently showed that the robust polymeric material can demonstrate the mixed gas H_2/CO_2 selectivity greater than 900 at the temperature of 250°C, and be stable in the presence of water vapors. Due to one of the highest hydrogen content, ammonia molecule is considered as perspective hydrogen carrier; meanwhile, the ammonia decomposition is equilibrium reaction that requires selective recovery of hydrogen from reaction mixture to achieve greater efficiency of the process. The metal-based membranes can provide production of the high purity hydrogen, but the high price of the noble metals and their limited presence in the environment make it necessary to explore alternatives such as polymeric membranes. Bearing this in mind, the ammonia permeability coefficient was estimated for large number of polymeric materials in the temperature range of 35-300°C to identify potential polymers for their future experimental study for both the Haber-Bosch process and the ammonia decomposition processes. Despite all current activities on wider introduction of electric vehicles, the internal combustion engines will be intensively used in the near future. Besides, crude oil is still major feedstock for bulk and fine chemistry. Meanwhile, up to 4-10% of crude oil is consumed for its processing in the refineries by generating the heat, electricity, and hydrogen. The direct crude oil fractionation by means of the filtration can be considered as promising approach due to the absence of phase transition. Particularly, it was recently shown that tight UF-range membranes based on polyacrylonitrile can ensure the separation of heavy fraction (>400-600 Da) from crude oil. These and related areas of application of polymeric membranes will be discussed in this talk.

Part of the activity was financially supported by the State Program of TIPS RAS.

Keywords: *High Temperature Gas Separation; Hydrogen; Ammonia; Crude Oil Fractionation; Regeneration of Used Engine Oil*

Paper ID: KS16

2D- Material-Based Nanofiltration Membranes for Precision Fluid Separation

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ABSTRACT

Reducing preparation difficulty and improving separation performance are the key challenges for ceramic nanofiltration membrane materials. Aiming at the problems of complicated preparation of ceramic nanofiltration membranes and difficult control of separation performance, this work intends to create low-cost, easy-to-prepare and high-performance composite ceramic nanofiltration membrane by using two-dimensional MXene, which is easy to construct a precise separation layer and can be thermally transformed into a solid ceramic phase. A special SiC support layer can be constructed by directional reaction sintering or in-situ deposition of ceramic nanostructures on its surface for supporting and thermal fusion with MXene. MXene-based separation layer could be assembled on the surface of a SiC support by the pressure-assisted deposition method. The interface of the support and the separation layer could be fused by the in-situ thermal transformation, and the physicochemical structure of the separation layer could be controlled simultaneously. The simultaneous mechanism of the interface fusion and mass transport channel reconstruction for MXene/SiC composite ceramic nanofiltration membranes can be revealed by in-situ characterization techniques. Based on molecular dynamics simulation and separation performance experiment, the structure-performance relationship between the physicochemical structure of the MXene-derived mass transport channel and its separation performance could be elucidated, and the confined mass transport mechanism of small molecules or ions in the special transport channel was revealed in the nano/micro-scale. This work may provide novel insights into the design and preparation of new ceramic nanofiltration membrane materials and will lay a foundation for promoting the application of high-performance ceramic nanofiltration membranes in precise separation processes.

Paper ID: KS17

CO_2 Methanation through Ceramic Membranes

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ABSTRACT

Capturing low-concentration CO_2 emissions from small-scale combustion systems is crucial. This study focuses on a catalytic membrane reactor (CMR). The fundamental concept behind this CMR is to feed CO_2 in a distributed manner and directly converting it into CH_4 through reaction with H_2. Ni catalytic substrate was prepared on tubular γ-Al_2O_3 porous substrate. The catalytic silica membrane was prepared by counter-diffusion chemical vapor deposition on the Ni catalytic substrate. CO_2 methanation tests were carried out in the temperature range of 325 °C to 400 °C, with H_2 and CO_2 fed at 200 [mL min^{-1}] on the inner and outer sides of the substrate or membrane, respectively. ANSYS Fluent computational fluid dynamics software was used for the simulations. The CMR was operated over 350 °C. The performance of the membrane used was CO_2 permeance of 7.7×10^{-8} [mol m^{-2} Pa^{-1} s^{-1}] and a CO_2/CH_4 permeance ratio of 2.0 (380 °C). CO_2 conversion was higher in the membrane reaction test over the entire operating temperature range of 350 -400 °C, with a maximum of 92.3 % at 350 °C. This result can be attributed to the lower CO_2 permeance due to the membrane; CO_2 permeance of the membrane was about one-tenth that of the catalytic substrate. The heat generation was up to 910 K at the reactor inlet due to CH_4 generation in the normal feed by the simulation. In the distributed feed, on the other hand, CH_4 generation was more active near the reactor outlet. The temperature was about 675 K near the reactor inlet and up to 689 K near the reactor outlet, where the reaction was more active. This result supports the contention that distributed supply is better suited for temperature control.

Keywords: *Distributor Type Membrane Reactor, Methanation, Temperature Control*

Paper ID: KS18

Building Up Mass-Transportation Channels in Polymeric Membranes with Surface-Functionalized Carbon Nanotubes

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ABSTRACT

Membrane separations involve selective mass transportation through the membrane matrix, especially for the processes utilizing dense-membranes without pores. The diffusion rates of the selective species to be transported through the membranes play critical roles on the membrane performance, saying diffusivity and permeability. In addition to simple diffusion and hopping motion, transportation channels in the membrane matrixes are attractive to provide a high efficiency of promoting species movements in the membranes. Our continuing studies have established a platform for building up mass-transportation channels in dense polymeric membranes through utilization of surface-functionalized carbon nanotubes (CNTs). The first step is chemically incorporating the functional groups, which have high interaction with the transported species, to CNTs surfaces. Then the surface-functionalized CNTs are used as additive in fabrication of polymer-CNTs mixed matrix membranes. Taking advantages of the one-dimensional nano-structure and the relatively high aspect ratios of CNTs, the transported species have high interaction with the functional groups attached on CNTs and could move smoothly along with the outer surfaces of CNTs. The CNT-based channels for mass transportation are established. With various functionalized CNTs and different polymer matrix, the above-discussion effect and mechanisms have been successfully applied to transporting protons in proton exchange membranes, OH^- ions in alkaline ion-exchanging membranes, lithium ions in gel polymer electrolytes, and water in pervaporation desalination membranes.

Keywords: *Carbon Nanotubes, Surface Functionalization, Proton Exchange Membranes, Polymer Electrolytes, Pervaporation, Desalination*

Paper ID: KS19

MOF-Based Membranes for Molecular Separation: The Role and Elimination of Defects

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ABSTRACT

Polymeric membranes generally do not possess regular and continuous subnanometer channels, leading to an inherent trade-off between permeability and selectivity. Nanoporous crystalline materials, represented by zeolites and metal-organic frameworks (MOFs), can address this challenge by providing excellent permeability and selectivity through their well-defined pore systems. There are two types of MOF-based membranes: MOF crystalline membrane and MOF mixed-matrix membrane (MMM). Identifying the role of defects and the defects elimination are critical for developing high-performance MOF-based membranes. This talk will present our strategies to identify atomic-level defects and eliminating defects in MOF-based membranes for molecular separation. We eliminated lattice defects in MOF crystalline membranes based on a high-probability theoretical coordination strategy creating sufficient chemical potential to overcome the steric hindrance that occurs when completely connecting ligands to metal clusters. We proposed a solid-solvent processing strategy to fabricate a defect-free ultrathin MOF MMM (thickness less than 100 nm) with filler loading up to 80 vol.%. Polymer is used as a solid solvent to dissolve metal salts to form an ultrathin precursor layer, which immobilizes the metal salt and regulates its conversion to a MOF, and provides adhesion to the MOF in the matrix. These MOF-based membranes showed high and stable separation performance for hydrogen purification and organic solvent azeotrope separation.

Paper ID: KS20

Ambient-Temperature Hydrocarbon Separations Enabled by Fluorine-Rich Poly(arylene amine) Membranes

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ABSTRACT

The potential of membrane materials to reduce energy consumption and carbon emissions in the separation of aliphatic hydrocarbon feedstocks and products was explored. We developed a series of fluorine-rich poly(arylene amine) polymer membranes, characterized by rigid polymer backbones with segregated perfluoroalkyl side chains. This molecular design confers resistance to dilation upon hydrocarbon immersion while preserving the feasibility of solution-based membrane fabrication methods. The resulting materials exhibit effective separation of liquid-phase alkane isomers at ambient temperatures. To evaluate their practical application, these membranes were integrated into fuel and chemical feedstock separation processes, and a series of experimental tests were conducted. Technoeconomic analyses based on these experiments indicate that the best-performing membranes can reduce energy costs and carbon emissions associated with hydrocarbon separations by a factor of two to ten, depending on product specifications.

Keywords: *Membrane Separation, Liquid Hydrocarbon Separation*, *Organic Solvent Reverse Osmosis, Fluorine-Rich Polymers, Poly(Arylene Amine)*

Paper ID: K21

Polyfluorene-Based Electrolyte Membranes for Hydrogen/Oxygen Gas Separation under Humidified Conditions

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ABSTRACT

To enable the large-scale utilization of renewable energy, a hydrogen-based society that addresses the temporal and spatial mismatch between energy supply and demand is essential. Among the various hydrogen production technologies, Anion Exchange Membrane Water Electrolysis (AEMWE) has attracted growing interest due to its potential to achieve high efficiency without relying on precious metal catalysts. However, the development of highly durable and chemically stable anion exchange membranes remains a critical challenge for practical implementation. We have developed a series of polyphenylene-based anion exchange membranes that exclude ether and other hetero-elements from the main chain, significantly improving oxidative and alkaline stability. Recently, we discovered that these membranes also exhibit high hydrogen/oxygen separation performance under wet conditions. In particular, the newly developed PFST-C8-SO_3H membrane features a poly(fluorene-alt-tetrafluorophenylene) backbone with long alkyl sulfonic acid side chains. This design introduces a three-dimensionally twisted backbone structure and increases the free volume within the membrane matrix. As a result, hydrogen permeability is enhanced, while oxygen crossover is effectively suppressed. The PFST-C8-SO_3H membrane exhibits lower water vapor absorption due to π stacking compared to typical polyelectrolyte membranes, enabling it to retain high gas separation selectivity even under humid conditions. These findings suggest that careful molecular design of both the main chain and side chains in anion exchange membranes can lead to new functionalities for hydrogen purification.

Keywords: *Hydrogen Separation, Humidified Condition, Polyfluorene, Electrolyte Membrane, Water Electrolysis*

Paper ID: KS22

Boron-nitride Nanosheets as Membrane Building Blocks for Water Purification and Gas Separations

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ABSTRACT

Two-dimensional analogues, such as graphene oxide, carbon nitride nanosheets and boron nitride (BN) nanosheets, have been studied extensively for their potential to develop functional membranes with superior ion and molecular separation capabilities attributed to their Angstrom-scale channels, customizable channel wall properties, and remarkably low transport resistance. Among these analogues, BN nanosheets, comprising multiple layers of hexagonal planes formed by alternating B and N atoms interconnected through robust B−N covalent (sp2) bonds, have been widely studied for their higher thermal conductivity, mechanical robustness, and resistance to oxidation and harsh chemical environments. Owing to these distinctive characteristics, BN nanosheets have found applications in diverse fields such as energy storage, insulation, waterproof coatings, electrocatalysis, gas and ion separation, as well as water purification. In this presentation, we discuss techniques for synthesizing BN nanosheets and leveraging them as building blocks to fabricate nanocomposite membranes with enhanced separation efficiency, particularly in gas separation, nanofiltration, and reverse osmosis. We present two scalable exfoliation techniques for large-scale production of BN nanosheets and their functionalized variants. Additionally, we explore contemporary approaches for crafting membranes with heterostructures that exhibit novel properties.[1-4] The fabrication techniques and membrane design strategies discussed herein hold significant promise for advancing membrane-based separation processes, offering avenues for more efficient and sustainable separation technologies.

Paper ID: KS23

Hybrid Membrane Processes for Sustainable Nutrient Recovery from Aquaculture Effluent

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ABSTRACT

Aquaculture effluent contains valuable nutrients, including ammonium (NH_4^+) and phosphate (PO_4^{3-}), but their low concentrations and high salinity pose challenges for recovery. This study explores three innovative membrane-based approaches for nutrient recovery: (1) a zeolite-assisted forward osmosis (FO) system for PO_4^{3-} recovery via chemical precipitation and NH_4^+ rejection, (2) a hybrid vacuum membrane distillation-nanofiltration (VMD-NF) process for simultaneous ammonia concentration and sodium removal, and (3) a pilot-scale reactive vacuum membrane distillation (RVMD) system for high-efficiency ammonia recovery. The FO system achieved 98.6% PO_4^{3-} rejection and 94.8% NH_4^+ rejection, with subsequent 98.46% PO_4^{3-} recovery as amorphous magnesium phosphate (AMP). NH_4^+ was recovered at 88.7% efficiency via zeolite regeneration. The hybrid VMD-NF process demonstrated superior performance, concentrating ammonia 77-fold (49.33 to 3,790 mg/L) and phosphate 6-fold (16.67 to 92.52 mg/L) while removing 98% sodium via diafiltration-NF. The optimized RVMD system achieved a 490-fold ammonia concentration (25 to 12,240 mg/L) under optimal conditions (50°C, 1 GPM). These integrated processes provide sustainable, high-efficiency solutions for nutrient recovery from aquaculture wastewater, enabling resource reuse as liquid fertilizers or soil conditioners while mitigating environmental risks such as eutrophication. The findings highlight the potential of hybrid membrane technologies in advancing circular economy practices in aquaculture wastewater management.

Keywords*: Nutrient Recovery, Aquaculture Wastewater, Membrane Distillation, Forward Osmosis, Circular Economy*

Paper ID: KS24

Solvent-Resistant Membranes for Energy-Efficient Separation Processes

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ABSTRACT

The development of sustainable membrane materials is crucial for advancing organic solvent nanofiltration (OSN), an energy-efficient separation technology widely used in the pharmaceutical and fine chemical industries. Conventional membranes rely on fossil-based materials, prompting a shift toward bio-based alternatives. We explore the fabrication of solvent-resistant nanofiltration membranes using biomass and green monomers via phase inversion and interfacial polymerization, ensuring high selectivity and stability, while minimizing environmental impact. Complementing these material innovations, data-driven approaches are transforming OSN process optimization. The OSN Database, an open-access platform, enables the development of machine learning (ML) models that integrate molecular structure data for solute rejection predictions. These models, achieving high accuracy, offer valuable insights into membrane performance and process efficiency. By combining sustainable membrane design with predictive modeling, we aim to drive greener, more efficient separations. Case studies will illustrate how explainable ML models and next-generation materials together enhance OSN technology.

Paper ID: KS25

Resource Recovery from Seawater Reverse Osmosis (SWRO) Desalination Brine

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ABSTRACT

Seawater reverse osmosis (SWRO) desalination is crucial for water production. However, it is often associated with issues such as brine disposal. SWRO brine contains many salts and minerals, there is a growing interest on SWRO brine valorization to upcycle the brine into valuable products. In this work, an integrated system was developed to recover low bromide sodium chloride brine from SWRO brine, which can be used in chloro-alkali process for producing sodium hypochlorite, a common disinfectant. Na and Cl are the main components in SWRO brine, but other components such as Ca, Mg, SO4, Br, organics, etc. are presence which are potential impurities, thus they need to be removed (i.e., these compounds can be recovered, but they are not the focus in this presentation). The proposed integrated system consists of sequential units of i) nanofiltration (NF)-ion exchange (IX) to remove Ca, Mg, SO4 and organics (≥90% removal); and ii) oxidation by peroxymonosulfate (PMS) to convert bromide to bromine followed by air stripping (≥90% removal). The key performance indicators include energy consumption, cost of recovery, quality and quantity of final brine that is suitable for use in sodium hypochlorite production.

Keywords: *SWRO Brine, Resource Recovery, Nanofiltration, PMS Oxidation, Chloro-Alkali*

Paper ID: KS26

Harnessing Electroconductivity in New Generation Membranes for Desalination and Microbial Fuel Cell

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ABSTRACT

Laser-induced graphene (LIG) has gained significant attention due to its chemical-free fabrication process, enabling the direct conversion of various substrates, from commercial polymers to waste organic materials like cloth, paper, and food, into graphene electrodes. This versatility allows for the development of cost-effective, recyclable materials for flexible electronics and environmental applications. The porous structure of LIG has shown great potential in electrochemical sensing for medical diagnostics, food safety, and environmental monitoring. In membrane-based desalination, wastewater recycling, and microbial fuel cell biofouling, the trade-off between selectivity and permeability remains a key challenge. Electroconductive membranes offer a promising solution for mitigating biofouling while optimizing performance. LIG, fabricated using a 10.6 μm CO_2 laser, enables a single-step, chemical-free conversion of polyethersulfone (PES) membranes into LIG-based filters. Further surface modifications transform these filters into ultrafiltration (UF) and TFC composite membranes, ion-exchange membranes, and membrane electrode assemblies with exceptional catalytic and anti-biofouling properties. The catalytic mechanisms of doped LIG membranes arise from the intrinsic properties of graphene, the 3D porous texture, and heteroatom doping, which enhance performance. These laser-printed membranes hold immense potential for energy and environmental applications, offering a scalable and sustainable approach to water treatment and resource recovery.

Paper ID: KS27

Development and Application of Various Membrane Technology for CO_2 Capture and Decarbonization Efforts Towards Net Zero Carbon Emission

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ABSTRACT

Membrane technology plays a pivotal role in mitigating CO_2 emissions and combating climate change, which significantly contributes to global warming. This technology is integral to carbon capture processes across various stages, including pre-combustion, post-combustion, and others, by preventing CO_2 from being released into the atmosphere. CO_2 emissions from diverse sources, particularly from offshore facilities, industrial plants, and factories, must be captured, transported, and stored. A portion of this captured CO_2 can also be repurposed or converted into valuable products. Achieving the Net Zero Carbon Emissions (NZCE) target by 2050 necessitates significant advancements in CO_2 capture technologies to ensure economic viability and project sustainability. Currently, the maturity of CO_2 capture technologies varies by application. Some, such as those employed in pre-combustion processes, are well-established and commercially available, although enhancements to further refine the technology remain essential. Conversely, others, particularly those pertaining to post-combustion CO_2 capture technology, are still in the prototype or demonstration phase, requiring further scale-up, performance validation, and technical refinement. Depending on specific operational requirements such as plant capacity, CO_2 concentration in the feed gas, contaminants, product specifications, and acceptable hydrocarbon losses, either gas separation membranes or membrane contactors with solvents may be selected. Therefore, continuous innovation, knowledge exchange, and global collaboration are imperative to expedite the commercialization of these technologies across various industries. Industrial sectors such as oil and gas, cement, chemicals, steel, and power generation urgently require cost-effective solutions to diminish their carbon footprint. However, decarbonization efforts face challenges, including elevated capital and operational expenditures, market uncertainties, lack of incentives, and associated risks. In conclusion, innovation in membrane technology is essential for constructing a sustainable future aimed at achieving net zero carbon emissions. Accelerated research and development are vital to de-risk these solutions and pave the way for a cleaner and greener world for future generations.

Keywords: *CO_2 Removal, Membrane Technologies, Decarbonization, Carbon Capture.*

Paper ID: KS28

Engineering Next-Generation Membranes with 2D Materials: Structure–Function Innovations and Applications

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ABSTRACT

The global membrane market is projected to grow from $28.66 billion in 2023 to $39.46 billion by 2027, reflecting a compound annual growth rate (CAGR) of 8.3% (GlobeNewswire, 2023). This growth is driven by escalating global challenges such as climate change, environmental degradation, industrial expansion, and population increase—all of which intensify the demand for sustainable resource management. In this context, membrane technology has emerged as a strategic solution due to its low energy requirements, modularity, and compatibility with hybrid systems, making it indispensable in a wide range of separation and purification processes. Despite the widespread use of polymeric membranes, their performance is often limited by fouling, poor selectivity, limited scalability, and inadequate thermal, mechanical, and chemical stability. To address these limitations, the rational design of membrane architectures—particularly in terms of pore size and distribution—has become a focal point of innovation. In recent years, advanced functional nanomaterials, especially 2D materials, have enabled breakthroughs in membrane science. Materials such as graphene, GO, rGO, MXenes, h-BN, and MOFs have attracted significant attention due to their atomic-level thickness, high aspect ratio, tunable surface chemistry, and exceptional physicochemical properties. These 2D materials offer precise molecular sieving, enhanced mass transport, and improved resistance to fouling, making them ideal for constructing high-performance membranes. Their integration to the membranes enables customizable structures for advanced applications in water desalination, gas separation, organic solvent nanofiltration, and ion sieving. Additionally, the incorporation of machine learning (ML) and computational modeling into membrane design workflows has accelerated the prediction and optimization of structure–function relationships, bridging experimental gaps and advancing materials discovery. The recent developments in 2D-material-enabled membrane technologies, critical challenges in scalability, durability, and cost, and explores emerging strategies for their sustainable and industrially viable implementation will be highlighted. Together, these advancements represent a promising pathway toward next-generation membranes capable of meeting the performance demands of modern separation science and contributing to a circular and sustainable economy.

Paper ID: KS29

Brine Resource Recovery Using Membrane-based Processes for a Circular Economy

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ABSTRACT

Electrochemical desalination is an emerging desalination technology, which becomes more energy efficient for the desalination of less saline water sources. In particular, capacitive deionisation (CDI) is of interest in low-carbon and low-energy electrochemical process. However, the application potential of CDI has certainly widened beyond brackish water desalination. Now, the CDI application includes water softening, heavy metal and nutrient removal. Over the years, different types of CDI architectures have been proposed such as membrane capacitive deionisation (MCDI), flow electrode capacitive deionisation and development of intercalated electrode materials for MCDI application. This presentation covers the current state of MCDI development and focus more on the application potential of MCDI for brine resource recovery options based on some lab-scale and pilot-scale studies conducted. Further, some perspectives on the future direction of membrane-based electrochemical processes with brine resource recovery will be shared for potential applications.

Keywords: *Brine, Resource Recovery, Electrochemical, Desalination, Circular Economy.*

Paper ID: KS30

The progress in the Development of Composite Electrolytes in Lithium Batteries

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ABSTRACT

For next-generation energy storage, lithium-based batteries have attracted widespread attention due to their long cycle life, high energy density, and potential for next-generation applications. However, the use of conventional liquid electrolytes poses significant challenges in terms of safety, interfacial instability, and limited electrochemical stability windows. To address these limitations, composite electrolytes comprising polymers, ceramics, ionic liquids, or hybrid fillers have been extensively developed through tailored material design, optimized synthesis routes, and structural engineering to overcome the limitations of conventional liquid electrolytes. These materials integrate the advantages of both organic and inorganic phases, offering enhanced ionic conductivity, mechanical strength, and thermal stability. In particular, their application in all-solid-state lithium batteries, lithium-metal batteries, lithium-sulfur batteries, lithium-ion batteries, and lithium-air batteries has demonstrated considerable progress in recent years. In recent years, intensive research has propelled the development of composite electrolytes, and this work presents a critical overview of their design strategies and functional advancements. Various structural configurations, including polymer-ceramic hybrids, gel-polymer matrices, 3D frameworks, in situ formed composites, and quasi-solid-state architectures are discussed with emphasis on interface engineering, ion transport mechanisms, and design principles. Furthermore, critical challenges related to interfacial resistance, dendrite suppression, and scalable fabrication are analyzed. Finally, the technical challenges are summarized, and the possible future research directions are outlined to guide the rational design of composite electrolytes toward high-performance next-generation lithium batteries.

Paper ID: KS31

Machine Learning-Driven Dynamic Prediction and Optimization for Ammonia Recovery in Membrane Distillation System

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ABSTRACT

Ammonia recovery is crucial for environmental protection and resource sustainability, as it helps mitigate nitrogen pollution and enables recycling of valuable resources. Membrane distillation (MD) is a promising approach for high-purity ammonia recovery, but optimizing its performance relies on understanding dynamic ammonia transport under varying conditions. Conventional theoretical models often lack the flexibility to capture complex system dynamics, while empirical models fail to generalize beyond specific experimental scenarios. Here, we integrate machine learning (ML) with dynamic simulation techniques to model complex nonlinear interactions, embedding empirical inference into theoretical frameworks. Key input variables influencing the instantaneous rate of ammonia concentration change, such as temperature, pH, and ammonia partial pressure gradient, were identified through theoretical analysis. An artificial neural network (ANN) was developed to simulate the instantaneous rate of change of ammonia concentration on the feed side, achieving a high accuracy on the test set (R2 = 0.8537). The ANN was further combined with the fourth-order RungeKutta (RK4) algorithm to predict real-time ammonia concentrations and the cumulative ammonia recovery rate. To optimize the instantaneous MD performance for ammonia, a wide range of ML-based operational condition grid predictions was performed to identify optimal parameters. This study enhances the comprehension of ammonia transport mechanisms in MD systems while simultaneously advancing real-time process control and adaptive optimization, promoting both theoretical development and practical implementation.

Paper ID: KS32

Development of Membrane Based Unit Operations for Emerging Bioseparations Challenges

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ABSTRACT

Membrane based separations are attractive for a number of reasons such as easy scale up, lower operating cost and the potential for significant process intensification. For applications in bioseparations linear scale up is important given the regulatory approvals needed for a manufacturing process. In this presentation the potential use of membrane-based process to address emerging challenge in the downstream processing of biotherapeutics will be discussed. Biopharmaceutical manufacturing processes make use of cell lines to produce therapeutics such as monoclonal antibodies, fusion proteins etc. Membrane based processes such as sterile filtration, tangential flow microfiltration and ultrafiltration, membrane adsorbers, and virus filtration are routinely used in the purification of these products. An overview of some of the challenges associated with obtaining adequate performance from these unit operations will be reviewed. As a specific example, validation of virus clearance will be discussed. The level of virus clearance required by regulatory authorities depends on the specific manufacturing process. There is growing interest in emerging complex therapeutics, e.g., live attenuated virus vaccines, viral vectors for delivery of gene therapy, virus like particles (VLPs), plasmid DNA, etc. These more complex therapeutics create additional challenges when attempting to validate virus clearance. Now the contaminating virus particles must be removed from the desired virus particles that are the product of interest. The use of virus filtration to separate desired and undesired virus particles could be more challenging than validation of virus clearance for protein-based therapeutics. Today there is a great deal of interest in developing continuous biomanufacturing processes in order to minimize batch to batch variation and reduce manufacturing costs. However current membrane-based processes are typically designed for batch operation. Adapting virus filtration for use in a continuous biomanufacturing process will be complex. Some of the challenges will be discussed.

Keywords: *Bioseparations, Continuous Biomanufacturing, Virus Clearance, Virus Filtration, Virus Purification*

Paper ID: KS33

Innovative Reverse Osmosis Membrane Manufacturing with Green and Nanocomposite Carbon Quantum Dots for Desalination Purposes

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Abstract

The incorporation of innovative nanomaterials into the membrane structure has been demonstrated to enhance the efficacy of reverse osmosis (RO) membranes, addressing the persistent challenges associated with conventional membrane technology. Since 2013, carbon-based quantum dots (CQDs) have emerged as a leading contender in membrane applications, owing to their exceptional properties that set them apart from other carbon nanomaterials. CQDs are artificial semiconductor crystals on the nanometer scale, typically ranging from 1 to 10 nanometers (Korkut et al., 2023). Due to their minute size, these particles exhibit quantum mechanical effects. The salient feature of these dots is their capacity for modulating light absorption and emission based on their size. CQDs have emerged as a subject of considerable research interest in the domain of membrane technologies. This is primarily due to their inherent properties, which include the presence of various functional groups, the capacity for facile synthesis based on carbon, high dispersibility, and significant biodegradability (Shao et al., 2017). CQDs synthesized from renewable and sustainable biomass sources are commonly referred to as green CQDs. These precursors include a vast variety of natural resources including medicinal plants, fruits, vegetables, agricultural waste, and other organic biomaterials. The exploration of the common point of green chemistry and nanotechnology is facilitated by the plant-based production of CQDs (Mindivan & Göktaş, 2023). The primary operational challenges associated with RO membranes pertain to fouling by organic or microbial substances, vulnerability to chlorine, and suboptimal performance in boron removal. The solution to these issues has been found in the production of innovative membranes by placing CQDs on the polyamide layer. In pursuit of this objective, a comparative analysis was conducted on the performance of two distinct RO membranes. One of these membranes contained synthetic nanocomposites, specifically TiO_2-quantum dots (TQDs), while the other membrane incorporated CQDs derived from green raw materials.

Keywords: *Reverse Osmosis, Quantum Dots, Antibacterial, Antifouling, Desalination*

Paper ID: KS34

Nanomaterials enhanced mixed matrix membranes and integrated membrane process for wastewater treatment

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ABSTRACT

Mixed matrix membranes (MMMs) have gained increasingly importance due to their ability to combine the features of the aforementioned membrane materials, offering better solutions in terms of performance, fouling, permeate quality and longevity Enhanced membrane performance could be achieved by tuning their physicochemical properties and introducing unique functionalities via addition of novel nanomaterials and intelligent design of advanced nanocomposite membranes for attainment of exceptionally permselective materials and antiwetting/antifouling property, which is highly beneficial for advancing emerging technology like Membrane distillation (MD) and Forward osmosis (FO) for desalination and wastewater treatment. In our recent works, we have explored a range of different dimensional nanomaterials including metal-organic frameworks (MOFs), graphene oxide, Mxene, CNT and their influence on the physiochemical properties, morphologies and micro/nano structures of the nanocomposite membrane. We report here how the incorporation of these nanomaterials with various properties modifies the membrane micro/nano-structure, surface property and separation performance of nanocomposite membranes to achieve the enhanced separation efficiency for wastewater treatment. Strategy for making hydrophobic/hydrophilic dual layer MD membranes and interlayered FO membranes using 2D materials are also discussed. The membranes were subject to industrial wastewater treatment and its integrated process for treating real wastewater like textile wastewater and landfill leachate. The membranes exhibited high water recovery (>90%) while demonstrating excellent robustness and integrity, showing great potential for practical application of applying the emerging membrane technologies in treating wastewater to enhance water recovery towards circular economy.

Paper ID: KS35

Geopolymer Innovation in Membrane Science and Technology: From Waste Valorization to Functional Water Treatment Systems

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ABSTRACT

Geopolymers have emerged as a promising class of inorganic materials for membrane science, offering an environmentally friendly and cost-effective alternative to traditional ceramic and polymeric membranes. Derived from industrial by-products such as fly ash and metakaolin, geopolymer membranes exhibit tailorable porosity, chemical durability, and thermal stability, enabling diverse applications in water and wastewater treatment. This keynote presents a comprehensive exploration of recent advancements in geopolymer membrane design, performance, and multifunctionality. Our studies have demonstrated the successful fabrication of geopolymer membranes with enhanced mechanical strength and controlled pore architecture through chemical foaming techniques, such as H_2O_2 incorporation, and reinforcement strategies using glass fibers. Type C and F fly ash-based geopolymers were compared, revealing that Ca-rich fly ash contributes to superior compressive strength, while Ca-poor variants offer higher water flux due to increased porosity. Further innovation was achieved by integrating TiO_2 into the geopolymer matrix, creating hybrid membranes capable of simultaneous filtration and photocatalytic degradation of methylene blue—a model organic pollutant. This coupling not only enhances membrane self-cleaning properties under UV irradiation but also addresses the fouling limitations commonly found in conventional systems. In parallel, our research has extended geopolymer application to the immobilization of toxic heavy metals (Cd^{2+} and Pb^{2+}), showcasing their dual role in contaminant retention and structural reinforcement. Through these efforts, geopolymer membranes demonstrate potential as sustainable, multifunctional materials that bridge the gap between advanced membrane technology and circular economy principles. This talk will provide insights into synthesis strategies, structure–property relationships, and future directions for geopolymer membranes in environmental engineering.

Paper ID: KS36

Advancing PFAS Treatment: From Nanofiltration–Carbon Adsorption to Membrane Distillation

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ABSTRACT

In industrial wastewater treatment and reuse, the management of both short- and long-chain perfluoroalkyl substances (PFASs) remains a critical challenge due to their strong C–F bond energy, which hinders the effectiveness of destructive methods such as chemical degradation and advanced oxidation, while often generating toxic intermediates. As a result, non-destructive separation technologies have emerged as promising alternatives for PFAS control.This study explores two complementary non-destructive strategies for effective PFAS removal and concentration. First, a synergistic nanofiltration (NF)–magnetic activated carbon (MAC) process was developed to remove short-chain PFASs, specifically perfluorohexanoic acid (PFHxA) and perfluoropentanoic acid (PFPeA). A commercial hollow-fiber NF membrane achieved removal efficiencies of 96.6% for PFHxA and 86.1% for PFPeA under optimized conditions. MAC, prepared via ball milling to obtain uniform fine particles, demonstrated high adsorption capacities (q_e = 43.80 mg g^{-1} for PFHxA and 32.70 mg g^{-1} for PFPeA) and offered enhanced reusability compared to conventional powdered activated carbon. By integrating NF and MAC, PFAS concentrations were effectively reduced to the part-per-trillion range, with 50.6 ppt for PFHxA and 474 ppt for PFPeA. Second, membrane distillation (MD) was investigated using asymmetric Janus polydopamine/polyvinylidene fluoride (PDA/PVDF) membranes with a hydrophilic–hydrophobic dual-layer structure to separate and concentrate PFASs from highly contaminated water while mitigating membrane wetting and fouling. Under direct contact MD operation with 0.1 M NaCl containing 20 mg L^{-1} PFPeA and perfluorooctanoic acid (PFOA), the Janus membranes exhibited stable flux, high salt rejection (~99.5%), low PFAS concentrations in permeate (6 μg L^{-1} for PFPeA and 3.5 μg L^{-1} for PFOA), and feed enrichment up to 1.89-fold. Collectively, these results demonstrate that combining NF–MAC removal with MD-based concentration provides a practical and robust platform for PFAS management, enabling effective separation and pre-concentration prior to destructive treatment, in alignment with increasingly stringent environmental regulations.

Keywords: *Adsorption, Industrial Wastewater, Membrane Distillation, Nanofiltration, Polyfluoroalkyl and Perfluoroalkyl Substances, Separation*

Paper ID: KS37

Radiation Grafted Selective Adsorptive Sheets for Upgrading Natural Gas with Extreme CO_2 Concentrations

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ABSTRACT

The removal of carbon dioxide (CO_2) from natural gas (NG) is essential to improve its heating value, reduce pipeline corrosion, and meet environmental standards. Various technologies such as amine absorption, cryogenic separation, adsorption, and membrane separation have been developed for CO_2 removal. Of all, membrane technology is attractive for its modularity and low energy requirements. However, conventional membrane technology faces major challenges when applied to NG streams with high CO_2 concentrations. These include plasticization of membranes under high CO_2 partial pressures leading to CO_2/CH_4 selectivity reduction, stability deterioration, and methane losses. In this lecture, we introduce a promising alternative selective adsorptive sheet tailored for high-CO_2 NG upgrading. Unlike diffusion-based membranes, these adsorptive sheets rely on selective adsorption to achieve high CO_2 uptake. Radiation-induced grafting (RIG) was used to covalently incorporate side chain grafts functionalized with amine to polymer substrate enhancing selectivity and resistance to plasticization. Monomers such as vinylbenzyl chloride (VBC) was grafted onto polyethylene/polypropylene (PPE/PP) nonwoven sheets and subsequently treated with ethylenediamine (EDA). The properties of the aminated sheets were evaluated using FTIR, SEM, EDX, BET, XRD and TGA. The performance of adsorptive sheet showed greater selectivity for CO_2 over CH_4, and their adsorption capacities were found to be strongly dependent on pressure, temperature, and gas compositions in which CO_2 content was varied in the range of 10-80%. The EDA-containing adsorptive sheet demonstrated high capacity (4.4 mmol/g) at 30 bar and high CO_2 content in the feed. The adsorptive sheets were stable, easily regenerable at 80°C, and highly promising for column and scaled CO_2 separation from NG. Overall, radiation-grafted adsorptive sheets offer strong potential for a low-energy, robust, and scalable solution for CO_2 removal from NG streams with extreme CO_2 concentrations.

Keywords: *Radiation grafting, Adsorptive sheets, CO_2 separation, Natural gas purification, Selective adsorption*

Paper ID: KS38

PVDF-TiO2 Mixed-Matrix Membranes for Treating Natural Rubber Skim Latex

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ABSTRACT

Natural rubber Skim latex is frequently thrown away as garbage or used to make skim natural rubber goods like skim blocks and crepe. Since skim latex contains a lot of non-rubber components, such as protein, and very little rubber, it is difficult to extract the remaining rubber. Concentrated sulfuric acid is typically used by manufacturers as a coagulant. This process produces toxic chemicals and effluents that harm the environment. The objective of this research is to create a hydrophilic PVDF-TiO2 mixed-matrix membrane. After undergoing a membrane-based ultrafiltration process, the skim latex was separated into two products: skim serum and skim latex concentrate. SEM-EDX and FTIR analysis can be used to identify skim latex deposits that result in fouling on the membrane surface. The mixed-matrix PVDF–PVP–TiO2 membrane produced the highest. SEM-EDX and FTIR analysis can be used to identify skim latex deposits that result in fouling on the membrane surface. Compared to PVDF pure membranes, which had a lesser flux of 8.14 L/m2h, the PVDF–PVP-TiO2 mixed-matrix membrane produced the highest skim serum flux of 12.72 L/m2h. According to CHNS research, the membrane separation procedure was successful in extracting a higher quantity of nitrogen, which is a sign of the protein composition. During filtration, these particles could stick to the membrane surface and block or reduce the number of fluid flow channels. The flow rate decreases because of the deposition's reduction of the membrane pores' effective size. The study's hydrophilic PVDF-TiO2 mixed-matrix membrane exhibits great promise for use in the latex sector, particularly in the treatment of natural rubber skim latex, a problematic by-product with a high fouling potential. By facilitating more effective separation and recovery, this novel ultrafiltration technique is a viable way to increase the value of skim latex.

Keywords: *Natural Rubber, Skim Latex, Skim Serum, Concentrate Latex, Pvdf Ultrafiltration*

INVITED SPEAKERS

Paper ID	
IS01	**Naixin Wang** *Beijing Key Laboratory for Green Catalysis and Separation, Department of Chemical Engineering, College of Materials Science and Engineering, Beijing University of Technology, 100 Pingleyuan, Chaoyang District, Beijing, 100124, China* Fabrication and structural regulation of organic solvent separation membranes with high performance
IS02	**Ahamd Ilyas Rushdan** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor Malaysia* Nanocellulose: a new ageless bionanomaterial for advanced water treatment
IS03	**Sherub Phuntsho** *ARC Research Hub for Nutrients in a Circular Economy, Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology Sydney, 15 Broadway, NSW 2007, Australia* Composite electrode design for selective bromide recovery using membrane capacitive deionization for bromine production
IS04	**Hamdy Abdel-Ghafar** *Central Metallurgical Research and Development Institute (CMRDI), 1 Elflezat st, PO 87 Helwan, Cairo, Egypt.* Developing ceramic hollow fiber membranes from Egyptian kaolin for a cost-effective wastewater treatment
IS05	**Sang Hoon Han** *Airrane Co. Ltd., Cheongju-si, Choongcheongbuk-do 28121, Korea* Pilot-scale demonstration of gas separation membrane processes for carbon dioxide capture: progress and perspectives from Korea
IS06	**Siew Chun Low** *School of Chemical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia* Controlling interfacial fouling through surface chemistry: Superhydrophobic PVDF membranes for desalinating algae-contaminated brine
IS07	**Wai Fen Yong** *School of Energy and Chemical Engineering, Centre of Excellence for Green and Advanced Technologies in Efficient Separations (GATES), Xiamen University Malaysia, Jalan Sunsuria, Bandar Sunsuria, 43900, Sepang, Selangor, Malaysia* Towards the development of green and sustainable membranes for gas and liquid separation
IS09	**Watsa Khongnakom** *Department of Civil and Environmental Engineering, Faculty of Engineering, Prince of Songkla University, Songkla Province, Thailand* Performance and 51odelling of an anaerobic membrane bioreactor for landfill leachate treatment using a modified ADM1 framework

IS10	**Masakoto Kanezashi** *Chemical Engineering Program, Graduate School of Advanced Science and Engineering, Hiroshima University, 739-8527, Japan* Tailoring the microporous silica-based structure and application to oxygen separation at low temperature
IS11	**Ryo Nagumo** *Department of Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan* Unveiling the antifouling mechanisms in acrylate and methacrylate polymers: Insights from molecular dynamics simulations
IS12	**Bhaskar Deka** *Advanced Membrane Research Lab, Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, 247667, India* Advancing forward osmosis desalination through engineered thin-film composite membranes: design and performance studies
IS13	**Jeong-Hoon Kim** *C1 gas & Carbon Convergent Research Center, Chemical & Process Technology Division, Korea Research Institute of Chemical Technology, Gajeong-ro 141, Yuseong-gu, Daejeon 34114, South Korea* Membrane hybrid process for CO separation from byproduct gas (FOG) in steel industry
IS14	**Bishnu Prasad Biswal** *School of Chemical Sciences, National Institute of Science Education and Research (NISER) Bhubaneswar Jatni, Khurda, Odisha 752050, INDIA* Covalent organic framework membranes for molecular separations and beyond
IS16	**Mohd Ridhwan Adam** *Materials Technology Research Group (MaTReC), School of Chemical Sciences, Universiti Sains Malaysia, 11800 Minden, Penang, Malaysia* Revolutionizing dye removal in wastewater by utilizing the curcumin-loaded natural zeolite clinoptilolite filled in alginate adsorptive beads
IS17	**Sumarni Mansur** *Bioresource Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia* Harnessing bioresources for functional material development
IS18	**Siti Khadijah Hubadillah** *School of Technology Management and Logistics, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia* Green, sustainable, and eco-friendly bioplastic membrane filtration towards oil-water separation
IS19	**Mohd Riduan Jamalludin** *Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia* One-step engineering of low-cost composite hydroxyapatite-kaolin ceramic hollow fibre membrane for efficient adsorption/separation arsenic removal
IS20	**Tutuk Djoko Kusworo** *Department of Chemical Engineering, Faculty of Engineering, Diponegoro University, 50275 Jl. Prof. Soedarto, Semarang, 50275, Central Java, Indonesia*

	Fabrication and Performance Evaluation of PSf- TiO_2/UiO-66-NH_2 Photocatalytic Membranes under UV-Vis Irradiation for Produced Water Treatment
IS21	**Qianhong She** *School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798, Singapore* Electrodialysis with mediating solution (EDM) for eliminating alkaline scaling during desalination
IS22	**Vikky Anand** *Department of Chemical Engineering, Indian Institute of Technology Jodhpur, Rajasthan, India* Tailored low-cost clay based ceramic membrane for treatment of wastewater
IS23	**Woon Chan Chong** *Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Sungai Long Campus, Jalan Sungai Long, Cheras 43000 Kajang, Selangor, Malaysia* Restoring functionality: a smart self-healing membrane for industrial textile wastewater treatment
IS24	**Hyung Gyu Park** *Nanoscience for Energy Technology & Sustainability (NETS), Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Gyeongbuk 37673, Republic of Korea* Molecular transport in the low-dimensional environment towards efficient separation
IS25	**Bhaskar Deka** *Advanced Membrane Research Lab, Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, 247667, India* Advancing forward osmosis desalination through engineered thin-film composite membranes: design and performance studies
IS26	**Yong Yeow Liang** *Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakob, 26300, Kuantan, Pahang, Malaysia* Modeling the impacts of spacers on osmotically assisted reverse osmosis systems
IS27	**Hasrinah Hasbullah** *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81300, Johor Bahru, Johor* Biochar-based functionalised adsorptive membranes for waste water treatment
IS28	**Hao Yang** *Nanjing University, China* Molecularly selective organic framework membranes for liquid separations
IS29	**Dayang Norafizan Awang Chee** *Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia* Enhanced lead (II) removal using CQD-modified ZIF-8 membranes: A novel hybrid approach
IS30	**Wei-Fan Kuan** *Department of Chemical and Materials Engineering, Chang Gung University, Taiwan* Interfacial design on polymer membranes for high performance lithium metal batteries

IS31	**Jenn Fang Su** *Department of Chemical and Materials Engineering, Chang Gung University, Taiwan* Polyethersulfone ultrafiltration membranes with tailored skin layer structure for selective nitrate removal
IS34	**Gayathri Naidu** *School of Civil and Environmental Engineering, University of Technology Sydney (UTS)NSW 2007, Australia* Selective electrochemical extraction of critical metal rubidium from brine: Role of ion exchange membrane
IS35	**Nadzirah Mohd Mokhtar** *Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26300 Kuantan, Pahang, Malaysia* Advancing membrane distillation with renewable energy and IoT: A smart and sustainable water treatment solution
IS36	**Mohamad Fairus Rabuni** *Sustainable Process Engineering Centre (SPEC), Department of Chemical Engineering, Faculty of Engineering, Universiti Malaya, Kuala Lumpur 50603, Malaysia* Advances in microbial electrochemical cells for integrated wastewater treatment and resource recovery
IS38	**Fu Liu** *Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences, No. 1219 Zhongguan West Rd, Ningbo 315201, China* Breaking through the permeability-reactivity trade-off in catalytic membranes
IS39	**Jiangtao Liu** *University of Science and Technology of China* Smart covalent organic framework (COF) membranes for molecular sieving
IS40	**Wei Lun Ang** *Universiti Kebangsaan Malaysia* Turning waste into wonder: biomass-derived graphene membranes for microalgae harvesting
IS41	**Atikah Mohd Nasir** *Centre for Diagnostic, Therapeutic and Investigative Studies, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia* Detection of illicit drug unique marker in wastewater: The role of advanced membrane technologies
IS42	**Jianchuan Wang** *Chemistry and Chemical Engineering, Chongqing University, Chongqing401331, China* High performance anion exchange membranes for hydrogen conversion
IS43	**Helen Julian** *Institut Teknologi Bandung, Indonesia* Removal of microplastic in polluted water by membrane distillation
IS44	**Zhouyou Wang** *Department of Chemical and Biological Engineering, Monash University, Clayton VIC 3800, Australia.* A lithium-ion conducting polymer composite membrane for ultra-efficient, selective lithium recovery
IS46	**Nadia Adrus**

	Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor Malaysia Hydrogels as versatile platforms: how far have we come?
IS47	**Triyanda Gunawan** *Department of Chemistry, Faculty of Science and Data Analytic, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia* Carbon and zeolite based mixed matrix membrane for gas separation, a trial in the real world scenario for biogas upgrading
IS48	**Lanying Jiang** *Central South University, China* PAN/PVA nanofibrous membranes for hydrometallurgical oil-in-water emulsion separation
IS49	**Nurul Widiastuti** *Institut Teknologi Sepuluh Nopember, Indonesia* Development of sustainable membranes from polyethylene terephthalate (PET) and high density polyethylene (HDPE) waste for water treatment and gas separation
IS50	**Nur Hashimah Alias** *Universiti Teknologi Mara, Malaysia* Two-dimensional materials-based evaporators for sustainable clean water production
IS51	**Yusuf Wibisono** *Universitas Brawijaya, Indonesia* Tailored CA/DES composite membranes with microcrystalline cellulose for efficient orange juice clarification

Paper ID: IS01

Fabrication and Structural Regulation of Organic Solvent Separation Membranes with High Performance

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ABSTRACT

Membrane separation technology, characterized by its eco-friendly, energy-efficient, and highly effective nature, represents a typical low-carbon process and technology, playing a crucial role in fields such as chemical engineering, energy, environmental protection, and pharmaceuticals. The key to advancing this technology lies in the fabrication of high-performance separation membranes. In the domain of organic solvent separation, membrane performance is constrained by the trade-off effect between selectivity and permeability, and developing novel membrane materials offers an effective solution to this challenge. Metal-Organic Frameworks (MOFs), with advantages such as high porosity, interconnected pore structures, and exceptional design flexibility, hold significant potential for application in separation membranes. However, a major challenge currently lies in preparing ultrathin, defect-free MOF separation membranes. Strategies like in-situ induction can be employed to form MOF selective layers on porous supports, leveraging their pore size sieving and confined mass transfer mechanisms to achieve precise molecular sieving of organic solvents. This approach enhances internal mass transfer pathways within the membrane, ultimately yielding high-flux organic solvent separation membranes.

Key words: *Organic Solvent Separation, Pervaporation, Metal-organic Framework, High Performance*

Paper ID: IS02

Nanocellulose: A New Ageless Bionanomaterial for Advanced Water Treatment

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ABSTRACT

Nanocellulose and its derivatives have emerged as promising bio-based materials for water treatment, attributed to their high surface area, strength, and renewable nature. The presence of hydroxyl groups on cellulose nanocrystals (CNCs) and cellulose nanofibrils (CNFs) facilitates various surface modifications, leading to nanocomposites with customizable properties. This presentation investigates into the applications of nanocellulose-based materials in adsorption, catalysis, filtration, and flocculation, with a focus on removing heavy metals, dyes, and pharmaceutical compounds from water. Additionally, it examines nanocellulose’s role in environmental sustainability, particularly in wastewater remediation through adsorption, filtration, catalysis, and pollutant sensing. The presentation also highlights recent advancements in the production of nanocellulose-based adsorbents and membranes, emphasizing synthesis techniques, surface modifications, and durability, which bolster their potential for commercial application in cleaner wastewater treatment technologies. This comprehensive overview addresses the challenges and future prospects for the industrial use of nanocellulose in environmental remediation, underlining its importance in tackling global concerns related to resource depletion and harmful contaminants.

Paper ID: IS03

Composite Electrode Design for Selective Bromide Recovery using Membrane Capacitive Deionization for Bromine Production

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ABSTRACT

Bromide (Br^-) is a critical ion with diverse industrial applications; however, its selective removal and recovery from water remain underexplored, particularly in the context of capacitive deionization (CDI) systems. While CDI has demonstrated high efficiency, its potential for targeted Br^- recovery and total dissolved solids (TDS) reduction has not been fullIn this study, we developed a bromide-selective composite electrodes (BrSCE) by combining statistical modelling and electrochemical characterisation to enhance Br^- selectivity and total dissolved solids (TDS) reduction. The effects of Br^--selective resin content, feed solution ion ratios, and applied voltage on electrode performance were systematically evaluated using response surface methodology, yielding highly significant quadratic models ($p < 0.0001$, $R^2 > 0.97$) for both selectivity and TDS reduction. Electrochemical characterisation through cyclic voltammetry revealed ideal capacitive behaviour with quasi-rectangular curves maintained across scan rates (5-100 mV/s), while EIS analysis demonstrated efficient charge transfer kinetics with minimal interface resistance. The optimised electrodes, containing 43.6% Bromide Plus/9218 resin and operated at 1.2 V, achieved a Br^- selectivity of 2.5 over Cl^- in solutions where Cl^- was 5× more concentrated than Br^-, and TDS reduction efficiencies of 60-90%. Desorption studies revealed a distinctive two-phase mechanism with 40% Br^- release within the first stage followed by slower secondary desorption, achieving an overall recovery efficiency of 60%. This behaviour indicates a trade-off between selective adsorption and recovery, attributed to strong ion-resin interactions and mass transfer resistance within the composite electrode. These findings provide both fundamental insights into selective ion removal mechanisms and practical solutions for resource recovery industries seeking efficient bromide removal and extraction methods.

Keywords: *Bromine, Bromine, Selectivity, Resource Recovery, Capacitive Deionisation*

Paper ID: IS04

Developing Ceramic Hollow Fiber Membranes from Egyptian Kaolin for A Cost-Effective Wastewater Treatment

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ABSTRACT

Hollow Fiber Membrane (HFM) technology offers a cost-effective and efficient solution for water treatment, with simpler fabrication than traditional spiral-wound membranes. It features compact design, high surface area, low energy use, and adaptability to various materials including polymers and ceramics. Recently, researchers have focused on using naturally abundant and low-cost minerals like kaolin to produce inorganic HFMs, which are more resistant to harsh wastewater conditions. In Egypt, which faces severe water scarcity, HFM technology presents a promising and scalable solution. This study proposes developing low-cost, clay-based HFMs, offering a practical approach to wastewater treatment and addressing national water challenges through technology transfer and localized material use. The HFMs were fabricated using a combined phase inversion and sintering technique, aimed at simplifying the production process and enhancing membrane performance. Different loading ratios of kaolin were applied to reach the optimum ratio in terms of good mechanical properties of the resulted membrane. Furthermore, the spinning parameters were optimized. The resulted membranes were investigated by SEM, mechanical strength and water flux. In addition, polypyrrole layer were deposited on the optimized membranes for solar desalination and wastewater treatment. The modified ceramic HFM showed an evaporation rate of about 1.3 kg/m2.h using solar simulator at 1 sun, which is 2.1 times higher than the ceramic HFM without polypyrrole deposition. This confirms the capability of using the modified ceramic HFM for solar-based wastewater treatment technology. So, these resulting membranes offer a promising alternative to conventional polymeric or inorganic membranes, particularly in regions facing water scarcity such as Egypt. The utilized Egyptian clay in ceramic HFM fabrication encourages applying clay-based HFMs for industrial-scale wastewater treatment. The proposed approach not only reduces material and production costs but also supports sustainable water purification strategies tailored to local resources and needs.

Keywords: *Egyptian Kaolin, Ceramic, Hollow Fiber membrane, Solar-Driven Evaporation*

Paper ID: IS05

Pilot-Scale Demonstration of Gas Separation Membrane Processes for Carbon Dioxide Capture: Progress and Perspectives from Korea

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ABSTRACT

Global warming, driven by the combustion of fossil fuels and the emission of greenhouse gases, is accelerating environmental, economic and social crisis worldwide. As of April 2025, atmospheric CO_2 concentration has reached 429 ppm. Mitigating these emissions requires both transitioning to renewable energy sources and deploying carbon capture, utilization and storage (CCUS) technologies, which are among the most promising options for existing power plants and industrial facilities. CCUS encompasses a suite of technologies designed to reduce greenhouse gas emissions by capturing CO_2 and, in many cases, converting it into valuable products. Among current CCUS approaches, including amine-based wet scrubbing and sorbent-based capture, membrane-based gas separation is emerging as one of the most viable solutions. Membrane technology offers several key advantages: (i) low energy consumption due to the absence of phase changes, (ii) a compact footprint and scalability through modular cascade systems, and (iii) a clean process with minimal secondary emissions. Over the past decade, we have developed a comprehensive CO_2 separation membrane system, encompassing material design, hollow fiber membrane spinning, module assembly, and demonstration at both bench- and pilot-scale levels. These systems were tested across various flue gas sources, each with differing CO_2 concentrations and gas compositions. We optimized membrane performance by adjusting design and operational parameters to meet specific capture goals such as CO_2 purity, recovery rate, system footprint, and cost-effectiveness. In this presentation, we will share results from several field demonstrations, including applications in boilers, LNG power plants, cement production, petrochemical, and H_2 generation facilities. These case studies highlight the adaptability and efficiency of membrane-based CO_2 capture technologies under real-world conditions.

Keywords: *Carbon Capture, CO2 Separation, Gas Separation Membrane, Scale-Up, Pilot Demonstration*

Paper ID: IS06

Controlling Interfacial Fouling through Surface Chemistry: Superhydrophobic PVDF Membranes for Desalinating Algae-Contaminated Brine

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ABSTRACT

Understanding the interaction between membrane surface properties and complex fouling mechanisms is essential for optimizing membrane performance in desalination processes. In this study, a superhydrophobic polyvinylidene fluoride (PVDF) membrane was fabricated using an ethanol-assisted phase inversion method to enhance interfacial control during membrane distillation (MD) of hypersaline wastewater rich in microalgae. The engineered membrane exhibited a high static water contact angle of 156.2° and a low gliding angle of 8.6°, indicating significant hierarchical roughness and reduced surface energy. Fouling resistance was markedly improved, with only 29.2 g/m^2 of foulant accumulation after 10 hours of continuous operation, which is approximately 50% less than that observed for the unmodified membrane. A fouling-kinetics-based flux prediction model effectively described the long-term performance trend (coefficient of variation: 6.6%), and the membrane consistently achieved a salt rejection rate of 99.9% over 20 hours. These findings highlight the critical role of surface chemistry and fouling dynamics in the rational design of advanced membranes for the treatment of saline and bio-organic-laden wastewater streams.

Keywords: *Superhydrophobic; Membrane Distillation; Desalination; Fouling Mechanism*

Paper ID: IS07

Towards the Development Of Green and Sustainable Membranes for Gas and Liquid Separation

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ABSTRACT

The growing global emphasis on environmental sustainability has accelerated the demand for green and sustainable membrane technologies for gas and liquid separations. Conventional membrane fabrication often relies on toxic solvents, non-renewable polymers, and energy-intensive processes, leading to significant environmental and health concerns. This work explores emerging strategies for developing environmentally friendly membranes, focusing on the use of green solvents and energy-efficient fabrication techniques. In addition, innovations in membrane design, such as the incorporation of nanofillers and low-energy processing methods, are paving the way for enhanced performance and sustainability. The integration of green chemistry principles throughout membrane development aims not only to achieve high separation efficiency but also to minimize lifecycle impacts, from raw material sourcing to end-of-life disposal. By addressing current challenges and highlighting successful case studies, this work underscores the critical role of green membrane technologies in achieving cleaner industrial processes, promoting resource efficiency, and supporting global sustainability goals.

Keywords: *Green Solvents, Polymeric Membranes, Gas Separation, Liquid Purification, Nanofillers*

Paper ID: IS09

Performance and Modeling of an Anaerobic Membrane Bioreactor for Landfill Leachate Treatment Using a Modified ADM1 Framework

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ABSTRACT

This study investigates the performance and modeling of an anaerobic membrane bioreactor (AnMBR) for landfill leachate treatment using a modified Anaerobic Digestion Model No. 1 (ADM1), integrated with membrane-specific parameters. The AnMBR system was operated under mesophilic conditions at an organic loading rate (OLR) of 3.04 ± 0.41 kg COD/m^3·d. Chemical oxygen demand (COD) removal efficiency of 95% was achieved, along with a biogas production of 18.87 L/d and methane yield of 0.33 ± 0.07 L CH_4/g COD removed. Enhanced methane generation was associated with elevated volatile fatty acid (VFA) accumulation and high degradation rates. The optimum ORP values during acidogenesis and methanogenesis phases were –284 ± 32.71 mV and –335.63 ± 28.97 mV, respectively. Membrane fouling mechanisms were also examined under operating conditions with an initial flux of 13–15 LMH, a gradual decline in flux was observed, indicating progressive fouling. At a SRT 15 days, gel polarization was the dominant fouling mechanism, caused by the accumulation of proteins, humic substances, and carbohydrates on the membrane surface and within its pores. At a 45-day SRT, fouling was primarily due to cake layer formation, resulting from sludge accumulation and compaction on the membrane surface. SEM and FTIR analyses identified both organic and inorganic foulants, including functional groups such as C–O, C–C, C–O–C, C=O, Si–O–Si, and S=O. Major fouling constituents included silica oxides and amines, while inorganic scaling comprised calcite, dolomite, and ikaite, with manganese and iron acting as co-precipitants. The experimentally derived kinetic parameters were used to update the ADM1 model, replacing its default constants. Model calibration and validation against experimental AnMBR data showed improved accuracy, with the average total simulation error 10.38 + 2.84%. These results demonstrate the enhanced predictive performance and robustness of the modified ADM1-AnMBR model for simulating landfill leachate treatment.

Keywords: *AnMBR, ADM1, Leachate, Fouling, Kinetic Parameters*

Paper ID: IS10

Tailoring the Microporous Silica-based Structure and Application to Oxygen Separation at Low Temperature

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ABSTRACT

Industrial oxygen is purified by cryogenic distillation, in which cryogenic fluids of O2, Ar, and N2 flow inside the distillation column at a temperature of -180℃. The relative volatility of argon to oxygen is only 1.1, so that energy consumption is high due to the large number of shelf stages and large reflux ratio. Thus, the development of high O2 selective permeation membranes for oxygen purification will enable a significant reduction in energy consumption via process intensification. In the present study, bis(triethoxysilyl)methane (BTESM), which is known to have one of the most rigid and dense pore structures for bridged organosilica, was selected as the active separation layer, and its gas permeation properties were evaluated under temperatures ranging from -115 to 200 ◦C. Binary separation (O2/He, O2/Ar) was also conducted to evaluate the effect of O2 adsorption and its blockage of separation properties under extremely low temperatures. O2 selectivity strongly depended on network pore size and O2 selectivity for a membrane with small network pore size largely increased at -115℃.

Keywords: *Organosilica Membranes, Cryogenic Temperature, Gas permeation, Air Separation; Molecular Sieving*

Paper ID: IS11

Unveiling the Antifouling Mechanisms in Acrylate and Methacrylate Polymers: Insights from Molecular Dynamics Simulations

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ABSTRACT

Membrane fouling is a critical challenge in the development of water permeable membranes. This issue impacts the efficiency and longevity of membrane systems used in various water treatment processes. To address this, we have focused on polymeric biomaterials known for their excellent fouling resistance, such as nonionic poly(2-methoxyethyl acrylate)[1)]. We have investigated the mechanisms behind this resistance using molecular dynamics (MD) simulations. In recent studies[2,3)], we successfully reproduced experimental trends in fouling resistance in polymeric biomaterials, by evaluating the dispersion/aggregation properties of binary mixtures consisting of model organic foulants and oligomers constituting the polymer material. This approach enabled us to model the interactions between foulants and the polymer substrate at a molecular level, shedding light on the factors that contribute to fouling resistance. Building on these findings, we explored the thermodynamic aspects of fouling resistance through free energy calculations using MD simulations. We focused on simplified systems consisting of monomer molecules, and the results revealed a clear correlation between the shape of the free energy profiles and experimental fouling resistance. These findings show that even in simplified model systems composed of monomers/oligomers, the fouling resistance of polymeric materials can be accurately estimated. Our theoretical approaches offer valuable insights into the design of novel antifouling materials. We will present our methodologies and discuss the detailed results, which could contribute to the future development of high-performance water treatment membranes.

Keywords: *Free Energy Profiles, Membrane Fouling, Molecular Dynamics, Radial Distribution Function, Second Virial Coefficient*

Paper ID: IS12

Advancing Forward Osmosis Desalination through Engineered Thin-Film Composite Membranes: Design and Performance Studies

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ABSTRACT

Forward osmosis (FO) offers a promising, energy-efficient approach for water production from saline feeds. This study reports the development of a thin-film composite (TFC) FO membrane tailored for desalination applications. The membrane support layer was fabricated using polyether sulfone (PES), modified with poly(2-ethyl-2-oxazoline) (PEOx) and goethite nanoparticles to enhance hydrophilicity. The FTIR peak at 1637 cm^{-1} confirmed the incorporation of PEOx, while X-ray diffraction (XRD) spectra showed characteristic peaks at 21.40°, 33.53°, 34.8°, and 36.73°, indicating the presence of goethite nanoparticles. Scanning electron microscopy (SEM) revealed highly porous structures, with increased porosity and enlarged average pore size. The support layer exhibited a superhydrophilic loose side (~0° water contact angle, WCA) and a hydrophilic dense side (~50.7° WCA), demonstrating improved wettability. Furthermore, a selective polyamide layer was successfully formed on the support. The TFC-FO membrane showed enhanced water permeability (A) and a significantly reduced structural parameter (S). Notably, the optimized membrane (TFC-M4) achieved fluxes of approximately 5.62 LMH under FO mode and 11.25 LMH under PRO mode, using 2 M NaCl as the draw solution and deionized water as the feed.

Keywords: *Poly(oxazoline), Goethite, Hydrophilicity, Forward osmosis, Poly(ether sulfone), Nanoparticles*

Membrane Hybrid Process for Co Separation from Byproduct Gas (FOG) in Steel Industry

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ABSTRACT

Carbon monoxide (CO) plays an important role in the chemical and steel industries. CO is produced through catalytic reforming of methane, partial oxidation of hydrocarbons, and coal gasification. The steel industry produces large amounts of by-product gases containing high concentrations of valuable CO. Due to the current lack of CO separation technology, it is mainly used to generate electricity through incineration, which emits huge amounts of CO2 by burning CO, resulting in severe global warming. Separation of CO from the by-products is of economic and environmental importance as they can be used to produce valuable chemical or steel products. Absorption and adsorption technologies are currently being studied for CO separation via π-complexation. Membrane technology has outstanding advantages such as low energy consumption, easy operation, and fusion with other separation technologies, which can be a promising means to recover CO from the by-product gases. In this study, we designed a new hybrid CO separation process to increase CO separation efficiency from POSCO's by-product gas, FOG (28.9% CO, 3.4%, CO2 44.9%, N2 21.4% and CH4 1.1%) as follows; 1) Asymmetric polysulfone hollow fiber membranes for gas separation were developed by dry-wet spinning and used in membrane process to remove H2 and CO2 from FOG to concentrate CO/N2/CH4. 2) Chitosan/Ag(I) facilitated composite membranes were developed by introducing AgNO3 into CS selective layers coated on porous polysulfone supports and used in membrane process to separate CO from the concentrated CO/N2/CH4 mixture via *π-complexation*. This work could provide valuable insights for the separation of CO from steel industry by-product gases.

Keywords: *Steel Industry, CO Separation, Chitosan-Ag(I) Facilitated Composite Membrane, π-Complexation*.

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Paper ID: IS14

Covalent Organic Framework Membranes for Molecular Separations and Beyond

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ABSTRACT

Membrane-based separation is vital in various industrial processes because of its low energy consumption, compact design, and ease of operation. The advancement of this technology hinges on the development of innovative membrane materials. While polymer-based membranes have been used for a long time, their efficiency is limited by the trade-off between permeability and selectivity. Thus, the quest for novel membrane materials is a primary focus for academia and industry. Nanoporous materials, such as zeolites, metal-organic frameworks (MOFs), and covalent organic frameworks (COFs), based membranes provide better separation performance due to their ordered porous structures. COFs, in particular, are promising for advanced gas and liquid-phase separation processes because of their crystalline nature, well-defined porosity, tunable functionalities, and versatile architectures.[1] Since the first COF membrane (COFMs) for gas separation was introduced in 2015, there has been rapid progress in their development, underscoring their potential in membrane-based separations of gas mixtures (CO_2/N_2; CO_2/CH_4; H_2/N_2 etc.), molecular separation (ions and dye separation), solvent nanofiltration, oil-water separation and more.[2] Not limited to molecular separation, recently, COFMs have also been emerged as potential semiconducting materials for photonics and optoelectronic device applications.[3] In my talk, I will discuss two of our recent works on optical conductivity of free-standing 3D COFMs using terahertz (THz) spectroscopy and nonlinear optical (NLO) response of free-standing COFMs along with molecular separation potentials of our inhouse developed COFMs.

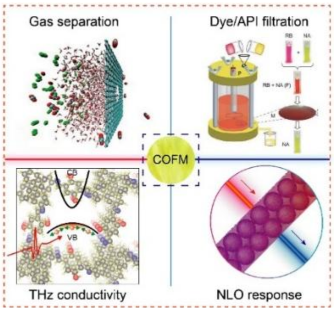

Figure 1. Schematic of the distinct applications of COFMs for molecular separation and light-matter interaction.

Keywords: *COFs, Membranes, Separation, Light-Matter Interaction, Oil-Water*

Paper ID: IS16

Revolutionizing Dye Removal in Wastewater by Utilizing the Curcumin-Loaded Natural Zeolite Clinoptilolite Filled in Alginate Adsorptive Beads

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ABSTRACT

The curcumin-modified natural zeolite clinoptilolite (CUR-CPTMS-NZC) beads were successfully synthesised using acid-treated natural zeolite clinoptilolite (HCl-NZC) and curcumin, which were then fabricated into alginate beads. These beads were designed to enhance the adsorption of methylene blue (MB) dye while being environmentally friendly. Characterisation tests were conducted, involving the use of FTIR, BET, TGA, SEM-EDX, and zeta potential analysis. The effects of pH, adsorbent dosage, and initial MB concentration on the removal of MB were studied using Response Surface Methodology (RSM) through the central composite design (CCD) method to optimise the adsorption process. The results demonstrated that the adsorption process adheres to a quadratic polynomial model, as evidenced by the high R^2 value obtained ($R^2 = 0.9985$). The optimal conditions for 100% MB removal were predicted to be a pH of 7.8, 0.5 g/L of CUR-CPTMS-NZC beads, and an MB concentration of 13 ppm, with a treatment time of 60 minutes. A visible colour changes in the beads from yellow to blue, along with elemental mapping images showing the presence of sulphur and nitrogen on the bead surface after adsorption, qualitatively confirms the successful uptake of MB dye. The SEM-EDX analysis also verified the adsorption of MB dye on the beads. The experimental data on the adsorption of MB on CUR-CPTMS-NZC beads followed the Redlich-Peterson isotherm, indicating a preference for the Langmuir isotherm, which suggests that monolayer adsorption is the dominant mechanism. Zeta potential analysis indicates that adsorption occurs primarily through physisorption, facilitated by electrostatic attraction between the negatively charged beads and cationic MB molecules. Good adsorption properties were demonstrated in reusability investigations after six consecutive cycles. This study found that CUR-CPTMS-NZC beads offer several advantages, including efficacy, stability, and reusability as adsorbents for adsorption applications.

Keywords: *Adsorption, Clinoptilolite Natural Zeolite, Surface Modification, Cationic Dye, Wastewater Treatment*

Paper ID: IS17

Harnessing Bioresources for Functional Material Development

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ABSTRACT

The growing demand for sustainable and high-performance materials has led to increased interest in using bioresources as renewable feedstocks for functional material development. Agricultural residues, forestry byproducts, and other biomass-derived materials offer abundant, low-cost, and environmentally friendly alternatives to conventional synthetic resources. By utilizing agricultural waste such as rice husk ash, wood chips, and bamboo residues, these materials can be engineered into high-performance adsorbents through controlled thermal and chemical treatments. Rice husk ash and wood ash, rich in reactive silica and alumina, were utilized as precursors in the synthesis of geopolymers via alkali activation. The resulting materials exhibited high porosity, improved structural integrity, and strong adsorption affinity toward heavy metals such as lead and copper, enabling their effective use in wastewater treatment. Bamboo-derived graphene oxide was synthesized through controlled oxidation routes, leveraging the high carbon content of bamboo culms. The graphene oxide produced demonstrated a high surface area and abundant functional groups, which contributed to excellent adsorption performance against organic dyes like methylene blue. These bio-derived materials offer tunable physicochemical properties, including surface charge, hydrophilicity, and reactivity, making them suitable for integration into multifunctional systems. Physicochemical characterization using SEM, FTIR, XRD, and static adsorption confirmed successful material synthesis and functional enhancement. Testing in simulated wastewater environments validated the efficacy of the biobased-geopolymer and bamboo graphene oxide materials in capturing heavy metals and organic pollutants, respectively. These findings highlight the potential of bioresource-derived functional materials in addressing wastewater challenges. By transforming agricultural byproducts into value-added materials, this approach supports circular economic principles while addressing pressing environmental challenges. Bioresource-based functional materials thus represent a promising platform for sustainable innovation across water treatment, textile processing, and beyond.

Keywords: *Bioresource, Agricultural Waste, Functional Material, Bamboo-Derived Graphene Oxide, Ash-Derived Geopolymer*

Paper ID: IS18

Green, Sustainable, and Eco-Friendly Bioplastic Membrane Filtration Towards Oil-Water Separation

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ABSTRACT

The acceleration of industrialization has led to an upsurge in both product output and environmental pollution, with plastic waste emerging as a dominant contributor. In 2023, global plastic waste generation reached approximately 353 million tonnes, adding to the growing environmental crisis. At the same time, aquatic ecosystems are increasingly threatened by the presence of diverse pollutants such as oils, heavy metals, and synthetic dyes. Membrane filtration technology has emerged as a globally endorsed solution for water purification due to its operational simplicity, cost efficiency, longevity, and minimal energy requirements. By 2022, the membrane technology market was valued at USD 26.3 billion, growing at an annual rate of 8.5%. However, conventional membranes typically composed of polyether sulfone (PES), polyvinyl chloride (PVC), polypropylene (PP), and polyvinylidene fluoride (PVDF) pose environmental risks, as microplastics from these materials have been detected in drinking water treatment plants (DTWPs). Addressing this challenge aligns with Sustainable Development Goals (SDG 6 and SDG 12), prompting a shift towards bioplastics derived from agricultural residues such as cellulose, fiber, and starch. Despite rising interest, no bioplastic membranes have been commercialized for water treatment applications. This study introduces a novel cellulose-based bioplastic membrane synthesized from rice husk waste, developed through three phases: cellulose extraction, membrane fabrication via conventional drying, and performance evaluation for oil-water separation. The optimized membrane, containing 1 wt.% cellulose and 0.2 wt.% PEG as a pore-forming agent, exhibited exceptional properties—88 MPa tensile strength, 55% porosity, 0.32 μm average pore size, 233 L/m²·h permeate flux, and 100% oil rejection. Notably, the high oil rejection efficiency was consistently achieved across various oil types, including palm oil mill effluent (POME), used cooking oil from restaurants, and synthetic motor oil, demonstrating the membrane's broad applicability in real-world wastewater scenarios.

Keywords: *Bioplastic Membrane, Cellulose Extraction, Rice Husk Waste, Oil-Water Separation, Sustainable Water Treatment*

Paper ID: IS19

One-Step Engineering of Low-Cost Composite Hydroxyapatite-Kaolin Ceramic Hollow Fibre Membrane for Efficient Adsorption/Separation Arsenic Removal

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ABSTRACT

The application of ceramic hollow fibre membranes from clay and animal bone waste have attracted great attention due to their potential applications especially water and wastewater treatment. Interestingly, numerous studies have demonstrated hydroxyapatite extraction from animal bone waste has ability towards adsorption features for water purification. However, ceramic hollow fibre membrane from hydroxyapatite showed lower mechanical strength. In this study, composite hydroxyapatite/kaolin ceramic hollow fibre membrane prepared at different concentration and sintering temperature were successfully prepared via phase inversion and sintering technique. Hydroxyapatite used in this study was prepared from cow bone waste through calcination process at 800 °C. The mechanical strength for composite ceramic hollow fibre membrane from hydroxyapatite was improved when hydroxyapatite was mixed into membrane matrix at composition kaolin:hydroxyapatite at ratio 30:10. In addition, the sintering temperature used was 1200°C, in which lower than sintering temperature for commercial alumina ceramic membrane. This situation can be explained through Al_2O_3-CaO-SiO_2 phase ternary diagram system, in which the arrangement of the crystal lattice of the ceramic particle was improved when incorporation of kaolin into hydroxyapatite. The composite hydroxyapatite/kaolin ceramic hollow fibre membrane sintered at 1200°C was successfully applied for arsenic removal, with rejection of 90.4% at pH 7.

Keywords: *Kaolin; Hydroxyapatite, Composite Ceramic Hollow Fibre Membrane, Arsenic*

Paper ID: IS20

Fabrication and Performance Evaluation of PSf- TiO_2/UiO-66-NH_2 Photocatalytic Membranes under UV-Vis Irradiation for Produced Water Treatment

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ABSTRACT

Produced water, a highly complex effluent generated during oil and gas extraction, presents a substantial environmental burden due to its elevated concentrations of persistent organic and inorganic pollutants. In response to this challenge, a novel photocatalytic membrane system was engineered by integrating TiO_2 and UiO-66-NH_2 into a polysulfone (PSf) matrix via the non-solvent induced phase separation (NIPS) technique. Composite membranes were fabricated with varying nanoparticle loadings (0–2 wt%), facilitating a comprehensive assessment of the influence of photocatalyst incorporation on structural and functional membrane. Advanced morphological and physicochemical characterizations verified the uniform dispersion and successful immobilization of TiO_2/UiO-66-NH_2 within the PSf framework, resulting in enhanced surface hydrophilicity, increased porosity, and superior photo-responsiveness. The optimized membrane with 2 wt% filler demonstrated outstanding photocatalytic treatment performance under UV-Vis irradiation, achieving removal efficiencies of 89% for chemical oxygen demand (COD), 92% for ammonia nitrogen (NH_3–N), and 95% for total dissolved solids (TDS), while maintaining a high permeate flux of 135 $L/m^2.h$. Furthermore, the membrane exhibited excellent antifouling behavior and operational durability, retaining 99.38% of its original performance and reducing fouling by 97.95% after five continuous filtration cycles. This results highlight the potential of PSf-TiO_2/UiO-66-NH_2 membranes as a highly efficient and scalable solution for the advanced treatment of produced water. Future research should focus on evaluating long-term stability under real wastewater conditions and conducting pilot-scale trials to validate industrial feasibility.

Keywords: *Photocatalytic Membranes; Polysulfone Membrane, TiO_2/UiO-66-NH_2, Antifouling; Produced Water Treatment*

Paper ID: IS21

Electrodialysis with Mediating Solution (EDM) for Eliminating Alkaline Scaling during Desalination

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ABSTRACT

Alkaline scaling in the cathode chambers of conventional electrodialysis (ED) stacks presents significant challenges when desalinating solutions containing divalent cations. This scaling, resulting from the combined effects of water electrolysis and the migration of divalent cations from the feedwater into the catholyte, further extends from the cathode chamber to the surfaces of both the cation ion exchange membrane (CEM) and the anion exchange membrane (AEM) in the adjacent dilute chamber. This study aims to mitigate alkaline scaling, without pre-treatment or anti-scalant dosing, by optimizing the ED stack design to restrict divalent cation transport toward the cathode. We evaluated three ED stack configurations, each forming the cathode chamber with a distinct ion transport control mechanism: (1) a monovalent selective cation exchange membrane (SCEM), (2) a bipolar membrane (BPM), and (3) a mediating solution chamber adjacent to the cathode chamber (EDM). Our results indicated that stacks employing the SCEM or BPM partially restricted divalent cation migration but remained vulnerable to scaling under higher feed salinities, due to weakened Donnan exclusion within the SCEM, and strong internal ion polarization at the BPM interface. In contrast, the EDM stack exhibited superior anti-scaling performance by combining strong Donnan exclusion through an AEM with ionic buffering in the mediating solution chamber, effectively blocking cation transport and eliminating conditions conducive to scaling. Additionally, the EDM stack maintained low electrical resistance and high operational stability, making it a simple, efficient, and cost-effective solution for scaling mitigation in ED systems.

Keywords: *Electrodialysis With Mediating Solution (EDM), Electrode Scaling, Stack Design, Ion Transport, Ion Exchange Membrane (IEM)*

Tailored Low-Cost Clay Based Ceramic Membrane for Treatment of Wastewater

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ABSTRACT

The generation and discharge of wastewater poses a greater threat to the nation's economy and environment. Strict regulations have been implemented for handling, discharging, and treating waste and wastewater. Membrane technology, being one of the cleanest methods, can be used to treat the wastewater. The utilization of inorganic membranes is gaining more attention for the treatment of wastewater due to their known advantages, like higher chemical resistance, mechanical strength, and thermal resistance in comparison to their polymeric counterparts. The overall cost of fabrication of ceramic membranes is far higher than that of polymeric membranes. To overcome this aspect, cheap and locally abundant raw materials are required for the fabrication of ceramic membranes. This work shows the utilization of waste marble dust as a key raw material for membrane fabrication, along with the locally available and inexpensive raw materials such as natural clay, fuller's earth clay, and kaolin. Two different compositions were used to fabricate the membrane: waste marble dust (WMD) and natural clay-based ceramic membrane (CM). The novel fabricated membrane by using WMD and CM has a pore radius of 320 nm and 580 nm with a permeability of 459 L/hr m^2 bar and 1457 L/hr m^2 bar, respectively. The CM membrane was tested against the treatment of sewage effluent and has an excellent flux recovery ratio of 85.71 %. On the other hand, the WMD membrane was evaluated against laundry effluent with an excellent turbidity removal of up to 99%.

Keywords: *Ceramic Membrane, Dry Moulding, Microfiltration Membrane, Negatively Charged Membrane, Sewage Effluent*

Paper ID: IS22

Tailored Low-Cost Clay Based Ceramic Membrane for Treatment of Wastewater

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ABSTRACT

The generation and discharge of wastewater poses a greater threat to the nation's economy and environment. Strict regulations have been implemented for handling, discharging, and treating waste and wastewater. Membrane technology, being one of the cleanest methods, can be used to treat the wastewater. The utilization of inorganic membranes is gaining more attention for the treatment of wastewater due to their known advantages, like higher chemical resistance, mechanical strength, and thermal resistance in comparison to their polymeric counterparts. The overall cost of fabrication of ceramic membranes is far higher than that of polymeric membranes. To overcome this aspect, cheap and locally abundant raw materials are required for the fabrication of ceramic membranes. This work shows the utilization of waste marble dust as a key raw material for membrane fabrication, along with the locally available and inexpensive raw materials such as natural clay, fuller's earth clay, and kaolin. Two different compositions were used to fabricate the membrane: waste marble dust (WMD) and natural clay-based ceramic membrane (CM). The novel fabricated membrane by using WMD and CM has a pore radius of 320 nm and 580 nm with a permeability of 459 L/hr m^2 bar and 1457 L/hr m^2 bar, respectively. The CM membrane was tested against the treatment of sewage effluent and has an excellent flux recovery ratio of 85.71 %. On the other hand, the WMD membrane was evaluated against laundry effluent with an excellent turbidity removal of up to 99%.

Keywords: *Ceramic Membrane, Dry Moulding, Microfiltration Membrane, Negatively Charged Membrane, Sewage Effluent.*

Paper ID: IS23

Restoring Functionality: A Smart Self-healing Membrane for Industrial Textile Wastewater Treatment

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ABSTRACT

Pinholes may form in membranes during manufacturing, and physical damage can occur during installation and operation. Identifying the exact location of damage on membrane is challenging, and even minor damage might eventually develop into significant defects. Therefore, exploring membranes with smart features such as reversible and self-repairing abilities is crucial for restoring their original functions. In this study, a smart membrane with self-healing ability was fabricated by coating a polyethersulfone (PES) substrate with layers of polyethyleneimine (PEI) and poly(acrylic acid) (PAA) incorporated with amine-functionalised carbon quantum dots (A-CQDs). The membrane's performance was evaluated based on permeability and rejection using industrial textile wastewater. Healing was achieved by immersing the damaged membrane in distilled water at 60°C for 6 hours. With 0.6 vol% and 0.4 vol% of A-CQDs in the PEI and PAA solutions, respectively, the membrane exhibited a 93.2% self-healing efficiency based on permeability recovery. Furthermore, the recovery chemical oxygen demand (COD) and colour (measured in ADMI) reached 95.5% and 91.1%, respectively. Scanning electron microscopy (SEM) images further confirmed the successful self-repair ability. This study highlights the feasibility of a dual-responsive, self-healing membrane for wastewater treatment applications.

Keywords: *Intrinsic Self-Healing, Carbon Quantum Dots (CQDs), Polyelectrolyte, Polyethyleneimine (PEI), Poly(Acrylic Acid) (PAA)*

Molecular Transport in the Low-Dimensional Environment Towards Efficient Separation

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ABSTRACT

Fast mass transport inside and across nanoscale graphitic surfaces such as carbon nanotubes and graphene, respectively, forms the basis of Carbon Nanofluidic phenomena and poses potential applications in energy and clean technologies. This talk will review an existing paradigm of the fast transport in carbon nanotube conduits with a proposal of a new scaling relation to answer a question, “How fast is fast?” Then follows our story of shifting the paradigm with recognition of equivalence between a nearly frictionless channel and no-channel-but-only openings. Synthesis, transfer, perforation, and device integration of graphene enable altogether the preparation of an atomically thin, porous membrane for the embodiment of this new concept. Transport physics across the orifice points to an ultimate permeation of fluids (both in molecular and viscous transport regimes), heralding a high-flux membrane. High-flux membranes are in need of proper applications in membrane technology, for which this talk introduces active endeavors of producing porous graphene at large scales, furthering our understanding of transport theories and designing composite membrane materials for enhanced chemical separation.

Keywords: *Fast Mass Transport, Carbon Nanotube Conduit, Graphene Orifice, High-Flux Membrane*

Paper ID: IS25

Enhanced Lead(II) Removal Using CQD-Modified ZIF-8 Membranes: A Novel Hybrid Approach

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ABSTRACT

Carbon nanomaterials with a large surface area that are 10 nm in size are known as carbon quantum dots (CQDs). A brand-new class of carbon nanomaterial called carbon dots (CDs) is made up of distinct, practically spherical nanoparticles. As the human risk and ecological health can be affected by lead(II) in water. The removal of lead ions from water and wastewater requires the development of low-cost adsorbents. CDs prepared from sago hampas via simple hydrothermal synthesis processes at two different temperatures, 200℃ and 160℃, are compatible as one of the nanomaterials for a new hybrid membrane to remove lead (II) from wastewater. In this study, a novel composite (CDs@ZIF-8) based on carbon dots and zeolitic imidazolate framework (ZIF-8) on the alumina membrane support was successfully synthesized by incorporating CDs into the pores of ZIF-8 through a simple in-situ solvothermal method. The morphology and physicochemical properties of the hybrid membranes were characterized using the UV–visible (UV-vis) spectrophotometer, field emission scanning electron microscope (FESEM), Energy-dispersive X-ray (EDX) spectroscopy, Fourier-Transform Infrared Spectrophotometer (FTIR). The synthesized 160℃ CDs@ZIF-8 membrane has a greater adsorption performance as opposed to the 200℃ CDs@ZIF-8 membrane, with a maximum potential for absorption of lead(II) is 95.16 mg/g was obtained at 100 ppm lead(II) aqueous solution and 95.16% removal. The adsorption mechanism of lead(II) onto the CDs@ZIF-8 membrane was best fitted to the Freundlich isotherm and pseudo-second order model. The findings of this study indicate a strong potential for employing CDs@ZIF-8 modified alumina membrane wastewater treatment systems for removing lead(II) metals.

Keywords: *Carbon Dots, Zeolitic Imidazolate Framework-8,A lumina Membrane, Adsorption, Lead(II) Removal*

Paper ID:IS26

Modeling the Impacts of Spacers on Osmotically Assisted Reverse Osmosis Systems

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ABSTRACT

Osmotically assisted reverse osmosis (OARO) has been recently suggested as a promising alternative to improve water recovery in reverse osmosis (RO) applications where conventional RO has reached its operational limits. In our previous work, we developed a computational fluid dynamics (CFD) model that accurately captures the key physical phenomena occurring in the feed, porous, and draw sides of OARO membranes. The CFD simulations showed good agreement with experimental data and predicted water flux more reliably than simplified analytical models. This analysis revealed that external concentration polarization (ECP) on the feed side plays a more dominant role than internal concentration polarization (ICP) within the porous support layer, particularly under high transmembrane pressures ($\Delta p \geq 40$ bar). Furthermore, unlike conventional RO, where CP on the permeate side is negligible, OARO systems exhibit significant ECP on the draw (permeate) side, especially under high Δp conditions. However, the prior study was limited to an empty channel without spacers and was limited to small-scale simulations, without addressing the flow and mass transfer complexities present in practical and full-scale OARO modules. To address these limitations, this study focuses on improving mixing and mass transfer in the spiral-wound membrane (SWM) module of OARO systems. We present a multi-scale modeling approach that combines small-scale and large-scale transport phenomena within spiral-wound configurations specifically designed for OARO applications. This approach enables detailed visualization of the local flow structure and mass transfer for OARO SWM module, providing valuable insights that can guide the early-stage design of spacer geometries for spiral-wound membranes (SWMs) in OARO systems.

Keyword: *Osmotically Assisted Reverse Osmosis, Modeling, Spiral Wound Membrane Module*

Paper ID: IS27

Biochar-Based Functionalised Adsorptive Membranes for Waste Water Treatment

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ABSTRACT

Biochar-based adsorptive membranes present a sustainable and effective solution for water treatment, particularly in removing organic dyes and heavy metals from industrial wastewater. This study focuses on the development of polymeric membranes embedded with biochar derived from two abundant agricultural wastes; specifically empty fruit bunch (EFB) and copra. The biochar was produced through optimized pyrolysis and torrefaction–pyrolysis processes to enhance its surface area, porosity, and functional groups critical for adsorption performance. The incorporation of EFB biochar into polysulfone membranes and torrefied copra biochar into Polyvinylidene fluoride (PVDF)/polyvinylpyrrolidone (PVP) membranes demonstrated significant improvements in membrane characteristics. These include enhanced hydrophilicity, higher water permeability, improved membrane morphology with increased porosity, and better antifouling properties. Both membranes showed effective removal of target pollutants—dyes in the case of EFB biochar and hexavalent chromium (Cr(VI)) for copra biochar; this confirmed the adsorptive function of the biochar within the membrane matrix. Characterisations indicated that biochar addition influenced the membrane structure, forming more favourable pore geometries and surface interactions that enhanced contaminant adsorption. The trends observed from both systems suggested that biochar loading must be optimized to balance structural integrity with adsorption efficiency. Overall, the study highlights the potential of using lowcost, renewable biochar as a functional additive in polymeric membranes for advanced wastewater treatment. Combining the strengths of different biomass sources allow for targeted pollutant removal, offering a green and versatile approach for treating diverse industrial effluents.

Paper ID: IS28

Molecularly Selective Organic Framework Membranes for Liquid Separations

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ABSTRACT

Aligned with the innovation demands of membrane technology for the purification and resource recovery of solvents under China's "dual-carbon" strategy, this study focused on the fabrication and mechanism optimization of molecularly selective organic framework membranes. Targeting three key scientific challenges encompassing synergistic optimization of multiple mass transfer mechanisms, effective suppression of irreversible structural evolution, and precise regulation of sub-nanometer membrane pore channels, the following innovative achievements have been accomplished: (1) A strategy of bioinspired hierarchical membrane design was proposed to establish synergistic optimization methods for multiple mass transfer mechanisms, overcoming the inherent membrane permeability/selectivity trade-off effect. (2) A strategy of fully rigid framework membrane design was proposed to create an anti-deformation reinforcement mechanism, effectively inhibiting the structural evolution of membranes. (3) A strategy of solvent-responsive membrane design was proposed to construct a smart stimulus-responsive mechanism, achieving precise regulation of sub-nanometer membrane pore channels. The newly developed organic framework membrane materials are widely used in separation processes within cutting-edge fields such as biomass energy, industrial catalysis, and fine chemicals, which provides a theoretical foundation for the design of high-performance molecularly selective membrane materials.

Paper ID: IS29

Enhanced Lead(II) Removal Using CQD-Modified ZIF-8 Membranes: A Novel Hybrid Approach

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ABSTRACT

Carbon nanomaterials with a large surface area that are 10 nm in size are known as carbon quantum dots (CQDs). A brand-new class of carbon nanomaterial called carbon dots (CDs) is made up of distinct, practically spherical nanoparticles. As the human risk and ecological health can be affected by lead(II) in water. The removal of lead ions from water and wastewater requires the development of low-cost adsorbents. CDs prepared from sago *hampas* via simple hydrothermal synthesis processes at two different temperatures, 200℃ and 160℃, are compatible as one of the nanomaterials for a new hybrid membrane to remove lead (II) from wastewater. In this study, a novel composite (CDs@ZIF-8) based on carbon dots and zeolitic imidazolate framework (ZIF-8) on the alumina membrane support was successfully synthesized by incorporating CDs into the pores of ZIF-8 through a simple in-situ solvothermal method. The morphology and physicochemical properties of the hybrid membranes were characterized using the UV–visible (UV-vis) spectrophotometer, field emission scanning electron microscope (FESEM), Energy-dispersive X-ray (EDX) spectroscopy, Fourier-Transform Infrared Spectrophotometer (FTIR). The synthesized 160℃ CDs@ZIF-8 membrane has a greater adsorption performance as opposed to the 200℃ CDs@ZIF-8 membrane, with a maximum potential for absorption of lead(II) is 95.16 mg/g was obtained at 100 ppm lead(II) aqueous solution and 95.16% removal. The adsorption mechanism of lead(II) onto the CDs@ZIF-8 membrane was best fitted to the Freundlich isotherm and pseudo-second order model. The findings of this study indicate a strong potential for employing CDs@ZIF-8 modified alumina membrane wastewater treatment systems for removing lead(II) metals.

Keywords: *Carbon dots; zeolitic imidazolate framework-8;alumina membrane;adsorption,*
lead(II) removal

Interfacial Design on Polymer Membranes for High Performance Lithium Metal Batteries

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ABSTRACT

The future of electrochemical energy storage relies heavily on advancements in science and technology that facilitate the development of rechargeable batteries utilizing reactive metal anodes. Among various materials, lithium-metal anodes are particularly promising due to their remarkable theoretical specific capacity, ten times higher than that of the graphite anodes used in current lithium-ion batteries. However, several challenges including parasitic reactions between Li-metal and liquid electrolytes, unstable and dendritic electrodeposition, and dendrite-induced short circuits, have restricted the commercialization of lithium-metal anodes in energy storage devices. To overcome the above-mentioned limitations, this presentation will discuss our approach for the rational design of electrolytes and Li-metal/electrolyte interfaces in order to achieve stable, dendrite-free lithium-metal batteries. On the basis of fundamental understanding of the key variables that govern the stability of electrodeposition on the lithium-metal surface, we propose an asymmetric design of polyvinylidene fluoride (PVDF) polymer membrane with tailored interfacial porous structure in order to suppress the lithium dendrite growth while promoting the transport of lithium ions. We will also present the potential for this asymmetrically porous membrane as a scaffold to host a 1,3-dioxolane (DOL)-based solid polymer electrolyte that can exhibit outstanding ion transport properties, which is crucial for realizing lithium-metal battery applications.

Keywords: *Energy, Lithium Metal Battery, Membrane, Separator, PVDF*

Polyethersulfone Ultrafiltration Membranes with Tailored Skin Layer Structure for Selective Nitrate Removal

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ABSTRACT

In this presentation, a series of asymmetric polyethersulfone (PES) membranes are introduced for the wastewater treatment applications. Firstly, the effects of different additives during membrane preparation on the morphologies and physical properties of fabricated membranes are discussed. It is found that the asymmetric membranes with three-dimensional pore networks in PES matrix without the presence of macrovoids can be achieved under optimal loading of water or polyvinylpyrrolidone (PVP) additives using non-solvent induced phase separation (NIPS) process. The resulted PES membranes exhibit a remarkable water permeation flux and a BSA rejection, which are suitable for ultrafiltration. Secondly, the synthesized PES membranes can be utilized as ion-selective membranes to concentrate the nitrate ions in water. Our results demonstrated that the high selectivity of nitrate ions over fluoride ions and sulfate ions can be obtained at low applied potential less than 3 V. The collected nitrate ions in water are further converted to ammonia through electrochemical reduction process, offering a promising avenue to address the environmental impacts associated with nitrate-containing wastewater and reduce the energy intensity as well as the carbon footprint linked to the traditional Haber-Bosch method for producing ammonia.

Keywords: *Polyethersulfone, Ion-Selective Membrane, Nitrate, Water Treatment*

Selective Electrochemical Extraction of Critical Metal Rubidium from Brine: Role of Ion Exchange Membrane

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ABSTRACT

Rubidium (Rb) is a highly valuable critical metal used for developing precision laser technology and magnetic sensors for military devices. The high price of Rb (USD 14720/kg), compared to other critical metals in demand namely lithium (Li, USD 10/kg), is attributed to the rarity of extracting Rb in land ore form. Seawater is an unlimited natural alternative source of Rb. Economically, extracting Rb from seawater brine is strategic due to the higher Rb concentrations in brine and as a potential revenue to offset treatment costs at desalination plants. Technically, recovering Rb over other major competitive ions in seawater brine is a challenge. Membrane capacitive deionization (CDI), an electrosorption process, offers the capacity to extract Rb rapidly with the incorporation of selective ion exchange membranes. This study fabricated membranes with ion exchange nanomaterials -potassium cobalt hexacyanoferrate (KCoFC-AC) and ZIF-embedded KCoFC (KCoFC@ZIF-AC) nanomaterials to achieve selective Rb uptake. Compared to conventional cation membranes, the fabricated potassium ion exchange membranes exhibited superror Rb selectivity over other major ions in seawater due to the exclusive Rb-K ion exchange. Specifically, the Rb uptake capacities of the membranes with single Rb and mixed monovalent solution (Rb, Na, K) ranged from 78-127 mg/g and 57-103 mg/g, respectively. The enhanced performance of KCoFC@ZIF-AC compared to KCoFC-AC membrane was attributed to the presence of the ZIF component, which promotes Rb penetration into the lattice structure of KCoFC. Moreover, the membranes demonstrated reusability multiple times with periodic chemical regeneration processes. In seawater, both fabricated electrodes exhibited an excellent Rb extraction rate (~ 90%) with minor uptake of major cations (Na, Mg, K, and Ca). The superior Rb selectivity of the fabricated membranes underscore the role of ion -exchange nanomaterial in CDI electrode for achieving rapid Rb extraction from brine

Keywords: Rubidium, Ion Exchange Membrane, Potassium Cobalt Hexacyanoferrate Nanomaterial, Seawater Mining, Electro-Sorption

Advancing Membrane Distillation with Renewable Energy and IoT: A Smart and Sustainable Water Treatment Solution

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ABSTRACT

Membrane distillation (MD) is a promising thermal-based separation technology for water purification, particularly in treating high-salinity and industrial wastewater. However, its practical application is hindered by high energy consumption and limited process control. This review highlights recent advancements in integrating renewable energy sources—such as solar thermal, photovoltaic, and geothermal energy—with MD systems to improve energy efficiency and enable off-grid operation. In parallel, the incorporation of Internet of Things (IoT) technologies has introduced real-time monitoring, automation, and remote control capabilities into MD systems. IoT-based sensors allow continuous tracking of temperature, flow rate, and water quality, enabling early fault detection and optimized system performance. The review synthesizes findings from recent studies to assess the performance, limitations, and benefits of combining renewable energy and IoT in MD applications. The integration of these technologies presents a scalable and sustainable approach to water treatment, particularly for decentralized and resource-limited environments.

Keywords: *Membrane Distillation, Renewable Energy, Internet of Things, Water Treatment*

Paper ID: IS36

Advances in Microbial Electrochemical Cells for Integrated Wastewater Treatment and Resource Recovery

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ABSTRACT

Global pressures from water scarcity, nutrient depletion, and energy insecurity have intensified the demand for integrated and sustainable solutions. Wastewater, once regarded solely as an environmental liability, is now increasingly recognised as a resource-rich medium, containing recoverable water, energy-dense organic matter, and essential nutrients such as nitrogen and phosphorus. This paradigm shift has driven the development of technologies aimed at resource recovery alongside pollution mitigation. Among the most promising of these technologies are microbial electrochemical cells (MECs), which utilise electroactive microorganisms to catalyse redox reactions at electrode surfaces, thereby enabling the simultaneous treatment of wastewater and recovery of energy or nutrients. This work highlights recent advances in MEC research, with a particular focus on system enhancements that improve chemical oxygen demand (COD) reduction, nutrient separation, and bioelectricity generation. The performance of MECs is highly dependent on the anode interface, where microbial colonisation and electron transfer occur. Innovations in anode membrane fabrication, particularly those employing phase inversion techniques with activated carbon-based precursors have led to significant improvements in porosity, electrical conductivity, and biocompatibility. Further improvements through additive blending and surface functionalisation have shown to increase microbial adhesion and operational stability over prolonged periods. This work also discusses the microbial nutrient recovery cell (MNRC), an advanced three-chamber MEC configuration designed to selectively recover nutrients while maximising energy output. In contrast to conventional designs, the MNRC offers a more integrated and circular approach to resource management in wastewater treatment. Despite encouraging laboratory results, real-world application remains limited due to challenges such as scaling membrane production, maintaining microbial community stability under variable conditions, and achieving efficient continuous operation. This work identifies key technological breakthroughs, unresolved research challenges, and future priorities required to advance MECs as viable solutions for sustainable wastewater treatment and resource recovery.

Keywords: *Microbial Electrochemical Cells, Wastewater Treatment, Nutrient Recovery, Resource Valorisation and Sustainable Technology*

Paper ID: IS38

Breaking through the Permeability-Reactivity Trade-off in Catalytic Membranes

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ABSTRACT

Membrane catalysis that couples AOPs with membrane filtration process has been regarded as a promising technology to overcome the environmental pollution challenges. The nano-confined membrane allows for the optimum interaction of catalytic active sites, oxidants, and pollutants, resulting in high degradation efficiency . However, the practical applications are impeded due to the trade-off effect between catalytic efficacy and membrane permeance. The short-lived radicals limited its diffusion distance in the membrane channel (e.g. the 38 nm of •OH diffusion). The pore width was usually limited below 20 nm to ensure the effective concentration of radicals in MoS2 two-dimensional (2D) membrane, Fe3O4-AAO membrane, Co-TiOx 2D membrane, thereby resulting in low permeance (e.g. 20~200 L m-2 h-1 bar-1). Moreover, the reported catalytic membranes are mainly flat sheet configuration used for batch treatment of single pollutant models , no integrated catalytic membrane module achieving robust and continuous operation for real CCIW is so far developed. Herein, we developed a tubular macroporous ceramic catalytic membrane (MCM) with high permeance, efficient and robust degradation of CCIW. The intrapore catalytic interface activated PMS to mainly produce $^1O_2$, which exhibited a wide pH and high-salinity tolerance. Sufficient diffusion distance of long-lived $^1O_2$ and intrapore channel length allow for thorough degradation of pollutants in the macropoers (~ 130 nm). We developed a diffusion-reaction model to understand the spatiotemporal distribution and mass transfer process of $^1O_2$ in the macropores. Under continuous cross-flow operation, the membrane could achieve instantaneous catalytic degradation of tetracycline (TC, 99.9%), bisphenol A (BPA, 98.9%), methylene blue (MB, 99.9%). At the same time, MCM could achieve high total organic carbon (TOC) removal rates of the real high-salinity CCIW, indicating its application in real CCIW treatment.

Keywords: Catalytic Membranes, Singlet Oxygen, Diffusion-Reaction, Permeability-Reactivity

Paper ID:IS39

Smart Covalent Organic Framework (COF) Membranes for Molecular Sieving

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ABSTRACT

Inspired by the magical nature, which can create sophisticated systems with smart functions via the atomic-level assembly. Research scientists are seeking in constructing smart membranes by assembling diverse building blocks in well-defined ways. Covalent organic frameworks (COFs) are an emerging class of crystalline porous materials with low density, high porosity, and excellent physicochemical stability. However, it's still a paramount challenge to fabricate smart COF membranes with self-regulating pore apertures for gradient separation. Here, we propose a new covalent organic network membrane with light response. Azobenzene derivatives act as linkers, which photo-switch between trans- and cis-isomers by irradiation under ultraviolet or visible light, connected by crosslinking nodes. As shown in Figure 1, the resultant smart CON membranes have nanopores that can be photo switched between On- (open pores) and Off-state (smaller pores) valves for molecular separation. The CON membranes were tested in different organic solvents and exhibit permeances as high as 56.7 L m-2 h-1 bar-1, in the following order: acetonitrile > acetone > methanol > ethanol > isopropanol > DMF. Interestingly, the smart cis-CON membranes with Off-state valves under UV show higher rejection for dye molecules than the trans-CON analogue with On-state valves. Different from the traditional membranes with immutable pore channels, the pore size of CON membranes can be remotely controlled by controlling the trans-to-cis isomerization of azobenzene via UV/Vis light, the permeance and separation factor can be tuned as needed.

Paper ID: IS40

Turning Waste into Wonder: Biomass-Derived Graphene Membranes for Microalgae Harvesting

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ABSTRACT

The transition toward sustainable bioproducts and green energy has elevated the role of microalgae as a high-potential feedstock. However, harvesting microalgal biomass remains a costly and technically challenging step in large-scale production. In this study, we present a novel and sustainable approach to address this challenge through the development of biomass-derived graphene-coated ceramic membranes for efficient microalgae harvesting. Utilizing sugar molasses a low-cost, carbon-rich byproduct of the sugar industry as a precursor, graphene-like layers were synthesized in situ on α-alumina ceramic membranes via thermal graphitization. The resulting surface modification significantly altered membrane properties, yielding smoother surfaces, reduced effective pore sizes, and moderately decreased hydrophilicity. Comprehensive characterization via Raman spectroscopy, FESEM, EDX, and water contact angle analysis confirmed the successful deposition of uniform graphene layers. Performance assessments demonstrated substantial improvements in membrane selectivity and antifouling properties. While the graphene coating reduced pure water permeability, it increased microalgae rejection from 76% to over 99%, and enhanced harvesting efficiency up to 94%. Notably, the modified membranes exhibited improved operational stability and significantly higher flux recovery ratios after cleaning rising from 18% in uncoated membranes to over 50% in coated variants indicating superior fouling reversibility and long-term usability. These findings not only highlight the feasibility of converting industrial biomass waste into high-performance membrane materials but also establish a new direction in sustainable membrane engineering. The developed membranes provide a robust, scalable, and eco-friendly solution for microalgae harvesting, with broader implications for wastewater treatment and bioprocessing industries. This work underscores the synergy of green chemistry and materials science in solving critical challenges in the bioeconomy.

Paper ID: IS41

Detection of Illicit Drug Unique Marker in Wastewater: The Role of Advanced Membrane Technologies

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ABSTRACT

Recently, Malaysia has been unofficially recognized as a hub for illicit drug manufacturing due to increased cases and reports. Wastewater-based epidemiology (WBE) has become a vital approach for monitoring illicit drug use and identifying clandestine drug manufacturing activities at the community level. However, the accurate detection of drug precursors, synthesis byproducts, and metabolites in wastewater is hindered by their ultra-trace concentrations, chemical diversity, and the presence of complex organic and inorganic interferences. Conventional extraction methods such as solid-phase extraction (SPE) and liquid–liquid extraction (LLE) often face limitations, including low selectivity, high solvent usage, and poor adaptability to dynamic wastewater matrices. This work presents a critical overview of recent advances in membrane-based purification technologies, particularly nanocomposite membranes, molecularly imprinted membranes (MIMs), and hybrid systems for enhancing the selectivity and efficiency of analyte isolation in WBE applications. Membranes functionalized with graphene oxide, metal-organic frameworks (MOFs), and zwitterionic polymers have shown promise in overcoming fouling and matrix interferences, offering improved recovery and compatibility with downstream analytical techniques such as LC-MS/MS. Despite these advancements, significant challenges remain in terms of long-term membrane stability, scalability, and integration into routine surveillance workflows. This presentation highlights the comparative performance of membrane technologies against conventional methods, identifies key research gaps, and discusses future directions for their application in forensic and environmental monitoring.

Keywords: *Wastewater-Based Epidemiology, Advanced Materials, Membrane Separation, Illicit Drug Precursors, Nanotechnology*

High Performance Anion Exchange Membranes for Hydrogen Conversion

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ABSTRACT

Hydrogen energy is one of the most promising clean energy sources for the future and can effectively achieve the goals of the carbon neutrality. In the hydrogen energy ecosystem, the most crucial links are hydrogen production and utilization, with water electrolysis hydrogen production and hydrogen fuel cells being representative. In theory, hydrogen energy conversion devices operating in alkaline media offer greater cost advantages due to the possibility of using non-precious metal catalysts—such as anion exchange membrane water electrolysis (AEMWE) and alkaline membrane fuel cell (AEMFC). However, the core component of these systems, the anion exchange membrane (AEM), faces significant challenges. Compared to the well-established acidic proton exchange membranes (PEM) like Nafion and Gore membranes, AEMs conduct larger hydroxide ions (OH^-) and contain quaternary ammonium groups that are susceptible to nucleophilic attack by OH^-. As a result, current AEMs still suffer, to varying degrees, from low ionic conductivity and poor stability. It remains difficult to achieve AEMs that simultaneously possess high ionic conductivity, strong alkaline resistance, excellent mechanical strength and toughness, low swelling, and optimal water uptake. This report will present the speaker's recent efforts to improve AEM performance in terms of ionic conductivity, mechanical properties, and chemical stability. It will also demonstrate the potential of these membranes in AEMFC and AEMWE applications, along with the team's progress in developing scalable, continuous casting processes for AEM fabrication.

Keywords: *Anion Exchange Membrane, Fuel Cell, Water Electrolysis, Hydrogen Conversion*

Paper ID: IS43

Removal of Microplastic in Polluted Water by Membrane Distillation

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ABSTRACT

The presence of microplastics (MP) in aquatic ecosystems worldwide has become a stressful issue in the last decade. It is emphasized that the amount of MP is positively correlated with the plastic waste in a region, can be accumulated in living organisms, and poses a negative impact on the health of ecosystems. In the treatment of wastewater and drinking water, membrane technology has been appointed as the most effective and promising technology to remove MP. In general, pressure-driven membranes, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, have been extensively studied to remove the MP. However, the removal of MP cannot reach 100%, despite the significantly smaller membrane pores than the microplastics size. In most cases, the remaining MP in the permeate streams consists of fiber-shaped MP, showing an indication that MP can pass the membranes longitudinally. The application of another membrane technology that prohibits the convective flow of water is necessary. Membrane distillation (MD) involves a hydrophobic membrane that passes through water vapor, instead of water. This approach theoretically allows for 100% rejection of MP. In this research, polluted river water was used as the feed. Various MPs, such as PVC, PE, and PS, were detected in the feed. Treatment using MD was able to remove most of the MPs. Fouling occurrence during MD was prominent; however, straightforward pretreatment by filtration successfully reduced the fouling propensity.

Keywords: *Microplastic, Membrane Distillation, Fouling, Water Treatment*

Paper ID: IS44

A Lithium-Ion Conducting Polymer Composite Membrane for Ultra-Efficient, Selective Lithium Recovery

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ABSTRACT

Lithium mining is an energy-intensive, slow and environment-polluting process. Membrane separation technology is desirable for sustainable and efficient lithium mining, but scalable fabrication of thin and lithium-selective membranes remains a major challenge. We created a solution-processable, large-area lithium-selective membrane from solution-processing a lithium superionic conductor that is selective exclusively to lithium ion, enabling sustainable recovery of lithium ion from other monovalent and divalent ions with lithium selectivity of at least 4 order of magnitude higher than other ions. The membrane-based lithium extraction represents a significant saving in chemical reagents used in traditional lithium mining from brine with the potential to reduce current lithium mining operating costs by more than 35%.

Keywords: *Membrane Separation Technology, Large-Area Lithium-Selective Membrane, Sustainable Recovery of Lithium Ion*

Paper ID: IS46

Hydrogels as Versatile Platforms: How Far Have We Come?

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ABSTRACT

Hydrogels have evolved from simple polymer networks to multifunctional platforms with diverse applications. Initially, our work focused on developing hydrogel-based composite membranes, where temperature-responsive poly(N-isopropylacrylamide) (PNIPAAm) hydrogels were grafted onto polyethylene terephthalate (PET) substrates to produce hydrogel-pore-filled composite membranes (HPFCM). These membranes demonstrated tunable sieving properties and switchable barrier functions in response to temperature changes, highlighting the potential for selective solute transport and smart separation processes. Building on this foundation, we advanced the design of hydrogel-based textiles via surface grafting of PNIPAAm, producing switchable, oil-repellent surfaces with potential in oil-water separation and smart textiles. Further, we explored the integration of natural fibers derived from agricultural waste—such as pineapple leaf fibers, rice straw, and herbal byproducts like Tongkat Ali and Orthosiphon aristatus—to create environmentally friendly, cellulose-rich hydrogel components. Using eco-conscious solvent systems and tailored pretreatments, these natural fibers were incorporated into double network (DN) hydrogels with synthetic acrylate-based matrices. This approach resulted in hybrid hydrogels with enhanced mechanical strength, water retention, and anti-freezing properties, suitable for various sustainable applications. Notably, our recent work demonstrated that these hybrid hydrogels exhibit excellent anti-freezing and energy storage capabilities, making them promising candidates for biomedical devices such as contact lenses, where durability and functionality are critical. Overall, the progression of our research—from temperature-responsive membranes to natural fiber-reinforced, anti-freezing hydrogels—illustrates the versatility and expanding scope of hydrogel platforms. These innovations pave the way for sustainable, multifunctional materials addressing challenges in separation, biomedical, and environmental applications.

Keywords: *Functional Hydrogels, Composite Membranes, Natural Fibers, Anti-freezing Properties, Contact Lenses*

Carbon and Zeolite Based Mixed Matrix Membrane for Gas Separation, a Trial in the Real World Scenario for Biogas Upgrading

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ABSTRACT

Gas separation is important process in human life. Valorization of biogas to biomethane is a one important step towards energy sustainability, particularly in regions rich in palm oil mill effluent (POME). However, the large CO_2 content significantly reduces its calorific value. In this study, mixed matrix membranes (MMMs) were prepared to enhance CO_2/CH_4 separation efficiency by combining the processability of polymers with the high selectivity of inorganic fillers. Several carbon-based and zeolite-templated fillers, including APTMS-functionalized zeolite and few-layer graphene, were synthesized and incorporated in polysulfone (PSf) matrices. The most performing membranes featured CH_4 purity above 95% and had real selectivity values close to the border of commercial biomethane production. Bench-scale production and field trials, carried out in partnership with PT Energi Agro Nusantara (ENERO), validated the proficiency of PSf-FLG membranes in removing CO_2 and H_2S without any pretreatment processes. Stable flux, scalability, and plasticization resistance were displayed by the membrane modules. Yet, the phenomenon of gas competition for multi-component mixtures was an issue, and this impacted real selectivity in comparison to ideal conditions. The study highlights the importance of filler morphology and interfacial compatibility on membrane performance. Ongoing research is focused on developing simpler, scalable fillers and optimizing membrane lifespan for industrial application. This research bridges the gap between laboratory development and practical implementation, strengthening Indonesia's potential for biogas upgrading.

Keywords: *Gas Separation, Biogas Upgrading, Carbon, Zeolite, Mixed-Matrix Membrane*

Paper ID: IS48

PAN/PVA Nanofibrous Membranes for Hydrometallurgical Oil-in-Water Emulsion Separation

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ABSTRACT

In this work, nanofibrous membranes for separating oil-in-water (O/W) emulsion were prepared by electrospinning. The membrane material was polymer blend of polyacrylonitrile (PAN)/polyvinyl alcohol (PVA), and by adjusting polymer composition and concentration, as well as applying crosslinking by glutaraldehyde (GD) and hydrolysis inside NaOH solution, membrane with desired properties, particularly hydrophilicity and underwater oil repellency were obtained. For PAN/PVA composite membrane modifed by glutaraldehyde for 1.5 h and NaOH for 1.5 h, the water contact angle initially was around 5° and decreased to 0o with a transition time of only 0.3 s. The membrane also showed recommendable performance in O/W emulsion separation. Under a driving force of 0.8 kPa, the highest starting fux of 953 L/m2 h and 532 L/m2h were registered with the treatment of surfactant-free emulsion (SFE) and surfactant-stabilized emulsion (SSE), respectively. The membrane recovered 96% of its initial fux in a 5-cycle reusability test using SFE, and the oil rejection coefcient maintained higher than 97%. FTIR and XPS characterizations confirmed the success in chemical modifications. It was also found that glutaraldehyde crosslinking helped to improve the macroscopic structure integrity of the membrane in aqueous environment.

Paper ID: IS49

Development Of Sustainable Membranes from Polyethylene Terephthalate (PET) and High Density Polyethylene (HDPE) Waste for Water Treatment and Gas Separation

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ABSTRACT

This presentation highlights the development of sustainable membranes from plastic waste and advanced fillers. Modified PET and HDPE membranes, using additives like LiCl, PEG-400, zeolite-NaY, and EVA, demonstrated effective performance in water purification, including dye and chromium ion removal. In parallel, mixed matrix membranes (MMMs) incorporating zeolite-templated carbon (ZTC) into PSf and P84 matrices showed significantly improved permeability and selectivity for CO_2/CH_4 and H_2/CH_4 separation. These results, supported by annealing and surface coating strategies, exceed Robeson upper bounds. Together, these studies demonstrate the promising role of waste-derived and hybrid materials in advancing membrane technology for environmental and energy applications. This presentation discusses the development of sustainable membranes from plastic waste and mixed matrix systems for water purification and gas separation. Polyethylene terephthalate (PET) and high-density polyethylene (HDPE) waste were repurposed into membranes using phase inversion. PET membranes modified with 5 wt% LiCl, PEG-400, and zeolite-NaY achieved turbidity reductions from 400 NTU to below 2 NTU and chromium ion rejections up to 50.9%. HDPE membranes blended with 6 wt% ethylene–vinyl acetate (EVA) showed dye rejections of 99.7% for methylene blue (MB) and 89.8% for methyl orange (MO), with water flux increasing from 2.71 to 15.06 $L\cdot m^{-2}\cdot h^{-1}$ after EVA addition. For gas separation, mixed matrix membranes (MMMs) were fabricated by incorporating zeolite-templated carbon (ZTC) into polysulfone (PSf) and P84 matrices. ZTC provided high microporosity (~0.9 nm) and surface area (>2000 m^2/g), enabling a 7-fold increase in CO_2 permeability and up to 900% improvement in CO_2/CH_4 selectivity. Post-treatments such as annealing at 190 °C and TMOS surface coating significantly enhanced membrane compatibility and performance, surpassing the Robeson upper bound. These findings confirm that plastic waste and carbon-based fillers can be engineered into high-performance membranes, offering cost-effective and environmentally sustainable solutions for water and gas treatment applications.

Two-Dimensional Materials-Based Evaporators for Sustainable Clean Water Production

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ABSTRACT

The global demand for clean water continues to rise due to rapid population growth, industrial expansion, and increasing pollution of freshwater sources. In response, photothermal evaporators have emerged as a sustainable and energy-efficient solution for water purification, particularly when powered by solar energy. This study explores the design and development of two-dimensional (2D) materials-based evaporators for sustainable clean water production. Leveraging the unique properties of 2D materials such as high surface area, superior light absorption, excellent thermal conductivity, and tunable hydrophilicity, these evaporators exhibit enhanced photothermal conversion efficiency and water evaporation rates. Materials such as graphene oxide, MXene, and molybdenum disulfide (MoS_2) were synthesized and integrated into porous substrates to fabricate advanced photothermal layers through a one-pot synthesis approach. The performance of the resulting systems was evaluated under standard solar irradiation, demonstrating high evaporation efficiency, robust stability, and effective rejection of common waterborne contaminants. This work highlights the potential of 2D materials-based evaporators as a scalable and eco-friendly technology for decentralized water purification, contributing to the advancement of sustainable clean water solutions in resource-limited settings.

Paper ID: IS51

Tailored CA/DES Composite Membranes with Microcrystalline Cellulose for Efficient Orange Juice Clarification

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ABSTRACT

Clarification is a critical step in orange juice processing, enhancing visual quality, stability, and shelf life. Conventional clarification methods often rely on additives and are labor-intensive, which can compromise juice quality and processing efficiency. To address these limitations, this study explores the development of sustainable, high-performance membranes based on cellulose acetate (CA) modified with deep eutectic solvents (DES) and microcrystalline cellulose (MCC). CA membranes were fabricated via the non-solvent induced phase separation (NIPS) technique. DES, synthesized from choline chloride and oxalic acid, was used as a pore-forming and dispersion-enhancing agent. MCC was incorporated to improve membrane permeability and interfacial interactions. Membranes were characterized for morphology, pore size, mechanical strength, hydrophilicity, and clean water permeability. The most effective membrane (DMAc-DES/M2) was identified using the effectiveness index method and tested for orange juice clarification. The optimized membrane (DMAc-DES/M2) showed high clean water permeability (4042.52 L/m²·h·bar), moderate hydrophilicity (contact angle: 68.56°), and sufficient tensile strength (6.16 MPa). Capillary flow porometry confirmed a mean pore size of 0.3941 μm, classifying it as a microfiltration membrane. In orange juice clarification, it achieved a flux of 8.67 L/m²·h and completely removed suspended solids and alcohol-insoluble solids, while preserving essential juice attributes. These results affirm the potential of DES–MCC-modified CA membranes as effective and eco-friendly solutions for juice processing.

Keywords: Orange Juice Clarification; Cellulose Acetate Membrane; Deep Eutectic Solvent; Microcrystalline Cellulose; Sustainability; Membrane Filtration

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Oriented Superhydrophobic Bimetallic MOF Composite Membrane for Efficient Ethanol-Water Separation

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ABSTRACT

Extracting ethanol from aqueous solutions is crucial. However, this process faces significant challenges in industrial applications due to the highly similar physicochemical properties of ethanol and water, as well as the relatively large molecular size of ethanol.[1] Membrane-based pervaporation has shown great potential for the separation of ethanol and water, with the structural design of the membrane being crucial for enhancing performance.[2] To this end, we have developed an oriented bimetallic metal-organic framework (MOF) membrane, named ZIF-CoZn, for the pervaporation separation of ethanol and water. The oriented growth of the (211) crystal plane in ZIF-CoZn is induced by the nucleation of bimetallic salts and the competitive coordination of bimetallic ions.[3] This preferential growth effectively leverages the hydrophobic nature of the 2-methylimidazole ligands in ZIF-CoZn, preventing water molecules from penetrating into the pores. Moreover, the competitive coordination between bimetallic ions increases the pore size of ZIF-CoZn, facilitating the permeation of ethanol molecules. Compared with monometallic MOF membranes made of cobalt or zinc alone, the separation factor of the ZIF-CoZn membrane for ethanol/water mixtures has increased by 49% and 18%, respectively. Additionally, by integrating ZIF-CoZn with vinyl polydimethylsiloxane, the membrane achieves superhydrophobic properties, further enhancing separation performance. The oriented ZIF-CoZn membrane has also been scaled up to an area of 1 m^2, laying the foundation for its industrial promotion and application.

Keywords: *Pervaporation; Bimetallic MOF membrane; Orientation; Superhydrophobic*

Paper ID: A002

Computer-Aided Molecular Design and Fabrication of Advanced Membrane Materials: An insight into the Application in Nitrogen/Methane Gas Separation

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ABSTRACT

Membrane engineering has proven to be an excellent tool for achieving the goals of process intensification. One of these goals is the optimization of the driving forces/resistances in a chemical system at every scale within the spatial domain. This can be achieved by a purposeful introduction of reproducible structure using a combination of computer-aided molecular design and print assisted technique. Molecular models of two polymers (Methylendianiline (MDA) and Oxydianiline (ODA)) were developed using Avogadros (a molecular design) software. The molecular model of the structure of polymer was then made into membrane using a print assisted fabrication method. Specifically, the printing was done by using a LaserJet printer to fabricate structured flat sheet composite membranes that were evaluated for $N_2/CH_{4\ \text{separation}}$. Membrane characterization was done using XRD, and microscopy (using SEM and optical microscope). The gas transport properties and the separation performance were evaluated using constant-pressure gas permeation test to measure the permeability and hydraulic resistance. Although the sheet of paper on which the two polymers were printed are the same, however, the hydraulic resistance was found to be different for each polymer as well as for each gas. For example, the hydraulic resistance to the flow of N_2 and CH_4 gases in MDA ranges from 38,560.78 to 95,697.10 kPa.s/m^3 while that of ODA ranges from 28,132.33 to 88,124.16 kPa.s/m^3. The selectivity of ODA for N_2/CH_4 is 2.34 and 3.10 for single layer and 7-layer membrane samples, respectively while it is 1.71 and 1.92 for single layer and 7-layer MDA membrane samples, respectively. In addition, the morphological analysis results showed that the printed membranes have well-structured morphology and evenly distributed voidage which can enhance their reproducibility and the predictability of their performance. Overall, the resulting properties of the fabricated membrane demonstrated its potentials for enhancing the intensification of a membrane system that is used in N_2/CH_4 separation.

Keywords: *Membrane Engineering, Process Intensification, Driving Forces/Resistances, Computer-Aided Molecular Design, Print-Assisted Membrane Fabrication, Hydraulic Resistance*

Paper ID: A003

Development Rubber-Based Membranes for Water Permeation by Sugar Palm Nano-Fibrillated Cellulose

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ABSTRACT

The quest for efficient and sustainable water treatment technologies has led to significant interest in developing advanced membrane materials. This study investigates the potential of Sugar Palm Nano-fibrillated Cellulose (SPNFC) as a reinforcing agent in rubber-based composite membranes to enhance water permeation properties. In this study, ENR/PVC composite membrane was fabricated by solution blending method with varying concentrations of SPNFC (0 %, 1%, 3%, and 7%). The preparation involved a phase inversion method, followed by characterization using Scanning Electron Microscopy (SEM), contact angle (CA), water flux, and mechanical testing to assess the structural and mechanical enhancements. The finding demonstrates that incorporating SPNFC into rubber matrices markedly improves the membranes' water permeation flux and mechanical strength. Specifically, SEM analysis revealed a large and well-distribution porous structure within the rubber matrix for 7% SPNFC loading, contributing to the enhanced water permeation of the composite membrane. The reduction of contact angle with the increasing concentration of SPNFC from 85.16° for the pristine membrane to 49.84° showed the increasing membrane's hydrophilicity contributing to the water permeation up to 73.23 L/m2. h. The membranes with 7% SPNFC showed an increase in Young's modulus and elongation at break compared to the pristine membrane. Thus, the incorporation of SPNFC into rubber-based membranes presents a promising approach to revolutionizing water filtration technologies. The enhanced mechanical properties and water permeation rates underscore the potential of these composite membranes for industrial water treatment applications.

Keywords: *Sugar Palm Fiber, Nano-Fibrillated Cellulose, Composite Membrane, Water Treatment*

Paper ID: A004

Ultra Permeable Positively-Charged TMA/VBC-*G*-PSF Loose Nanofiltration Membranes for Effective Salt/Dye Separation

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ABSTRACT

The high-salinity wastewater generated by the textile industry presents a substantial challenge in the effective separation of dyes and inorganic salts, particularly concerning cationic dyes, which pose severe environmental pollution risks. Leveraging the combined effects of size exclusion and electrostatic repulsion, positively charged and porous nanofiltration (LNF) membranes have demonstrated the capability to efficiently reject cationic dyes while ensuring high permeance of inorganic salts. Herein, a new type of positively charged LNF membrane was prepared with trimethylamine (TMA) nucleophilic substitution reaction on the 4-Vinylbenzyl chlorostyrene (VBC)/polysulfone (PSf) chloride-grafted (TMA/VBC-*g*-PSf) membranes. VBC, a highly reactive small molecule featuring two functional groups (active vinyl (CH_2=CH-) and benzyl chloride (C-Cl)), was stably anchored onto the surface of PSf ultrafiltration (UF) membranes via vinyl groups. Furthermore, the C-Cl was nucleophilically replaced by the tertammonium group of TMA, forming a quaternary ammonium layer. Thereby, an ultra-thin positively charged selective layer with micro-convex structure was formed onto the PSf membrane surface, endowing the LNF membrane with ultra permeance and high Na_2SO_4/Victoria blue B (VB) selectivity. The optimized M-2 membrane, with 0.5 wt% VBC and 30 wt% TMA grafting concentration, yielded both high levels of pure water permeance (186.42 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$) and an excellent Na_2SO_4/VB selectivity of 497.5 (high VB rejection of 99.8% compared to low Na_2SO_4 rejection of 0.5%). After 16 hours of continuous operation, the separation efficiency of the M-2 membrane for both mixed solution and single-component solution remained consistent and stable, demonstrating its feasibility and high potential in the field of inorganic salts/cationic dyes separation. This study offers valuable insights into innovative methodologies for the production of LNF membranes tailored for dye wastewater treatment.

Keywords: *Loose nanofiltration membrane; Positively Charged; 4-Vinylbenzyl Chlorostyrene (VBC); Cationic Dye/Salt Separation*

Paper ID: A005

Bioinspired Design of Antifouling Membrane Modules for Bio-Separation

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ABSTRACT

Although increasing shear force can mitigate membrane fouling, excessive shear force in bio-separation processes may lead to the inactivation of bioactive molecules and increased energy consumption, imposing significant limitations on the antifouling design of membrane modules. In this study, a bioinspired antifouling spacer mimicking coral tentacle was first designed, effectively suppressing spacer fouling and reducing flow channel pressure drop caused by fouling. Then drawing inspiration from fish school swimming, a drag-reducing structure and array were proposed. The bioinspired fish school array effectively converts vortices into driving forces for mass transfer, while minimizing energy losses associated with vortex capture. As demonstrated in our study, the streamlined fish tail structure, combined with the fish school array, delivers superior performance in both drag reduction and mass transfer enhancement. Such design reduces energy consumption by 44.9% in spiral wound modules and by 59.5% in disk tube modules, also mitigates membrane fouling. Furthermore, the mechanisms underlying foulant-membrane interactions and the effects of shear force on membrane fouling were systematically investigated, leading to the development of a multi-stage membrane fouling model. Additionally, a membrane module fouling model based on multi-physics coupling was established, elucidating the impact of membrane deformation induced by the permeate-side spacer under high pressure on membrane fouling.

Keywords: *Membrane Module, Membrane Fouling, Bioinspired Design, Spacer, Mass Transfer*

Paper ID: A006

Structural Regulatory Strategies of Polypropylene Hollow Fiber Oxygenation Membranes with High Gas Permeability and Exceptional Resistance Against Plasma Leakage

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ABSTRACT

Extracorporeal membrane oxygenation (ECMO) is a critical technology that provides temporary support for cardiac and pulmonary functions during clinical surgeries. Compared with commercially available polymethylpentene (PMP) hollow fiber oxygenation membranes, traditional polypropylene (PP) oxygenation membranes prepared via thermally induced phase separation (TIPS) or the melting-stretching method exhibit significantly shorter plasma-leakage resistance time due to their microporous outer-surface structures. In this study, two novel preparation strategies for PP hollow fiber oxygenation membranes were developed to extend the plasma-leakage resistance time. First, hybrid induced phase separation (HIPS) combining TIPS and non-induced phase separation was employed to prepare gradient-structured PP hollow fiber membranes. The resulting PP membranes exhibited exceptional N_2 permeability of 23.4 mL/(cm²·min·bar) and an extended plasma-leakage resistance time of 4300 minutes. Second, mesoporous silica nanoparticles were grafted onto the surface of PP membranes to maintain high N_2 permeability while ensuring excellent resistance against plasma leakage. The obtained mesoporous silica nanoparticle-grafted PP hollow fiber oxygenation membranes demonstrated superior N_2 permeability of 59.5 mL/(cm²·min·bar) and excellent plasma-leakage resistance time of 4140 minutes. Consequently, these findings provide valuable insights into optimizing the structure of PP membranes for the development of high-performance oxygenation membranes.

Keywords: *Polypropylene, Hollow Fiber Oxygenation Membranes, Plasma-Leakage Resistance Time, Hybrid Induced Phase Separation, Grafting*

Paper ID: A007

Development of Mixed-Matrix Membranes-containing MOF-303 for CO_2 Separation and Air Dehumidification Applications

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Abstract:

Membrane-based CO_2 separation is emerging as an effective technology for climate change mitigation. Furthermore, membrane-based air dehumidification is gaining attention as a promising alternative to conventional methods. In this study, mixed-matrix membranes (MMMs) incorporating MOF-303 were fabricated to characterize CO_2/N_2 and water vapor/N_2 separations. MOF-303 was synthesized via an environmentally friendly water-based method and has been widely studied as an adsorbent due to its high surface area. Polyactive^{TM} is distinguished by its high gas separation performance and its capacity to undergo biodegradation under specific conditions. When incorporated into Polyactive^{TM} at a loading of 1 wt%, the membrane exhibited a threefold increase in CO_2 permeability and slightly enhanced CO_2/N_2 selectivity compared to the neat polymer, surpassing the 2008 upper bound. Additionally, the superior water vapor sorption capability of MOF-303 significantly enhanced the membrane's air dehumidification performance. This study demonstrates a cost-effective, environmentally sustainable, and high-performance approach to membrane-based gas separation with low filler loading.

Keywords: Gas separation, Mixed-matrix membranes (MMMs) , Metal-organic framework (MOF), Carbon dioxide, Water vapor

Paper ID: A008

Machine Learning-Assisted Evaluation and Regulation of Nanofiltration Membrane Performance for Micropollutant Removal

Yangling Liu

ABSTRACT

Nanofiltration (NF) membranes play an increasingly important role in the removal of organic micropollutants (OMPs) from water, which puts higher demands on the selection and customization of membranes efficient for OMPs removal. Due to the diversity of OMPs, the number and properties of OMPs tested by each individual membrane in the literature could be rather different, which hindered the nonbiased evaluation and fair comparison of membrane removal performances for various OMPs. Moreover, it is hard to achieve the clear identification of proper membrane properties targeting the removal of any specific (especially emerging but not yet tested) OMPs. Here, the performance data of numerous commercially available and lab-made NF membranes in removing OMPs were collected from the literature. Machine learning (ML) models were then constructed to capture the correlations between OMPs removal efficiency with properties of membranes and OMPs. On this basis, the current membranes could be fairly evaluated according to the ML-predicted rejections for a same set of OMPs, which for the first time demonstrates the trade-off effect and upper-bound relationship between water permeance and water/OMP selectivity of NF membranes. This helps to recognize more superior strategies for membrane preparation or modification, and provides a valuable benchmark for assessing the performance of future developed membranes in removing OMPs. Conversely, the established ML model could be also used to quantitively determine the desired membrane properties (i.e., range of pore size and surface charge density) that ensures specific removal efficiency for a given kind or group of OMPs. This ML-based framework is useful for the rational selection and tailored design of NF membranes for the targeted removal of OMPs.

Keywords: *Nanofiltration, Organic Micropollutants, Machine Learning; Performance Evaluation, Membrane Properties*

Paper ID: A009

Rich Amine Regeneration Using High Pressure Membrane Contactor System

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ABSTRACT

Membrane contactor (MBC) for the purpose of amine regeneration has been developed since 2017; however, its development was originally focused for the application of conventional natural gas acid gas removal system (AGRU), which operated the regeneration system at low pressure (i.e. close to ambient). Expanding the technology for flue gas carbon capture application, the operating pressure of the regeneration system is increased at slightly higher pressure of 5 bar. This can significantly save on compression duty to subsequent processes (either CO2 utilisation process or for CO2 storage), which improves on the total technoeconomic of the technology. However, several challenges had to be overcome. In terms of hardware, the membrane epoxy and solvent selection was further tuned and improved to withstand higher temperature. For process, standard operating procedure is established to achieve a smooth start-up and operation, whilst protecting the integrity of the membrane fibres. The system successfully regenerated the rich amine from rich loading of 0.4 mol CO2/ mol amine down to 0.2 mol CO2/ mol amine with CO2 outlet purity of >95%. The mass flux is more than 6.0 x 10-3 mol/m2.s. It is proven stable over hours of operation, with transmembrane differential pressure maintaining within range of 50-70kPa. The system was also tested by doping the solvent to simulate presence of contaminant 100ppm of SOx and NOx and performance was proven robust.

Keywords: *Membrane Contactor, Carbon Capture, Amine Regeneration*

Paper ID: A010

Full-Scale Plant Operation for the Reuse of Semiconductor (CMP Process) Wastewater Using A Unique Dead-End UF Membrane Module, Including “Center-Distributor” and “End-Free” Structures

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ABSTRACT

In semiconductor manufacturing plants, the use of large volumes of pure and ultrapure water makes the reuse of wastewater a critical management issue from the perspective of securing water resources and fulfilling environmental responsibilities. Among the various types of wastewater generated in semiconductor manufacturing processes, CMP (Chemical Mechanical Polishing) process wastewater is one of the most challenging to reuse due to its high concentration of fine suspended solids (SS), such as SiO_2 and CeO_2 particles. Generally, wastewater with high SS concentrations, such as CMP process wastewater, is reused using cross-flow membrane filtration. However, dead-end membrane filtration is an extremely attractive process because it does not require energy for the circulation of feed water and achieves a higher water recovery rate compared to cross-flow membrane filtration. Nevertheless, when the membrane feed water has a high SS concentration, dead-end membrane filtration faces difficulties in maintaining stable operation. This study investigated the reuse of CMP process wastewater using a unique dead-end UF hollow fiber membrane module named "GL module", which includes “center distributor” and “end-free” structures. The GL module can filter wastewater up to the SS concentration of drain from module reach to approximately 40,000 mg/L with its unique structure and cleaning technology by dead-end filtration [1]. Optimization experiments using actual CMP process wastewater demonstrated that the GL module can filter CMP process wastewater using the dead-end filtration method. The full-scale plant is currently operating stably. This presentation will discuss the key features of the GL module and the optimization experiments for CMP process wastewater.

Keywords: *Semiconductor Wastewater, CMP (Chemical Mechanical Polishing), UF Membrane, Wastewater Recycle, Full-Scale Plant*

Paper ID: A011

Closed-Loop Recyclable Membranes for Circular Membrane Industry

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ABSTRACT

In the state-of-the-art membrane industry, membranes have linear life cycles and are commonly disposed of by landfill or incineration, sacrificing their sustainability. For the first time, by combining membrane technology and dynamic covalent chemistry, we have developed innovative strategies to make high-performance sustainable membranes for water purification, which can be closed-loop recycled after long-term usage. Covalent adaptable networks (CANs) with thermally reversible Diels-Alder (DA) adducts were synthesized and employed to fabricate nanofiber and integrally skinned asymmetric membranes via the electrospinning technique and non-solvent induced phase separation technique, respectively. The used CAN membranes can be closed-loop recycled with consistent properties and separation performance by depolymerization to remove contaminants, followed by refabrication into new membranes through the dissociation and reformation of DA adducts. Moreover, the recyclable membranes demonstrate excellent mechanical properties, thermal and chemical stabilities as well as separation performance in dye/salt fractionation and oil remediation, which are comparable to or even higher than the state-of-the-art non-recyclable membranes. This study may fill in the gaps in closed-loop recycling of membranes and inspire the advancement of recyclable membranes for a sustainable and green membrane industry.

Keywords: *Closed-Loop Recyclable Membrane, Covalent Adaptive Network, Water Purification.*

Paper ID: A012

Synthesis of Low-Cost, High-Performance Inorganic Membranes for Efficient Water Treatment

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ABSTRACT

The water sector is faced with a number of issues, including population growth and climate change, as well as dwindling water resources. To face these challenges, it is essential to find innovative solutions for the efficient management of water resources. These solutions include seawater desalination and wastewater treatment, which are important for ensuring a sustainable supply of water for both human and industrial needs. In this context, membrane filtration technologies play a decisive role in managing water stress and are increasingly competitive with other technologies. Today, a variety of membranes are available, each with specific characteristics to suit the type of separation process required. Among these membranes, those made from ceramics are promising, with remarkable properties such as higher thermal and chemical stability, changeable micro-structure, reduced energy consumption at gentler conditions, raised cleaning efficiency, High permeability and Low environmental impact are only a handful of its advantages. As a matter of fact, commercial porous ceramic membranes are made from oxides such as aluminum (Al), zirconium (Zr), silicon (Si), and titanium (Ti). However, their high cost has driven earlier research to investigate the use of more economical materials such as sand, fly ash, clay, pozzolan, phosphate, etc., for membrane manufacture. In this respect, our study deals with the preparation of ceramic membranes from natural Moroccan resources, mainly phosphate and red clay. Such a choice is based on their excellent properties. Red clay, rich in aluminosilicates, has excellent thermal resistance and presents favorable characteristics for the paste shaping due to its plasticizer and binder role. The latter, after hardening by firing, will contribute to stability and robustness of the membranes. Phosphate will be chosen because of its high CaO and P_2O_5 content; the high CaO/P_2O_5 ratio, higher than 1.3, confers on the final material high mechanical strength and makes it suitable for applications requiring robustness and durability. It can be realized that the properties of the membranes synthesized in this work were outstanding, with high mechanical, thermal, and chemical resistance, besides its highly porous nature with a high retention capacity of 99 %.

Keywords: *Water Treatement, Membrane Technologies, Ceramic Membranes, Moroccan Phosphate, Red Clay .*

Paper ID: A013

Carbazole-Derived Anion Exchange Membranes Reinforced by Crosslinking and Pore- Filling: Fabricated and Performance Evaluation in Water Electrolysis

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ABSTRACT

A cross-linked reinforced composite anion exchange membrane (AEM) QPC-BDMETMA@PE20μm was fabricated to improve chemical durability in anion exchange membrane water electrolysis (AEMWE). Fabrication involved 9-(6-bromohexyl)-9H-carbazole (BHC), the cross-linker bis[2-(N,N-dimethylamino)ethyl] ether (BDME), and a porous polyethylene substrate. SEM imaging revealed a dense, uniform structure with no visible pores. Under alkaline electrolysis conditions, the membrane demonstrated excellent thermal and mechanical stability, high ion exchange capacity, and maintained over 97% of its OH^- conductivity after 1000 hours in 1M KOH. At 1.8 V, it achieved a current density of 875 mA/cm² and maintained stable performance for 120 hours. These findings indicate that the membrane has outstanding alkali resistance and promising electrochemical performance for AEMWE applications.

Keywords: *Anion Exchange Membrane Water Electrolysis, Crosslinking, Pore-Filling, Carbazole, Alkaline Resistance*

Paper ID: A014

The Effect of Sintering Temperature Towards Nickel Modified Montmorillonite Ceramic Membrane on OH^- ion Conductivity Properties for Microbial Fuel Cell Application

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ABSTRACT

With annual outputs nearing 80 million m^3, Palm Oil Mill Effluent (POME) poses a growing environmental challenge, demanding more effective and sustainable treatment technologies. Microbial Fuel Cells (MFCs) have emerged as a promising technology for POME remediation, offering simultaneous waste treatment and bioelectricity generation. However, their widespread implementation is limited by suboptimal membrane performance, particularly in terms of ion conductivity and mechanical stability. This study explores the development and characterization of a novel nickel-modified montmorillonite (Ni-MMT) ceramic membrane, addressing the dual challenge of ion transport and membrane durability in MFCs. The membrane, synthesized via the non-solvent induced phase separation (NIPS) method and subjected to sintering at various temperatures (1000–1300°C), demonstrates improved structural integrity, reduced porosity, and enhanced OH^- ion conductivity. Comprehensive morphological (SEM), elemental (EDX), and spectroscopic (FTIR) analyses confirm the successful incorporation of Ni and its beneficial effects on membrane properties. Electrochemical impedance spectroscopy (EIS) reveals that Ni addition significantly lowers ion resistance, supporting enhanced electrochemical performance. These findings highlight the potential of Ni-MMT membranes to advance MFC technology for more effective and scalable POME treatment.

Keywords: *Microbial Fuel Cell, Ceramic Anion Exchange Membrane, Nickel Modified Montmorillonite, Sintering Temperature Effect*

Preparation and Characterization of PEEK/PPS-Based Diaphragms via TIPS for Enhanced Alkaline Water Electrolysis

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ABSTRACT

Greenhouse gas mitigation efforts have spurred the development of renewable energy technologies, including green hydrogen production via alkaline water electrolysis. In this study, diaphragms were fabricated using the thermally induced phase separation (TIPS) method with a blend of engineering polymers, PEEK and PPS, and diphenyl ketone (DPK) as a diluent. Diaphragms with polymer contents ranging from 20 wt% to 40 wt% were evaluated. The 20 wt% diaphragm exhibited a thickness of 321 μm and a porosity of 38.9%, resulting in a tensile strength of 31.9 MPa sufficient for operational conditions in electrolysis systems. Long-term alkaline resistance tests in 25–30 wt% KOH showed weight changes below 1%, confirming excellent chemical stability. Furthermore, electrochemical tests revealed that the 20 wt% sample achieved the highest performance with a current density of 188.7 mA/cm² at 2.0 V, while permeability measurements demonstrated that increased polymer content correlated with reduced transport of the electrolyte. These results underscore the potential of low polymer-content PEEK/PPS diaphragms for enhancing the efficiency and durability of alkaline water electrolysis in sustainable hydrogen production.

Keywords: *Alkaline Water Electrolysis, Thermally Induced Phase Separation, PPS, Peek, Diaphragm*

Paper ID: A016

The Effect of Solution Flow Rate on Selective Layer Formation for Improved Dye Separation in Hollow Fiber Membranes

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ABSTRACT

Separation technologies are essential across multiple sectors, such as food manufacturing, petrochemical processing, and pharmaceuticals, particularly for eliminating large molecules like dyes. While thin-film composite membranes typically employ a polyamide layer for separation purposes, creating a selective polyamide layer on hollow fiber (HF) membranes remains a significant challenge. This study explores the fabrication of polyamide-based HF membranes via interfacial polymerization, involving the circulation of both aqueous and organic solutions. By adjusting the flow rates of these solutions, the research investigates the effect on dye rejection performance, membrane structure, polyamide layer thickness, mechanical properties, and surface hydrophilicity. All membranes developed in this study demonstrated consistent congo red rejection exceeding 98%, with the highest methyl orange rejection observed at around 92%. The best-performing membranes were obtained using an aqueous flow rate of 180 ml/min and an organic flow rate of 220 ml/min. These membranes also showed high ethanol permeance, with congo red rejection reaching 99.75% and methyl orange rejection at 91.68%. Moreover, their performance indicates potential suitability for reverse osmosis applications, especially in salt removal.

Keywords: *Hollow Fiber, Water Treatment, Selective Layer.*

Paper ID: A017

Microstructure Manipulation of MFI Zeolite Membranes on Hollow Fibers for Advanced Separation

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ABSTRACT

Membrane separation has been recognized as a promising alternative to traditional separation techniques such as distillation and adsorption because of its low energy consumption and cost-effectiveness. MFI zeolite membrane, owning 3D pore structure comprising a sinusoidal channel (0.51 nm × 0.55 nm) and straight channel (0.53 nm × 0.56 nm), has been recommended as an ideal candidate for some industrially important separations such as xylene isomers separation. However, current MFI membranes are still expensive, which hinders their widespread application. Reducing the thickness of MFI membrane can improve its flux and therefore to lower the membrane cost. Synthesizing ultrathin (<1 μm) MFI membrane is highly desired but remains challenging, especially on scalable tubular supports. To address this issue, first we demonstrated a rapid and facile strategy to synthesize a kind of hierarchical MFI zeolite membrane on ceramic hollow fiber from multi-dimensionally assembled (2D@0D) seeds. Owing to the rapid growth of 0D MFI seeds and the voids-preserved growth of stacked 2D MFI seeds, the hierarchical MFI membrane synthesized for 2 h yielded an ultrathin skin layer (≈255 nm thick) and many macro-voids within the sublayer (void fraction: 14.86%), which facilitated molecular permeation and simultaneously maintained high separation selectivity of zeolitic pores. The membrane exhibited over sevenfold higher p-xylene permeance (2.81×10^{-7} mol m^{-2} s^{-1} Pa^{-1}) and over threefold improved p-/o-xylene separation factor (1228) than the conventional MFI membrane. Next, we developed a facet engineering methodology for fabricating b-oriented thin MFI zeolite membranes on ceramic hollow fibers. The growth of twin crystals was restrained by using ammonium sulfate as an additive. Owing to sub-micron membrane thickness (ca. 740 nm), the resultant b-oriented MFI zeolite membrane showed high performance in gas separations.

Keywords: *MFI Zeolite Membrane, Xylene Separation, Ultrathin Membrane, Hollow Fiber*

Paper ID: A018

Machine Learning Accelerates High Throughput Design and Screening of MOF Mixed-Matrix Membranes Towards He Separation

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ABSTRACT

Helium (He) is a non-renewable resource and membrane technology shows great potential for separating He from natural gas. [1] Mixed matrix membrane (MMM) is a promising candidate for He separation, while the design of MMMs is still in the stage of “trial and error” due to the wide variety of fillers and complex membrane structures.[2,3] In this work, we report machine learning accelerated high throughput design and screening of mixed matrix membranes. High throughput grand canonical Monte Carlo calculations and molecular dynamics simulations were performed to calculate the reliable structure and performance features of thousands of MOFs fillers. [4,5] The high throughput computational data were combined with experimental data of polymer membranes to construct a big dataset of 456,872 MMMs. Four machine learning regression models were trained to predict the permeation and the separation performances and to reveal the underlying structure-performance relationships of MMMs. Our studies show that the XGBoost model has the best performance indicated by high R2 value and lower RMSE and MAE values compared with the other models (Figure 1(a-c)). The thorough data-driven model interpretation quantitatively revealed the key properties and structural parameters for fabricating MMMs with high He/CH4 separation performance (Figure 1(d-e): for polymer matrices, *S*1He/CH4 > 900, *P*1He > 1600 Barrer and *P*1CH4 as low as possible; meanwhile for MOF fillers, porosity (ϕ) > 0.5 and 2.6 Å < PLD < 3.2 Å. The XGBoost model shows good transferability on the dataset constructed from the hypothetical MOFs (Figure 1(f)). This work provides guidance for designing He separation membranes.

Keywords: *He Separation, Mixed Matrix Membrane, Metal Organic Framework, High Throughput Computer Simulation, Machine Learning*

Paper ID: A019

Studies of The Functionalized Graphene Oxide Incorporated Polymeric Membranes for Selective CO_2 Capture from N_2 and H_2

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ABSTRACT

Graphene Oxide (GO) incorporated membranes were studied to have excellent CO_2 separation and shown high CO_2/N_2 selectivity because of the improved selective diffusion of gases across the membranes. Surface modification of graphene oxide (GO) with a tailored triazole (Tz) derivative produced Tz-GO, a material optimized for selective CO_2 separation which would lead to removal of hazardous combustion byproducts. In the current study, the varying weight percentages of Tz-GO are incorporated into the EXTEM polymeric dope solution for the fabrication of mixed matrix membranes. Various analytical techniques were used to examine the thermal, mechanical as well as morphological characteristics of the prepared membranes (e.g. FTIR, TGA, DSC, FESEM etc.), and their impact in CO_2, H_2, and N_2 gas separation was explored. Studies show that 0.8 weight percent Tz-GO/EXTEM mixed matrix membranes (MMM) could obtain a significant CO_2/N_2 selectivity and CO_2 permeability of 391.5 Barrer. In summary, considerable improvements were observed in CO_2/N_2 separation with the Tz-GO/EXTEM mixed matrix membranes which were produced in this investigation.

Keywords*: Graphene Oxide, Membranes, Gas Separation.*

Paper ID: A020

Molecular Sieving Silica Membranes on Polymeric Supports via Atmospheric-Pressure Plasma-Induced Polymerization at Gas-Liquid Interface

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ABSTRACT

Silica membranes exhibit excellent molecular sieving properties and are promising candidates for gas separation applications such as hydrogen purification and CO_2 capture. While conventional silica membranes are typically formed on ceramic supports, the use of polymer supports has attracted attention for large-scale, low-cost production and the development of high-packing-density modules. This concept, known as layered-hybrid membranes, remains challenging due to the difficulty in forming uniform silica layers on thermally sensitive polymer supports, as traditional fabrication methods generally require high temperatures. In this study, we propose a novel fabrication strategy utilizing atmospheric-pressure plasma-induced polymerization at the gas-liquid interface to form silica layers on polymeric ultrafiltration membranes under ambient conditions. This technique involves the oxidative polymerization of liquid precursors such as PDMS oligomers using atmospheric pressure plasma, enabling membrane formation at room temperature while avoiding thermal damage to the polymer substrate. To verify the feasibility of the proposed method, a PSF ultrafiltration membrane was used as the support and was infiltrated with PDMS oligomer, followed by exposure to atmospheric pressure plasma to induce polymerization. As a result, a silica-like layer was successfully formed on the surface of the PSF support, exhibiting exceptional molecular sieving ability with an H_2/N_2 permeance ratio reaching 330, as demonstrated by gas permeation measurements. Moreover, by tuning plasma parameters such as plasma power, the membrane structure could be tailored for specific separations, for example, achieving a CO_2/N_2 permeance ratio of 30. These results demonstrate that the proposed method offers a low-temperature, scalable approach for fabricating molecular-sieving silica membranes on polymer supports, making it a promising platform for advanced gas separation technologies.

Keywords: *Atmospheric-Pressure Plasma, Silica Membrane, Molecular Sieving, Gas Separation, Polymer-Supported Ceramic Membrane*

Paper ID: A021

Eco-Friendly Surface Engineering of UF Membranes Using Spray-Coated Zwitterionic Biopolymers: Recent Progress and Potential for Palm Oil Mill Effluent Treatment

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ABSTRACT

Palm Oil Mill Effluent (POME) is a highly polluting wastewater generated in large volumes by the palm oil industry, particularly in Malaysia. Its complex composition—rich in organic matter, suspended solids, and persistent colorants—makes effective treatment a critical environmental priority. Ultrafiltration (UF) membranes have shown promise in POME treatment due to their high separation efficiency and operational simplicity; however, their widespread application is hindered by membrane fouling and limited antifouling resilience. Recent advancements in membrane surface modification have focused on enhancing antifouling properties through the incorporation of hydrophilic and antibacterial materials. Among these, zwitterionic polymers have emerged as highly effective due to their charge neutrality and strong hydration layers. This review highlights the development of zwitterionic biomaterials coatings applied via spray coating as a novel and eco-friendly strategy to improve UF membrane performance. The integration of biocompatible and biodegradable materials offers a sustainable alternative to traditional synthetic modifiers, with enhanced hydrophilicity, reduced biofouling, and improved dye removal capabilities. Challenges related to coating stability, optimization of blend ratios, and scalability of spray techniques are also discussed. This review concludes by outlining future research directions focused on real wastewater validation, long-term durability, and industrial-scale implementation.

Keywords: *Palm Oil Mill Effluent (POME), Ultrafiltration Membrane, Zwitterionic Chitosan, Wastewater Treatment, Dye Removal*

Paper ID: A022

One-Step Synthesized Self S-Doped Porous Carbon from Polyphenylene Sulfide for CO2 Adsorption and Membrane Separation

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ABSTRACT

Self sulfur-doped porous carbon (PCs) derived from polyphenylene sulfide (PPs) presents a promising pathway toward efficient CO2 capture and separation, leveraging the inherent sulfur content of the polymer to introduce functional sites that enhance gas–solid interactions. Despite growing interest in S-doped carbons, a comprehensive understanding of their adsorption mechanisms and integration into membrane systems remains limited. In this work, PCs was synthesized via a one-step chemical activation using potassium carbonate (K2CO3), resulting in a porous structure with a high specific surface area of 2023 m2/g and a CO2 uptake capacity of 4.59 mmol/g at 30 °C. The adsorption behavior was evaluated through kinetic and thermodynamic modeling. The data fit best with the pseudo-second-order kinetic model, indicating multilayer adsorption on heterogeneous surfaces. Thermodynamic analysis confirmed the process was spontaneous and exothermic, with CO2 exhibiting significantly stronger affinity compared to CH4 and N2 due to polar interactions and acid–base affinities. Furthermore, PCs was incorporated as a filler into polysulfone-based hollow fiber mixed matrix membranes (MMMs), significantly improving gas separation performance. CO2 permeability increased from 7.64 GPU (bare membrane) to 67.49 GPU with PCs loading, while CH4 and N2 permeabilities remained stable, enhancing CO2/CH4 and CO2/N2 selectivity. The membranes demonstrated stable performance over 60 minutes of continuous testing. These findings underscore the synergistic potential of S-doped porous carbon in integrated adsorption–membrane systems and provide valuable insights into gas–solid interaction mechanisms. The dual functionality of PCs—high adsorption capacity and membrane compatibility—positions it as a scalable and efficient material for advanced CO2 separation technologies in environmental and industrial applications.

Keywords: *Self S-Doped Porous Carbon, Polyphenylene Sulfide, CO2 Adsorption, Gas Separation, Hollow Fiber Membranes*

Paper ID: A023

Incorporation of Ionic Liquid into Membrane for Proton Exchange Membrane (PEM): Comparative Method

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ABSTRACT

Hydrogen production via proton exchange membrane water electrolysis (PEMWE) is a widely adopted technology. However, the anticipated future ban on per- and polyfluoroalkyl substances (PFAS), such as Nafion, necessitates the development of alternative membrane materials with comparable performance as the PFAS membrane. In this study, sulfonated poly(ether ether ketone) (SPEEK) identified as a potential replacement and ionic liquid (IL) is used to further enhance its proton conductivity. This work compares the methodology to incorporate IL into the membrane, namely 1) immersion impregnation in highly polar medium (water), 2) immersion impregnation in less polar medium (methanol) and 3) IL co-activation impregnation in acid. Optimizations of key fabrication parameters, including ionic liquid loading, immersion time, and sulfuric acid molarity, using Response Surface Methodology (RSM) are performed. Characterization analyses confirmed successful IL incorporation into the SPEEK membrane. Fourier Transform Infrared Spectroscopy (FTIR) and Proton Nuclear Magnetic Resonance (1H NMR) verified structural modifications, while Differential Scanning Calorimetry (DSC) indicated plasticization effects that influenced the membrane's thermal properties. Contact angle measurements and water uptake analysis demonstrated improved hydrophilicity. Electrochemical Impedance Spectroscopy (EIS) showed a remarkable enhancement in proton conductivity for all cases, with co-activation methods shows the highest improvement from 0.07 S/cm to 0.7 S/cm, compared to other methodology (0.47 S/cm for impregnation in water, and 0.40 S/cm for impregnation in methanol). The findings confirm that the coactivation method effectively enhances the ionic conductivity and hydrophilic properties of SPEEK membranes, making them a promising alternative to Nafion for PEMWE applications.

Keywords: *Ionic Liquid, Proton Exchange Membrane, SPEEK, Water Electrolysis, Fuel Cell*

Paper ID: A024

Green Materials & Approach in Focus: Enhancing Catalytic Activity of Hydrogen Fuel Cells – A State of an Art Review.

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ABSTRACT

Hydrogen fuel cells are pivotal for clean energy, yet conventional catalysts face challenges of high cost, material scarcity, and environmental harm, limiting their sustainability and scalability. This review explores green catalytic materials—carbon-based biomass derivatives, non-precious metals (Fe, Co, Ni), bio-inspired systems, and metal-organic frameworks (MOFs)—as sustainable alternatives to mitigate these issues. Carbon-based catalysts leverage renewable biomass feedstocks and low-energy pyrolysis, reducing dependence on fossil-derived precursors. Non-precious metals address Platinum group metal (PGM) scarcity by utilizing Earth-abundant elements, while bio-inspired designs mimic natural enzymatic efficiency through biodegradable, low-toxicity frameworks. MOFs, tailored with eco-friendly linkers and solvent-free synthesis, offer tunable active sites without heavy metals. Key mechanisms such as electron transfer, adsorption dynamics, and reaction kinetics are discussed to elucidate catalytic enhancement strategies. Despite their potential, challenges persist in optimizing cost-effective scalability, minimizing environmental footprints during synthesis, and ensuring long-term catalytic stability. By prioritizing renewability, energy efficiency, and reduced toxicity, green materials present a pathway to overcome the limitations of conventional catalysts. Future efforts must focus on advancing synthesis techniques, enhancing material recyclability, and aligning scalable production with circular economy principles to realize eco-efficient hydrogen fuel cell technologies.

Keywords: *Hydrogen Fuel Cells; Green Catalytic Materials; Non-Precious Metals (Fe, Co, Ni); Bio-Inspired Catalysts; Metal-Organic Frameworks (MOFs).*

Paper ID: A025

Perfluoroalkyl Substances Concentration from Groundwater via Direct Contact Membrane Distillation – Long-Term Fouling and Membrane Materials Stability Study

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ABSTRACT

Poly- and perfluoroalkyl substances (PFASs) are ubiquitous contaminant and globally distributed in water bodies. A significant yet largely untapped reservoir of polluted water arises from groundwater, where the diffusion of PFAS has been shown to be alarmingly on the rise, driven by prolonged accumulation and restricted avenues for degradation. Direct contact membrane distillation (DCMD) was used to concentrate and remove perfluorooctanoic acid (PFOA) compounds from contaminated groundwater for the first time using commercially available poly(tetrafluoroethylene) (PTFE) and poly(vinylidene fluoride) (PVDF) membranes. The temporal membrane fouling propensity over DCMD test was assessed by analysing the morphological and chemical structural changes of the pristine and used membranes. Over 120 h of DCMD test using 10 mg/L PFOA contaminated model groundwater as feed, the PVDF membrane exhibited lower extent of flux decline of 15% compared to that 43% obtained by PTFE membrane using feed temperature of 60 ^{o}C. The PVDF membrane achieved higher PFOA removal (80 vs. 51%) and salt rejection (70% vs. 30%) performance, revealing the surface diffusion attributed to F–F interaction between the PVDF membrane and PFOA molecules was less pronounced. This study provides a practical route to pre-concentrate and remove the amphiphilic PFAS contaminants from groundwater and could be potentially applied in downstream treatment.

Keywords: *Membrane Distillation, PFAS Management, Hydrophobic Interactions, Surface Diffusion, Membrane Autopsy*

Paper ID: A026

Comparative Characterization of NH_2-Mil-101(Fe) Synthesized via Hydrothermal and Room Temperature Routes

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ABSTRACT

Amine-functionalized MOFs like NH_2-MIL-101(Fe) are typically synthesized using the conventional hydrothermal method. However, it has certain drawbacks such as high energy consumption due to high pressure and temperature during synthesis steps. This study explores the potential of room temperature synthesis as a sustainable alternative by comparing another variant of hydrothermally synthesized NH_2-MIL-101(Fe). These MOF variants were characterized using XRD, XPS, FESEM, UV-Vis spectroscopy, and zeta potential measurements. The comparison highlights the synergetic effects of both synthesis temperature and amine modifications on crystallinity, surface morphology, surface chemistry, chemical states, optical properties and surface charge behaviour. The findings showed that at room temperature synthesis, NH_2-MIL-101(Fe) retained similar XRD peaks at 2θ values of 9.40, 12.56, 16.19, 18.86, and 22.0°. The room temperature variant displayed a cocoa pod-like morphology with elongated ridges, larger crystals, and surface irregularities, indicating less control over crystal formation compared to the hydrothermally synthesized version. Notably, the room temperature variant had a narrower band gap (2.57 eV) compared to the hydrothermal version (2.86 eV). This enhanced optical property is due to higher amine retention in the room temperature MOF, with XPS N 1s spectra showing a significantly greater C–NH_2 bond contribution (27.91%) than the hydrothermal version (16.27%), confirming the role of –NH_2 groups as electron donors. These findings indicate that room temperature synthesis of NH_2-MIL-101(Fe) could be a promising alternative for applications in water treatment.

Keywords: *NH_2-MIL-101(Fe), Room Temperature Synthesis, Hydrothermal Synthesis, Water Treatment, Optical Properties*

Paper ID: A027

Advanced Ion-Exchange Membranes for Enhanced Performance in Membrane Capacitive Deionization (MCDI) Technology

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ABSTRACT

Conventional capacitive deionization (CDI) technologies face several limitations, notably the undesired adsorption of co-ions and the accumulation of divalent ions on the electrode surfaces. This accumulation leads to the formation of layers on the electrodes, ultimately reducing the desalination efficiency. To address these challenges, we have developed two approaches that incorporate both anion and cation exchange membranes into the CDI system. The first approach involves integrating the synthesized ion exchange membranes adjacent to the electrodes within the CDI system. The second approach focuses on directly incorporating the membranes onto the electrode surfaces. In this study, we synthesized a series of anion-exchange membranes (AEMs) using a poly(styrene-co-butadiene) polymer backbone, which underwent a series of chemical modifications. These included chloromethylation, followed by crosslinking with diamine and subsequent quaternization, using varying ratios of the crosslinking and quaternizing agents. This strategy enabled fine-tuning of the membrane properties by controlling both the swelling behavior and the degree of quaternization factors that directly influence the ion-exchange capacity and overall performance of the membranes in membrane capacitive deionization (MCDI).
The synthesis process was optimized to produce membranes with enhanced anion conductivity, permselectivity, and dimensional stability. The presence of functional groups was confirmed using nuclear magnetic resonance (NMR) and Fourier transform infrared (FTIR) spectroscopy. Membrane morphology was characterized via scanning electron microscopy (SEM). A comprehensive evaluation of the membranes' physicochemical and electrochemical properties was conducted, including measurements of ion exchange capacity, water uptake, volume expansion ratio, tensile strength, electrical resistance, and transport number. This work aims to enhance the efficiency of CDI systems by overcoming the limitations associated with co-ion adsorption and the presence of divalent ions, thereby improving desalination rates.

Paper ID: A028

Reassessing CCRO Performance and Inefficiencies Through Time-Dependent RO Modeling: Challenges and Potential Solution via Novel RO Design

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ABSTRACT

Close-circuit reverse osmosis (CCRO) is an emerging desalination process known for its enhanced energy efficiency compared to conventional single-stage methods. Featuring a semi-closed stream setup, CCRO customizes hydraulic pressure application to save energy and employs standard RO components for cost-effectiveness. However, this semi-closed system requires concentrate purging at lower pressures after achieving recovery. This results in coexisting solutions with significant concentration disparities within the membrane pressure vessel, causing reverse water flux at the rear elements and potentially affecting CCRO's practical performance. To assess the energy loss from reverse flux and other purging inefficiencies, a multi-cycle time-dependent finite differential model was developed in this study. This model quantified CCRO's flux, applied pressure, and energy consumption. Findings reveal that reverse flux contributes to 5% of energy consumption in practical seawater desalination with CCRO at 50% recovery. While increasing flow rates during concentrate purging reduces reverse flux, it escalates pressure loss and mandates larger pump installations, presenting implementation challenges for CCRO. A novel RO design that avoids brine mixing and frequent concentrate replacement may offer improved energy efficiency and operational performance.

Keywords: *Close Circuit Reverse Osmosis (CCRO); Desalination; Energy Efficiency; Reverse Osmosis; Membrane Finite Differential Model*

Paper ID: A029

Development of a Fouling Model for Single-Pass Tangential Flow Filtration at Constant Flux

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ABSTRACT

The fouling process in batch ultrafiltration of protein solutions under constant transmembrane pressure has been well characterised and is readily described by pore blockage and cake filtration models. There are fewer studies under constant flux conditions, which are more representative of industrial application. Further, single-pass tangential flow filtration (SPTFF) is increasingly prevalent in biopharmaceutical manufacturing, due to its ability to continuously concentrate biomolecules while minimizing hold-up volume and shear stress-induced protein aggregation. The extended channel length of the SPTFF unit, results in fouling varying spatially along the membrane, with higher concentrations and lower cross flow velocity occurring near the retentate outlet, leading to greater fouling at this end of the filtration module. A key challenge in SPTFF is understanding how process parameters, such as protein concentration, feed flow rate and volumetric concentration factor impact the progression of this fouling. To examine the progression of fouling, SPTFF experiments were conducted using whey protein isolate solutions filtered through a 10 kDa membrane. The system operated under constant flux conditions of 25 litres/m^2.hr and 50 litres/m^2.hr, with a concentration factor of 10. Pressure sensors monitored the evolution of the transmembrane pressure, while real-time protein concentration measurements ensured system stability under conditions of constant flux. A model of this fouling behaviour was then developed by combining existing models of SPTFF without fouling and batch ultrafiltration at constant flux. The resulting model showed significant spatial variation in fouling, with the highest pressure drop occurring near the module outlet and fouling gradually decreasing toward the inlet. As retained proteins built up, membrane resistance increased, accelerating the transition from pore blockage to cake formation.

Keywords: *Ultrafiltration, Protein Fouling, SPTFF, Whey, Modelling*

Paper ID: A030

Entirely Biopolymer-Supported Reverse Osmosis Membranes

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ABSTRACT

Thin-film composite (TFC) membranes, consisting of a polyamide (PA) selective layer on a porous support, are widely used in reverse osmosis (RO) and nanofiltration for water purification. However, the fabrication of conventional TFC membranes requires petroleum-based synthetic polymers and toxic organic solvents, raising concerns about their environmental impact. In particular, the support layer, typically made of polysulfone or polyethersulfone, backed by a polyester backing fabric, occupies a large volume fraction of the TFC membrane, causing significant environmental issues. Although green alternatives formed using natural biopolymers or green solvents have been explored, they suffer from low mechanical durability, limiting their use in high pressure-driven separation processes.This study presents the fabrication of an entirely biopolymer-supported TFC RO membranes. The ecofriendly support was fabricated by forming a porous chitosan (CHS) layer on Korean traditional paper (K-paper), a cellulose-based backing fabric, via pH-induced aqueous phase separation. The mechanical robustness of the CHS support was further reinforced by crosslinking with pyrogallol (PG), a natural plant-derived compound. The interfacial polymerization process was performed on the fabricated CHS support to form a PA TFC membrane.The resultant CHS-supported TFC membrane exhibited high compaction resistance and long-term operability even under high pressure RO conditions owing to the excellent mechanical integrity of its underlying CHS support layer. The CHS-supported TFC membrane also displayed good water permeance and NaCl rejection, which are comparable to those of commercial RO membranes. Furthermore, the membrane showed excellent biodegradability, which was not achievable by conventional RO membranes. This study demonstrates an ecofriendly and sustainable strategy for fabricating TFC membranes applicable to various separation processes, including water and organic solvent purification and gas separation.

Keywords: *Biopolymer, Water Treatment, Reverse Osmosis, Biodegradation, Thin-Film Composite Membrane*

Structural Engineering of Matrimid Using an Amino-Terminated Polydimethylsiloxane Crosslinker to Enhance CO2 Permeability

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ABSTRACT

Polyimides have been utilized for gas separation because of their high gas diffusivity selectivity. Matrimid is one of glassy polyimides that show high selectivity for CO_2/light gases. However, its applications for gas separation have been limited due to its low gas permeability. We report here a novel and facile method to enhance its gas permeability by crosslinking it with high molecular weight poly(dimethylsiloxane) bis(3-aminopropyl) terminated (PDMS-NH_2). PDMS-NH_2 was chosen because of its known high gas permeability due to its flexible siloxane linkages. The structural rearrangement and chemical interactions between Matrimid and PDMS-NH_2 were investigated using various characterization methods. Both XRD and position annihilation lifetime spectroscopy (PALS) results confirmed that the d-spacing and fractional free volume (FFV) significantly increased after incorporating PDMS-NH_2 into the Matrimid polymer matrix. The EDX elemental mapping of both top and cross-sectional surfaces show uniform distributions of elements. The resultant membranes display synergistic separation performance, not only exhibiting high gas permeability but also maintaining high CO_2/N_2 selectivity close to Matrimid. Specifically, the additions of 10, 25, and 50 wt.% of PDMS-NH_2 into the Matrimid matrix enhance the CO_2 permeability from the initial 12.01 to 58.22, 82.60, and 260.51 Barrer, respectively (i.e., increasing CO_2 permeability by about 385%, 588%, and 2069%, respectively) without much compromise in CO_2/N_2 selectivity. Interestingly, the mixed gas tests have higher CO_2/N_2 selectivity than those pure gas tests, possibly due to strong interactions between CO_2 and the amine groups of PDMS-NH_2. In addition, the plasticization phenomenon of the Matrimid/PDMS-NH_2 membranes reduces due to the less CO_2 adsorption. Comparing with other studies, the newly developed membranes show a relatively higher CO_2 permeability, while exhibiting a comparable CO_2/N_2 selectivity. This study may provide new insights to design advanced polymeric membrane materials for CO_2 capture.

Keywords: *Carbon Dioxide Capture, Polyimide, Amino-Terminated Polydimethylsiloxane, Gas Separation, Clean Energy*

Solvent-Driven Design of Catalyst Layers Enhancing Performance and Durability in Water Electrolysis

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ABSTRACT

This study investigates the influence of dispersing solvents on the structural integrity and operational stability of catalyst layers (CLs) in water electrolysis (WE). The findings demonstrate that the selection of solvent plays a critical role in governing ionomer dispersion behaviour, which directly affects the microstructure of the catalyst ink and the homogeneity of the resulting CL. A well-dispersed ionomer leads to more uniform and interconnected CL morphologies, which are essential for efficient electrochemical reactions. Solvents exhibiting more negative solvation energies, such as ethylene glycol (EG) and propylene glycol (PG), were found to enhance the compatibility and dispersion of both ionomer and catalyst particles. These improvements in dispersibility facilitated the formation of CLs with superior structural uniformity, thereby contributing to enhanced electrochemical performance. The optimized morphology promoted efficient electron and proton transport, as well as more effective reactant access to catalytic sites. In addition to performance, the durability of the CLs was also significantly influenced by the choice of solvent. Particularly, PG-based CLs showed exceptional stability, with slower degradation rates and minimal increases in charge transfer resistance over time. These results underscore the dual impact of solvent selection on both the performance and longevity of WE systems. Overall, this work highlights solvent engineering as a powerful strategy for tuning catalyst layer properties and advancing the development of high-efficiency, long-lasting water electrolysis technologies.

Keywords: *Dispersing Solvent, Ionomer Dispersion, Catalyst Layer, Microstructure, Proton Exchange Membrane Water Electrolysis*

Paper ID: A033

Synthesis of Two-Dimensional Ordered Graphdiyne Membranes for Highly Efficient and Selective Water Transport

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ABSTRACT

With increasing population, industrialization, and freshwater contamination, seawater purification has emerged as a sustainable freshwater source. Membrane separation technologies, which block ions while allowing water transport, offer great potential due to their high efficiency and low energy consumption. Bottom-up synthesized two-dimensional nanoporous membranes with precise pore size and high pore density have emerged as promising candidates for next-generation desalination. However, fabricating these membranes with well-defined, angstrom-scale channels that are both dense and stable remains significantly challenging, mainly due to difficulties in rational channel design at the molecular level and in eliminating lattice defects to achieve precise water/ion sieving and high water flux simultaneously. In this study, we report the successful bottom-up synthesis of ultra-thin, centimetre-scale graphdiyne (GDY) films with ordered one-dimensional (1D) channels using single-crystalline Cu(111) as the growth substrate and demonstrate their exceptional performance as molecular sieves for highly efficient water/ion separation. The optimized membrane exhibits an ultra-high water/NaCl selectivity of 5.96×10^4, outperforming state-of-the-art membranes, at a water permeance of ~32.9 mol m^{-2} h^{-1} bar^{-1} and a salt rejection exceeding 99.7% for small ions in seawater. Mechanism studies reveal that the hydrophobic angstrom-scale channels in GDY crystals force water molecules into a single-file configuration with 1D hydrogen bonding during water permeation. The 1D water chain enables the GDY membrane to facilitate rapid and selective proton transport (diffusion constant as high as 1.3×10^{-4} cm^2 s^{-1}) via the Grotthuss mechanism. This work contributes to the development of carbon nanomaterial membranes for precise molecular sieving and biomimetic protonophores.

Keywords: *Graphdiyne, Crystalline Membrane, Molecular Sieving, Water Desalination, Proton Transport*

Paper ID: A034

Oriented 2D Covalent Organic Framework Membranes for Precise Ion/Molecule Transport

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ABSTRACT

Two-dimensional (2D) covalent organic frameworks (COFs) are a class of crystalline porous materials with atomically ordered and modular channel architectures. Their structural tunability and rich chemistry offer unique opportunities for membrane-based separations. In this presentation, I will introduce scalable fabrication strategies for highly crystalline 2D COF membranes, focusing on controlling crystallinity, domain orientation, and channel surface chemistry to enable targeted separation. First, I will present a facile method to fabricate large-area, vertically oriented 2D COF membranes on smooth substrates by modulating the reaction rate[1]. The resulting membranes exhibit highly ordered, vertically aligned nanochannels that deliver ion transport performance 2–3 orders of magnitude higher than conventional nanofluidic systems. In reverse electrodialysis for osmotic energy conversion, a pair of 100 nm thick, oppositely charged COF membranes achieved a record-high power density of 43.2 W m^{-2} under a 50-fold salinity gradient, and up to 228.9 W m^{-2} using Dead Sea and river water[2]. Further surface engineering of the channel walls enabled fast, unidirectional ion transport and switchable selectivity between K^+ and Na^+ ions, offering new opportunities for ion sieving and energy harvesting[3, 4]. Next, I will discuss the use of electric fields to guide the nucleation, crystal growth, and domain alignment of COF membranes over large areas. This approach enables the formation of single-crystalline COF domains with vertically aligned through-pores across the membrane thickness. These pores can be directly visualized with an ultrahigh resolution of 2 Å using low-dose high-resolution transmission electron microscopy (HRTEM), with an observed pore density of 1.2×10^{17} m^{-2}, closely matching theoretical values[5]. These advances result in COF membranes with ultrahigh solvent permeability – over 10 times higher than current state-of-the-art organic solvent nanofiltration membranes – positioning them as promising candidates for next-generation molecular separations and energy conversion applications.

Keywords: *COF Membranes, Oriented Channel, Nanofluidic, Molecular Sieving, Organic Solvent Nanofiltration*

Paper ID: A035

Highly Efficient CO_2 Splitting via Oxygen-Permeable Membrane Reactor

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ABSTRACT

The thermocatalytic splitting of CO_2 into CO and O_2 represents a promising route for sustainable carbon utilization, yet conventional approaches suffer from low efficiency, high thermal energy demands, and catalyst instability under reactive conditions. In this presentation, an advanced oxygen-permeable membrane (OPM) reactor system that overcomes these limitations through synergistic material engineering and innovative reactor design will be discussed. Our approach combines tailored perovskite-based membranes with high oxygen-ion conductivity and exceptional stability under CO_2-rich atmospheres, enabling sustained operation without degradation. To minimize carbon emissions from the process itself, we integrate renewable energy inputs, including non-thermal plasma for low-temperature activation and solar-thermal heating for high-temperature operation. A key advancement is the development of a multichannel hollow fiber membrane configuration, which achieves unprecedented packing density and efficient gas transport while maintaining mechanical robustness. This modular design significantly enhances scalability, addressing critical barriers to industrial deployment.

Keywords: *CO_2 Splitting, Oxygen-Permeable Membrane, Plasma Catalysis, Solar-Thermal, Hollow Fiber Reactor, Perovskite Oxide*

Paper ID: A036

Mixed Solvent Phase Separation Ultrafiltration Membrane: From Lab to Large-Scale Pilot

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ABSTRACT

Ultrafiltration (UF) membranes, characterized by pore sizes ranging from 2 to 100 nm, are widely employed in wastewater treatment, desalination pretreatment, and processes within the food, pharmaceutical, and petrochemical industries. However, conventional commercial UF membranes, typically fabricated via non-solvent induced phase separation (NIPS) or temperature induced phase separation (TIPS), often suffer from broad pore size distributions. This compromises both permeation flux and separation accuracy due to inconsistent pore structures and limited porosity. In this study, we introduce a novel mixed solvent phase separation (MSPS) process for UF membrane fabrication. This method leverages a mixed solvent system exhibiting upper critical solution temperature (UCST) behavior to induce the formation of highly uniform porous structures. To demonstrate the versatility of the MSPS method, a range of commonly used polymers, including PVDF, PAN, PMP, PES, CA, and PVDF-co-HFP, were employed to fabricate UF membranes with uniform pore distributions. The resulting membranes exhibit significantly enhanced permeation flux and separation precision compared to commercial UF membranes, owing to their highly uniform pore structure and elevated porosity. These structural performance improvements make them well-suited for demanding applications such as membrane distillation, hemodialysis, extracorporeal membrane oxygenation, and advanced wastewater treatment. Furthermore, pilot-scale production of both hollow fiber and flat-sheet membranes confirmed that the MSPS process is reproducible and scalable. This establishes MSPS as an optimal fabrication method for UF membranes with controlled pore sizes between 8 and 80 nm. Overall, the MSPS approach demonstrates superior pore structure regulation compared to NIPS and TIPS, enabling the fabrication of UF membranes with sharp pore size distribution, high porosity, ultra-high flux, and excellent separation accuracy. Such membranes are particularly ideal for high-value applications in drug separation, biopharmaceuticals, and the food industry, where pore structure uniformity is of critical importance.

Keywords: *Ultrafiltration Membrane, Mixed Solvent Phase Separation, Uniform Porous Structure, High Porosity, Separation Efficiency*

Paper ID: A037

Hollow Fiber Membrane Applications with Continuous Surface Modification Technologies: Super-Antifouling and Nanocoating for Gas Separation

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ABSTRACT

The development of super antifouling surface chemistry represents a significant breakthrough in enhancing the performance and longevity of hollow fiber membrane processes. This study introduces an innovative approach utilizing in-situ continuous coating technology to create highly durable and effective antifouling surfaces on hollow fiber membranes. Furthermore, this coating technologies must be related to to modifiy the pore size and zone of hollow fiber membrane using green-solvent induced phase separation technology. From them, the coating technology can fabricate a uniform and ultrathin layer of functional materials directly onto the membrane surface during operation, enabling real-time antifouling performance without interrupting the process. From screening and understanding various chemistries, the optimized surfaces exhibit exceptional resistance to organic fouling, biofouling, and scaling, achieved through tailored surface chemistries that combine hydrophilicity, charge control, and low-surface-energy materials. By mitigating fouling, the technology reduces operational costs, extends membrane lifespan, and enhances process efficiency, particularly in applications such as water treatment, bioprocessing, and chemical separations. Comprehensive evaluations demonstrate the coating's long-term stability under operational conditions, with minimal impact on membrane permeability and selectivity. This approach represents a paradigm shift in fouling management, offering scalable, cost-effective, and environmentally friendly solutions for hollow fiber membrane applications.

Keywords: *Hollow Fiber Membrane, In-Situ Surface Modification, Anti-Fouling, Nano Coating*

Paper ID: A038

Highly Efficient Li-Selective Fully Aromatic Polyamide Membranes Fabricated via a Combinatorial Strategy

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ABSTRACT

The growing demand for lithium (Li) has spurred the development of technologies to recover Li from industrial and natural resources. Among various Li separation technologies, nanofiltration (NF) membranes have gained significant interest because of their easy operation and high separation efficiency. Conventionally, semi-aromatic polyamide (PA) NF membranes formed using aliphatic piperazine- and polyethylene imine as amine monomers have been widely explored for Li separation owing to their good Li selectivity and high water permeance. However, their poor acid stability critically limits their practical applications. Fully aromatic PA membranes formed using aromatic amine monomers (e.g., *m*-phenylene diamine, MPD) offer strong acid resistance but exhibit low water permeance and Li selectivity owing to their tight structure. In this study, we present the fabrication of a highly permeable and Li-selective fully aromatic PA nanofiltration (NF) membranes by combining two strategies among various techniques to tailor PA structure, including surfactant/additive/cosolvent addition and thermal/acid/alkaline/solvent post-treatment. The rationally designed combinatorial strategy enabled the formation of a PA pore structure suitable for selective Li separation in a high-throughput manner. The resultant membrane exhibited high water permeance and excellent Li selectivity under both single- and mixed-salt conditions, outperforming commercial and other laboratory-made counterparts. In addition, the membrane maintained Li separation performance for 4 weeks under acidic conditions, demonstrating its excellent acid resistance. This strategy provides a simple and versatile approach to fabricate highly divalent-ion-selective membranes applicable to diverse industrial processes, including lithium extraction from spent batteries, hydrometallurgical mining, and acid dye removal in textile wastewater.

Keywords: L*ithium Recovery, Thin-Film Composite Membrane, Nanofiltration, Water Treatment, Acid Stability*

Paper ID: A039

Anion Exchange Membranes Fabricated via a One-Pot Monomeric Menshutkin Reaction for Water Electrolysis

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ABSTRACT

Green hydrogen (H_2) is considered an ecofriendly energy source without emitting carbon-based greenhouse gases. Among various water electrolysis (WE) techniques, anion-exchange membrane (AEM) WE (AEMWE) is considered the most cost-effective means to produce green H_2 using renewable energy, because it allows for the use of non-platinum-group (non-PGM) electrodes. In AEMWE operation, an AEM separates the cathode and anode while mediating hydroxide ions and blocking the gas crossover of the generated gases (H_2 and oxygen). The AEM is a key material to achieve efficient and stable AEMWE operation. However, previously reported AEMs have limited AEMWE performance and durability owing to their unsatisfactory chemical structures. Most AEMs consist of a hydrophobic polymer backbone with cationic pendant groups forming anisotropically aligned ion channels. Furthermore, the attainable density of anion-conducting cationic groups pendanted to the polymer backbone is limited. These characteristics limit the ion conducting ability of most AEMs.To overcome these limitations, we propose a one-pot monomeric Menshutkin reaction-based AEM, consisting of a three-dimensionally crosslinked quaternary ammonium (QA) network in a porous support. The isotropically aligned QA network provides numerous effective ion-conducting paths, resulting in high ion conductivity, while the support reinforces the mechanical and thermochemical stability of the AEM. The resultant AEM exhibited higher AEMWE performance than commercial AEMs owing to its higher ion conductivity. Furthermore, the AEM was stable in AEMWE operation for 1000 h using non-PGM electrodes. Our strategy provides a new approach to fabricate high-performance and durable AEMs.

Keywords: A*nion-Exchange Membrane, Water Electrolysis, Ion Conductivity, Menshutkin Reaction, Hydrogen Production*

Paper ID: A040

Entirely Biopolymer-Supported Reverse Osmosis Membranes

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ABSTRACT

Thin-film composite (TFC) membranes, consisting of a polyamide (PA) selective layer on a porous support, are widely used in reverse osmosis (RO) and nanofiltration for water purification. However, the fabrication of conventional TFC membranes requires petroleum-based synthetic polymers and toxic organic solvents, raising concerns about their environmental impact. In particular, the support layer, typically made of polysulfone or polyethersulfone, backed by a polyester backing fabric, occupies a large volume fraction of the TFC membrane, causing significant environmental issues. Although green alternatives formed using natural biopolymers or green solvents have been explored, they suffer from low mechanical durability, limiting their use in high pressure-driven separation processes. This study presents the fabrication of an entirely biopolymer-supported TFC RO membranes. The ecofriendly support was fabricated by forming a porous chitosan (CHS) layer on Korean traditional paper (K-paper), a cellulose-based backing fabric, via pH-induced aqueous phase separation. The mechanical robustness of the CHS support was further reinforced by crosslinking with pyrogallol (PG), a natural plant-derived compound. The interfacial polymerization process was performed on the fabricated CHS support to form a PA TFC membrane. The resultant CHS-supported TFC membrane exhibited high compaction resistance and long-term operability even under high pressure RO conditions owing to the excellent mechanical integrity of its underlying CHS support layer. The CHS-supported TFC membrane also displayed good water permeance and NaCl rejection, which are comparable to those of commercial RO membranes. Furthermore, the membrane showed excellent biodegradability, which was not achievable by conventional RO membranes. This study demonstrates an ecofriendly and sustainable strategy for fabricating TFC membranes applicable to various separation processes, including water and organic solvent purification and gas separation.

Keywords: B*iopolymer, Water Treatment, Reverse Osmosis, Biodegradation, Thin-Film Composite Membrane*

Paper ID: A041

Synergistic Intensification of Membrane Reactor with Biochar Catalyst for Efficient Production of Clean Syngas from Biomass Gasification

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ABSTRACT

Biomass gasification is one of the key operating units in the biomass utilization process, and the produced syngas has been considered as an important feedstock for manufacturing various fuels and chemicals (e.g. methanol, higher alcohols, dimethyl ether and sustainable aviation fuels). However, the complex particulate matter (PM) and tar in the syngas produced from the gasification of biomass are the primary causes being responsible for the physical blockage of reactor and the deactivation of catalyst, limiting the system stability and the overall conversion efficiency of biomass resources. This paper reports a highly integrated reactor that employs a silicon carbide (SiC) membrane and biochar catalyst to simultaneously and efficiently remove tar and PM from biomass gasification syngas at 800°C. The results indicate a synergistic effect between the SiC membrane and the activated biochar (A-biochar) catalyst, achieving tar conversion and PM removal efficiencies of approximately 96%, which outperforms the use of either the membrane reactor or A-biochar catalyst alone. More specifically, the membrane with a thickness of 2.6 μm effectively captured PM with an aerodynamic size larger than 0.24–0.28 μm. Additionally, mechanistic studies reveal that the porous carbon matrix in the catalyst exhibits strong cracking effects on heavy volatiles (≥3-ring aromatic compounds), while the Ca and Al species within the catalyst serve as the primary active sites for the cracking and reforming of relatively lighter tar fragments (1-2 ring aromatic compounds). Finally, cyclic testing confirms the relatively stable performance of the integrated reactor.

Keywords: *Biomass Gasification, SiC Membrane, Biochar Catalyst, Catalytic Mechanism, Synergies*

Paper ID: A042

Physics-Informed Neural Networks for Mechanistic Identification and Prediction of Membrane Fouling Dynamics in Filtration Processes

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ABSTRACT

Membrane technology is widely recognized for its energy efficiency and continuous operation; however, its full potential remains unrealized due to persistent fouling challenges. In our pioneering work, we broke new ground by merging the well-known Hermia fouling mechanisms with machine learning methods. Our innovative physics-informed neural network (PINN) architecture, validated using an extensive dataset of over 50 flux decline curves from more than 10 independent studies, demonstrated unprecedented accuracy (MSE ≈ 0.002) in quantifying the dominance of each fouling mechanism and predicting flux decline with a dramatically reduced dataset (train with 20% of data points). This breakthrough allowed us to extract mechanistic insights that were previously unreachable by standard black-box models. Building on this remarkable success, our current study elevates the approach to a new level of sophistication. We have developed an enhanced PINN framework that not only learns the kinetic parameters and assigns dynamic fractional weights to each fouling regime but also automatically determines the precise transition times between these mechanisms. By normalizing only the time dimension while preserving the real-scale flux data, our model captures the true physics with remarkable fidelity. Our novel introduction of smooth, differentiable switching functions and adaptive loss weighting further ensures robust and stable convergence, achieving an almost flawless match between predicted and experimental flux behavior. This project represents a bold leap forward in the field of membrane process modeling. Our work delivers both deep, quantitative mechanistic insights and exceptionally accurate, physics-guided predictions. This integrated and highly innovative approach heralds a new era for membrane-filtration optimization, setting a new benchmark for smart membrane technology applications. Our presentation will showcase these breakthrough achievements, highlighting the substantial progress and transformative potential of physics-informed machine learning in tackling one of the most stubborn issues in modern separation processes.

Keywords: *Membrane Fouling; Separation, Machine Learning, Physics-Informed Neural Network, Flux Decline*

Paper ID: A043

Engineering a Superhydrophobic PS-PVDF-WO_3 Membrane for Long-Term Stability in Membrane Distillation Processes

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ABSTRACT

Membrane distillation (MD) is a promising energy-efficient desalination technology capable of achieving near-zero liquid discharge and resource recovery. However, its large-scale application is hindered by the high cost and complexity of fabricating hydrophobic membranes, along with limited resistance to wetting and scaling. This study presents the development of a cost-effective hydrophobic electrospun membrane using a polystyrene (PS) polymer (~$1.057/kg) blended with polyvinylidene fluoride (PVDF, ~$80/kg). The membrane surface was further modified through electrospraying of silane-functionalized tungsten trioxide (WO_3) nanoparticles. Characterization revealed an ultra-high water contact angle (~172°) and a low sliding angle (<5°), indicating excellent superhydrophobicity. The membrane's low thermal conductivity (~0.166 W/m·K) helped mitigate temperature polarization during MD operation, thereby enhancing vapor transport from the feed to the permeate side. Additionally, the membrane exhibited strong antiwetting performance, maintaining a stable permeate flux (~25 LMH) and high salt rejection (>99.9%) even with low surface tension saline feeds (~28 mN/m). Mechanical testing showed high tensile strength (up to 45 N), while chemical resistance tests confirmed durability under extreme pH conditions (pH 2 and pH 12), underscoring the membrane's structural robustness and suitability for harsh operational environments.

Paper ID: A044

Thermoplastics as an Alternative Material for Membrane Contactor Casing in Post-Combustion Carbon Capture

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ABSTRACT

Membrane contactor (MBC) technology in the carbon capture space, which involves a liquid solvent (often amine-based) to remove carbon dioxide (CO_2) and hydrogen sulphide (H_2S) from a gas stream, has been proven to be one of the more efficient techniques in the gas sweetening process, with claims of up to 99% CO_2 removal from post-combustion flue gas. While MBC benefits from its modularity and the ease of scaling out to increase capture capacity, the CAPEX of a multi-module MBC exponentially increases due to the cost of the external casing, which often requires high-grade stainless steel, even under near-ambient conditions. In this paper, the author explores the material properties of thermoplastics as a substitute for stainless steel in MBC applications. A preselected thermoplastic, high-density polyethylene (HDPE), is first immersed and aged in different solvents commonly used in MBC CO_2 capture, before ISO tests are conducted to assess changes in the thermoplastic's physical properties, including tensile strength, Vicat softening temperature, Shore hardness, and Charpy impact resistance. Additionally, any changes to the solvent after the accelerated aging process were analysed using infrared spectroscopy and thermogravimetric analysis. The results indicate that for post-combustion carbon capture processes under less extreme conditions, HDPE is a suitable substitute for the casing material in MBC, with potential cost and weight savings of up to eightfold. Thermoplastic welding of the casing with membranes also proved to be simpler, with fewer detachment issues compared to stainless steel.

Keywords: *Membrane Contactor, Thermoplastic, Carbon Capture, Material Science, Solvent*

A Pragmatic Thermal Treatment Strategy for Improved Gas Separation in 2D Zeolite-based Mixed Matrix Membranes

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ABSTRACT

Mixed matrix membranes (MMMs) combine the desirable properties of polymers and inorganic fillers, yet interfacial incompatibility frequently results in non-selective voids that compromise selectivity. Here, we report a straightforward heat treatment (200-400°C) to enhance interfacial compatibility in MMMs composed of 6FDA-DAM-AB-TFMB polyimide (PI) and two-dimensional zeolite (MFI) fillers. Incorporating porous zeolite fillers increases gas permeability, particularly for polar molecules such as CO2, while heat treatment induces crosslinking and polymer chain rearrangement, effectively eliminating non-selective voids and boosting selectivity. Moreover, partial carbonization during the thermal process generates a microporous structure that substantially increases overall gas permeability. Consequently, the MFI/PI-30% membrane treated at 400°C achieves exceptional CO2 and H2 permeabilities of 2220.8 Barrer (12.7× higher) and 1767.2 Barrer (10.3× higher), respectively, while retaining CO2/CH4 and H2/CH4 selectivity—surpassing the 2008 Robeson upper bound. The key innovation of this study is leveraging a moderate-temperature heat treatment that simultaneously mitigates interfacial incompatibility and creates micropores, thereby significantly enhancing both permeability and selectivity. This simple, scalable strategy holds great promise for the development of high-performance MMMs in advanced gas separation applications.

Paper ID: A046

Hydrophobic Ceramic Hybrid Membranes for Membrane Distillation

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ABSTRACT

Membrane distillation (MD) has attracted attention as a promising method for water recovery from wastewater in semiconductor industries. MD allows for a compact system design by utilizing the membrane surface as an evaporation interface. PFAS-based surface modifiers are widely used due to their strong hydrophobicity, and MD membranes with water vapor permeance exceeding 10^{-6} [mol m^{-2} s^{-1} Pa^{-1}] have been reported. However, due to environmental and health concerns, there is a demand for safer and more sustainable alternatives. This study aims to improve the acid resistance of PFAS-free surface-modified ceramic membranes. Porous tubular α-alumina substrates (1TC, Iwao Jiki, average pore size: 0.9 μm) were treated with six types of silicon alkoxysilanes: three PFAS-free Trimethoxypropylsilane(C3),Hexyltrimethoxysilane (C6), Decyltrimethoxysilane(C10) and three PFAS-based Trifluoropropyltrimethoxysilane(C3),Nonafluorohexyltrimethoxysilane(C6), Perfluorodecyltriethoxysilane (C10). The membranes were heated at 250℃ for 2 hours. Unreacted alkoxysilane sites were post-treated with hexamethyldisiloxane (HMDS) or dimethylmethoxysilane (DMDMOS). Membrane performance was evaluated through N_2 and water vapor permeation tests at room temperature. Acid resistance was assessed by immersion in 10 wt% sulfuric acid at 90℃. After the initial surface treatment, the N_2 permeance of PFAS and PFAS-free membranes was 7.0×10^{-6} and 5.7×10^{-6} [mol m^{-2} s-1 Pa^{-1}]. After post-treatment, N2 permeance was increased to 7.5×10-6 , 5.7×10-6 . This may be due to reorientation of disordered hydrophobic chains within the initial layer. All membranes maintained water vapor permeance above 10^{-6} after post-treatment. In acid durability tests, PFAS membranes showed approximately 1.7 times higher resistance. Their high durability is attributed to their strong hydrophobicity and chemical stability. However, PFAS-free membranes post-treated with HMDS achieved over 300 hours. The bulky structure of PFAS groups may have inhibited the post-treatment reaction, whereas PFAS-free surfaces allowed for more effective secondary modification.

Keywords: *Membrane Distillation, Surface Modification, PFAS-Free, Acid Resistance*

Paper ID: A047

Charge-Sign-Independent Separation of Mono- and Divalent Ions with Nanofiltration Membranes

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ABSTRACT

Achieving precise selective separation of monovalent and divalent cations, aswell as anions, is vital yet challenging in practical applications involving complex component treatments. Current membranes are typically effective for separating either cation pairs or anion pairs. To address this issue, a straightforward strategy for fabricating a nanofiltration (NF) membrane is developed that selectively permeates monovalent ions. This study focused on neutralizing the surface charge and tuning the pore size distribution of the polyamide membranes through a secondary interfacial polymerization using a zwitterionic copolymer consisting of 2-methacryloyloxyethyl phosphorylcholine and 2-aminoethyl methacrylate hydrochloride. The optimized NF membrane prepared in this study, with a near-neutrally charged membrane surface and appropriate pore size distribution, demonstrates favorable performance in precisely separating monovalent and divalent ions, irrespective of the ion charge sign. The optimum NF membrane features high selectivity for both Cl^-/SO_4^{2-} (93) and Li^+/Mg^{2+} (67) ion pairs, along with high water permeance of 8.5 L m^{-2} h^{-1} bar^{-1}, making it competitive with many reported membranes. This study offers new insights into the ion-selective mechanisms of polyamide membranes for monovalent/divalent ions and may guide the development of advanced membranes with single-solute selectivity.

Keywords: *Polyamide Membrane, Zwitterionic Copolymer, Nanofiltration, Ion Separation*

Paper ID: A048

GOM-Based Membrane Electrode Assembly for Ozone Production by Water Electrolysis

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ABSTRACT

Ozonation production by water electrolysis has attracted increasing attention due to the environmental benign and high efficiency of O3. As an ion-conductive membrane for efficient and sustainable water electrolysis, graphene oxide membrane (GOM) has been recently found promise for a viable alternative to conventional Nafion membranes [1]. To know the feasibility of its further application in electrochemical ozone production (EOP), a graphene oxide (GO) series membranes (hydrophilic sulfonated GO (GO-SO3H) linked with monovalent alkali metal ions were synthesized to fabricate the membrane for ozone production by water electrolysis. The membrane was then used for fabrication of membrane assembly electrode (MEA), with the anode of a quasi-single-crystal PbO2 with (110) and (101) exposed facets for EOP by regulating the addition of PVP in the hydrothermal synthesis of PbO2. It demonstrated that when the mass ratio of PVP:Pb(CH3COO)2·3H2O was controlled as 48:100 (PVP-48), the structure of PbO2 exhibited a quasi-single-crystal structure with exposed (110) and (101) facets, which achieved the highest current efficiency of 11.9 % at a current density of 0.83 A/cm2, and showed excellent EOP performance and stability for the 120 h electrolysis [2]. The origin of the EOP activity of PbO2 was further unrevealed from the electrochemical surface state analysis using density functional theory (DFT) calculations, and found that rutile PbO2 (101) with the“*in-situ*”generated OV exhibited superior EOP activities, outperforming the (111) and (110) surfaces [3]. Finally, the transport of protons, electrons, and water and gases molecules in the proposed MEA were discussed altogether, providing theoretical support for the water electrolysis for ozone generation.

Keywords: *Sulfonated Graphene Oxide, Proton Exchange Membrane, Membrane Electrode Assembly, Electrochemical Ozone Production, Water Electrolysis*

Paper ID: A049

The Kinetics Study of Crosslinking Reaction in Polymeric Membranes for Gas Separation Performance Enhancement: A Review

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ABSTRACT

Polymeric membranes have been intensively developed for gas separation applications. Ongoing research has progressed rapidly to develop high-performance polymer-based membrane materials. Chemical crosslinking in polymeric membranes has become an emerging membrane modification to improve membrane performance by improving its permeation selectivity and resistance towards harsh operating conditions. Despite its significant achievement, the fundamentals behind this crosslinking reaction have been rarely discussed systematically, and even less is known about the kinetics of the crosslinking reaction that happens between the crosslinker and polymeric membrane. Controlling the kinetics is essential for enhancing and optimizing membrane performance, which by understanding the kinetics of the crosslinking reaction helps in refining the crosslinking strategy, leading to a developed membrane with desired properties. Therefore, this review focuses on the fundamental ideas behind the chemical crosslinking reaction, including the strategy for developing kinetics methodology and analysis. This review aims to provide comprehensive knowledge and motivation for advancing the development of crosslinked polymer-based membrane materials for gas separation.

Keywords: *Kinetics, Crosslinking, Polymeric membranes, Gas separation, Membrane*

Paper ID: A050

A Thermodynamic Controlled Sintering Strategy for Suppressing Element Evaporation and Enhancing Hydrogen Permeability in Perovskite Membranes

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ABSTRACT

Hydrogen, serving both as a clean energy source and an industrial feedstock, has experienced a substantial increase in global demand. The application of advanced membrane technology, notably perovskite membranes, has the potential to offer an economically viable solution for the recovery of hydrogen from raw hydrogen mixtures. The mixed proton and electronic conducting (MPEC) perovskite hydrogen permeable membrane enables hydrogen separation without the need for an external circuit. Theoretically, it offers 100% selectivity for hydrogen and works at temperatures ranging from 600 to 1000 ℃, making it highly promising for practical application of high purity hydrogen separation. However, it is imperative to consider the challenges associated with the evaporation of active metal elements during high-temperature sintering processes, particularly at ultra-high temperatures. In this presentation, a thermodynamic-controlled sintering strategy (TCS) has been employed to address the challenges. This strategy can reduce the vapor transport during the sintering process by enhancing the metal vapor concentration, thereby shifting the equilibrium towards the solid phase and reducing evaporation. The application of the controlled sintering process directly caused the hydrogen permeation flux to mark an improvement of approximately fivefold. And impact of varying fluorine doping levels was also investigated, demonstrating a further improvement in performance at low and medium temperatures. The combined use of anion doping and TCS strategy as an effective strategy for tailoring perovskite materials to meet the stringent requirements of critical operating conditions and proves to be versatile and highly relevant across a spectrum of demanding high-temperature applications, such as hydrogen separation, SOFCs, and membrane reactors.

Keywords: E*lements Evaporation, Hydrogen Separation, Mixed Proton and Electronic Conducting, Perovskite, Anion Doping*

Paper ID: A051

DPD Simulation on the Formation of Polyamide Thin-Film via Interfacial Polymerization and Experimental Verification

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ABSTRACT

The structure and physicochemical properties of the polyamide (PA) layer formed via interfacial polymerization (IP) play a decisive role in determining the permeability and selectivity of thin-film composite (TFC) membranes. Therefore, optimizing this layer is crucial for enhancing TFC membrane performance in practical applications. However, due to the challenges associated with real-time monitoring and characterization of the IP process, the fundamental understanding of membrane formation mechanisms and the synthesis–structure–performance relationship remains limited. In this study, a novel large-scale model based on the dissipative particle dynamics (DPD) simulation method was developed to simulate the IP process, wherein aqueous- and oil-phase monomers react to form a thin PA layer. A water–piperazine (*water–PIP*)/n-hexane–trimesoyl chloride (*n-hexane–TMC*) system was employed as a representative example. The effects of reaction time and monomer concentration on IP kinetics and PA layer morphology were systematically investigated by analyzing parameters such as number-average molecular weight, total number of chains, polymer chain length distribution, membrane thickness, and reactive group distribution during the simulation. As the reaction progressed, monomers at the interface gradually reacted and aggregated, forming a thin layer with fine peak-valley structures. It was observed that increasing monomer concentration led to the formation of thicker films and shorter polymer chains, reducing membrane porosity while increasing membrane density. Furthermore, the simulation results were validated through support-free IP experiments, demonstrating excellent agreement with the simulation predictions. These findings provide valuable insights into PA layer formation and offer a theoretical basis for optimizing TFC membrane fabrication.

Keywords: *Dissipative Particle Dynamics, Interfacial Polymerization, Thin Film Composite Membranes*

Paper ID: A052

Preparation of a Polysulfone Loose Nanofiltration Membrane with Gradient Structure via Hybrid-Induced Phase Separation for the Efficient Separation of Dyes/Salts

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ABSTRACT

From a sustainable development perspective, loose nanofiltration (NF) membranes with high permeability and exceptional separation capabilities for dye/salt mixtures have gained increasing attention for treating dyeing wastewater. This study introduces a novel polysulfone (PSf) loose NF membrane with a gradient structure, prepared using a one-step hybrid induced phase separation (HIPS) method without post-treatment. Sulfolane (SFL) was initially selected as the diluent for PSf, enabling the formation of an asymmetric cross-sectional structure composed of a bi-continuous main body and a thin skin layer. This structure was induced by the mass transfer between SFL and the coagulation medium (cold water) during the HIPS process. Additionally, the membrane's surface pore size was reduced by incorporating PEG400 as an additive. The results showed that, with PSf and PEG400 concentrations of 20 and 2.5 wt.%, respectively, the optimized PSf loose NF membrane exhibited a significantly higher pure water permeability (49.53 L/(m²·h·bar)) and a superior rejection rate of 99.3% for a small molecular dye (EBT), while allowing over 90% of NaCl and Na_2SO_4 salts to permeate. The optimized PSf loose NF membranes demonstrated stable high dye rejection and maintained good permeability for NaCl during long-term stability testing. Moreover, this study provides a fundamental framework for developing loose NF asymmetric membranes for dye removal from salt wastewater.

Keywords: *Polysulfone, Loose Nanofiltration Membrane, Hybrid Induced Phase Separation, Sulfolane, Dyes/Salt Separation*

Paper D: A053

Thermal Shielding and Vapor Transport Enhancement in MOF-Enabled Membranes for Membrane Distillation

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ABSTRACT

Membrane distillation (MD) effectively treats high-salinity brines and achieves zero-liquid discharge by rejecting non-volatile solutes. Its ability to utilize low-grade heat (LGH) is advantageous, as LGH's low feed temperatures create the mild temperature gradient necessary for vapor transfer across a hydrophobic membrane. However, heat loss through membrane conduction raises permeate side temperatures and reduces the vapor transfer driving force, limiting MD performance. Enhancing thermal efficiency requires reducing membrane thermal conductivity, achievable by modifying membrane properties like chemical composition and porosity. This study presents a metal-organic framework-enabled membrane (MEM) with a hierarchical porous structure that significantly lowers thermal conductivity. Using a mild chemical bath deposition method, ZIF-8 is uniformly coated onto electrospun PVDF-HFP (PH) fibers, forming a composite structure with microporous ZIF-8 nanocrystals, mesoporous PH fibers, and a macro-porous network. The MEM features a mean pore size of 0.47 μm, a liquid entry pressure of 157 kPa, a thickness of 100 micrometers, and a water contact angle of 147 degrees. It achieves a thermal conductivity of 0.0316 W m^{-1} K^{-1}, nearly half that of commercial PVDF membranes. In direct contact MD tests, the MEM shows superior performance. At a feed temperature of 60 °C and permeate temperature of 20 °C, it achieves a water flux of 44.5 LMH, compared to 18.7 LMH for commercial PVDF. The MEM's thermal efficiency is 71.3%, significantly higher than the 35% of commercial PVDF. Its unique porous structure, filled with air, minimizes heat loss, impedes heat transfer, and restricts gas flow, reducing thermal conduction. Hierarchical channels slow energy migration, sustaining a high vapor transfer driving force. Multi-scale simulations confirm reduced thermal conductivity. The study highlights the potential of using metal-organic frameworks for enhancing MD processes, demonstrating significant advancements in utilizing low-grade heat for water desalination. By addressing the limitations of conventional membranes, the MEM offers a sustainable approach to energy-efficient and environmentally friendly desalination technologies.

Keywords: *Direct Contact Membrane Distillation, ZIF-8, Thermal Efficiency, Desalination*

Paper ID: A054

Concentration of Pineapple Juice Using Forward Osmosis (FO): Effects of Draw Solution and Membrane on Process Performance and Physicochemical Properties of Concentrated Juice

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ABSTRACT

The current study was conduct to concentrate pineapple juice by forward osmosis, studying the effect of micro-filtration pre-treatment and membrane type including Thin-Film Composite (TFC) and Cellulose Triacetate (CTA). Moreover, the FO performance while using monovalent substances (NaCl) and mixed of monovalent and divalent ($ZnSO_4$, $MgSO_4$) as draw solutions was investigated. It was found that pre-treatment by micro-filtration had a potential to decreased the all of microorganisms in pineapple juice with nonsignificant affect the total acid and vitamin C content ($p<0.05$). The turbidity of pre-treatment juice was also decreased as indicated by the lower value of %Haze. In comparing of permeate flux by using TFC and CTA membranes and 3 types of draw solutions (NaCl, NaCl:$MgSO_4$ and NaCl:$ZnSO_4$) pre-treatment juices presented the greater result compared to fresh juices. According to the specific characteristic as water permeability, the TFC membrane had approximately 2-times higher of permeate flux than the CTA membrane. At the same level of osmotic pressure of three different draw solution NaCl, mixed NaCl:$MgSO_4$ and NaCl:$ZnSO_4$, it was found the similar water permeate flux values while the significantly ($p<0.05$) different reverse flux values of Na+ ion. Reverse diffusion of Mg and Zn element from mixed draw solution present the beneficial to the final product. Forward osmosis concentration was able to increase the juices concentration 4.41- 4.27 times with slightly degrade of vitamin C and phenolic compound and 22 - 42 % of antioxidants capacity were preserved in final product. However, the colour of the final product was different from the original juice. The brightness greenness and yellowness of juice were improved with the increasing of total soluble solid content.

Keywords: *Forward Osmosis, Pineapple Juice, Draw Solution, Reverse Solute Flux*

Paper ID: A055

Anion-Doped Perovskite Membranes for Oxygen Permeation: A Leaching-Suppressed Fabrication Strategy

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ABSTRACT

Nitrogen-free combustion, characterized by fuel oxidation in O_2/CO_2 mixtures or pure oxygen, demonstrates strategic advantages in energy-intensive sectors. Mixed ionic-electronic conducting (MIEC) membranes, particularly hollow fiber architectures, are pivotal for such systems due to their intrinsic oxygen selectivity and mechanical resilience. Nevertheless, industrial implementation faces critical barriers from elemental leaching during conventional membrane fabrication, which detrimentally impacts oxygen permeability and operational stability. To address the above issues, we proposed a fluorine-doping strategy to enhance the oxygen permeability of the parent material, while simultaneously employing a saturated solution to inhibit elemental leaching during the preparation of the perovskite-type membranes. Among various perovskite-type membranes, $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}\ O_{3-\delta}$ (BSCF) stands out as the preferred doping candidate, owing to its superior ionic conductivity and tunable defect chemistry. By introducing fluoride ions with high electronegativity, the electronic structure of the F-doped BSCF can be effectively regulated, thereby improving its electrical conductivity. Meanwhile, the doping of fluoride ions helps to stabilize the crystal structure of the material and enhance its thermodynamic stability. Compared with the undoped parent material, its performance is improved by approximately 300%. A modified phase-inversion technique employing precursor-saturated coagulation baths to mitigate elemental leaching during hollow fiber formation. This synergistic approach of anion substitution and leaching suppression establishes a viable fabrication protocol for high-performance oxygen transport membranes, these findings establish a novel pathway toward industrial implementation of oxygen permeation membranes in nitrogen-free combustion systems.

Keywords: *Anion-Doped Perovskite, Elemental Dissolution, Oxygen-Permeable Membrane, Hollow Fiber Membrane*

Paper ID: A056

Exploring the Potential of Membrane-Based Hybrid Process for Drill Site Wastewater Treatment

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ABSTRACT

Drilling site wastewater resulting from drilling activities is complex natured wastewater that, on disposal to the environment, could cause severe environmental issues. The treatment of oil drill-site wastewater has not been explored much, and understanding its characteristics and optimizing the treatment process is required. The study examines the potential of a membrane-based treatment system for drill site wastewater treatment and possible options for fabricating a portable treatment system. This study investigates the possibility of UF and RO-based membrane-based hybrid wastewater using electrocoagulation (EC) as a pre-treatment step with aluminum electrodes for drill-site wastewater treatment followed by membrane treatment. The EC has been optimized with current density, pH and reaction time as optimizing parameters. The hybrid process aims to remove the oxidizing matter as chemical oxygen demand (COD) from drilling site wastewater. The percentage of COD achieved from the EC unit varied from 45 to 79 %. Adding a PSF-based UF membrane unit enhances the process and gives an additional COD removal of 15-20%. The effluent passing through the RO membrane provides a COD removal of around 99%, making it reusable for many purposes. The results show that UF and RO membrane-based hybrid units can efficiently treat drilling site wastewater. The inclusion of more process parameters and more emphasis on optimization can lead to better results. This study's findings could be effectively used to develop large-scale membrane-based treatment processes through electrocoagulation.

Keywords: *Membrane, Electrocoagulation, Hybrid Process, Drilling Wastewater, Current Density.*

Paper ID: A057

Directed Assembly of SSZ-13 Zeolite Membranes with Controllable Thickness and Scale

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ABSTRACT

Zeolite membranes with uniform pore sizes are ideal candidates for molecular sieving separation. CHA zeolite membranes are particularly promising for Kr/Xe [1] and natural gas upgrading [2]. Previously, we addressed the issue of thermal stress mismatch between the zeolite membrane and its support using template modulated crystal transition approach [3]. However, critical challenges persist in efficiently controlling membrane thickness to enhance permeation flux and reproducing scaled-up membranes. Herein, we present a facile strategy to synthesize highly CO_2-selective SSZ-13 zeolite membranes by the ball-milled seeds integration. The preformed d6r species functioned as structural binders, promoting the integration of discrete seed particles into a continuous membrane through the non-classical crystallization pathways. The membrane thickness is equivalent to the seed layer, which can be well modulated by the facile dip-coating technique. The 4-fold reduction of membrane thickness (from 2 to 0.56 μm) led to an exceptionally high CO_2 permeance of 1.0×10^{-6} mol m^{-2} s^{-1} Pa^{-1} (~ 3000 GPU) and a CO_2/CH_4 selectivity of 158, exceeding Robeson's upper bound. The membranes demonstrate robust adhesion to the substrates, which resist a pressure difference of 2 MPa regardless of the pressure applied from the membrane or substrate side. The scalability of our novel method is validated by the successful synthesis of more than 100 membrane samples (40 cm length) in a single batch with uniform performance. The reliable synthesis protocol and the exceptional stability pave the way for the industrial application of zeolite membranes for gas separation.

Keywords: *SSZ-13 membrane, Crystallization, Scale up, Ultrathin membrane, CO_2 separation*

Paper ID: A058

Thermal Cross-Linking as a Versatile Route to High-Performance Gas Separation Membranes

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ABSTRACT

Membrane-based separations offer a compact and energy-efficient alternative to conventional thermal processes. However, many polymeric membranes suffer from plasticization under high pressures of condensable gases, resulting in a loss of selectivity and long-term performance. This study presents a thermal cross-linking strategy to simultaneously enhance gas permeation and plasticization resistance in polymeric membranes. Two distinct polymer systems are explores: (1) a blend of polyimide and ladder-structured polysilsesquioxane (LPSQ), and (2) perfluorinated aromatic polymers (PAPs). In the former, amidation and decarboxylation reactions drive thermal cross-linking between polyimide and LPSQ, yielding a membrane with increased cavity interconnectivity. This structural evolution leads to a significant enhancement in gas permeation rate and a plasticization resistance extended up to 22 bar. Molecular dynamics simulations confirm that the improved performance stems from the formation of larger and more interconnected free volume elements during cross-linking. In the second system, defluorination-induced thermal cross-linking of PAPs produces a rigid, extrinsically microporous network. This transformation results in over a 40-fold increase in CO_2 permeation rate and a plasticization threshold exceeding 40 bar. These cross-linked membranes also retain structural integrity and performance over extended use, demonstrating excellent long-term stability. Overall, this work underscores the potential of thermal cross-linking as a scalable and effective approach to overcoming the intrinsic limitations of conventional polymeric gas separation membranes, paving the way for next-generation materials with superior performance under industrial conditions.

Keywords: *Thermal Cross-Linking, Plasticization Resistance, Microporous Polymers, Gas Permeation, Membrane Stability*

Paper ID: A059

A Novel Green Plasma-Assisted Nonsolvent-Induced Phase Separation Method to Fabricate Superhydrophobic, Self-Cleaning, Piezoelectric PVDF Membranes for Direct-Contact Membrane Distillation

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ABSTRACT

Superhydrophobic, self-cleaning, and piezoelectric membranes based on poly(vinylidene difluoride) (PVDF) hold significant promise for addressing global water and energy challenges. Here, we present a novel plasma-assisted nonsolvent-induced phase separation (PANIPS) method to fabricate multifunctional PVDF membranes without chemical modifications or post-treatments. In the PANIPS process, as-cast membranes were exposed to argon microplasma under controlled humidity conditions before immersion into a water-based coagulant bath. The plasma treatment induced localized vapor condensation and surface coarsening, enabling rapid and precisely tailored phase separation. Additionally, the plasma treatment promoted the formation of electroactive β and γ phases and suppressed the non-electroactive α phase, significantly enhancing the piezoelectric properties of PANIPS membranes. Ternary phase diagrams, dynamic phase inversion studies, and optical emission spectroscopy were utilized to elucidate the underlying mechanisms. By systematically varying the PVDF molecular weight (255–1367 kDa) and the number of plasma treatment cycles, membrane morphology could be accurately modulated from globular to bicontinuous structures. Optimized PANIPS membranes exhibited water contact angles ranging from 151.2° to 166.4°, sliding angles between 6.7° and 29.7°, and contained more than 99% electroactive β and γ phases. Piezoelectric performance tests revealed that PANIPS membranes achieved a piezoelectric coefficient (d_{33}) of up to 10.5 pC N^{-1} and generated an output voltage of up to 10 Vpp. In direct contact membrane distillation (DCMD) tests, these membranes demonstrated excellent fouling and wetting resistance, effectively producing pure water from hypersaline solutions (10 wt% NaCl) and feeds containing dye (1000 ppm Rose Bengal), organic foulant (humic acid), or surfactant (SDS). This study highlights the PANIPS method as an innovative, versatile, and environmentally friendly technique for precisely tailoring membrane morphology and functionality. The approach significantly advances PVDF-based materials for seawater desalination and opens promising opportunities in fields such as motion sensing and piezoelectric energy harvesting.

Keywords: *Membrane Distillation, Superhydrophobic Membrane, Piezoelectric, Anti-Fouling, Anti-Wetting*

Paper ID: A059

Development of Trimethylmethoxysilane-Derived Silica Membranes via Chemical Vapor Deposition for High Hydrogen Permeance with High Hydrogen/Nitrogen Selectivity

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ABSTRACT

Silica membranes having high H_2 permeance, high H_2/N_2 selectivity and high hydrothermal stability are strongly required for developing membrane reactors to produce high-purity hydrogen from a variety of feedstocks. It is known that the chemical structure of the silica precursor often determines the membrane performances. For this purpose, we successfully developed novel hydrogen-selective silica membranes via the counter-diffusion chemical vapor deposition (CVD) of trimethylmethoxysilane (TMMOS) as a silica precursor with oxygen. Throughout systematically varying the CVD conditions, in particular the concentration of TMMOS vapor, the CVD reaction time and the flow rate of N_2 to supply the TMMOS vapor in the CVD furnace, we determined the optimal preparation conditions for these parameters were 0.81 - 0.94 mol m^{-3}, 60 min and 200 mL min^{-1}, respectively. The permeances of H_2 and N_2 at 773 K were 2.9×10^{-7} and 1.7×10^{-10} mol m^{-2} s^{-1} Pa^{-1}, respectively. The average pore size estimated by the normalized Knudsen-based permeance (NKP) method was 0.37 nm. We also examined the hydrothermal stability of the TMMOS-derived membranes, which indicated that H_2 permeance after the exposure to the gas mixture of steam and H_2 with a molar ratio of 3 to 1 under 0.3 MPa and 773 K was higher than the dimethoxydimethylsilane-derived silica membrane and that N_2 permeance was almost stable even after the exposure. In conclusion, the TMMOS-derived membranes are superior in H_2 permeance, H_2/N_2 selectivity and hydrothermal stability, which will be used for developing membrane reactors to produce high-purity hydrogen from methane in biogas.

Keywords: *Trimethylmethoxysilane, Chemical vapor deposition, Silica membranes, Hydrogen*

Development of Trimethylmethoxysilane-Derived Silica Membranes via Chemical Vapor Deposition for High Hydrogen Permeance with High Hydrogen/Nitrogen Selectivity

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ABSTRACT

Silica membranes having high H_2 permeance, high H_2/N_2 selectivity and high hydrothermal stability are strongly required for developing membrane reactors to produce high-purity hydrogen from a variety of feedstocks. It is known that the chemical structure of the silica precursor often determines the membrane performances. For this purpose, we successfully developed novel hydrogen-selective silica membranes via the counter-diffusion chemical vapor deposition (CVD) of trimethylmethoxysilane (TMMOS) as a silica precursor with oxygen. Throughout systematically varying the CVD conditions, in particular the concentration of TMMOS vapor, the CVD reaction time and the flow rate of N_2 to supply the TMMOS vapor in the CVD furnace, we determined the optimal preparation conditions for these parameters were 0.81 - 0.94 mol m^{-3}, 60 min and 200 mL min^{-1}, respectively. The permeances of H_2 and N_2 at 773 K were 2.9×10^{-7} and 1.7×10^{-10} mol m^{-2} s^{-1} Pa^{-1}, respectively. The average pore size estimated by the normalized Knudsen-based permeance (NKP) method was 0.37 nm. We also examined the hydrothermal stability of the TMMOS-derived membranes, which indicated that H_2 permeance after the exposure to the gas mixture of steam and H_2 with a molar ratio of 3 to 1 under 0.3 MPa and 773 K was higher than the dimethoxydimethylsilane-derived silica membrane and that N_2 permeance was almost stable even after the exposure. In conclusion, the TMMOS-derived membranes are superior in H_2 permeance, H_2/N_2 selectivity and hydrothermal stability, which will be used for developing membrane reactors to produce high-purity hydrogen from methane in biogas.

Keywords: Trimethylmethoxysilane, Chemical Vapor Deposition, Silica Membranes, Hydrogen

Paper ID: A061

Tailoring Substrate Structure and PDMS Surface Coatability to Develop Advanced Pebax Hollow Fiber Membranes for CO2 Separation

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ABSTRACT

Eco-friendly CO_2 capture technologies are critical for mitigating global warming. This study systematically elucidates the design and fabrication principles of composite hollow fiber membranes consisting of an inner polyethersulfone (PES) substrate, a polydimethylsiloxane (PDMS) gutter layer, and an outer Pebax selective layer were revealed for CO_2/N_2 separation. The resultant Pebax/PDMS/PES composite hollow fiber membranes exhibit a CO_2 permeance of 1253 GPU and an ideal CO_2/N_2 selectivity of 34.9 at 0.1 MPa and 25 ℃. They exhibit comparable CO_2/N_2 selectivity but boast a CO_2 permeance that is 1 to 2 times higher than other Pebax based composite hollow fiber membranes reported in the literature. The much higher CO_2 permeance highlights the effectiveness of proposed strategies in designing multi-layer composite hollow fiber membranes for CO_2 capture. Two major challenges were systematically addressed during the development of these composite membranes. The first involved the minimization of PDMS intrusion during the coating process onto PES substrates. This was achieved by optimizing the spinning parameters, including air gap distance, coagulation bath temperature, and bore fluid composition, to fabricate substrates with a dense outer surface and a porous inner structure, thereby reducing PDMS intrusion and gas transport resistance. The second challenge concerned the inherently hydrophobic nature of PDMS surfaces, which was mitigated by plasma treatment to enhance surface wettability and facilitate the subsequent Pebax coating. The optimal Pebax/PDMS/PES membranes also demonstrated stable mixed gas performance using an N_2/CO_2 feed of 85/15 (mol/mol%) at 0.2 MPa and 25℃ over one month, achieving a CO_2 permeance of 829 GPU and a CO_2/N_2 selectivity of 32.5.

Keywords: *CO_2 Capture; Composite Hollow Fiber Membranes; PDMS Modification; Dip-Coating; PEBAX Based Membranes*

Paper ID: A062

Tuning Membrane Structure and Fouling Resistance with Chitin-Based Additives: Study on Polyketone-Chitin Propionate Membrane

ABSTRACT

Reusability remains a critical challenge commonly encountered in membrane applications for separation processes [1]. In water-in-oil (W/O) emulsion separation, fouling is specifically caused by hydrophilic interactions between water molecules and the membrane surface [2]. Enhancing membrane hydrophobicity offers a promising solution to this issue. However, most developments in hydrophobic modification rely on fluorinated compounds, which are known to pose environmental and human health risks [3,4]. In this study, we introduce chitin propionate (CP), a naturally derived material, as a more environmentally friendly alternative for hydrophobic membrane modification. CP remains largely unexplored, particularly inmembrane development, making it a novel and valuable candidate for advancing modified membrane materials. We incorporated CP into the polyketone (PK) membrane matrix through the Non-solvent Induced Phase Separation (NIPS) method, resulting in flat-sheet membranes. Characterization results confirmed the presence and influence of CP on the PK membrane structure, including changes in morphology, functional groups, chemical composition, and wettability. The water contact angle (WCA) measured in oil exceeded 150º, indicating excellent hydrophobicity. Separation performance was evaluated using a W/O emulsion (toluene-based) in cross-flow mode over 20 cycles. The modified PK-CP membrane exhibited improved reusability, with up to a 55% enhancement compared to the pristine PK membrane. Oil purity in the permeate reached over 99.8%, demonstrating high separation selectivity. The Cassie – Baxter wetting state of the PK-CP membrane under oil facilitated easier membrane cleaning and reduced the potential for water fouling compared to unmodified PK membranes. Although the hydrophobicity achieved may not be as high as that obtained with fluorinated compounds, CP shows promising potential as a green hydrophobic modifier and warrants further exploration to optimize its performance in membrane applications.

Keywords: *Anti-Fouling Membrane, Water-Oil Separation, Chitin Propionate, Polyketone, Hydrophobicity*

Paper ID: A063

Optimization of Scale Inhibition Performance of Nanofiltration Membranes Modified with Nanoscale Ca-DTPMP

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ABSTRACT

Mineral scaling, driven by high concentrations of calcium and sulfate ions, remains a major challenge in water treatment processes such as seawater desalination and industrial wastewater management. In this study, nanoscale Ca-DTPMP was incorporated into polyamide-based nanofiltration membranes to enhance their scaling resistance. The modified membranes achieved a scale inhibition rate exceeding 95% in scaling tests. Stability assessments showed that flux ($9.26\ L/m^2 \cdot h \cdot bar$) and rejection rate (> 90%) remained stable over one week of cross-flow testing in 25 mM CaSO4 solution, with no significant decline. These results demonstrate the effectiveness and durability of nano-Ca-DTPMP-modified membranes, offering a promising strategy to extend membrane lifespan and reduce operational costs in real-world water treatment applications.

Keywords: *Nanoscale Ca-DTPMP, Scale Inhibition, Nanofiltration Membrane, Scaling Fouling*

Paper ID: A064

Optimization of Seawater Desalination Plants Utilizing High-Recovery Brackish Reverse Osmosis Systems

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ABSTRACT

Seawater reverse osmosis (SWRO) is widely adopted for water production in water-scarce regions. To meet strict water quality standards and increase output, recent SWRO plants often employ a two-pass reverse osmosis (RO) system, with the second pass typically using two-stage brackish water reverse osmosis (BWRO). However, conventional two-stage BWRO faces limitations in maximizing recovery. Recent studies have demonstrated that semi-batch reverse osmosis (SBRO) can achieve higher recovery than two-stage BWRO, offering a promising alternative. Building on these findings, integrating SWRO with SBRO in two-pass systems could further enhance overall water recovery in SWRO desalination. This study investigates the performance of SWRO desalination plants utilizing SBRO as a high-recovery BWRO process. The specific energy consumption (SEC) of SBRO and the overall RO system exhibited different trends as system recovery increased. As SBRO recovery rose from 70% to 98%, the corresponding RO system recovery improved from 38.3% to 44.6%, and the SEC of SBRO increased from 0.14 to 0.20 kWh/m^3. However, due to the greater product volume resulting from high-recovery SBRO, the overall SEC of the RO system decreased from 3.09 to 2.73 kWh/m^3. Although blended permeate quality was influenced by SBRO operation, the change remained minimal. With a feed total dissolved solids (TDS) of 203 mg/L (i.e., SWRO permeate), SBRO achieved significant TDS reduction, with SBRO permeate TDS increasing only modestly from 3 to 20 mg/L as recovery increased. The blended permeate TDS rose slightly from 108 to 120 mg/L, indicating low impact on overall water quality. These results suggest that increasing SBRO recovery enhances the overall RO system performance, but optimal SBRO operation is essential to maximize energy and water quality benefits. This study represents the first attempt to integrate SWRO and SBRO to develop more energy-efficient SWRO desalination plants.

Keywords: *Seawater Desalination, Two-Pass Reverse Osmosis, Semi-Batch Reverse Osmosis, Specific Energy Consumption, Optimization.*

Paper ID: A065

Fabrication of Photothermal Membrane by Depositing Molybdenum Disulfide on Mullite Hollow Fiber Membrane for Seawater Desalination Using Photothermal Membrane Distillation

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ABSTRACT

Membrane distillation (MD) is a hybrid separation process that combines membrane and thermal technologies. While MD offers several advantages over conventional desalination methods, such as lower operating temperatures and the ability to treat high-salinity feeds, its progression toward large-scale industrial deployment remains constrained by significant energy demands. Photothermal membrane distillation (PMD) has emerged as a promising and sustainable alternative for seawater desalination, utilizing solar-absorbing coatings on membrane surface to harness solar energy and reduce external heating requirements. In this study, a mullite-based ceramic hollow fiber membrane was coated with MoS_2 using a hydrothermal deposition technique. The effect of varying the concentrations of the precursors—ammonium molybdate tetrahydrate and thiourea—was investigated, while maintaining a fixed synthesis temperature of 200 °C and duration of 20 hours. The resulting membranes were characterized using scanning electron microscopy (SEM) to evaluate MoS_2 morphology, energy-dispersive X-ray spectroscopy (EDX) for elemental composition, and water contact angle measurements to assess hydrophobicity. Preliminary results indicated that a higher sulfur-to-molybdenum (S:Mo) ratio led to the formation of thinner, more flower-like MoS_2 structures with enhanced surface coverage and increased surface roughness—attributes beneficial for light absorption and potentially improved hydrophobicity. This study highlights the in-situ hydrothermal synthesis of MoS_2 on mullite ceramic substrates, demonstrating how variation in precursors concentration can effectively tailor the surface morphology of MoS_2 and lays the groundwork for future performance evaluation in direct contact membrane distillation (DCMD) applications using light as energy source.

Keywords: *Photothermal, Molybdenum Disulfide, Hydrothermal, Membrane Distillation, Desalination*

Paper ID: A066

Machine Learning Analysis of Membrane Performance in Semi-Batch Reverse Osmosis

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ABSTRACT

The global water scarcity crisis has significantly increased the demand for water reuse, yet public concerns regarding treated water quality highlight the necessity for advanced treatment technologies. Membrane-based processes, particularly reverse osmosis (RO), have been recognized as solutions capable of achieving stringent water quality standards. However, conventional RO systems are limited by low water recovery, reducing their suitability for large-scale water reuse applications. Semi-batch reverse osmosis (SBRO) has been developed to address this constraint, offering enhanced water recovery and improved energy efficiency. Despite these advancements, SBRO systems remain vulnerable to membrane fouling and scaling, which hinder high-recovery operation and increase energy consumption. Although various input variables influence membrane performance, their impacts have not been systematically analyzed. This study aims to employ machine learning (ML) techniques to investigate membrane performance in SBRO systems. Experimental data were collected under diverse operating conditions, with input variables such as feed flow rate, permeate flux, feed conductivity, permeate conductivity, operating pressure, temperature, and pH. Several regression models were tested to predict changes in water permeability as the output variable, including linear regression, rational quadratic Gaussian process regression, and boosted trees. Among these, the linear model exhibited the lowest root mean square error and the highest R-squared value, indicating its suitability for further analysis. Subsequently, ML interpretation techniques were applied to assess the influence of operating variables on membrane fouling, generating an importance index based on Shapley value analysis. The feed flow rate exhibited the highest impact on model output, while operating pressure, feed conductivity, and temperature had comparatively lower effects. Further analyses under varying salt types, pH levels, water fluxes, and concentration rates were conducted to deepen the understanding of operational impacts. These findings provide valuable insights into optimizing SBRO performance for energy-efficient water reuse.

Keywords: *Semi-Batch Reverse Osmosis, High Recovery, Water Reuse, Machine Learning, Membrane Performances*

Paper ID: A067

Microporous Materials with Tailored Structural Properties for Enhanced Greenhouse Gas Separation

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ABSTRACT

Extensive research on gas separation has been performed, as industrial separation processes, namely cryogenic distillation and liquefaction, are considerably energy-intensive. In this regard, adsorbents and membranes that demonstrate favorable interaction with the desired greenhouse gases (i.e., carbon dioxide (CO2) and sulfur hexafluoride (SF6)) are selected due to their capability in performing effective separation at a lower energy penalty and a smaller plant footprint. Thus, this presentation shares several research works on novel nanoporous materials and membranes towards effective separation and capture of greenhouse gases. First, for the case of nanoporous materials, various material categories (zeolites, metal-organic frameworks, porous polymers, and porous carbons) are investigated for greenhouse gas adsorption. In general, adsorbents with hierarchical structures improve the adsorption kinetics of greenhouse gases without sacrificing their equilibrium and kinetic gas adsorption performance substantially. On the other hand, porous materials are utilized as fillers in mixed-matrix membrane (MMM) to improve the undesirable permeability-selectivity trade of relation in polymeric membranes. This can be investigated by utilizing fillers with various functionalities to tune the overall CO2-based separation performance. This behavior will potentially translate towards enhanced CO2 permeability as well as CO2/N2 (or CO2/CH4) selectivity.

Paper ID: A068

Organic Gatekeeper-Integrated Pebax®1657 Membranes with Enhanced Compatibility for Efficient CO_2 Capture

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ABSTRACT

CO_2 emission is a critical and urgent environmental issue contributing to global warming. Membrane separation technology is a promising method for CO_2 capture due to its easy fabrication, small footprint, and high scalability. In this study, sulfocalix[6]arene (SCA6), an organic macrocyclic cavitand, was utilized as the gatekeeper with an open cavity of 6 ~ 6.3Å and introduced into the Pebax®1657 membranes for efficient CO_2 separation. The effect of SCA6 in the polymer matrix was systematically investigated by various characterizations and experiments. The organic SCA6 molecules demonstrate good compatibility with the polymer matrix due to the strong interaction as confirmed by FTIR, thermal properties and EDX analyses. Upon to the addition of 1% SCA6, the CO_2 permeability of the membrane significantly increases from 155.56 Barrer to 224.62 Barrer (an enhancement of 45%), while the ideal CO_2/N_2 selectivity only slightly drops from 67.49 to 66.28 (a reduction of 2%). However, the excessive SCA6 addition may increase the membrane crystallinity, result in reducing the gas permeability, as validated by XRD and DSC analyses. Sorption studies indicate that the gas separation mechanism of the Pebax/SCA6-1% membrane shifts from solubility-dominated to diffusivity-dominated ones. On the other hand, the optimal Pebax/SCA6-1% membrane displays stable long-term mixed gas performance over 108 h using a CO_2/N_2 feed of 15/85 (v/v%) at 6 bar and 25℃. It has an average CO_2 permeability of 228.67 Barrer and a CO_2/N_2 selectivity of 70.01. The enhanced gas separation performance by incorporating SCA6 into Pebax arises from both gatekeepers and synergistic effects between them in MMMs, highlighting their potential for gas separation applications.

Keywords: *CO_2 Capture, PEBAX Membrane, Sulfocalix[6]Arene, Gatekeepers, Mixed Matrix Membranes, Gas Separation.*

Fibrous Materials for Solar-Driven Steam and Electricity Generation

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ABSTRACT

Solar-driven steam generation (SSG) systems, which enable sustainable clean water desalination and purification through photothermal conversion, have been extensively studied. Integrating solar-driven electricity generation (SEG)-including hydroelectricity, saline electricity, moisture electricity, and thermoelectricity-during the evaporation process offers an effective approach to comprehensive energy utilization. Fibrous materials, renowned for their outstanding processability, flexibility, robustness, lightweight nature, portability, and scalability, have garnered significant attention in the field of solar-driven steam and electricity generation (SSEG). These materials can be engineered to excel in critical processes such as water harvesting, proton dissociation, ion separation, and charge accumulation. To date, SSEG has made remarkable progress due to extensive research efforts focused on advanced materials, structural designs, techniques, and mechanistic studies. Hence, we propose to summarize developments of fibrous materials-based SSEG and reveal insights into principles of water-electricity cogeneration. The proposed prospective analyses and insights will be pivotal in driving practical development.

Keywords: *Fibrous Materials, Solar Desalination, Electricity Generation, Interfacial Engineering*

Paper ID: A070

Polydopamine-Coated HDPE Membranes: A Sustainable Approach for Efficient Pb(II) and Ni(II) Removal from Aqueous Solutions

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ABSTRACT

This study explores the utilization of high-density polyethylene (HDPE) plastic waste as a base material for membrane fabrication aimed at removing heavy metals from water. The membranes were prepared using the Thermal Induced Phase Separation (TIPS) method with mineral oil, followed by surface modification through dopamine dip-coating to enhance hydrophilicity. Water contact angle measurements indicated a significant decrease from 123° to nearly 0° after 24 hours of dopamine coating, confirming increased hydrophilicity. Fourier-transform infrared spectroscopy (FTIR) analysis revealed the presence of N-H functional groups, while scanning electron microscopy (SEM) showed no significant change in pore size (~0.08 μm). Pure water flux measurements demonstrated an increase from 685 $L/m^2 \cdot h$ (uncoated) to 8,228.7 $L/m^2 \cdot h$ after 6 hours of coating, followed by a decrease to 1,218.2 $L/m^2 \cdot h$ after 24 hours, likely due to pore blockage from excessive coating. Heavy metal rejection tests showed that the uncoated membranes achieved rejection rates of 66% for Pb(II) and 61% for Ni(II). After 6 hours of dopamine coating, the rejection rates increased significantly to 96.4% for Pb(II) and 94.8% for Ni(II), indicating that dopamine modification enhances both hydrophilicity and heavy metal ion adsorption. These findings suggest that dopamine-coated HDPE membranes offer a cost-effective and environmentally friendly solution for heavy metal removal in water treatment applications.

Keywords: *Plastic Waste HDPE, Polymeric Membrane, Water Treatment, Dopamine, Heavy Metal*

Paper ID: A071

Chitosan Membrane-Based Eco-Friendly Ammonia Recovery

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ABSTRACT

Ammonia, a predominant nitrogenous compound in wastewater, poses significant environmental risks while simultaneously serving as a valuable resource for fertilizers, refrigerants, and various industrial chemicals. Conventional ammonia removal methods, such as biological nitrification and denitrification, are highly energy-intensive and contribute substantially to greenhouse gas emissions. While ammonia stripping and adsorption techniques are widely used for ammonia recovery, these methods are often limited by high chemical consumption, costly regeneration, and poor scalability. Recently, membrane-based technologies have emerged as promising alternatives, offering higher recovery efficiency and lower energy requirements. Unlike pressure-driven processes such as reverse osmosis and nanofiltration, membrane contactors (MC) operate via passive diffusion mechanisms, thereby significantly reducing energy demands. In this study, chitosan, a biopolymer with a strong affinity for ammonia, was used to fabricate ammonia recovery membranes. Unlike the commercial membrane, which required adjustments in temperature or pH to achieve significant recovery, the chitosan membrane demonstrated an ammonia recovery efficiency that was 10,433.33% higher under standard conditions. Furthermore, the chitosan membrane maintained high ammonia recovery even under low pH conditions and showed minimal sensitivity to temperature variations. These highlights underscore the superior performance of chitosan-based membranes in enabling efficient and sustainable resource recovery without the need for external operational controls. Overall, the integration of chitosan membranes into ammonia recovery systems enhances the environmental sustainability of wastewater treatment processes by minimizing chemical and energy inputs, thereby contributing to greener and more energy-efficient resource recovery strategies.

Keywords: *Resource Recovery, Ammonia Recovery, Chitosan Membrane, Membrane Contactor, Wastewater Treatment*

Paper ID: A072

Sorpvection-Driven Liquid-Phase Butanol Separation Using Graphene Oxide–Lignin Composite Membranes

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ABSTRACT

With the growing interest in sustainable biofuels, lignocellulose-derived biobutanol has gained attention as a renewable alternative to fossil fuels. However, energy-intensive separation processes remain a major hurdle. To address this, we propose graphene oxide–lignin (GOL) composite membrane technology for efficient liquid-liquid separation of biobutanol. Lignin, a byproduct from biobutanol production, was combined with graphene oxide (GO) using a scalable blade-coating method, resulting in chemically crosslinked composite layers with improved structural stability and butanol selectivity. Sorption tests confirmed enhanced butanol uptake and reduced water absorption compared to neat GO. Structural stability under aqueous butanol conditions was also increased due to the crosslinking.Permeation evaluation under high-pressure cross-flow conditions revealed that GOL membranes increased permeate flux and preferential butanol enrichment relative to GO membranes. Moreover, simulated ABE fermentation broth experiments confirmed that the GOL membranes have the capability for effectively separating butanol from complex liquid mixtures. An analysis of the transport mechanism identified a sorpvection process, wherein selective butanol adsorption is coupled with convective bulk liquid transport, as demonstrated by a clear linear correlation between butanol flux and overall permeate flow. Large-scale membrane coating experiments further supported the feasibility of commercial-scale membrane production, and process evaluations highlighted significant benefits of employing hybrid membrane cascades. Such systems not only exhibited approximately 50% lower energy demands for pumping operations but also significantly reduced material costs by over 90%, primarily due to the utilization of economically advantageous lignin. Overall, the GOL composite membrane offers a scalable, energy-efficient, and economically attractive solution for sustainable biobutanol recovery.

Keywords: *Lignin, Biobutanol, Liquid-Liquid Separation, Membrane, Graphene Oxide*

Paper ID: A073

Potential of Post-Combustion Co_2 Capture by Amine-Containing Polymeric Membrane

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ABSTRACT

Energy-saving membrane separation processes are attracting attention as an efficient CO_2 capture technology. Our research group has studied and developed CO_2 separation membranes based on an facilitated transport mechanism using amines as CO_2 carriers. Based on the results of our previous studies, we found that a polymeric membrane material, in which an alkanolamine with an amino group and a hydroxyl group in the molecule was physically fixed in the polymer matrix, exhibited extremely high CO_2 separation performance under humidified conditions. This is because under highly humidified conditions, the polymeric membranes swell by absorbing water vapor and the dissolved CO_2 migrates as bicarbonate ions in the polymeric membrane. To demonstrate the resulting amine-containing polymer membrane, we successfully formed a thin layer of this polymer membrane material on the inner surface of a hollow fiber membrane module using a technique called "*in situ*" modification method. In the preparation of CO_2 separation membrane modules, the concentration of membrane materials, circulation time and circulation rate determine the thickness of the CO_2-selective layer, i.e. the CO_2 separation performance. In this technique, an aqueous solution of CO_2 separation membrane material was passed through the hollow fiber membrane module to form a thin-film composite structure with a CO_2-selective layer on the inner surface of the hollow fiber membrane. The CO_2 separation performance of the resulting hollow fiber membrane module was determined using a CO_2/N_2 mixed gas with a CO_2 concentration of 10 % under 90 % relative humidity, and it was found to simultaneously achieve a CO_2 permeance of over 1,000 GPU and a CO_2 selectivity of over 140. Therefore, the resulting membrane module shows promise for post-combustion CO_2 capture at thermal power stations. The results of the bench tests are also introduced.

Keywords: *Amine, CO_2, Facilitated Transport, Membrane Module, Post Combustion*

Sustainable Solar Desalination through Carbon-Enhanced Ceramic Hollow Fiber Photothermal Membrane Distillation

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ABSTRACT

A sustainable method for seawater desalination is presented by merging solar energy with photothermal membrane distillation (PMD) through carbon-modified ceramic hollow fiber membranes. The work focuses on developing tough ceramic membranes enhanced with carbon-based nanomaterials, boosting solar absorption and localized heating to lower energy needs in desalination. Ceramic materials were selected because of their strong mechanical properties, chemical resistance, and ability to resist fouling, while hollow fiber designs were preferred for their efficient packing and simple module construction. The project's main targets include building ceramic membranes with better permeability, selectivity, and strength. It also refines the material make-up and fine-tunes processing elements like sintering temperatures, applied pressures, and heating durations. Special attention is given to selecting and testing carbon nanomaterials—such as reduced graphene oxide, carbon nanotubes, and carbon dots—based on their efficiency at turning sunlight into heat and their cost effectiveness. The findings offer a promising way forward for creating scalable, energy-saving, and eco-friendly desalination technologies, helping to solve freshwater shortages while reducing the environmental damage linked with older desalination methods.

Keywords: *Photothermal, Membrane Distillation, Hollow Fiber Membranes, Carbon Nanomaterials.*

Paper ID: A075

Enhancing the removal of organic micropollutants by nanofiltration membrane with Fe (III)–tannic acid interlayer: Mechanisms and environmental implications

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ABSTRACT

In the context of global water scarcity, the membrane-based potable water reuse is a less costly strategy to augment drinking water supply. However, conventional membranes suffer the insufficient rejection toward organic micropollutants (OMPs) in the practice of potable reuse. In recent years, the interlayered thin-film nanocomposite (TFNi) membranes have shown enhanced salt rejection and improved water permeance, while their efficacy in removing OMPs has not been well investigated. To address this issue, this work examined the feasibility of using a TFNi membrane with iron-tannic acid interlayer to remove various OMPs, studied both the direct and indirect effects of interlayer on enhancing the OMPs rejection. It is found that the TFNi membrane can be effective in enhancing the rejection of some OMPs thanks to the indirect effects of interlayer in facilitating a better formation of the polyamide layer (e.g., higher crosslinking degree, narrower pore size distribution) as well as the direct effects of interlayer in acting as a barrier layer. A simple theoretical analysis suggests that an ideal interlayer needs to be more intrinsically selective to OMPs and meanwhile impose moderate resistance to water compared with the polyamide layer. This work may contribute to the understanding of the synthesis-property-performance relationship of membranes targeting OMPs removal. It may also provide useful guidelines for the design of high-performance membranes toward broad environmental applications.

Paper ID: A076

Designing Adsorptive Membranes for Removing Protein-Bound Uremic Toxins via Π-Π and Cation-Π Interaction

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ABSTRACT

Protein-bound uremic toxins (PBUTs) are recently thought to critically influence overall organ dysfunction, morbidity, and mortality of chronic kidney disease (CKD) patients. However, traditional hemodialysis and/or hemoperfusion processes fail to remove PBUTs efficiently due to their strong affinity with albumins. Herein, we fabricated a novel adsorptive membrane incorporating amine/polyphenol/bimetal ions complexation in the polysulfone membrane substrate, which has a higher affinity with hippuric acid, *p*-cresol sulfate, and indoxyl sulfonate. The complexation is a synergy of polyelectrolyte (polyethyleneimine-tannic acid) and metal-phenolic (tannic acid/metals) networks. The adsorption behavior of those three uremic toxins on the optimized adsorptive membrane was investigated by kinetic and adsorption isotherm studies. From X-ray photoelectron spectroscopy analysis assisted by Fourier transform infrared reflection spectrum, we attribute the high adsorption capacity to π-π and/or cation-π interaction with aromatic ring groups of uremic toxins. The adsorptive membrane could effectively remove albumin bounded uremic toxins and water-soluble urea through a continuous dialysis process. Besides, the membrane showed excellent hemocompatibility and minimized immune responses by suppressing complement activation. The above results showed the potential clinical application of adsorptive membranes.

Keywords: *Chronic kidney disease patients, Adsorption-Diffusion, Hemodialysis Membrane, Hemocompatibility, Protein-bound uremic toxins*

Electrospun Nanofibrous Membranes Based on A Semi-Alicyclic Polyimide for Efficient Oil Spill Remediation

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ABSTRACT

Oil spill pollution poses severe risks to water resources, causing significant harm to marine ecosystems and presenting an ongoing threat to environmental health. To address this issue, various oil sorbent materials have been researched and evaluated for their effectiveness in mitigating such pollution. In this study, we successfully fabricated a highly efficient hydrophobic nanofibrous membrane using 4,4′-(hexafluoroisopropylidene) diphthalic anhydride (6FDA)-based semi-alicyclic polyimide through electrospinning technology. The resulting membrane exhibits a uniform nanofibrous structure with a bead-free surface morphology. Contact angle measurements of approximately 133° confirmed the membrane's hydrophobicity, a critical property for effective oil sorption. Oil uptake tests demonstrated exceptional performance, with the sorbent showing a high adsorption capacity of 78, 50 and 45 $g\ g^{-1}$ for crude oil, diesel, and kerosene, respectively. Given its rapid adsorption rate and robust performance, this polyimide-based nanofibrous membrane is a promising material for sustainable oil spill cleanup applications.

Keywords: *Semi-Alicyclic, Polyimides, Electrospun Nanofibrous Membranes, Oil Spill Removal, Sustainability.*

Non-Thermal Ultraviolet Detemplation of Dd3r Zeolite Membranes for High-Selective CO_2 Separation

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ABSTRACT

Pure-silica DD3R zeolite membrane has been of significant interest in CO_2 separation because of its appropriate pore size (0.36 nm × 0.44 nm) to distinguish CO_2 from other gases. However, it is challenging to remove its organic template but simultaneously minimize defects by conventional calcination at high temperature. Herein, we proposed a non-thermal ultraviolet (UV) detemplation strategy to prepare defect-free DD3R zeolite membranes for CO_2 separation. The 185/254 nm UV radiation not only excited the organic template, adamantanamine (ADA) filled in the membrane but also generated reactive oxygen species (ROSs), which caused decomposition of the template at near-ambient temperature. After being exposed in UV radiation for 4 days, the resultant membrane exhibited an ultrahigh CO_2/CH_4 selectivity of 876 as well as a good CO_2 permeance of 1.37×10^{-7} mol m^{-2} s^{-1} Pa^{-1}. The scalability of such strategy was demonstrated by a large-area hollow fiber membrane module (ca. 800 cm^2), which performed a notably high CO_2/CH_4 selectivity of 170 at 4.1 MPa.

Keywords: *DD3R Zeolite Membrane, Detemplation; Uv Radiation, CO_2 Separation*

DFT-Assisted Machine Learning for Polyester Membrane Design and Application

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ABSTRACT

Resource recovery from textile wastewater has attracted increasing interest because it simultaneously addresses wastewater treatment and maximizes the utilization of the residual dyes. Although polyester membranes have demonstrated great potential for textile wastewater recovery, tailoring high-performance polyester membranes remains a multidimensional challenge because of the complex nonlinear relationships between the membrane materials and their performance. Here we developed density functional theory (DFT)-assisted machine learning models that integrates DFT descriptors with fabrication and operation parameters to facilitate the generative design of polyester membranes. The developed machine learning model demonstrated the ability to accurately predict permeance and dye and salt rejection. The contribution analysis revealed that the fabrication parameters emerged as the critical factors influencing permeance, whereas the DFT descriptors played important roles in determining the dye and salt rejection. Additionally, optimal combinations of monomer, fabrication, and operation conditions were identified from a chemical space of 8,000 candidates using the developed model combined with Bayesian optimization, targeting dye/salt and dye/dye selectivity. Five polyester membranes were then fabricated under these identified combinations. These membranes surpassed the current performance upper bound and achieved efficient recovery of the dyes from textile wastewater. Overall, a feasible and universal machine learning model aimed at driving a paradigm shift in the inverse design of polyester membranes was developed.

Keywords: *Machine Learning, Polyester Membrane, Density Functional Theory, Resource Recovery, Textile Wastewater*

Surface Patterning Design of Ultrafiltration Membranes Enables Efficient Protein Concentration

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ABSTRACT

Biological proteins, such as insulin, antibody, and cytokines play crucial roles in regulating physiological processes, mediating immune responses, and serving as therapeutic agents for a wide range of diseases. The ultrafiltration (UF) process, known for its mild and efficient separation capabilities, is widely utilized for protein drug purification, concentration, and buffer exchange. However, the severe concentration polarization and membrane fouling of the UF process lead to a rapid decline in filtration flux and thus reduce production efficiency. In this study, the membrane surface was patterned by the arrays of nano protrusions, which acted as a turbulence promoter to enhance localized shear forces while minimizing mechanical damage to proteins in the bulk solution. This approach effectively inhibited the formation of the cake layer and alleviated concentration polarization during protein concentration. Compared to the pristine membrane, the as-prepared membrane exhibited great anti-fouling performance with a 40.5% increase in average filtration flux and a 57.0% reduction in permeability decline after protein concentration. This work offers an insightful approach for designing an anti-fouling UF membrane with a more gentle filtration process, which is promising to reduce protein denaturation and minimize energy consumption during operation.

Keywords: *Ultrafiltration, Protein Concentration, Membrane Fouling, Anti-Fouling*

Paper ID: A081

Functionalization of Graphene Oxide using Natural Deep Eutectic Solvent for Pervaporation Desalination

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ABSTRACT

Global water scarcity, affecting over half the population due to limited freshwater availability (less than 1%), demands an innovative and sustainable desalination technology. This study aimed to enhance pervaporation desalination efficiency by functionalizing graphene oxide (GO) with natural deep eutectic solvents (NADES). NADES, known for their biocompatibility and tunable characteristics, were used to modify GO, enhancing its hydrophilicity and selective transport properties. The resulting GO-NADES composite membranes were characterized using various techniques, including Fourier-transform infrared spectroscopy, X-ray photoelectron spectroscopy, Raman spectroscopy, water contact angle, X-ray diffraction, atomic force microscopy, and scanning electron microscopy, to confirm successful functionalization and morphological changes. Pervaporation performance, including water flux and salt rejection, was evaluated under different conditions and long term. Incorporating NADES improved the pervaporation performance compared to pristine GO membranes. The findings demonstrate the potential of GO-NADES composite membranes as a promising material for efficient and sustainable seawater desalination, offering a pathway to address global water scarcity.

Keywords: *Deep Eutectic Solvent, Lamellar Membranes, Graphene Oxide, Pervaporation Desalination, Salt Removal*

Paper ID: A082

Keratin-Mediated Silver Nanoparticles as Photothermal and Antimicrobial Fillers for Next-Generation Membrane Distillation Membranes

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ABSTRACT

The integration of functional nanomaterials into membrane matrices is critical for advancing membrane distillation (MD) technologies toward greater efficiency, durability, and fouling resistance. In this study, we introduce a sustainable strategy to enhance MD membranes by incorporating keratin-mediated silver nanoparticles (Keratin–AgNPs) as multifunctional fillers. Silver nanoparticles were synthesized in an eco-friendly manner using keratin extracted from duck feathers as both a natural reducing and stabilizing agent, eliminating the need for hazardous chemicals. Synthesis parameters were statistically optimized through Response Surface Methodology (RSM) to achieve ideal nanoparticle size and stability. The keratin-capped AgNPs, with average diameters of 8–15 nm, were subsequently embedded into polyvinylidene fluoride (PVDF) membranes via a phase inversion process. Comprehensive characterizations confirmed the uniform dispersion and crystalline nature of the incorporated nanoparticles. The resulting composite membranes exhibited enhanced photothermal responsiveness under solar irradiation, robust antibacterial activity against *Escherichia coli*, *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus* (MRSA), and *Pseudomonas aeruginosa*, along with improved water flux and salt rejection during direct contact membrane distillation (DCMD). This work highlights the potential of keratin-mediated AgNPs as sustainable, multifunctional fillers for the development of next-generation, high-performance MD membranes.

Keywords: *Biogenic Silver Nanoparticles, Keratin, Membrane Distillation, Photothermal Membranes, Antibacterial Membranes, Sustainable Nanotechnology*

Paper ID: A083

Hollow Fiber Silicalite-1 Zeolite Membrane for Alkane Separation in Light Naphtha

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ABSTRACT

Light naphtha is rich in C5 and C6 alkanes. Developing energy-efficient separation technologies to distinguish linear and branched isomers for optimal industrial utilization has become a focal point. Membrane separation, an emerging technology with advantages such as low energy consumption, high efficiency, and compact system design, has garnered significant attention. Among membrane materials, MFI zeolite membranes, with a pore size of 0.55 nm intermediate between the kinetic diameters of linear and branched C5/C6 alkane isomers, demonstrate promising potential for this separation system. In this study, silicalite-1 (all-silica MFI) zeolite membranes were successfully synthesized on four-channel hollow fiber supports. The membrane exhibits a smooth, uniform surface without visible defects and a consistent thickness of approximately 5 μm. The effects of operational conditions (e.g., temperature and pressure) on membrane performance were systematically investigated. For the binary n-pentane/i-pentane (n-/i-C5) system, at 80°C and a feed partial pressure of 5 kPa, the n-C5 permeance reached 1.12×10^{-7} mol·m^{-2}·s^{-1}·Pa^{-1} with a n-/i-C5 separation factor of 109. For the ternary n-hexane/3-methylpentane/2-methylpentane (n-C6/3MP/2MP) system under identical conditions, the n-C6 permeance was 1.83×10^{-7} mol·m^{-2}·s^{-1}·Pa^{-1}, achieving a remarkable n-/i-C6 separation factor of 132. Long-term stability was evaluated for both n-/i-C5 and n-C6/3MP binary mixture at 80°C, with sweep and feed flow rates both maintained at 80 mL·min^{-1}. The n-C5 permeance remained stable at 1.5×10^{-7} mol·m^{-2}·s^{-1}·Pa^{-1} over 120 h of continuous operation, while the separation factor consistently exceeded 100. After a continuous operation of 58 h, the n-C6 permeance remained stable at 3.2×10^{-8} mol·m^{-2}·s^{-1}·Pa^{-1} with a separation factor of 113. This study lays the foundation for technological innovation and upgrading in the petrochemical industry.

Keywords: *Hollow Fiber; Silicalite-1 Zeolite Membrane; Light Naphtha; Vapor Permeation; Alkane Separation*

Paper ID: A084

High-Performance Lamellar GO-PEAA Nanocomposite Membranes for Organic Solvent Nanofiltration

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ABSTRACT

Graphene oxide (GO) membranes have gained considerable attention for organic solvent nanofiltration (OSN) applications; however, their practical deployment remains limited by challenges such as swelling, long diffusion pathways, and narrow interlayer d-spacing. In this study, an effective strategy is developed to overcome these limitations by integrating GO with a newly synthesized supramolecular polymer, poly(ethylene adenine carboxylic acid)/ (PEAA). These GO-PEAA nanocomposite membranes were fabricated via pressure-assisted filtration assembly, wherein PEAA not only expanded the interlayer distance between GO nanolayers but also crosslinked on the surface of GO nanosheets. This structural tuning was enabled by covalent bond formed between hydroxyl/epoxide groups of GO and carboxyl acid groups of PEAA. This modification effectively tailored the membrane microstructure, enhancing solvent transport channels while mitigating swelling tendencies. The GO-PEAA membranes demonstrated remarkable improvements in solvent flux, excellent dye rejection rate, and outstanding chemical robustness against harsh organic solvents. The optimized GS13 membrane consistently maintained high rejection rates for dyes such as Congo red (CR) and Methyl Blue (MB) across a variety of organic solvents, along with stable operational performance during long-term filtration cycles. Overall, this work demonstrates an effective molecular engineering strategy to tune GO-based membranes, achieving a synergistic balance between permeability, selectivity, and stability. These findings open new avenues for the practical deployment of GO nanocomposite membranes in advanced organic solvent separation technologies.

Keywords: *Go-Supramolecule Lamellar Framework, Membranes; OSN, Dyes Removal*

Effect of Thermal Annealing and Cerium Oxide Nanoparticle Additions on the Stability of Perfluorosulfonic Acid Fuel Cell Membranes

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ABSTRACT

Polymer electrolyte membranes based on perfluorosulfonic acid (PFSA) exhibit excellent proton conductivity and thermal stability. However, PFSA membranes remain vulnerable to radical-induced degradation during prolonged fuel cell operation, which compromises long-term membrane integrity. To address this limitation, we investigated a stabilization approach combining thermal annealing and cerium oxide (CeO_2) nanoparticles incorporation as a route to improve membrane durability under harsh conditions. Oxidative degradation was simulated using the Fenton's test, and membrane durability was assessed through structural and functional analyses before and after oxidative stress exposure. The PFSA membranes examined in this study included Nafion, thermally annealed Nafion, and thermally annealed Nafion incorporating CeO_2 nanoparticles. Fluoride ion emission rate analyses, scanning electron microscopy, atomic force microscopy, water uptake measurements, and gas permeability analyses demonstrated that thermal annealing and the incorporation of CeO_2 nanoparticles effectively suppressed radical-induced chemical degradation and improved the physical stability of the PFSA membranes. The pore structure, mechanical properties, and proton conductivity of the thermally annealed PFSA membrane containing CeO_2 nanoparticles were similar to those before the Fenton's test. The results from this study demonstrate that the combination of thermal annealing and incorporation of CeO_2 nanoparticles enhances the chemical, structural, and functional stability of PFSA membranes.

Keywords: *Perfluorosulfonic Membranes, Thermal Annealing, Cerium Oxide, Fenton's Test, Durability*

Paper ID: A086

Enhancing Membrane Distillation Performance Through Heatable Membrane Feed Spacers

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ABSTRACT

Membrane Distillation (MD) is a thermal separation process that utilizes vapor pressure differences across a hydrophobic membrane. Due to its low energy consumption and simple operation process, MD has garnered significant attention in wastewater treatment and seawater desalination applications. However, one of the major limitations of MD is temperature polarization (TP), which arises from the temperature gradient between the hot feed and the cold distillate streams. TP increases thermal resistance and deteriorates the overall performance of the MD process. To mitigate TP, previous studies have proposed methods involving membrane surface heating. These approaches involve the incorporation of photothermal materials or electrically conductive materials onto the membrane, providing photothermal heating or Joule heating effects, respectively. Elevating the surface temperature of the membrane can enhance the vapor flux across the membrane, thereby reducing TP. However, these approaches may lead to pore blockage or a reduction in permeate flux due to direct modification of the membrane. In this study, a heatable membrane feed spacer was applied to address these issues. By heating the spacer, the membrane surface temperature can be elevated without direct damage to the membrane itself. This enhances vapor flux near the membrane surface and improves the recovery efficiency of volatile compounds such as ammonia. Ultimately, this approach effectively reduces TP while simultaneously increasing flux, presenting a promising strategy for improving MD performance. It holds strong potential for future applications in wastewater treatment and desalination processes.

Paper ID: A087

Slippery Hydrogel Surface on PTFE Hollow Fiber Membranes for Sustainable Emulsion Separation

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ABSTRACT

Establishing an efficient and sustainable membrane module is of great significance for practical oil/water emulsion separation[1]. Superwetting membranes have been extensively studied but cannot meet long lasting separation owing to inevitable membrane fouling[2]. Herein, we constructed a hydrogel-mediated slippery surface on polytetrafluoroethylene (PTFE) hollow fibers and then designed a flexible and swing hollow fiber membrane module inspired by fish gill respiration, which achieved sustainable emulsion separation. A vinyl silane-crosslinked polyvinylpyrrolidone (PVP) hydrogel was interpenetrated with nano-fibrils of the PTFE hollow fibers, thus facilitating fast water permeance while resisting oil intrusion. Liquid-like polydimethylsiloxane (PDMS) brushes were then grafted to promote oil aggregation-release from the membrane surface. Owing to the heterogeneous surface and gill-like structure, the designed PTFE hollow fiber membrane module could separate emulsion in a long-term filtration process, maintaining a high water permeability of 500 L m−2 h−1 bar−1 with a separation efficiency of over 99.9% for 5000 min. This novel technique shows its great potential to realize practical emulsion separation by solving the persistent problem of membrane fouling and permeance decay.

Keywords: *Oil Fouling, Slippery Hydrogel Membrane, Emulsion Separation*

Paper ID: A088

Effects of Different Organic Solvent Application and Metal Oxide Modifications in the Fabrication of Hybrid Microcrystalline Cellulose (MCC)-Polyvinylidene Fluoride (PVDF) Membrane

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ABSTRACT

This study was conducted to observe the influences of the type of organic solvent used in the microcrystalline cellulose (MCC)-incorporated polyvinylidene fluoride (PVDF) membrane fabrication towards the membranes' morphology, chemical and physical properties, and also water permeability. The hybrid MCC-PVDF membranes were prepared by non-solvent induced phase separation, using two types of solvent; dimethylformamide (DMF) and N,N-dimethylacetamide (DMAc). The MCC and PVDF content were fixed at 5.0 wt. % and 20.0 wt.% respectively. The membranes were casted into thin sheets via a glass rod and characterized by using scanning electron microscopy (SEM), Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), mercury porosimeter analysis, water contact angle (WCA) measurement, tensile strength test, and thermogravimetric analysis (TGA). Interestingly, the hybrid MCC-PVDF membrane produced using DMAc exhibited elongated finger-like pores, while the pore structure for the DMF-generated hybrid MCC-PVDF membranes appeared shorter and less uniform. In addition, the XRD and FTIR analyses confirmed that both DMAc- and DMF-based hybrid membranes had amorphous structures and contained similar functional groups. The porosity, hydrophilicity, tensile strength and thermal stability of the hybrid MCC-PVDF membrane fabricated using DMAc were better than DMF-based hybrid membranes. The water permeability of the hybrid MCC-PVDF membrane was improved with the use of DMAc, achieved approximately 116.10 L m^{-2} h^{-1}. Subsequently, the effects of the surface modification by incorporating zinc oxide (ZnO) and titanium dioxide (TiO_2) nanoparticles into the polymer matrix were also studied. Both of the metal oxides were chosen due to their reported reactivity towards CO_2. The concentration of ZnO and TiO_2 were set to 0.5 wt.%. It was observed that the addition of the ZnO and TiO_2 did not significantly affect the hydrophilicity of the hybrid MCC-PVDF membranes, although a slight decrease in water permeability was recorded compared to the unmodified composite membranes.

Keywords: *Microcrystalline Cellulose, Mixed Matrix Membrane, Organic Solvent, Hydrophilic, Metal Oxide*

Large-area Nanoporous Graphene Oxide Membrane by Post-reduction for Organic Solvent Nanofiltration

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ABSTRACT

Graphene-based membranes are promising for organic solvent nanofiltration because of precise separation and chemical stability under harsh conditions. However, graphene-based membranes have a tortuous pathway that limits the solvent flux. Therefore, the methods of activating pores on graphene basal planes have been studied intensively. Conventionally, pores are generated by chemical or thermal reduction, which decreases the dispersibility of graphene-based materials. As a result, the nanoporous graphene membranes are usually fabricated on a laboratory scale because of the toxic solvents for dispersion. Herein, we fabricated nanoporous multilayer graphene (NMG) membranes on a large scale by post-reduction treatment. Graphene oxide membranes are prepared using a scalable slot-die coater and then hot pressed in a membrane state for nanopore generation. The NMG membrane achieved ultrafast permeance in various organic solvents and 500 g/mol of MWCO. In addition, during the hot-pressing, the polymer substrate is welded with the graphene layer, which can improve stability. Therefore, the large area NMG membrane maintained a high rejection under the cross-flow system for 30 days. To enhance the membrane performance, we further reduced the NMG membrane with hydriodic acid vapor. By controlling the activated nanopore size and forming a more well-aligned interlayer structure, the solvent permeances increased, and rejection of dyes (>500 g/mol) showed above 99%. This method proposes a novel approach for fabricating NMG membranes that can be applied on an industrial scale.

Keywords: *Nanopore, Graphene Oxide, Organic Solvent Nanofiltration, Scale-Up*

Nanocellulose-Based Materials for Advanced Water Treatment: Applications, Challenges, and Future Prospects

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ABSTRACT

Nanocellulose and its derivatives have emerged as promising bio-based materials for water treatment, attributed to their high surface area, strength, and renewable nature [1]. The presence of hydroxyl groups on cellulose nanocrystals (CNCs) and cellulose nanofibrils (CNFs) facilitates various surface modifications, leading to nanocomposites with customizable properties [2]. This review investigates the applications of nanocellulose-based materials in adsorption, catalysis, filtration, and flocculation, with a focus on removing heavy metals, dyes, and pharmaceutical compounds from water. Additionally, it examines nanocellulose's role in environmental sustainability, particularly in wastewater remediation through adsorption, filtration, catalysis, and pollutant sensing [3]. The review also highlights recent advancements in the production of nanocellulose-based adsorbents and membranes, emphasizing synthesis techniques, surface modifications, and durability, which bolster their potential for commercial application in cleaner wastewater treatment technologies. This comprehensive overview addresses the challenges and future prospects for the industrial use of nanocellulose in environmental remediation, underlining its importance in tackling global concerns related to resource depletion and harmful contaminants.

Paper ID: A091

Enhance CO2/CH4 Separation Performance of Polysulfone (PSf)-Based Mixed Matrix Membranes with Incorporating Silane-Modified Zeolite-NaY

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ABSTRACT

Indonesia as the largest palm oil producer in the world produces a huge amount of palm oil waste (palm oil mill effluent, POME) every year. POME can naturally form biogas when decomposed through an anaerobic digester (AD) process. Utilization of POME-based biogas as an alternative fuel is still very limited because the CO2 impurities in it can reduce the calorific value and cause corrosion in pipes. Mixed matrix membrane (MMM) has been widely used for biogas upgrading because the process is simple and requires relatively low operational costs. In this study, polysulfone (PSf) membrane with silane coupling agent modified Zeolite-NaY (Zeolite-silane) filler was prepared for CO2/CH4 separation. Zeolite-NaY was modified with (3-aminopropyl)trimethoxysilane (APTMS) before used to prepare the MMM. Modification of Zeolite-NaY with APTMS was done to improve filler and polymer matrix compatibility. The adsorption performance of the Zeolite-NaY filler was evaluated using a barometric method, and thermodynamic and kinetic analyses showed enhanced CO2 and CH4 adsorption. The CO2 adsorption capacity of Zeolite-silane decrease by 54% compared to unmodified Zeolite. However, based on the adsorption evaluation, the filler remains effective for CO2/CH4 separation, as the CO2 adsorption capacity is still higher than CH4. MMM PSf/Zeolite-silane 1.5 wt% showed 15.13% increase in CO2/CH4 selectivity compared to pristine PSf membrane. Membrane coating with polydimethylsiloxane (PDMS) successfully sealed membranes surface defects, causing a trend where permeability decreases but selectivity increases. MMM PSf/Zeolite-silane 0.5 wt% coating PDMS showed CO2/CH4 selectivity 106.6% increase from pristine PSf membrane and is 79.3% higher when compared to the uncoated PSf/Zeolite-silane. MMM PSf/Zeolite-silane showed potential considering its low filler loadings benefit. The enhanced selectivity demonstrates the potential of the MMMs for application in biogas upgrading, particularly in removing CO_2 to improve methane purity.

Keywords: *Mixed Matrix Membranes, CO2/CH4 Separation, Zeolite-Nay, Adsorption, Biogas*

Copolymerisation of Microporous Ion-Exchange Membranes in Redox Flow Battery Applications

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ABSTRACT

Redox flow batteries (RFBs) offer transformative potential for grid-scale energy storage but are limited by ion-exchange membranes (IEMs) that struggle to balance ionic conductivity with effective selectivity against redox-active species. Conventional nanophase-separated IEMs suffer from inherent performance trade-offs, while emerging charged microporous polymer membranes, despite their promise, face commercial barriers due to complex synthesis routes and high production costs. Here, we present a one-step copolymerisation strategy that simultaneously integrates rigid nanopore-forming, hydration-regulating and ion-conductive monomers into a microporous membrane architecture with highly adjustable properties. This design generates interconnected ultra-microporous channels that combine dimensional stability, optimised hydration networks and uniformly distributed ion-conductive sites, enabling both rapid ion transport and strong blocking capability against redox-active species. When assembled into anthraquinone||ferrocyanide aqueous RFBs, these membranes demonstrate reduced cell resistance, enhanced power output and significantly lower capacity fade. By further adopting cost-effective monomers or scaling the production of existing raw materials, the projected manufacturing cost of these membranes can be reduced to below 50 € m^{-2}. This work introduces a synthetically accessible and scalable approach to designing high-performance IEMs with recyclability and economic advantages, advancing the commercial viability of aqueous organic RFBs for sustainable energy storage.

Keywords: *Ion Exchange Membrane; Aqueous Organic Redox Flow Battery, One-Step Copolymerisation, Ultra-Microporous Channels*

Paper ID: A093

PEDOT:PSS Nanoparticle Membranes for Organic Solvent Nanofiltration

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ABSTRACT

Recycling of valuable solutes and recovery of organic solvents via organic solvent nanofiltration (OSN) are important for sustainable development. However, the trade-off between solvent permeability and solute rejection hampers the application of OSN membranes. To address this issue, the poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) nanoparticle membrane with hierarchical pores is constructed for OSN via vacuum filtration. The small pores (the free volume of the polymer chain) charge for the solute rejection (high rejection efficiency for low molecule weight solute) and allow solvent passing while the large pores (the void between two PEDOT:PSS nanoparticles) promote the solvent transport. Owing to the lack of connectivity among the large pores, the fabricated PEDOT:PSS nanoparticle membrane enhanced solvent permeance while maintaining a high solute rejection efficiency. The optimized PEDOT:PSS membrane affords a MeOH permeance of 7.2 L m^{-2} h^{-1} bar^{-1} with over 90% rejection of organic dyes, food additives, and photocatalysts. Moreover, the rigidity of PEDOT endows the membrane with distinctive stability under high-pressure conditions. The membrane is used to recycle the valuable catalysts in a methanol solution for 150 h, maintaining good separation performance. Considering its high separation performance and stability, the proposed PEDOT:PSS membrane has great potential for industrial applications.

Keywords: *PEDOT:PSS Nanoparticle Membrane, Organic Solvent Nanofiltration, Acid Treatment, Interparticle Distance, Free Volume*

Paper ID: A094

In-situ Growth of MOF Nanoparticles at Confined Membrane Space

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ABSTRACT

Mixed-matrix membranes (MMMs), which combine the flexible processability of polymers with the high mass-transfer capabilities of porous fillers such as metal-organic frameworks (MOFs), are widely regarded as next-generation, high-performance materials for CO_2 capture. However, challenges such as MOF aggregation and poor compatibility between MOFs and polymers often lead to the formation of defects within the membrane, ultimately reducing CO_2/N_2 selectivity.To address this issue, we propose a strategy of in situ MOF crystallization within confined spaces to construct defect-free MMMs for CO_2 capture. By mixing prepolymers with MOF precursors at the molecular level, the complexation between metal ions and prepolymers enhances interfacial interactions during membrane formation, thereby minimizing defect formation. Additionally, the confined environment created by polymer chain crosslinking slows MOF growth, reducing particle size and mitigating aggregation. In this study, we tailored the polymer's confined space and optimized MOF crystallization conditions. As a result, we achieved a MOF loading of up to 31.3 vol.%. The resulting MMMs demonstrated a remarkable 18-fold increase in CO_2 permeability compared to the pristine polymer membrane, along with improved CO_2/N_2 selectivity, rising from 30 (pristine) to 38. Moreover, the membrane exhibited high mechanical stability under applied pressure and maintained consistent performance over 200 hours of continuous operation, owing to its highly crosslinked polymer structure and well-dispersed MOF loading. This method presents a novel and effective approach for fabricating uniform, defect-free MMMs for advanced CO_2 separation applications.

Keywords: *PEO membrane, ZIF-8, Mixed matrix membranes, CO_2 capture, Gas separation.*

Paper ID: A095

Synthesis of Few Layer Graphene/P84 Composite as Filler in Polysulfone Based Membrane for H2/CO2 Separation

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ABSTRACT

Hydrogen is one of the key solutions for achieving Net Zero Emissions (NZE) due to its combustion process, which produces no carbon emissions, as well as its high energy efficiency and sustainability. Membrane technology is a promising method for the separation and purification of hydrogen. This study aims to investigate the effect of incorporating few layer graphene/P84 composite at various annealing temperatures, specifically 250, 300, and 350℃, into a polysulfone based membrane matrix in small loading amounts. The membranes were fabricated using the dry phase inversion method in a flat sheet modulation. The fabricated membranes were characterized using X-Ray Diffraction (XRD), Fourier-Transform Infrared (FTIR), Scanning Electron Microscopy (SEM), and raman spectroscopy. The gas separation performance was evaluated for H2 and CO2 gases using a single gas permeation reactor. The study found that polysulfone with the addition of few layer graphene/P84 composite annealed at 350℃ exhibit the best separation performance. This membrane performance exceeded the Robeson upper bound curve for both 1991 and 2008, with increases in H2 permeability and H2/CO2 selectivity by +233.54% and +25.59%, respectively as compared to the pristine membrane. These findings indicate that polysulfone based membrane with the addition of few layer graphene/P84 composite at elevated annealing temperatures significantly enhance H2/CO2 gas separation performance. The result showed that the membrane has promising properties in the production of blue hydrogen and have the potential for further development in other gas separation applications.

Keywords: *Few-Layer Graphene, Gas Separation Membrane, H2/CO2 Separation, Few Layer Graphene/P84 Composite, Polysulfone*

Paper ID: A096

Development of Layered Materials for High Temperature CO_2 Permselective Membranes

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ABSTRACT

To achieve a carbon-neutral society by 2050, the capture and utilization of carbon dioxide are essential. The current mainstream method, amine-based absorption, requires large-scale equipment, which poses challenges for CO_2 capture from small emission sources. In this study, we focus on a membrane reactor (m-DAC) capable of directly separating and converting CO_2 from ambient air. Conventional membranes rely on differences in molecular size, making it difficult to obtain high-purity products due to the easy permeation of hydrogen. Therefore, we aimed to develop a novel membrane material with high CO_2 absorption performance even under low concentrations, suitable for use in membrane reactors. Layered double hydroxides (LDHs), expressed as $[M^{2+}_{1-x}M^{3+}_{x}(OH)_2][A^{n-}\cdot yH_2O]$, were selected as candidate materials. LDH powders were synthesized using co-precipitation from $M(II)(NO_3)_2\cdot 6H_2O$ and $M(III)(NO_3)_3\cdot 9H_2O$ (where M = Mg^{2+}, Zn^{2+}, Ca^{2+}, Al^{3+}, Fe^{3+}), followed by centrifugation and drying at 80°C for 24 hours. The CO_2 adsorption capacity at 300°C was evaluated, and gas permeance tests were conducted to determine membrane selectivity. Several LDH compositions were synthesized and their CO_2 capture performance was compared. Among them, $Mg_{0.75}$-$Al_{0.25}$-CO_3 LDH exhibited the highest CO_2 adsorption capacity of 1.12 mmol/g, which was approximately 56.2% higher than other Mg-Al-CO_3 ratios. X-ray diffraction (XRD) analysis confirmed the successful synthesis of Mg-Al-CO_3 LDHs, all showing d_{003} = 7.56–7.62 Å. No significant change in interlayer distance was observed with varying metal ion ratios. These results indicate that Mg-Al-based LDH is a promising membrane material for efficient CO_2 capture and resource utilization under low-concentration conditions, such as in direct air capture applications.

Keywords: *CO_2 Separation, CO_2 Capture Membrane, m-DAC, Layered Double Hydroxide (LDH), Carbon-Neutral*

Lithium-Selective Electrodialysis via a PDMS-LATP Hybrid Membrane with Near-Complete Rejection of Competing Ions

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ABSTRACT

The growing demand for lithium necessitates advanced extraction technologies capable of selectively recovering Li^+ from complex brines with high Mg^{2+}/Li^+ and Na^+/Li^+ ratios. While NASICON-type LATP ($Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$) offers exceptional Li^+ selectivity, its brittleness limits practical applications. Here, we present a flexible, hydrophobic PDMS-LATP mixed matrix membrane (MMM) that synergistically combines LATP's ion-sieving channels with PDMS's processability and dehydration energy modulation for high-performance electrodialysis (ED). The optimized PDMS-50% LATP membrane achieves unprecedented Li^+ selectivity with Near- Complete Rejection of Competing Ions by leveraging (1) LATP's rigid 3D Li+-conducting channels to exclude larger ions and (2) PDMS's hydrophobicity to amplify dehydration energy differences. TEOS-modified LATP particles ensure uniform dispersion, maintaining continuous Li^+ transport pathways. In H-cell diffusion tests using a mixed $Li^+/Na^+/K^+/Mg^{2+}/Ca^{2+}$ solution (feed) and DI water (receiving) under 2V applied potential, the PDMS-LATP membrane demonstrates exceptional mono-valent cation selectivity, achieving a stable Li^+ flux of 12 mmol m^{-2} h^{-1} while maintaining >99% rejection of Na^+, K^+, Mg^{2+}, and Ca^{2+} ions over 24 hours of operation. This performance surpasses conventional cation-exchange membranes, which typically exhibit no selectivity under similar conditions. This work provides a scalable strategy to bridge the gap between ceramic selectivity and polymeric practicality, offering a viable solution for energy-efficient lithium extraction from high-salinity brines.

Keywords: *Lithium Extraction, Electrodialysis, Mixed Matrix Membrane, Ion Selectivity, NASICON*

Ion Exchange Membranes in Microbial Fuel Cell and Electrodialysis Desalination- A review

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ABSTRACT

Ion exchange membranes are integral to the performance of microbial fuel cells and electrodialysis desalination systems, both key technologies for addressing water scarcity and rising energy demands driven by rapid population growth. Ion exchange membranes are pivotal in advancing sustainable water treatment technologies, notably in microbial fuel cells and electrodialysis desalination systems. In microbial fuel cells, ion exchange membranes facilitate the separation of anodic and cathodic chambers, enabling efficient electron flow and ion transport, which are essential for simultaneous wastewater treatment and bioelectricity generation. Similarly, in electrodialysis desalination processes, ion exchange membranes are integral for selective ion removal, contributing to effective desalination with reduced energy consumption. Ion exchange membranes used in microbial fuel cells and electrodialysis desalination systems face several challenges that can impact their performance and longevity. A primary issue is membrane fouling, which includes the accumulation of organic matter, inorganic salts, and microbial biofilms on the membrane surface. This fouling increases electrical resistance, reduces ion selectivity, and diminishes overall system efficiency. This review comprehensively examines the recent developments in ion exchange membrane materials, including cation and anion exchange membranes, their structural modifications, and functional enhancements aimed at improving performance metrics such as ion selectivity, conductivity, and fouling resistance. Furthermore, the paper discusses the challenges associated with membrane fouling and degradation, exploring innovative strategies for mitigation and membrane regeneration. By analysing current research trends and technological advancements, this review provides insights into the optimization of ion exchange membranes for enhanced efficiency and sustainability in microbial fuel cell and electrodialysis desalination applications, highlighting their role in addressing global water scarcity and energy challenges.

Keywords: *Ion Exchange Membrane, Microbial Fuel Cell; Electrodialysis Desalination, Membrane Fouling and Scaling, Membrane Performance, System Efficiency*

Catalyst Engineering for The Multilayer Porous Graphene Synthesis

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ABSTRACT

Despite the superb membrane performances that porous graphene promises, there is wide room for improving the porous graphene formation process. As its two significant pillars are the synthesis of graphene and the formation of pores in it, the process for securing both aspects can take dual avenues: top-down & bottom-up methods. The top-down method, which separates graphene synthesis and perforation, normally detaches carbon atoms from the graphitic lattice by energetic collision after graphene synthesis. Well-controlled post-synthesis perforation can create sub-nm-wide pores in graphene, though a slight miscue could lead to a defective structure at a larger scale. On the other hand, the bottom-up method is based on the idea of synthesizing porous graphene directly without including post-perforation. Designing a catalyst to synthesize graphene in the selected area, excluding where the pores should be, is crucial. Only a few studies have demonstrated the bottom-up porous graphene synthesis. Furthermore, the mechanical vulnerability of handling single-layer porous graphene has been disrupting its practical application. Interestingly, porous graphene can maintain the ultimate permeation even at increased thickness, depending on the aspect ratio. Such layer tolerance suggests employment of the multilayer structure rather than the vulnerable single-layer counterpart. Here, we introduce advanced catalyst engineering to synthesize multilayer porous graphene via the bottom-up method. Catalyst engineering consists of material selection, catalyst taming, and crystallinity alignment. The unprecedented Ni/Ag catalyst provides multilayer porous graphene with an average pore size of less than 20 nm and a pore density of 10^{10} cm^{-2}. As-synthesized multilayer porous graphene is promising as a high-performance membrane in filtration, breathable membranes, etc.

Keywords: *Porous Graphene, Chemical Vapor Deposition, Bottom-Up Synthesis, Catalyst Engineering, Crystallinity Alignment*

Paper ID: A100

Assessment of Ceramic Hollow Fiber Membranes Functionalized with MoS_2 Nanomaterials for Semiconductor Wastewater Purification

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ABSTRACT

As the semiconductor industry has grown rapidly in recent years, there has been increasing concern of the environmental impacts associated with its manufacturing processes, particularly those related to wastewater management. Among the various stages of semiconductor fabrication, the wet etching process, especially highly selective nitride (HSN) etching used in high-density 3D NAND flash memory production, generates wastewater containing exceptionally high concentrations of low molecular weight pollutants such as silica and ammonium phosphate [1]. These contaminants are particularly challenging to remove due to their small size, which limits the effectiveness of conventional ultrafiltration (UF) membranes that rely primarily on size exclusion mechanism. To overcome this limitation, this study explores the development of ceramic hollow fiber membranes incorporating two-dimensional molybdenum disulfide (MoS_2) nanomaterials, which are known for their outstanding chemical stability, large surface area, and tunable separation properties [2]. Comprehensive surface analyses confirmed the successful integration of MoS_2 into the ceramic membrane structure, resulting in enhanced selectivity. Performance evaluations revealed that the MoS_2-modified nanofiltration (NF) membranes achieved significantly higher removal efficiencies for both silica and ammonium phosphate compared to pristine UF membranes, even under harsh operating conditions. These results demonstrate that MoS_2-based ceramic NF membranes offer a highly effective and robust solution for treating challenging semiconductor wastewater, such as chemical mechanical planarization (CMP) effluents, and can contribute to more sustainable and environmentally responsible semiconductor manufacturing.

Keywords: *Semiconductor Wastewater, Nanofiltration, Ceramic Hollow Fiber Membrane, Molybdenum Disulfide (MoS_2)*

Paper ID: A101

The Integration of Conductive Carbon-based Materials for Biogas Production in Anaerobic Digestion Application

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ABSTRACT

This study explores the influence of conductive carbon-based materials in enhancing the anaerobic digestion (AD) of palm oil mill effluent (POME), a significant by-product of the palm oil industry. POME, characterised by its high organic content, presents both a waste management challenge and an opportunity for renewable energy generation. This research unlocks a novel approach to improving microbial activity and biogas production by integrating conductive carbon-based materials into the AD process. These materials increase surface area for microbial attachment, significantly boosting digestion efficiency and biogas yields. The study aims to demonstrate how the strategic addition of biochar and carbon-based fibre can enhance biogas production from POME. Three replicate AD systems were compared with and without conductive carbon-based materials using the serum bottle technique. Gas production was meticulously monitored using gas chromatography. The results are compelling, and the integration of conductive carbon-based materials led to a marked increase in biogas production. This research highlights a promising pathway to enhance the efficiency of POME treatment and maximise renewable energy recovery, offering a sustainable solution for the palm oil industry.

Keywords: *Palm Oil Mill Effluent (POME), Biogas Production, Anaerobic Digestion (AD), Conductive Carbon-Based Materials, Renewable Energy, Direct Interspecies Electron Transfer (DIET)*

Paper ID: A102

Membrane Chromatography for Downstream Purification of Biomolecules

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ABSTRACT

The downstream purification of high-value biomolecules such as monoclonal antibodies (mAbs) and viral vectors remains a pivotal stage in biomanufacturing, directly influencing final product quality, therapeutic safety, and production economics. Resin-based chromatography, including affinity and ion-exchange processes, has long been the dominant platform for large-scale purification. While robust and well-characterized, these packed-bed systems can be limited by slow intraparticle diffusion, incomplete ligand accessibility, and reduced process throughput at manufacturing scale[1]. Membrane chromatography has emerged as a compelling alternative, offering convective mass transfer, higher operational flow rates, and reduced processing times compared to bead-based formats[2,3]. In addition, membrane systems offer operational flexibility, as they can be employed either in single-use formats for rapid changeover or regenerated for multiple cycles, enabling efficient deployment in both academic research and large-scale industrial manufacturing[4]. Ion-exchange membrane systems, in particular, have shown strong potential across multiple classes of biomolecules. In mAb processing, they are increasingly adopted as polishing steps for the removal of host cell proteins, DNA, aggregates, and viral contaminants[5]. For viral vectors, ion-exchange membranes exploit the charge characteristics of the particles for selective capture and impurity removal, offering scalability advantages over traditional methods. This work provides an overview of membrane chromatography for the downstream purification of diverse biomolecules. By addressing performance bottlenecks inherent to conventional purification platforms, membrane chromatography offers an adaptable and scalable solution for next-generation biomanufacturing processes.

Keywords: *Membrane Chromatography, Downstream Purification, Anion Exchange, Cation Exchange, Therapeutic Proteins, Viral Vectors*

Paper ID: A103

PVA/Chitosan Membrane for Nutrient Recovery from Palm Oil Mill Effluent (POME) via Crossflow Filtration System

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ABSTRACT

The palm oil industry, while economically vital to Malaysia, generates substantial volumes of palm oil mill effluent (POME)—a high-strength wastewater rich in organic compounds and nutrients such as nitrogen, phosphorus, and magnesium. Improper discharge of POME poses significant environmental threats, including eutrophication and groundwater pollution. However, its nutrient-rich profile offers a promising avenue for resource recovery and sustainability. This study investigates the application of an ion exchange membrane (IEM) system integrated with crossflow filtration for the recovery of valuable nutrients from real POME samples. Membranes were fabricated using polyvinyl alcohol (PVA) and chitosan to enhance selectivity, hydrophilicity, and resistance to fouling and scaling—common challenges in POME treatment. Experimental trials were conducted to evaluate the influence of membrane composition and operational conditions on nutrient recovery efficiency. Analytical techniques such as ion chromatography, inductively coupled plasma optical emission spectroscopy (ICP-OES), and total organic carbon (TOC) analysis were used to quantify nutrient concentrations. Membrane properties were characterized using field emission scanning electron microscopy (FESEM), X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and contact angle measurements. The results demonstrated efficient recovery of nitrogen, phosphorus, and potassium, with significantly improved membrane performance and stability. Optimal conditions were identified that maximized nutrient recovery while maintaining membrane integrity. This membrane-based approach presents a sustainable solution for managing palm oil mill effluent and supports circular economy practices within the industry. The findings offer strong potential for scale-up and integration into existing wastewater treatment systems, contributing to environmental protection and resource valorisation.

Keywords: Palm *Oil Mill Effluent (POME), Nutrient Recovery, Ion Exchange Membrane, Crossflow Filtration, Sustainable Wastewater Treatment*

Paper ID: A104

CFD Modeling Of Flow and Concentration Polarization in Spacer-Filled Forward Osmosis System

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ABSTRACT

Computational Fluid Dynamics (CFD) modeling has become an essential tool for investigating complex flow, mass transfer, and concentration polarization (CP) phenomena in membrane systems. By resolving local velocity fields, solute distributions, and pressure gradients at high spatial resolution, CFD provides deep insights into membrane channel that are often difficult to capture experimentally. Unlike reverse osmosis (RO), forward osmosis (FO), an osmotically driven membrane process does not require high hydraulic pressure for water transport. FO can treat seawater, brackish water, and wastewater with minimal hydraulic pressure, making it especially attractive in addressing global water scarcity challenges. However, optimizing FO system performance requires a detailed understanding of hydrodynamics and the mass transfer behavior locally. The hydrodynamics and mass transfer within the porous support layer are simulated using Brinkman's model. This model is adopted in CFD studies of FO to better simulate internal concentration polarization (ICP) within membrane supports. Although spacer effects in FO systems have been numerically studied in priori research but most of them only focus on circular shape spacers rather than novel and optimized spacer designs. To address this gap, this study proposes CFD simulations with non-circular spacer filaments, including filament size, mesh length, and shape. The results will assess their impact on mass transfer, concentration polarization, and overall system efficiency across FO modules.

Keywords: *Brinkman Model, Modeling, Feed Spacer, Forward Osmosis*

Polyphenylsulfone-Based Membranes for Gas Separation

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ABSTRACT

A polymer system with high performance and scalability is critical for membrane gas separation. To develop such a system, we first investigated the relationship between the gas permeation behaviors of polyphenylsulfone (PPSU)-based materials and their chemical structures. It was found that as the 3,3’,5,5’-tetramethyl-4,4’-biphenol (TMBP)-based polyphenylsulfone (TMPPSf) content increases, the resultant copolymers have a larger gas permeability with a stable selectivity. Secondly, scalable PPSU and polybenzimidazole (PBI) polymers were homogeneously blended to create an enhanced polymer matrix that could utilize both the higher permeability and mechanical flexibility of the former and the excellent selectivity and thermal stability of the latter. With the incorporation of calix[6]arene (CA6), an organic macrocyclic cavitand (OMC), the H_2/CO_2 selectivity of PBI/PPSU membranes was significantly enhanced for energy-intensive molecular separation. Thirdly, we have developed a three-polymer membrane system based on a robust dual-polymer blend matrix consisting of (1) sulfonated polyphenylsulfone (sPPSU) and (2) PBI, infiltrated with poly(ethyleneimine) molecules that serve as amine-rich CO_2 retardants to enhance the H_2/CO_2 selectivity. The PEI infiltration dramatically increased the H_2/CO_2 selectivity of the dual-polymer matrix from 4.6 to up to 59.3 while maintaining a minimum H_2 permeability of 2.49 Barrer at a low temperature of 35^{o}C, which not only surpassed the Robeson upper bound but also placed the newly developed membrane among the best-performing polymer membranes.

Keywords: *Polymer Blends, Polymer Crosslinking, Three-Polymer System, Pre-Combustion CO_2 Capture, Industrial Scalability*

Paper ID: A106

Separation Mechanisms and Antifouling Properties of Microporous Graphene Oxide-Poly(vinyl pyrrolidone)/Poly(vinylidene fluoride) Composite Membranes for Various Charged Dyes

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ABSTRACT

In recent days, the increasing release of dye contaminants into aquatic environments has become a significant environmental concern, necessitating the development of efficient and sustainable treatment technologies. This study focuses on developing poly(vinylidene fluoride) (PVDF) and poly(vinyl pyrrolidone) (PVP) composite membranes with varying percentages of graphene oxide (GO) through the phase inversion method to form PVDF/PVP/GO microporous membranes. The addition of PVP enhanced membrane hydrophilicity, while increasing GO concentration from 1% to 10% significantly enhanced hydrophilicity (from 72.5° to 62.9°), porosity (from 76.7% to 97.3%), and surface charge (-12.0 ± 2.16 mV to -45.1 ± 2.68 mV) of the composite membranes. Moreover, GO blending in PVDF/PVP membranes also reduced the mean pore size from 102 to 65.9 nm. Evaluation of the separation performances of cationic methylene blue (MB) and anionic naphthol blue-black (NBB) dyes shows a reduction in filtrate permeance by 11% and 42%, respectively, due to decreased mean pore size. Rejection of MB dye increased by 21.7% with GO loading, attributed to electrostatic attraction and enhanced adsorption between MB dye and the negatively charged membrane surface. NBB dye rejection increased by 10.1%, driven by electrostatic repulsion due to its sulfonate-rich molecular structure and a highly negative zeta potential (−29.5 ± 0.26 mV). Long-term multi-cycle filtration tests over 72 hours showed that membranes with higher GO content maintained nearly 100% rejection efficiency. This was attributed to the hydrophilicity and negative charge of GO, which formed a protective barrier that reduced fouling by preventing dye molecules from penetrating the membrane matrix. Overall, the GO-based PVDF/PVP composite membranes exhibit excellent separation performance and antifouling properties, demonstrating strong potential for application in dye-contaminated wastewater treatment.

Keywords: *Graphene Oxide, Microporous Membrane, Dye Removal, Electrostatic Attraction and Repulsion, Antifouling*

Paper ID: A107

Modeling Multiple Solute System for Osmotically Assisted Reverse Osmosis Process

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ABSTRACT

Osmotically assisted reverse osmosis (OARO) is a promising emerging technology that uses both hydraulic and osmotic pressures to achieve energy-efficient desalination. In typical OARO systems with a single solute, reverse solute flux (RSF) is generally not observed, as the concentration gradient drives solute to move from the highly concentrated feed solution to the less concentrated draw solution. However, when different solutes are used in the feed and draw solutions, it is unclear whether RSF occurs, which could ultimately impact the overall osmotic driving force and system efficiency. Therefore, this study presents a simulation of a multiple-solute system in OARO. Systems containing sodium chloride and magnesium chloride were modeled to evaluate the behavior of solute transport and water flux. These findings offer valuable insights into mass transfer phenomena within a multiple solute system and optimize the OARO process.

Keyword: *Osmotically Assisted Reverse Osmosis, Computational Fluid Dynamic, Modeling, Multiple Solute System, Reverse Solute Flux*

Paper ID: A108

Polyethersulfone Membrane-Based Laser-induced Graphene Filters for Disinfection of Enteric Viruses from Wastewater: Mechanistic Insights from Experimental Studies and Molecular Dynamics Simulation

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ABSTRACT

Waterborne enteric virus inactivation is critical to ensure safe drinking water, yet conventional disinfection methods face significant limitations. Electrochemical disinfection using one-dimensional nanostructure-based electrodes are a promising alternative. Laser-induced graphene (LIG) fabricated by laser irradiation on polyethersulfone membranes offers great potential as an electrode material for electrochemical water disinfection. In this study, the disinfection performance of electrified LIG filters was evaluated against the bacteriophages MS2, T4, and Phi6, the model enteric viruses. Further, the underlying inactivation mechanism was elucidated through integrated experimental and computational approaches. Destruction of the capsid structures due to pore formation was revealed during the morphological examination of viruses by transmission electron microscopy. This indicated that electric-field-induced electroporation is a prominent mechanism for virus inactivation which was further confirmed by the scavenging experiments. The mechanism can be attributed to nanofibrous morphology of LIG, which significantly intensified the local electric field at fiber tips to magnitudes exceeding 10^7 Vm^{-1} on application of low voltage. The role of nanofibers was validated by mechanically modifying LIG into non-fibrous, flat surfaces. The electrochemical characterization of these flat surfaces exhibited reduced charge density, charge transfer rates, and compromised disinfection performance as compared to LIG. Moreover, atomistic molecular dynamics (MD) simulations demonstrated that an electric field of 10^7 Vm^{-1} applied for 1 μs to the MS2's capsid protein that is maturation protein induced conformational and structural destabilization. The protein also changed the spatial orientation of amino acid residues and surface charge of protein, potentially disrupting the host-virus interactions and inactivating the virus. Thus, this study highlights the potential of LIG in achieving low-voltage, sub-microsecond viral inactivation through enhanced local electric fields for the first time. These findings have significance for development of LIG-based disinfection systems in point-of-use water purification applications.

Keywords: *Virus Disinfection, Laser-induced Graphene, Inactivation Mechanism, Molecular Dynamics, Electric-Field Effect*

Paper ID: A109

Fabrication of salt-induced piezoelectric β-PVDF membrane: Ion specificity on the membrane formation, piezoelectric property, and anti-fouling performance

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ABSTRACT

As the growth of industrialization surges, it paved way into the emergence of different global issues such as water scarcity and energy depletion. The water-energy nexus refers to the interdependent relationship between water and energy systems wherein water is required for energy generation while energy is essential for water purification processes. In this study, a piezoelectric PVDF membrane with an exceptional nanofiltration performance and a potential energy harvesting property was developed. Through non-solvent induced phase separation method, additive-free β-PVDF membrane was fabricated utilizing the specific ion effect of different salts dissolved in the coagulation bath. The salts used in the study include sodium chloride (NaCl), sodium sulfate (Na_2SO_4), and sodium thiocyanate (NaSCN). Following the Hofmeister effect (HF), the thermodynamic stability and mass transfer kinetics of the membrane was explored. Kosmotropic salt represented by Na_2SO_4 produces membrane that has denser structure with smaller macro voids while chaotropic salt characterized by NaSCN produces larger macro voids. The effect of NaCl as an intermediate ion in HF series produces macro voids that have size in between the two other salts. Crystalline polymorphs of the membrane show an increasing fraction of electroactive phase with 47.4% from pristine PVDF to 71.6, 88.2, and 98.5 % corresponding to Na_2SO_4, NaCl, and NaSCN coagulation bath, respectively. Accordingly, the piezoelectric voltage output of the membrane increases from 0.02 V of the pristine PVDF to 0.17 V of the optimized membrane. This study successfully fabricated an additive-free PVDF membrane with high electroactive phase and increased in voltage output. The research introduced a new concept in controlling the polymorphs of PVDF membrane and paved possibilities in developing a multifunctional PVDF membrane with the ability to purify water and generate energy.

Keywords: *PVDF Membrane, Piezoelectric Effect, Membrane Formation, Antifouling, Hofmeister Effect*

Paper ID: A110

Simultaneous Fractionation of Transition Metal Ions from Simulated Wastewater Using Optimized Solvent Extraction-Based Membranes

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ABSTRACT

Achieving the fractionation of industrially relevant metal ion pairs, such as manganese (Mn^{2+}) and cobalt (Co^{2+}), from mixed streams is essential for producing high-purity commodities but remains challenging. In this study, we propose the application of solvent extraction-based membranes to fractionate and recover Mn^{2+} and Co^{2+} from simulated wastewater containing a high concentration of organic acid, representing the effluent obtained from the furandicarboxylic acid (green plastic constituents) production using homogeneous catalyst. Firstly, a novel approach was undertaken by fabricating polymer inclusion membrane (PIM) using various casting substrates. The application of more hydrophobic substrate with a higher surface roughness resulted in PIM with an improved Mn^{2+} transport rate by a factor of 2.4 compared to PIM fabricated with a more hydrophilic and smoother surface. The improvement was postulated to be due to the enhanced formation of continuous ion channel that facilitated the transport of target ion through fixed site jumping mechanism. For supported liquid membrane (SLM), the application of support membrane with a higher porosity and the use of diluent improved the Co^{2+} transport rate by 1.6 fold compared to supporting membrane with a lower porosity and in the absence of diluent. Ion fractionation was achieved by applying the Mn^{2+} selective PIM and Co^{2+} selective SLM simultaneously. By optimizing the feed solution pH, complete removal of metal ion from the feed stream can be achieved. However, it was observed that there is a trade-off between extraction efficiency and product purity. Overall, the findings in this study highlight the significance of casting substrate selection and operating conditions in optimizing ion transport rate and selectivity. This approach exhibits substantial potential for enhancing ion recovery efficiency and producing high-purity output streams, thereby contributing to the advancement of closed-loop systems for the sustainable utilization of critical metals.

Keywords: *Wastewater Treatment, Polymer Inclusion Membrane, Supported Liquid Membrane, Transition Metal, Ion Fractionation*

Paper ID: A111

Preparation OF DVB-G-PSF Ultrafiltration Membranes via Photo-Induced Surface Controlled/Living Graft Polymerization for the Efficient Separation of Low-Molecular-Weight Dextran

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ABSTRACT

Precise control over the molecular weight distribution of low-molecular-weight (LMW) dextran is a critical requirement to ensure its safety and therapeutic efficacy in pharmaceutical applications, making their selective separation particularly significant. However, commercial polysulfone (PSf) membranes exhibit insufficient retention precision for LMW dextran. In this study, a novel modified ultrafiltration (UF) membrane was prepared by photo-induced surface controlled/living graft polymerization of the bifunctional monomer divinylbenzene (DVB) onto the surface of commercial PSf membranes. Benzophenone (BP), employed as a photoinitiator, generates benzophenone ketyl radicals upon excitation via hydrogen abstraction, which reversibly couple with radicals present on the surface of the PSf membrane to form dormant species. Upon subsequent UV irradiation, these dormant species undergo bond cleavage to regenerate active chain radicals capable of initiating further chain propagation polymerization of DVB monomers. The termination of the chain growth reaction of DVB occurs through the collision of free radicals with either the surface of the PSf membrane or the adjacent polymer chains. The cross-linked three-dimensional network structure serves as a dense selective separation layer, enabling the DVB-g-PSf membrane to efficiently separate dextran with molecular weights of 2 kDa and 20 kDa. The optimized grafted membrane prepared with grafting concentrations of 2 wt% DVB and 1 wt% BP achieved a rejection rate exceeding 85% for 20 kDa dextran while maintaining a rejection rate below 1% for 2 kDa dextran, with a water permeability of 5.39 L·m-2·h-1·bar-1. Moreover, for the mixed solution of 2k Da and 20k Da dextran , the separation coefficient of this membrane can reach 10.69, confirming the feasibility and significant potential of the DVB-g-PSf membrane for selective retention of LMW dextran. This study provides an important reference for innovative approaches in the separation and purification of LMW dextran using UF membranes.

Keywords: *Ultrafiltration Membrane; Living/Controlled Polymerization; Divinylbenzene (DVB); Low Molecular-Weight Dextran Separation*

Paper ID: A112

Electron Beam-Initiated Hydrogel Modification of Hollow Fiber Membranes for Enhanced Fouling Resistance

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ABSTRACT

Membrane technologies are essential in biopharmaceutical production, particularly for the separation and purification of functional proteins. Hollow fiber membranes are widely used in such processes due to their high surface-area-to-volume ratio, mechanical self-support, and excellent scalability. However, fouling during protein filtration remains a significant challenge, reducing filtration efficiency and increasing operational costs. Surface modification of porous hollow fiber membranes with hydrogel layers has emerged as an effective strategy to reduce fouling and improve membrane performance. Achieving highly functional modification with irradiation-initiated polymerization, however, is challenging due to the unique geometry of hollow fiber membranes, which complicates the uniform distribution of the hydrogel layer on the surface in the entire pore space. This study investigates the modification of polyethersulfone hollow fiber membranes through electron beam (eBeam) initiated polymerization of hydrophilic monomers. Both ultrafiltration and microfiltration hollow fiber membranes were exposed to varying eBeam doses. Additionally, the ratio between functional and cross-linker monomers was varied to assess their impact on surface modification and fouling resistance. Key membrane properties, such as degree of grafting (DoG), permeance, zeta potential, nonspecific protein adsorption, and non-ionic surfactant adsorption were assessed before and after modification. Energy-dispersive X-ray spectroscopy (EDX) was used to analyze the distribution and uniformity of the hydrogel layer across the membrane cross-section. The results demonstrate that eBeam irradiation is a superior technique to functionalize the membrane surface, significantly reducing fouling by proteins and non-ionic surfactants without compromising performance too much. The geometry of the hollow fiber membranes and the location of the retentive layer were found to influence modification efficiency, with distinct irradiation parameters required for ultrafiltration in comparison to microfiltration membranes. This study highlights the potential of eBeam initiated hydrogel modification as a powerful strategy to enhance the performance and longevity of hollow fiber membranes for the biopharmaceutical filtration processes.

Keywords: *Membrane Modification, Low Fouling, Biopharmaceutical Industry*

Paper ID: A113

Fully Integrated Natural Gas Sweetening using Hybrid Membrane Contactor Technology

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ABSTRACT

Natural Gas Sweetening commonly uses membrane separation and chemical solvent absorption, but membranes can cause hydrocarbon losses, and solvent solutions are costly and large. A new hybrid process, the membrane contactor (MBC), uses 25% less energy, has a smaller size, and low hydrocarbon losses. This paper presents the development of a scaled-up MBC demo plant in Malaysia, demonstrating its capability to remove high concentrations of acid gases (CO2 = 23 mol%) and long-term stability versus conventional technologies.In the fully integrated MBC Acid Gas Removal unit, an MBC replaces the typical amine contactor tower where CO2-rich natural gas is fed to the tube side of the MBC, while lean amine is fed to the shell side in a counter-current configuration. Treated gas flows into a knockout drum before being sent to the sales gas header. The rich amine solvent is sent to the HP Flash Drum to degas light hydrocarbons, then to the LP Flash Drum to degas acid gas. The regenerated amine is recycled to the MBC for continuous sweetening. Plant data is analyzed against conventional AGR systems. The encouraging results from the MBC demo plant clocking continously thousand of hours in operation has demonstrated its reliability, flexibility, and effectiveness in natural gas sweetening, achieving required CO2 and H2S purity levels. MBC requires 25% less energy and occupies half the footprint compared to conventional Acid Gas Removal systems, leading to a significant reduction in carbon emissions. Additionally, MBC technology reduces hydrocarbon losses and offers 20-30% reduction in capital expenditures, making it cost-effective for onshore and offshore applications. This innovative method not only enhances gas sweetening efficiency but also has the potential for broader applications such as flue gas carbon capture for CCUS, thus contributing to advancements in the petroleum industry's knowledge base.

Keywords: *Natural Gas sweetening, Acid gas Remova, Membrane Contactor, Energy Efficient, Carbon Capture*

Paper ID: A114

Advanced Magnetic-Responsive Mixed Matrix Membranes (MMMs) for CO_2 Capture and Gas Separation

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ABSTRACT

Tackling the escalating threat of climate change demands innovative solutions, and CO_2 capture technologies are at the forefront. With their precision and adaptability, membrane-based systems redefine how we approach emissions reduction. Particularly, the fusion of polymers with inorganic fillers in mixed matrix membranes unlocks unparalleled potential for selective and efficient CO_2 separation, paving the way for cleaner industries and a sustainable future. This study explores the potential of amine-functionalized UiO-66-NH_2 MOFs combined with magnetic $MnFe_2O_4$ nanoparticles (MNPs) within a Pebax-based membrane system. The synergistic effects of these components significantly improve gas transport properties, focusing on enhanced CO_2 separation and incorporating MNPs at 5, 10, 15, and 20 wt.% within the polymer matrix resulted in a remarkable improvement in permeability and selectivity. For example, CO_2 permeability increased from 71 Barrer in the pristine Pebax membrane to 245 Barrer in the membrane containing 20 wt.% of MNPs. Concurrently, CO_2/N_2 selectivity increased from 43.6 to 73.26, and CO_2/CH_4 selectivity increased from 18.2 to 21.0. Observed enhancements were achieved through the controlled alignment of nanoparticles under an external magnetic field, which mitigated aggregation and sedimentation issues and optimized their dispersion within the matrix. Including $MnFe_2O_4$ as the magnetic component also provided additional advantages, such as forming ordered nanoparticle arrays that enhanced gas diffusion pathways. This approach resulted in membranes that surpassed the Robeson upper bound for CO_2/CH_4, CO_2/N_2, and O_2/N_2 separations and demonstrated exceptional stability and performance in gas separation applications. Our results underline the potential of MMMs incorporating UiO-66-NH_2 and $MnFe_2O_4$ as a scalable and efficient solution for industrial CO_2 capture and other gas separation processes, offering a blend of superior selectivity, permeability, and robustness and providing valuable insights for future research and industrial applications.

Keywords: *Post-Combustion CO_2 Capture, Mixed Matrix Membranes, Metal-Organic Framework Nanoparticles, Gas Separation Efficiency*

Paper ID: A115

Porous Contactor Membranes for Catalytic H_2 Gas Release from Aqueous Chemical Storage Media

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ABSTRACT

As a clean and renewable energy carrier, hydrogen can play a lead role for a more sustainable future, but storage and transportation remain challenging. Liquid aqueous chemical storage is a promising approach but lacks efficient on-demand hydrogen gas release methods. In this project, we investigate a novel approach, which utilises a catalytic membrane contactor for the H_2 gas release from aqueous ammonia borane or formic acid. Based on a method established in an earlier study [1], we fabricated catalytically active porous polymer-based multi-composite membranes by film casting cum non-solvent induced phase separation of the matrix polymer polyethersulfone, incorporating Ni or Pd nanoparticles as catalyst and carbon particles or a cationic ionomer as additives to alter the pore properties. We explored different strategies for incorporating catalysts, including mixing commercially available catalyst particles or in situ nanoparticle synthesis within the casting solution. By this approach, we obtained several membranes with varied properties, such as cross-section morphology, pore size, hydrophobicity, and associated catalytic activity. These membranes were then further investigated in batch experiments to benchmark catalytic activity [2] as well as in a cross-flow and a flow-through setup with aqueous ammonia borane as feed, allowing correlations of process performance with membrane properties and process parameter and thus evaluating the overall potential of the approach. Beyond ammonia borane, we also apply this membrane concept to hydrogen gas release from formic acid, representing a crucial step toward a more economic and fully recyclable hydrogen storage system. Additionally, the gained insights should facilitate a tailored fabrication of porous catalytically active capillary membranes as an option for a more flexible process design and potentially process intensification.

Keywords: *Membrane Contactor, Catalyst, Hydrogen Storage*

Paper ID: A116

Bottom-up CVD synthesis of multilayer porous graphene

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ABSTRACT

Recently, porous graphene has garnered attention for its potential applications in ultimate permeation, gas separation, and seawater desalination. The primary technical requirement for the active use of porous graphene lies in reliable synthesis, as tailoring pores in the graphene lattice demands intricate engineering. In fact, several studies have demonstrated the feasibility of porous graphene synthesis by top-down methods, such as plasma treatment, though the sporadic and uneven formation of pores fails to ensure reproducibility and practicality. On the other hand, bottom-up synthesis offers the advantage of ensuring uniform pore structures. However, the complexity of catalyst design remains a critical bottleneck to the progress of bottom-up methods. In this talk, we propose catalyst engineering for bottom-up multilayer porous graphene synthesis via catalytic chemical vapor deposition (CVD). We prepare a single-crystalline cobalt thin film paired with various inactive catalyst materials, such as metals and non-metals, and facilitate the formation of a platform for porous graphene synthesis through facile reductive dewetting. The cobalt-based composite catalyst successfully achieves the bottom-up synthesis of multilayer porous graphene, a feat rarely demonstrated, and demonstrates control over pore sizes ranging from 10 nm to several hundred nanometers.

Keywords: *Porous Graphene, Chemical Vapor Deposition, Bottom-Up Synthesis, Catalyst Engineering, Reductive Dewetting*

Paper ID: A117

A Facile Strategy to Improve Membrane CO2 Separation Performances: Non-solvent Induced Microstructure Re-arrangement

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ABSTRACT

Membrane materials with high CO2 separation performances are urgently needed to improve the competitiveness of membrane-based CO2 capture. PebaxTM has been intensively studied for CO2 separation . However, the inherently low CO2 separation performance of PebaxTM materials hindered its wide industrial application. Non-solvent induced micro-structure rearrangement method has been proven to be effective in promoting the gas separation performances without changing the chemical coposition of the polymeric membranes. The membrane was firstly fabricated via conventional solvent evaporation process. Followed by a micro-structure rearangment by combination of good solvents and non-solvents of the polymers under various conditions (e.g., composition, temperature, duration time). Here, a facile non-solvent induced micro-structure rearrangement method was developed to enhance the CO2 separation performance of PebaxTM 2533 membranes. DI water and 3 amino acid salt aqueous solutions were employed as non-solvents. After soaking in the non-solvents for 24 hours, the CO2 permeability of the PebaxTM 2533 membrane reached 1179.5 Barrer, an increment of nearly 4.5 times, compared with the pristine membrane, while the CO2/N2 selectivity of the PebaxTM membrane remained unchanged. Furthermore, the improved performance was maintained over 230-day testing, demonstrating the long-term stability of the rearranged microstructure in the PebaxTM 2533 membrane, outperforming most state-of-art block polymeric membranes. This rearrangement strategy represents a facile and green approach to CO2 separation performance improvement of block polymeric membranes.

Paper ID: A118

Unravelling Membrane Fouling Mechanisms in Reverse Osmosis of Rare Earth Wastewater: A Multiscale Perspective

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ABSTRACT

Rare earth element (REE) industrial wastewater is characterized by high concentrations of ammonium nitrogen and low-strength organic compounds, posing challenges for membrane-based treatment. Reverse osmosis (RO) is an effective method for REE wastewater treatment; however, its performance is significantly hindered by membrane fouling. In this study, the fouling mechanisms during RO treatment of REE wastewater were investigated using a multiscale approach. Bench-scale fouling tests were conducted with synthetic wastewater containing high NH_4^+–N and varying concentrations of 2-ethylhexyl phosphonic acid mono-(2-ethylhexyl) ester (P507), a widely used extractant in REE separation. A commercial RO membrane was used to evaluate fouling behaviour under different P507 loadings. A critical P507 concentration of 0.25 mg L⁻¹ was identified, at which the fouling pattern shifted markedly. Below this threshold, water flux increased and membrane surfaces became more hydrophilic. Above this concentration, severe fouling was observed, accompanied by increased surface hydrophobicity. Multiscale simulations—including molecular dynamics (MD) and dissipative particle dynamics (DPD)—revealed that the structure and composition of the fouling layer varied with P507 concentration. At low levels, P507 molecules aligned with their hydrophilic groups facing water, enhancing membrane wettability. In contrast, higher concentrations led to the formation of hydrophobic surface layers and the penetration of P507 into the polyamide matrix, blocking internal water transport pathways. These results suggest that the decline in membrane performance above the critical P507 concentration is due to both surface fouling and internal obstruction. This study provides valuable insights into the molecular-level interactions driving RO membrane fouling in REE wastewater treatment and offers guidance for developing fouling mitigation strategies and next-generation antifouling membrane materials.

Keywords: *Membrane Fouling, Polyamide Membrane, Dissipative Particle Dynamics, Molecular Dynamics, Rare Earth Wastewater*

Paper ID: A119

Dielectric Constant of Water in Nanofiltration Membranes Investigated by Molecular Dynamics

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ABSTRACT

Nanofiltration (NF) membranes with high ion rejection play a crucial role in industrial water treatment processes. To access the ion rejection properties, various models have been proposed, such as DSPM-DE (Donnan Steric Pore Model-Dielectric Exclusion) and SEDE(Steric Electric Dielectric Exclusion) model, with newer models incorporating the dielectric constant of the solvent. In general, the dielectric constant of the solvent in the polymer is different from that of the pure solvent, and changing the dielectric constant can drastically change the rejection characteristics. The reduction of the dielectric constant decreases an energy barrier for the solvation of ions, which affects their rejection properties [1-2]. However, the experimental estimation of the dielectric constant of the solvent in the NF membranes is still difficult. In this study, we applied molecular dynamics (MD) to estimate the dielectric constant of water in polyamide-type NF membranes. We investigated some polyamide models composed of diethylenetriamine (DETA) and trimethyl chloride (TMC) for MD calculations. Polyamide models with 8 Å pore size were prepared and Grand Canonical Monte Carlo (GCMC) simulations were performed to solvate the membrane pore by water molecules. Then, the dielectric constant of water inside the pores was calculated by MD simulations. The dielectric constant of water in the pore was estimated to be approximately 72.4% lower than that of bulk water. This reduction can be attributed to the relaxation time of molecular conformation in the pore. The restricted rotation of water molecules due to interactions between water molecules and the pore wall, where water molecules align along its surface, determines the dielectric constant. Furthermore, the dielectric constant of water inside the pore showed anisotropic properties. These findings contribute to the prediction of ion rejection properties of NF membranes.

Keywords: *Molecular Dynamics; Nanofiltration Membrane; Dielectric Constant; Polyamide*

Paper ID: A120

Engineering Positively Charged Uio-66 Derivative in Supported Liquid Membranes for Rapid Recovery of Gold From E-Water

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ABSTRACT

Recovery of gold ions from electronic wastewater is critical for resource conservation and environmental sustainability[1]. Supported liquid membranes offer a promising separation approach, but their performance is often hampered by weak ion-specific interactions. The incorporation of metal organic frameworks (MOFs) can enhance separation performance. UiO-66 is an acid-stability MOF with strong electrostatic interactions, making it suitable for metal ion separations. In this study, UiO-66 was functionalized with a quaternary ammonium silane agent to introduce ionic functionality, forming positive-charged UiO-66-DMOAP. This post-modification enhanced the membrane's Coulombic interaction with gold chloride complexes ($[AuCl_4]^-$), improving initial flux and extraction selectivity. Supported liquid membrane incorporating UiO-66-DMOAP was prepared and compared with supported ionic liquid membrane and supported liquid membranes with pristine UiO-66. The membrane based on UiO-66-DMOAP exhibited excellent gold ion extraction performance due to the enhanced interactions.

Keywords: *Positive-Charged UiO-66-DMOAP, Coulombic Interaction, Supported Liquid Membrane, Gold Recovery, E-water*

Paper ID: A121

Evaluation of $BaTiO_3$ Materials for Methyl Orange Piezo-photodegradation Performance in Slurry Mode and Immovable Flat-sheet PVDF Membrane

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ABSTRACT

The elimination of hazardous contaminants from wastewater is a significant global concern, addressed through various techniques. Photocatalysis, an emerging and environmentally friendly wastewater treatment technique utilizing semiconductor materials, exhibits low efficiency, which can be enhanced through various strategies. Piezoelectric catalysis is a possible approach for enhancing the efficiency of pollutant photodegradation. $BaTiO_3$ (BTO) is a material having piezoelectric characteristics that serves as an effective photocatalyst for the removal of hazardous organic contaminants from wastewater, with its efficacy augmented by external stress that induces spontaneous polarization. This study reports an enhanced piezo-photocatalytic degradation rate for tetragonal $BaTiO_3$ nanoparticles exhibiting piezoelectric properties, synthesized through the hydrothermal technique. This research employed ultrasonic waves to evaluate the piezoelectric characteristics of $BaTiO_3$ (BTO) within a slurry photoreactor and a stationary flat-sheet PVDF membrane, aiming to assess the piezo-photocatalytic degradation efficiency of methyl orange (MO). The photoactivity of the material was assessed by analyzing the photodegradation efficiency of MO under visible light (300 W, $\lambda \geq 480$ nm) irradiation. The optimal degradation performance of BTO in slurry and membrane, with or without ultrasonic stress induction, was evaluated through the measurement of MO absorbance using a UV-Vis spectrophotometer. After 120 minutes of exposure to visible light, the rates at which MO degraded were 62.7% in slurry mode without external stimulation and 89.5% with sonication. For the flat-sheet membrane BTO, the photodegradation rates were 49.2% without stress induction and 77% with sonication. The 89.5% degradation rate of BTO in slurry mode is attributed to the combined influence of extensive surface area exposed to light and the polarization effects arising from the material's piezoelectric properties. This study offers insights into the foundational aspects of piezoelectric materials and their efficient utilization of photocatalytic and piezoelectric effects to advance the field of piezoelectric-assisted photocatalysis.

Keywords: *Piezo-Photocatalytic Degradation; Flat-Sheet PVDF Membrane; Sonication; Visible Light; Methyl Orange*

Paper ID: A122

High Performances Carbon Molecular Sieve Membranes Developed via Hybrid Precursors

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ABSTRACT

The rational design of precursor structure serves as a critical determinant for the pore structure and gas separation performance of carbon molecular sieve (CMS) membranes. polyimides (PIs) hold the intrinsic advantages of designable structure, superior gas separation performances, as well as good thermal and mechanical strength, serves as excellent precursors for making CMS membranes. The preparation of hybrid CMS membranes by incorporating crosslinking agents, nanofillers with specific pore structures, or metallic nanoparticles into PI matrices can effectively modulate their pore microstructure and enhance gas separation performance [1, 2]. The precursor membranes were prepared by the solution casting method. Hybrid precursor membranes were fabricated by incorporating additives into a PI matrix, followed by high-temperature carbonization to prepare hybrid CMS membranes. The structural characteristics and separation performance of CMS membranes were optimized by adjusting the additive content and carbonization temperature. To enhance the gas separation performance of membranes, we fabricated hybrid precursor membranes by incorporating either crosslinking agents or nanofillers with tailored pore structures into PI matrices. On the one hand, the crosslinking groups reinforced interfacial interactions, thereby improving structural stability and mitigating micropore collapse during carbonization, which effectly enhanced gas permeability and stability. On the other hand, nanofillers with well-defined pore structures provide additional molecular transport pathways, thereby synergistically improving gas separation performance. Under optimized conditions, the hybrid CMS membrane demonstrated significantly enhanced CO_2 permeability (P_{CO2}: 257.2 → 1665.9 Barrer) compared to the pristine PI precursor membrane, while exhibiting a 247% enhancement in CO_2/CH_4 selectivity, surpassing the latest Robeson upper bound.

Keywords: *Gas Separation, Carbon Molecular Sieve Membrane, Polyimides; Hybrid*

Paper ID: A123

Exploring the Humidity-Dependent Performance of Amine-Containing Polymeric Membranes for CO2 Capture: Insights from Molecular Dynamics Simulation

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ABSTRACT

Carbon dioxide capture, utilization, and storage (CCUS) has recently gained significant attention as a key strategy for reducing CO_2 emissions. However, reducing the energy consumption involved in CO_2 capture remains a critical challenge. This study focuses on membrane separation technology, which offers the potential for both energy and space efficiency. Among various membrane materials, amine-containing polymeric membranes have shown excellent CO_2 permeance and selectivity under high relative humidity in a previous study1). However, for practical application, it is essential to develop polymer matrices that maintain high performance even under low-to-medium relative humidity conditions. This study aims to provide fundamental insights into the screening of optimal amine-containing polymeric membranes for CO_2 separation, with a focus on understanding how the swelling behavior of these materials under different water contents impacts their performance. To achieve this, the swelling behavior of amine-containing polymeric matrices was evaluated under a variety of water contents using molecular dynamics simulations. Specifically, simulation cells consisting of amines, oligomer chains, and water molecules were constructed to evaluate the effect of water content on the aggregation/dispersion state of the polymer matrix. The results revealed that when polyvinyl alcohol (PVA) is used as the matrix, the side chains of PVA tended to self-aggregate, independent of the water content. This finding suggests that the performance degradation of amine-containing PVA membranes under low relative humidity conditions is attributed to the aggregation of the PVA side chains. This aggregation likely obstructs CO_2 transport, reducing the CO_2 permselectivity of the membrane. This highlights the importance of controlling the swelling behavior of polymeric membranes to optimize their CO_2 separation efficiency under varying humidity conditions. In the presentation, we aim to discuss the relationship between water content and swelling behavior of several types of polymeric matrices other than PVA.

Keywords: *CCUS, CO_2 Permeance, Molecular Dynamics, Polyvinyl Alcohol, Self-Association*

Enhancing Fouling Resistance of PVDF Membranes by NIPS Process: Molecular Dynamics Study on the Compatibility with Antifouling Materials

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ABSTRACT

Polyvinylidene fluoride (PVDF) is widely utilized as a membrane substrate in filtration processes due to its favorable mechanical and chemical properties. However, its performance is often severely compromised by fouling, a phenomenon where suspended solids from feed water accumulate on the membrane surface, reducing filtration efficiency and increasing operational costs. To address this challenge, this study explores the development of antifouling membranes by blending PVDF with various antifouling materials via the nonsolvent induced phase separation (NIPS) method1). Specifically, nonionic materials (e.g. poly(2-methoxtethyl acrylate)) and zwitterionic materials (e.g. carboxybetaine polymer) were adopted as antifouling materials, and their compatibility with PVDF was systematically assessed using molecular dynamics simulations. The compatibility between the antifouling materials and PVDF was quantitatively evaluated using the second virial coefficient (B_2)2), an indicator that reflects the miscibility and phase separation tendency of the blended components. A larger B_2 value indicates better dispersion and higher compatibility, while a smaller B_2 suggests phase separation and poor blending. Notably, the results revealed that zwitterionic materials demonstrated significantly lower compatibility with PVDF compared to nonionic materials, consistent with previous experimental studies. These molecular-level insights into the interactions between PVDF and antifouling materials offer valuable guidance for designing more effective fouling-resistant membranes by NIPS process. By understanding the factors influencing material compatibility, this study paves the way for the selection of optimal antifouling materials, which could lead to the development of more efficient, cost-effective filtration technologies for a variety of industrial applications.

Keywords: *Antifouling Property, Betaine, Molecular Dynamics, PMEA, Zwitterionic Polymer*

Paper ID: A125

Visible-Light-Activated $BiVO_4$/PVA Membrane for Nutrient Recovery and Organic Load Reduction from Palm Oil Mill Effluent (POME)

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ABSTRACT

Palm Oil Mill Effluent (POME), a nutrient-rich byproduct of agro-industrial processing, contains high levels of phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and total nitrogen (TN), alongside complex organic contaminants. This study presents the development of a visible-light-responsive photocatalytic membrane designed for simultaneous nutrient recovery and organic load reduction from POME. The membrane was fabricated by depositing bismuth vanadate ($BiVO_4$) onto a cotton mesh substrate, embedded in a polyvinyl alcohol (PVA) matrix and crosslinked using citric acid. The $BiVO_4$ component enables photocatalytic activity under white LED illumination, allowing in situ mitigation of organic fouling while maintaining ion transport performance. A full 2^4 factorial experimental design was applied to assess the influence of membrane composition (with/without $BiVO_4$), feed type (raw vs anaerobically digested POME), operating temperature (room temperature vs 37 °C), and visible light irradiation (on/off) on system performance. Nutrient ions (P, K, Mg, Ca, TN) in the permeate were quantified using ion chromatography (IC) and inductively coupled plasma optical emission spectrophotometry (ICP-OES). Total organic carbon (TOC) was measured to evaluate organic compound permeation. The $BiVO_4$/PVA membrane demonstrated enhanced selectivity for nutrient ions under light-assisted operation and achieved significant TOC reduction relative to control membranes. Visible light irradiation also improved antifouling characteristics and supported stable flux over extended operation. This study supports the integration of solar-compatible photocatalytic membranes for sustainable wastewater valorization. The recovered ion-rich stream offers potential reuse as a nutrient source in fertilizer or irrigation systems, promoting circular resource recovery.

Keywords: *$BiVO_4$, Nutrient Recovery, Photocatalytic Membrane, POME, Visible Light*

Paper ID: A126

Effect of Carbonization Methods on Chicken Feather-Derived Activated Carbon for Potential Application in Biogas Upgrading

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ABSTRACT

The valorisation of poultry waste into functional carbonaceous materials represents a sustainable strategy to address both waste management and environmental challenges associated with greenhouse gas emissions. Chicken feathers a keratin-rich biowaste were utilized as a precursor for the synthesis of high-performance carbon material through urea-assisted pyrolysis in double crucible method. Urea generating a semi-inert atmosphere to facilitate controlled thermal decomposition. Carbonization was carried out at three fixed temperatures (650°C, 750°C, and 850°C) to investigate the effect of urea on the physicochemical properties like the BET surface area and CO2 adsorption capacity of the resulting carbon materials. The synthesized carbon material was characterized using CHNS elemental analysis to quantify the carbon content and present of the nitrogen source after the usage of urea in the sample and scanning electron microscopy (SEM) to elucidate morphological transformations and pore development. The results indicated that nitrogen doping via urea significantly influenced the surface structure and porosity, with optimal features observed at higher pyrolysis temperatures. CO_2 adsorption capacity of the carbon material reached significant values 2.8 mmol/g at 1 bar 273 K, thus, improved membrane compatibility when applied as fillers in asymmetric mixed matrix membranes (MMMs) for biogas upgrading. The study not only contributes to sustainable waste valorisation but also presents a promising route for developing advanced CO_2-selective membrane fillers, aligning with the goals of clean energy production and circular economy in the Malaysian context.

Keywords: Chicken feathers, urea-assisted pyrolysis, carbon capture, biogas upgrading, mixed matrix membranes.

Paper ID: A127

Precise Engineering of Ionic Nanochannels for Advanced Nanofiltration Membrane Design

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ABSTRACT

To address the trade-off effect between monovalent salt ion transport efficiency and selectivity in nanofiltration (NF) membranes, this study proposes a novel strategy based on the precise construction of magnetically aligned carbon nanotube (CNT) array channels. By combining magnetic alignment with interfacial polymerization, highly ordered CNT arrays were achieved within the selective layer of NF membranes. A polyamide (PA) NF membrane with aligned nanochannels was fabricated via vacuum-assisted interfacial polymerization using magnetic field-aligned multi-walled carbon nanotubes (MWCNTs). The results show that the amino-modified MWCNTs/PA composite NF membrane exhibits enhanced hydrophilicity, demonstrating a rejection rate of 93% and a water flux of 25.3 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ for 0.5 g/L $MgCl_2$ solution. However, the membrane's zeta potential remained unchanged, indicating that the PA/MWCNTs composite NF membrane surface retained a positive charge. To further improve permeation flux, MWCNTs-NH_2 were magnetically aligned and incorporated into the PA membrane to prepare an A-MCNTs-NH_2/PA membrane. The effect of different A-MCNTs-NH_2 loadings on membrane performance was investigated. At an optimal loading of 5 wt%, the A-M5CNTs-NH_2/PA membrane exhibited the best separation performance, achieving 93% rejection and a flux of 31.7 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ for 0.5 g/L $MgCl_2$. Compared to the unmodified PA membrane, the A-M5CNTs-NH_2/PA membrane nearly doubled the permeation flux while maintaining high rejection. This study provides a new approach for fabricating high-performance composite NF membranes with precisely aligned nanochannels.

Keywords: *Nanochannels; Ion, Ionic Sieving, Nanofiltration Membrane, Interfacial Polymerization*

Paper ID: A128

Effect Of Molecular Structure of Poly(Lactic Acid) on Membrane Structure and Performance of the Poly(Lactic Acid) Ultrafiltration Membranes

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ABSTRACT

The use of membranes for separation and purification applications is growing significantly. Poly(lactic acid) (PLA), a bio-source and biodegradable in compost, but not biodegradable in water, is expected as a potential membrane material for water treatment [1], but, the important relation between molecular structure (branch structure, molecular weight, and so on.) and phase separation structure (i.e., pore structure) has not been investigated. In this study, we synthesized PLAs (via ring opening polymerization) with different number of branches and molecular weight, and prepared ultrafiltration membrane with these PLAs by nonsolvent induced phase separation (NIPS) method. We investigated effect of molecular structure of PLA on porous structure and degradation behavior under the accelerated condition. We synthesized liner and star branched PLAs (branch number 4 or 8) with weight average molecular weight (Mw) approximately 95,000 and narrow dispersity ($Mw/Mn \leq 1.2$) by using organic catalyst. PLA membranes with different branch number were prepared by NIPS method. Molecular weight cutoff (MWCO) of these membranes evaluated by poly(ethylene glycol) increased with increasing branch number (liner: MWCO 15,000, 4 branches: 17,000, 8 branches: 52,000). The factor of this MWCO increasing is considered that increasing of branch number causes increasing of PLA molecule's mobility, and enhances phase separation (i.e., expansion of pore diameter). These membranes were soaked in pH9, 65°C buffer solution for accelerated hydrolysis test. After soak for 88 h, the order of molecular weight reduction rate was follows: 4 branches(37%) > 8 branches(24%) > liner(10%). It is considered that branch structure enhances hydrolysis at early stage, but so many branches increase PLA density around branch point, and this prevent from water penetration and hydrolysis.

Keywords: *PLA Membrane, PLA Molecular Structure, Porous Structure, Phase Separation, PLA Degradation*

Paper ID: A129

Boosting CO2/N2 Separation Performance of Pebax Membranes by Incorporating Modified Nanocellulose from Goosegrass

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ABSTRACT

This study investigates the potential of incorporating nanocellulose derived from goosegrass into Pebax® (polyether block amide) membranes to enhance their performance in CO2 gas separation. Nanocellulose was extracted from goosegrass through sulfuric acid hydrolysis, a cost-effective and sustainable approach. To improve its compatibility with the Pebax matrix and increase its affinity for CO2, the extracted nanocellulose was subsequently modified via esterification. Hybrid membranes were then fabricated by blending varying loadings of this modified nanocellulose with Pebax. The resulting membranes were characterized in terms of their morphology, thermal stability, mechanical properties, and CO2 permeability and selectivity. Scanning electron microscopy (SEM) was employed to examine the dispersion of nanocellulose within the polymer matrix. Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) were used to assess the thermal behavior of the hybrid membranes. Tensile tests were conducted to evaluate their mechanical strength and flexibility. The gas separation performance was evaluated using a gas permeation system with a single feed gas for CO2 and N2. The influence of nanocellulose loading on both CO2 permeability and CO2/N2 selectivity was systematically analyzed. The results demonstrate that the incorporation of modified nanocellulose significantly improved the CO2 separation performance of the Pebax membrane, likely due to enhanced CO2 solubility facilitated by the modified nanocellulose and altered membrane microstructure. This research highlights the promising application of sustainably sourced and modified nanocellulose as a filler material for developing high-performance CO2 separation membranes.

Keywords: *CO2 Separation, PEBAX, Nanocellulose, Goosegrass, Hybrid Membrane*

Paper ID: A130

Tailoring Membrane Support Properties via Controlled Air Gap and Etching Processes for Desalination through DCMD System

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ABSTRACT

A symmetric, rough-surfaced membrane supports consistent vapor transport and enhanced surface interactions, resulting in higher flux, better wetting resistance, and lower temperature polarization (TP), all of which are crucial for long-term MD efficiency. Therefore in this study, morphology of polysulfone (PSf) support membrane was tailored was tailored through variation of air gap distances during phase inversion and surface etching treatments to produce a membrane with balanced structural symmetry and enhanced surface roughness. The PSf support membrane was spun with different air gap lengths (40 cm, 50 cm, and 60 cm), followed by an etching process using 20 wt.% N, N-dimethylacetamide (DMAC) with varied etching duration from 30, 60, 90, 120, 150, 180, and 210 seconds. The support membrane was further characterized both morphologically and physically prior to performance evaluation. The findings revealed that the PSf support membrane was best fabricated at an optimal air gap length of 60 cm, which produced a symmetrical structure featuring finger-like voids with an average length of 139 μm. Additionally, the optimal etching condition was achieved by treating the membrane with 20 wt.% DMAc for 180 seconds. Under these conditions, the hydrophobicity of the PSf membrane was enhanced, resulting in a water contact angle of 96.82° and a surface roughness (Ra) of 41.37 nm. The formation of a symmetrical structure and rougher surface is expected to improve clogging resistance by promoting a more uniform dispersion of incoming materials across the membrane. Overall, the tailored morphology and surface properties of the PSf support membrane are anticipated to enhance membrane distillation performance by improving vapor transport, reducing wetting risks, and minimizing TP effects.

Keywords: *Symmetric Membrane, Finger-Like, Roughness, Air Gap, Etching, Membrane Distillation*

Paper ID: A131

Fabrication of Inner-Selective Hollow Fiber Nanofiltration Membranes for Water Treatment

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ABSTRACT

Water scarcity is an important issue worldwide, especially in arid regions. The situation is getting worse in the next decades. The lack of water has severe impacts on food production, industrial productivity and domestic needs. To deal with water scarcity, many efforts have been made to safely discharge and reuse the reclaimed wastewater. In this study, inner-selective hollow fiber nanofiltration membranes have been developed for effective removal of pollutants, such as heavy metal and dyes from wastewater. While using chemically stable materials polyethersulfone (PES) and sulfonated polysulfone (SPSf) to form the membrane substrate, two different techniques, including interfacial polymerization and functioning bore fluid have been investigated to reduce the membrane pore size to nanofiltration level. Possible methods in simplifying fabricating procedures of hollow fiber membranes have been learnt as well. By optimizing hollow fiber spinning conditions and modification parameters thereafter, membranes with good rejection to heavy metal ions or dye solutes could be achieved. The study may provide useful insights in designing hollow fiber nanofiltration membranes that are suitable for large-scale production.

Keywords: *Hollow Fiber Membranes, Nanofiltration, Water Treatment, Interfacial Polymerization, Functioning Bore Fluid*

Paper ID: A132

Fabrication of Dual-Layer Yttria-stabilized Zirconia/Nickel Oxide (YSZ/NiO) Hollow Fiber Membrane for Wastewater Treatment

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ABSTRACT

Developing advanced membranes for efficient wastewater treatment is crucial to addressing global water scarcity and pollution challenges. This study presents the fabrication and characterization of a dual-layer hollow fiber membrane (DL HFM) with an inner layer of yttria-stabilized zirconia (YSZ) and an outer layer of yttria-stabilized zirconia/nickel oxide (YSZ/NiO) composite. The inner YSZ layer provides exceptional mechanical strength and chemical stability, while the outer YSZ/NiO composite layer offers enhanced photocatalytic activity for pollutant degradation. The membrane was fabricated using a phase inversion and sintering technique, with optimized composition and sintering temperature to ensure a defect-free interface and high porosity. Comprehensive characterization using SEM-EDX and XRD analysis confirmed the uniform distribution of YSZ and NiO phases, along with excellent mechanical properties. The photocatalytic performance of the membrane was evaluated under UV and visible light for the degradation of persistent organic pollutants, demonstrating high removal efficiency and reusability. The membrane also exhibited superior fouling resistance and water flux, making it a promising candidate for industrial wastewater treatment. This work highlights the potential of dual-layer YSZ/YSZ-NiO hollow fiber membranes as a sustainable and multifunctional solution for addressing complex wastewater challenges.

Keyword: *Photocatalytic Membrane, Ceramic Membrane, Dual-Layer Hollow Fiber Membrane, Water Treatment, Nickel Oxide*

Paper ID: A133

Mechanism, Impacts and Mitigation Strategies of Carbon Deposition in Solid Oxide Fuel Cell: A Short Perspective

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ABSTRACT

Carbon deposition or coking remains a critical issue affecting the durability and efficiency of solid oxide fuel cells (SOFC) when operating on hydrocarbon fuels such as methane and syngas. This review summarizes an experimental investigation on the formation mechanisms of carbon deposition on Ni-based anodes in different operating conditions. Additionally, various technique including scanning electron microscopy (SEM), X-ray diffraction (XRD), and thermogravimetric analysis (TGA) were highlighted to monitor and characterise the initial phase of carbon deposition on the anode utilising methane and syngas fuels. To determine which conditions were most prone to coking, the effects of several parameters, such as temperature, steam-to-carbon ratio, and current load, were discuss in details. In addition, several mitigation strategies were also deliberated, including steam reforming, CO_2 co-feeding, as well as alternative anode material whereby it can enhance both cell stability and performance. This review aims to give a practical insight into operational guidelines and material design for enhancing the carbon tolerance of SOFC systems in real-world applications.

Keywords: *SOFC, Carbon Coking, Hydrocarbons, Carbon Mitigation, Fuel Cell*

Paper ID: A134

Desalination Strategy Using Ion-Exchange Membranes for Marine Farms

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ABSTRACT

The growing shortage of farmland caused by climate change and population growth led to efforts to cultivate crops on wastelands through urban agriculture and film farming. However, these approaches faced significant challenges, such as limited space and high irrigation costs. On the other hand, marine farming, which eliminates the need for farmland and directly utilizes seawater, was largely impractical due to salt stress, which inhibited plant growth and reduced crop yields. Here we developed an ion-selective membrane-based ion filter inspired by the salt-tolerant roots of mangroves, allowing plants to filter salt through root pressure. The nanoporous ionized membrane demonstrated excellent biocompatibility and mechanical durability, effectively filtering sodium ions using a high negative zeta potential based on the Donnan mechanism. By adjusting the membrane's surface potential and nanoporosity, we controlled desalination rates and water supply to make the system suitable for a wide variety of plants. This study showed that high-surface-potential membrane filters enabled energy-free marine farming, providing a sustainable and innovative solution to agricultural challenges.

Keywords: *Desalination, Marine farm, Ion-filter, Membrane, Polyelectrolyte*

Paper ID: A135

Enhanced H_2/CO_2 Separation Performance using Polysulfone-Based Mixed Matrix Membranes Incorporating ZnO-Modified Zeolite Composite Carbon

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ABSTRACT

"Blue" hydrogen is considered a promising short-term solution for achieving Net Zero Emissions due to its high energy efficiency, economic value, and zero carbon emissions. However, its production via the water-gas shift reaction (WGSR) generates a high concentration of CO_2 (~48%) as a by-product, which reduces the heating value of hydrogen. Therefore, an efficient H_2/CO_2 separation technology is essential for purifying WGSR products. In this study, mixed matrix membranes (MMMs) were selected due to their good separation performance, low production and maintenance costs, and ease of fabrication. Modification of zeolite composite carbon (ZCC) by adding ZnO as filler was expected to enhance the interaction between the MMM and H_2, which potentially increasing H_2 permeability. This research studied the effects of ZnO addition to ZCC on the enhancement of gas separation performance in PSf membrane. ZCC/ZnO was synthesized in-situ using polyvinyl alcohol (PVA) as the carbon precursor, Zeolite 13X as the structural template, and $Zn(NO_3)_2$ as the metal source, followed by carbonization at 800 °C with a heating rate of 2 °C/min. Membranes containing a low filler content (1.5 wt%) were fabricated by the phase inversion method. X-ray diffraction (XRD) analysis showed a reduction in zeolite pore structure, indicated by the decrease of the diffraction peak at $2\theta \sim 6°$, while diffraction peaks characteristic of hexagonal ZnO were observed. SEM images of ZCC/ZnO revealed slight particle agglomeration, leading to broader particle distribution. However, SEM images of PSf/ZCC and PSf/ZCC/ZnO membranes showed good filler dispersion, void-free surfaces, and asymmetric cross-sections. The PSf/ZCC/ZnO membrane exhibited the highest H_2/CO_2 separation performance, improving H_2 permeability and ideal H_2/CO_2 selectivity by 18444% and 276%, respectively, compared to the PSf neat. The performance was positioned close to the Robeson 2008 upper bound, indicating that the addition of ZCC/ZnO significantly enhanced H_2/CO_2 separation performance.

Keywords: *H_2/CO_2, MMM, Polysulfone, ZCC, ZnO*

Graphene Nanoribbon/Carbon Nanotube Hybrid Hydrogels for Efficient Fractionation of Organic Mixtures

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ABSTRACT

Carbon-based materials have attracted attention as next-generation organic solvent nanofiltration (OSN) membrane materials due to their excellent resistance to organic solvents, high permeance, and cost-effectiveness. Among these, one-dimensional carbon nanomaterials such as multi-walled carbon nanotubes (MWNTs) and graphene nanoribbons (GNRs) stand out for their highly porous bundle structures, which can greatly enhance membrane permeability and separation performance. In this study, we reported a one-pot synthesis method for producing a MWNT/graphene oxide nanoribbon (GONR) hybrid material. By carefully controlling the oxidation and unzipping conditions of MWNTs, we obtained MWNT/GONR hybrid that disperse readily in a variety of solvents and forms a hydrogel in water at concentrations of 40 mg/mL. This hydrogel exhibits viscoelastic shear-thinning properties, making it suitable for fabricating large-area MWNT/GONR coatings on polymeric porous supports using scalable slot-die coating techniques. The resulting MWNT/GONR membrane demonstrates outstanding nanofiltration capabilities in water, achieving a molecular weight cut-off of 300 Da. Notably, it exhibits superior dye/salt separation with a separation factor of 1000 and a water flux of 367.8 LMH, significantly exceeding the performance limits of current diafiltration membranes. Furthermore, we developed a MWNT/GNR(H) membrane that shows excellent permeability for alcohol-based solvents, attributed to the removal of oxygen-containing functional groups *via* an additional reduction (hot-press) process. This hot-pressed membrane also displays remarkable stability and selectivity, maintaining consistent performance in organic solvent even after 1,315 hours of continuous cross-flow operation, thanks to the welding effect induced by the reduction process. Finally, the membrane's capability for mixed molecule separation was confirmed by its outstanding performance in completely separating binary dye mixtures.

Keywords: *Graphene Nanoribbon, Hybrid Hydrogel, Organic Solvent Nanofiltration, Long-Term Operation, Mixture Fractionation*

Paper ID: A137

Torlon-Based Hierarchical Porous Membrane with Switchable Superettability for on-Demand Separation of Oil–Water Emulsions

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ABSTRACT

Switchable superwetting membranes have emerged as a promising solution for the efficient treatment of oily wastewater, but challenges remain in achieving facile fabrication and high permeance under practical conditions. Herein, we report a straightforward approach to fabricate symmetric Torlon membranes featuring macro/nano-structured porous surfaces and highly interconnected bulk. These membranes exhibit unique superamphiphilic properties in air, underwater superoleophobicity, and underoil superhydrophobicity, enabled by the synergistic effect of their hierarchical surface structure and molecular reorganization in liquid environments. Molecular dynamics simulations further reveal the selective interaction of hydrophilic and hydrophobic polymer segments, which drives the switchable wetting behavior. The membranes demonstrate ultrahigh permeance and separation efficiency for oil-in-water, water-in-oil, and crude oil/water emulsions in a gravity-driven process, requiring no external energy. Additionally, the membranes show excellent antifouling and self-cleaning properties, maintaining stable performance across multiple cycles. This study not only provides a scalable method for designing superwetting membranes but also offers insights into creating next-generation materials for efficient and sustainable oil/water emulsion separation.

Keywords: *Hierarchically Porous Structure, Oil/Water Separation, Polyamide-Imide Porous Membrane, Surface Composition Reorganization, Switchable Superwettability*

Paper ID: A138

Prebiotic Chemistry-Inspired Design of Anion-Exchange Chromatographic Membrane for Enhanced Protein Separation

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ABSTRACT

Membrane chromatography offers a promising platform for efficient protein separation and purification. Among various strategies, ion-exchange membrane chromatography is recognized as the most mature and widely applied technique. However, balancing antifouling performance with high ligand density remains a major challenge in the development of ion-exchange membranes. Herein, we report a prebiotic-chemistry-inspired aminomalononitrile (AMN) / PEI-mediated copolymerization strategy for fabricate homogeneous, antifouling anion-exchange membranes with enhanced protein separation. A sponge-like polyvinylidene fluoride (PVDF) substrate was fabricated via an unconventional nonsolvent thermally induced phase separation (NTIPS) method. Spontaneous polymerization of AMN endowed the membrane with antifouling properties, resulting in a static binding capacity (SBC) of ~20 mg/g for bovine serum albumin (BSA), compared to ~30 mg/g for pristine PVDF substrate. The ligand density was precisely tuned by adjusting the AMN:PEI ratio from 3:1 to 1:3. At an optimized ratio of 1:2, the membrane achieved a maximum SBC of 105.8 mg/g for BSA, a 10% dynamic binding capacity of 106.13 mg/g, and a recovery rate of 70.9%. Moreover, the membrane exhibited a high water permeance of 4857 L/m²·h·bar, and low protein rejection (<4%). Further increasing the PEI ratio to 1:3 led to a decrease in capacity, likely due to ligand oversaturation. In separation tests using a BSA/lysozyme mixture, the 1:2 membrane achieved a separation efficiency of 79.7% based on SBC experiments. This work provides a versatile approach for balancing antifouling performance and ligand density, offering valuable insights into the design of next-generation chromatographic membranes for bioprocessing.

Keywords: *Anion-Exchange Membranes, Membrane Chromatography, Protein Purification, Antifouling Modification, Ligand Density Optimization*

Paper ID: A139

Omniphobic Surface: A Mini Review on Recent Development of Surface Roughness Methodology

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ABSTRACT

Omniphobic surface has gained popularity in membrane industry. Its presence facilitates the properties of both polymer and ceramic membrane in capturing CO_2 especially in biogas upgrading industry. The wetting and fouling problem that has been experienced by these membranes will be countered by incorporating omniphobic on the membrane surfaces as it exhibits excellent liquid repellency in broad range of surface tension. One of the strategies to incorporate omniphobic on the membrane surface is by lowering the surface free energy and liquid contact area on the membrane surface. To achieve this strategy, the liquid contact angle of the membrane become higher by increasing the roughness on the membrane surface. This mini review will be highlighting the type of surface roughness and methodology used by researchers to increase the surface roughness on the membrane. This review will discuss the effect of each roughness method on wetting and fouling resistance, absorption capacity on CO_2 capture and durability of membrane during biogas upgrading process. This review hopes to encourage researchers in expanding membrane technology field as they will encounter new discovery to increase omniphobicity of membrane especially ways of roughening membrane surface with low cost, simple methodology and environment friendly.

Keywords: *Omniphobic, Surface Roughness, Biogas Upgrading, Membrane, CO_2 capture*

Paper ID: A140

Microstructure and Permeation Property of MOR-Type Zeolite Membrane

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ABSTRACT

MOR-type zeolite membrane has been widely studied for dehydration of acetic acid because of its superior acid resistance. In this study, we shed light on the separation mechanism for H_2O/acetic acid. In particular, the effect of crystal orientation in MOR-type zeolite membrane on its permeation and separation property for water/acetic acid mixtures was studied. The crystal orientation of MOR membrane was tuned by the water content of the synthesis gel for hydrothermal treatment. The orientation gradually changed from *c*-orientation to random orientation with increasing water content. The fluxes of water and acetic acid through MOR membranes were evaluated in unary and binary systems. Though the c-oriented MOR membrane showed a large water flux in the unary water system, the water flux decreased in the binary mixture, suggesting that acetic acid in the 12-ring along the c-axis hindered water permeation in binary systems. In contrast, a randomly oriented MOR membrane maintained a relatively large water flux even in the binary system because acetic acid was unable to enter the 8-ring along the b-axis. Regardless of their crystal orientations, both membranes exhibited extremely high separation performances (a > 10000). The microstructure inside a membrane was evaluated by vapor adsorption tests for MOR powder and membranes. From the results of the adsorption test, the adsorbed amount of acetic acid on the randomly oriented membrane was 30 % less than that on MOR powder, suggesting that acetic acid cannot access the entire of 12-ring in the membrane layer. The region inside the membrane, where acetic acid cannot enter, contributes to its extremely high separation performance.

Keywords: *Zeolite, MOR, Orientation, Microstructure, Acetic Acid*

Paper ID: A141

Pressure-Driven Conversion of CO2 in a Zeolite-based Catalyticn Membrane Reactor for Direct Dimethyl Ether Production

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ABSTRACT

The direct conversion of CO2 to dimethyl ether (DME) offers a sustainable pathway for fuel and chemical production. However, conventional fixed-bed reactors (FBR) often face equilibrium limitations and water accumulation, which deactivate catalysts and reduce DME yield. To address these issues, membrane reactor technology has emerged as a promising solution, enabling in situ water removal and shifting the reaction equilibrium toward DME formation. Coating membranes onto supports improves structural integrity and facilitates water removal, enhancing overall performance. This study investigates the influence of operating pressure on a zeolite-based catalytic membrane reactor for direct CO2-to-DME conversion. A ZSM-5 membrane was integrated into the reactor to enable in situ water removal and enhance methanol dehydration. Experiments were conducted at 200 °C, with an H2/CO2 ratio of 3:1 and a GHSV of 507 mL·h-1·g-1. Reaction pressures were varied from 20 to 40 bar to evaluate their effects on CO2 conversion, DME selectivity, yield, and methanol formation. In general, increasing pressure enhances CO2 conversion and DME yield by shifting the equilibrium towards product formation. In this study, CO2 conversion ranged from 37.23 % to 47.29 %, while DME yield increased from 34.93 % to 45.46 %. DME selectivity remained above 95 % across all conditions, with minimal methanol formation, indicating efficient ZSM-5 catalytic membrane reactor. Compared to a conventional FBR under identical conditions, the catalytic membrane reactor demonstrated significant improvements, which are about 9.75 % higher CO2 conversion and 9.89 % greater DME yield. This enhancement is attributed to the membrane's ability to continuously remove water, thereby shifting the equilibrium and promoting DME formation. These findings highlight the potential of ZSM-5-based catalytic membrane reactor for efficient DME production from CO2, demonstrating its ability to overcome equilibrium and water-related limitations of conventional systems while offering improved conversion and product selectivity.

Keywords: *ZSM-5, Catalytic, CO2 Conversion, Dimethyl Ether, Membrane Reactor*

Paper ID: A142

Interlayer-Modulated Nanofiltration Membranes for Precise Ion Separation in Lithium Extraction

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ABSTRACT

Nanofiltration (NF) offers a scalable and energy-efficient method for lithium extraction from salt lakes. However, the selective separation of lithium from magnesium, particularly in brines with high magnesium concentrations, remains a significant challenge due to the close similarity in their hydrated ionic radii. The limited Li^+/Mg^{2+} separation selectivity of current NF membranes is primarily attributed to insufficient control over pore size and surface charge. In this study, an interlayered thin-film composite membrane incorporating functionalized sulfonated carrageenan was developed to regulate the interfacial polymerization process. This integrated interlayer plays a crucial role in controlling the diffusion and spatial distribution of amine monomers, leading to the formation of dense, nano-striped polyamide networks. These structural improvements including refined pore size and reduced negative charge significantly enhanced Li^+/Mg^{2+} selectivity (133.5) and increased permeance by 2.5 times compared to pristine membranes.

Keywords: *Nanofiltration, Polyamide Membrane, Sulfonated Carrageenan Interlayer, Lithium Extraction*

Paper ID: A143

Fabrication of PSS-MOF-303/rGO Membranes for Effective Separation of Rare Metal Ions

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ABSTRACT

In this study, MOF-303/reduced graphene oxide (MOF-303/rGO) nanofiltration membranes were successfully prepared using the polyelectrolyte sodium polystyrene sulfonate (PSSNa) as a dispersing agent. This PSS-assisted strategy promotes a more uniform dispersion of MOF-303 within the rGO membrane, thereby enhancing its structural stability during membrane separation. The fabricated membranes demonstrate exceptional performance in the selective separation of rare earth elements (lanthanum) and radioactive contaminants (Strontium). A detailed investigation of the separation mechanism revealed that size sieving and electrostatic interactions are the primary factors driving selectivity. Compared to rGO membranes, the PSS-MOF-303/rGO membrane exhibits approximately four times higher water permeance while achieving a modest improvement in selectivity. Furthermore, the PSS-MOF-303/rGO membrane maintains excellent separation performance under varying pressures, different feed concentrations, diverse La/Sr mass ratios, and long-term stability tests. These findings highlight the potential of PSS-MOF-303/rGO membranes for the efficient separation of rare earth ions from radioactive wastewater.

Keywords: *Reduced Graphene Oxide, MOF-303, Selective Separation, Lanthanum*

Paper ID: A144

Ionic Liquid-Incorporated Triazine-Based Porous Organic Polymer Membranes for CO_2 Separation

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ABSTRACT

Porous organic polymers (POPs) have been considered promising materials for membrane-based gas separation technology. POPs incorporated with CO_2-philic media have been demonstrated to be effective in improving CO_2 permeance and CO_2/N_2 selectivity. Herein, an ionic liquid (IL)-assisted polymerization method was developed to *in-situ* incorporate CO_2-philic ILs on POP networks. In this structure, an ionic liquid with high CO_2 affinity is stabilized within the pores and interlayers of POP networks based on experimental and simulated results. Owing to the synergistic effect of the controllable formation of the POP structure and the incorporation of the CO_2-philic IL, sufficient CO2-philic channels were created in the membranes. After optimization of the membrane synthetic parameters and the IL loading amount, the as-prepared IL-POP-120 min membrane presented a CO2 permeance of 186 GPU and CO2/N2 selectivity of 39.1 at 120 °C. Furthermore, the prepared IL-POP membranes demonstrated long-term stability with great resistance to temperature (up to 120 ℃) and transmembrane pressure (4 bar), which could realize the CO2 separation directly at high temperatures.

Keywords: *Porous Organic Polymer Membranes, Ionic Liquids, Polymerization, CO_2 Separation*

Paper ID: A145

Design and Optimization of Flat-Sheet Membrane Modules for Membrane Chromatography: A Review on Flow Distribution Principles

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ABSTRACT

In downstream biopharmaceutical purification, traditional resin column chromatography has a production bottleneck due to its high pressure drop, harsh cleaning and sterilization conditions, and long operation cycles. These limitations hinder its ability to meet the increasing demand for higher productivity and throughput driven by advancements in upstream processes. Membrane chromatography (MC), characterized by rapid and efficient mass transfer, has emerged as a promising alternative, offering enhanced productivity and throughput with reduced resource consumption and shorter processing times. Among various membrane modules, flat-sheet membrane modules have been extensively investigated. Valuable insights into optimizing flow conditions can be derived from these studies, offering important guidance for the future design of membrane module systems. Therefore, this work systematically analyses the extensive research on the design and optimization strategies of flat-sheet membrane modules. Key findings indicate that achieving uniform flux and residence time across the membrane necessitates the alignment of the hydraulic flow directions on both the feed and permeate sides. Flow resistance changes on both sides should primarily attributed to uniform distribution of feed flow across the membrane, implying that the channel resistance should be significantly lower than the membrane resistance. Furthermore, pressure drop and velocity variations on the two sides should be equal in magnitude but opposite in direction. A smaller pressure drop gradient along the channel correlates with better flow distribution and overall performance. Through a critical review of the state-of-the-art, this work aims to summarize a general theoretical framework for optimizing flow conditions based on research on flat-sheet membrane modules, highlighting the trends of hydrodynamic resistance variations across flow channels, an aspect that has been largely overlooked in previous studies, to guide future module design and enhance membrane application in biopharmaceutical purification.

Keywords: *Biopharmaceutical Purification, Membrane Chromatography, Flow Distribution, Hydrodynamic Optimization*

Paper ID: A146

Facile Fabrication of Polyamide-Polyester Nanofiltration Membranes Regulated by Ionic Liquids for Efficient Antibiotic Desalination

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ABSTRACT

The effective separation and purification of antibiotics from fermentation broth is challenged by the presence of salts such as NaCl [1,2]. When these salts accumulate to high concentrations, they can interfere with antibiotic recovery and stability. Nanofiltration membranes provide an energy-efficient approach for antibiotic desalination, but improving selectivity while maintaining high permeability remains critical [3,4]. In this study, a novel NF membrane was fabricated via interfacial polymerization process using piperazine and choline hydrogen tartrate (CHT), an ionic liquid, as aqueous monomers, reacting with trimesoyl chloride. The hydroxyl-rich CHT functioned as both a co-monomer and a polymerization regulator, leading to the formation of a thinner, looser polyamide–polyester selective layer with enhanced hydrophilicity. The optimal membrane exhibited a water permeance of 14.2 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ (twice that of the control membrane) while achieving >99% antibiotic rejection and maintaining low NaCl rejection (~0.5%). The antibiotics/NaCl selectivity was significantly improved, with a tetracycline/NaCl selectivity of 111, a 1.6-fold increase over the control membrane. Furthermore, multi-stage filtration experiments (pre-concentration, diafiltration, and post-concentration) successfully demonstrated the potential for antibiotic enrichment while ensuring high-purity separation. This study provides a novel and effective NF membrane fabrication strategy, offering valuable insights into the development of high-performance antibiotic desalination membranes.

Keywords: *Polyamide-Polyester Nanofiltration Membrane, Antibiotic Desalination, Ionic Liquid, Interfacial Polymerization*

Paper ID: A147

Innovative PVDF/δ-MnO_2-Based Photocatalytic Membrane Reactor for Superior Tetracycline Elimination

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ABSTRACT

This study presents the development and evaluation of a novel photocatalytic membrane reactor (PMR) for the efficient removal of tetracycline (TC) from water. δ-Manganese dioxide (δ-MnO_2) nanoparticles with a unique flower-like morphology were synthesized and characterized to confirm their structure and surface properties. These nanoparticles were then used to modify polyvinylidene fluoride (PVDF) membranes fabricated via a wet immersion process, aiming to enhance their photocatalytic performance. Performance testing revealed that δ-MnO_2-modified membranes significantly improved TC rejection efficiency, though increased δ-MnO_2 loading led to a reduction in pure water flux due to higher frictional resistance. The membrane with the highest catalyst concentration (M5) achieved a TC rejection rate of 96.1%. Further investigation into the photocatalytic mechanism under UV light identified the generation of reactive oxygen species such as hydroxyl radicals (•OH) and singlet oxygen ($^1O_2$), which contributed to TC degradation. LC/MS analysis confirmed effective degradation of TC, with decreasing TC concentration and increasing formation of intermediates as δ-MnO_2 loading increased. Notably, the permeate from the M5 membrane showed complete removal of TC, achieving 100% elimination from wastewater. These findings demonstrate the potential of this integrated PMR system, combining membrane filtration and photocatalytic degradation, as a promising strategy for water purification and removal of emerging pharmaceutical contaminants.

Keywords: *Photocatalyst, Degradation; Membrane Filtration, Photocatalytic Membrane Reactor (PMR)*

Paper ID: A148

Promotion of Monovalent Ion Transport Enabled by Fast Nanochannelsfor Efficient Electrodialysis

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ABSTRACT

The development of cation exchange membranes (CEMs) with high monovalent/divalent cation selectivity has great potential for enhanced salt separation for wastewater reclamation. Polyelectrolyte-based films with high monovalent selectivities among cations have expanded their applications. However, the structure–property relationship for constructing such polyelectrolyte-based films with enhanced separation performance remains poorly understood [1]. To make an insightful investigation to unveil the underlying mechanism, a series of polyelectrolyte-based CEMs were introduced: (1) A novel CEM was engineered by coating a [polyethyleneimine/polystyrene sulfonate (PEI/PSS)]n alternate electro-deposition multilayer on a polyacrylate substrate membrane. The newly developed CEM exhibited a monovalent selectivity of 4.59 for Li^+/Mg^{2+} with an optimal permeation of 1.60 mol $m^{-2}\cdot h^{-1}$ for Li^+, demonstrating a competitive separation property compared to state-of-the-art permselective membranes [2]. (2) A novel class of membranes was developed by ionically crosslinking sulfonated (poly[ether ketone]) and quaternalized poly (2,6-dimethyl-1,4-phenylene oxide) via ionic crosslinking. 1(b). The CEM exhibited a high ionic permeation (1.20 mol $m^{-}2\cdot h^{-1}$ for Li^+) and high cationic selectivity of 4.61 for Li^+/Mg^{2+}, which were comparable with the commercial monovalent cation permselective CIMS membrane [3]. A detailed quantitative investigation provides the underlying insights into the monovalent selectivity for each CEM. The results indicate negligible interface impedance toward monovalent cations but strengthened repulsion against divalent cations, thereby promoting a quick passage for monovalent cations while imposing temporal retardation on divalent cations during the electrodialysis (ED) process. Therefore, this study elucidates the characteristic reason for the enhanced monovalent ion permselectivity of polyelectrolyte-based CEMs in electro-driven separation processes.

Keywords: *Electrodialysis, Polyelectrolyte Membrane, Mono/Multivalent Ion Separation, Nanochannel*

Paper ID: A149

Efficient Organic Solvent Nanofiltration Enabled by Synergistic Solvent Transport Channels in Sulfonated Polyaniline/Halloysite Composite Membrane

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ABSTRACT

Organic solvent nanofiltration (OSN) membranes are widely used for organic solvent treatment due to their high efficiency, affordability, energy efficiency, and strong separation capabilities, attracting significant research interest. Polyamide (PA) membranes are commonly used in OSN because of their excellent selectivity, but their dense structure results in low permeability, limiting their efficiency. As an alternative, sulfonated polyaniline (SPANI) has attracted attention for its loose network structure and high potential for achieving both permeability and selectivity. Despite these advantages, SPANI doping solution tends to penetrate into the porous substrate during spin-coating process, leading to an ill-defined selective layer and diminished membrane performance. To overcome this challenge, we propose the fabrication of a composite selective layer by incorporating halloysite nanotubes (HNTs) into the SPANI matrix. The synergy between HNTs and SPANI not only prevents the undesirable infiltration of the polymer into the porous substrate but also facilitates solvent transport via the tubular channels of HNTs. Owing to the transport channel, the SPANI-HNTs-4 membrane exhibited ultra-high permeance, with values of 32.2 L m^{-2} h^{-1} bar^{-1} for n-hexane and 13.8 L m^{-2} h^{-1} bar^{-1} for methanol. Meanwhile, the SPANI-HNTs-4 membrane also showed a relatively high methyl orange rejection rate (Mw = 327 $g{\cdot}mol^{-1}$) of 90%, attributed to both the sieving effect and charge interactions. Notably, this is the first study to discuss the charge effect in organic solvents in detail. This study underscores the potential of synergistic material design in developing high-performance OSN membranes through composite-layer engineering.

Keywords: *Halloysite nanotube; Composite selective layer; Organic solvent nanofiltration; Synergistic solvent transport channel; Charge effect*

Paper ID: A150

Enhanced Ethanol Dehydration Performance of Sodium Alginate Membranes by Incorporating Hydrophilic Activated Carbon

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ABSTRACT

Ethanol is a promising renewable resource for replacing fossil fuels and serving as an industrial feedstock. Although fermentation of biomass is a sustainable method for ethanol production, it yields ethanol at low concentrations. Pervaporation is an energy-efficient separation technique capable of overcoming azeotropic limitations to enhance ethanol concentration. Sodium alginate (SA), a hydrophilic polymer, can be employed as a membrane material for ethanol dehydration. The performance of SA membranes can be improved by incorporating fillers and enhancing the hydrophilic properties of the membranes. Hydrophilic activated carbon (HAC), a carbon-based material containing hydrophilic functional groups introduced through sodium hydroxide and ammonium persulfate treatment, shows potential for enhancing membrane performance in ethanol dehydration. This study investigated the enhancement of SA membrane performance through the incorporation of HAC as a filler. HAC was added at varying concentrations (0.4, 0.8, and 1.2 wt%) to SA membranes with alumina tubular support. The hybrid membranes were systematically characterized in terms of morphology, structural properties, mechanical strength, and thermal stability. Results indicated that HAC incorporation significantly altered the membrane structure and improved hydrophilicity, as shown by a decrease in water contact angle. The hybrid membrane containing 0.8 wt% HAC exhibited the best performance for dehydrating a 90/10 wt% ethanol/water mixture at 60 °C, achieving a permeation flux of 106 $g/m^2 \cdot h$ and a separation factor of 1704. Additionally, the SA/HAC membranes demonstrated good thermal and mechanical stability under operational conditions. These findings highlight the potential of SA/HAC membrane for efficient ethanol dehydration via pervaporation.

Keywords: *Sodium Alginate, Hydrophilic Activated Carbon, Hybrid Membrane, Ethanol Dehydration, Pervaporation*

Paper ID: A151

Silicon Oxide-Intercalated MXene-Coated Membranes for Enhanced Photothermal Membrane Distillation in Desalination

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ABSTRACT

Membrane distillation (MD) is a thermally driven separation process that employs hydrophobic membranes to exploit vapor pressure gradients across a temperature differential, enabling effective treatment of hypersaline and contaminated waters. Despite its inherent advantages, including moderate energy demands and high rejection rates, the scalability of MD is constrained by membrane fouling and pore wetting. These limitations have catalyzed the development of advanced membrane materials such as MXene and silicon oxide-modified composites and the integration of photothermal conversion strategies to enhance thermal efficiency and mitigate limitation of membrane distillation performance. Therefore, this study aims to explore the potential of silicon oxide-intercalated MXene-coated photothermal membranes to optimize the performance of membrane distillation for desalination. In this study, silicon oxide-intercalated MXene was coated on polyvinylidene fluoride (PVDF) membrane via polydimethylsiloxane (PDMS). The prepared photothermal membranes were characterized their physicochemical and thermal properties using FESEM, EDX, XRD, FTIR, and contact angle analysis. The separation performance of the fabricated photothermal membranes demonstrated a significant enhancement in water flux when treating simulated seawater (35 g/L NaCl), compared to uncoated membranes. Furthermore, the membranes maintained consistently high salt rejection (>99%) throughout the 3-hour operation, indicating stable desalination performance under continuous photothermal-driven membrane distillation. These excellent membrane performances are due to presence of silicon oxide intercalated MXene coating that helps in enhancing the localized heating, flux and membrane stability. This photothermal membrane also exhibited high hydrophobicity, thus improved the fouling resistance of the membranes. These results highlight a potential pathway toward high performance solar-driven photothermal membrane distillation for freshwater production from seawater.

Keywords: *Silicon Oxide, Mxene, PVDF, Photothermal, Membrane Distillation*

Paper ID: A152

Performance Insights into Omniphobic Hollow Fiber Membrane Distillation for Real Seawater: A Solution to Wetting, Scaling, and Fouling

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ABSTRACT

Membrane distillation (MD) is increasingly recognized as a viable pretreatment technology for seawater-fed electrolyzers, offering a compact, energy-efficient, and scalable method for producing high-purity water, even under conditions with elevated total suspended solids. As the hydrogen economy accelerates, the integration of MD units upstream of electrolysers offers a strategic approach to enhance operational efficiency and extend system durability, particularly in coastal or offshore settings where direct seawater utilization is both practical and beneficial. Despite its advantages, MD system performance could be significantly compromised by membrane wetting and fouling, particularly in the presence of low surface tension constituents such as dissolved organic matter and surfactants commonly present in seawater. To address these limitations, this study has focuses on evaluating the performance of omniphobic polyvinylidene fluoride (PVDF) hollow fiber membranes under real seawater conditions. While prior research has largely focused on synthetic solutions, limited data exists on the actual wetting, scaling, and fouling behaviours when real seawater is used, an essential consideration for validating the technology's practical viability. The performance of the sample was assessed based on flux production and salt rejection using both synthetic feed solutions and real seawater. The study's findings demonstrate that omniphobic hollow fibre significantly enhance membrane resistance to wetting, scaling, and fouling. These improvements directly contribute to more stable MD operation, lower maintenance requirements, and improved long-term reliability when seawater is used as the feedstock. Such insights are critical in guiding the adoption of MD systems as robust, pretreatment solutions in industrial-scale hydrogen production.

Keywords: *Omniphobic Hollow Fibre, Membrane Distillation, Wetting, Fouling, Scaling*

Paper ID: A153

Synthesis of NiO@Zeolite Y as a Filler in P84 Co-Polyimide-Based Mixed Matrix Membrane for CO_2 Separation

Muhammad Haikhal Fazad

ABSTRACT

To achieve Net Zero Emissions (NZE) by 2050 and keep the rising temperatures in the 1.5- 2 °C range, atmospheric CO_2 must be significantly reduced. Direct Air Capture (DAC) is a promising solution for CO_2 removal. This study explores synthesizing and fabricating a novel and selective mixed matrix membrane (MMM) by incorporating NiO@Zeolite-Y, a novel filler, onto P84 co-polyimide for gas separation applications. NiO@Zeolite-Y materials with different loadings were prepared using $Ni(NO)_3$ as the precursor and later mixed into P84 polymer to form dense membranes. FTIR and XRD characterization confirmed NiO particles are dispersed into the pores of the zeolite Y. SEM analysis revealed no significant morphological differences, while N_2 adsorption-desorption indicated decreased surface area. XPS identified abundant nickel atoms and two distinct oxygen species with different binding energies, confirming the formation of NiO particles in Zeolite Y. Among the synthesized materials, 5% wt NiO (N5) loading into zeolite-Y shows optimal gas separation performance by increasing the CO_2 permeability, and both CO_2/N_2 and O_2/N_2 selectivity. Furthermore, MMM with N5 were fabricated with 0.5%–10%wt loadings to find the optimum filler loading. The 5% loading shows the best gas separation performance, up to 61.64 and 11.39 for CO_2/N_2 and O_2/N_2, respectively, compared to pure P84 Membrane. XRD and SEM analysis show that high loading of fillers does change the crystallinity and morphology of the membrane, although its chemical and thermal stability behavior is still retained, as evidenced by its TGA and DSC characterization. Increasing the testing temperature enhanced gas permeability, consistent with diffusion trends, but reduced its selectivity. Meanwhile, pressure testing variation shows the MMM has low degrees of plasticization as its selectivity remains stable. This study highlights the suitability of NiO@Zeolite-Y-based MMMs as promising candidates for integration into DAC systems, enabling more efficient and selective CO_2 capture.

Keyword: *NiO@Zeolite Y, P84 Co-polyimide, Mixed Matrix Membrane, CO_2 Separation.*

Paper ID: A154

One Pot Green Synthesis of Zwitterionic Poly(MBAAm-co-VSPI) Nanoparticles for the Removal of Reactive Dyes

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ABSTRACT

Dyes have become a quintessential part of human existence and reactive dyes are no different since they are widely employed in the textile industry due to their excellent colour fastness. However, these dyes also possess potential drawbacks of being carcinogenic and mutagenic. Hence, one of the solutions to their removal is the utilisation of membrane technology. In this work novel poly(MBAAm-co-VSPI) zwitterionic nanoparticles were synthesised in an aqueous medium in a single step reaction via free radical polymerization between the cross linker N,N′-Methylene bis(acrylamide) (MBAAm) and the zwitterionic molecule 1-Vinyl-3-(3-sulfanatopropyl)-1H-imidazole-3-ium (VSPI) using water soluble 2,2'-Azobis-2-methylpropionamide dichloride (V-50) as the free radical initiator. These nanoparticles were further employed in the fabrication of mixed matrix membranes using polysulfone (PSf) polymer for the removal of Reactive Black 5 and Reactive Orange 16 dyes. The membranes were subjected to scanning electron microscopy (SEM), thermogravimetric analysis (TGA) and universal testing machine (UTM). Furthermore, the membranes were tested for their pure water permeability, dye rejection, antifouling property, hydrophilicity, porosity, roughness, and zeta potential. The optimized PM-2 membrane showed a good permeability of 82.34 Lm-2 h-1 bar-1 and the dye rejection of 98% and 86% for RB5 and RO16 respectively. Therefore these membranes have potential application in textile wastewater treatment.

Keywords: *Zwitterionic, Polysulfone, Reactive Dyes, Free Radical Polymerization*

Paper ID: A155

Improving Ammonia Recovery Performance During Sweep Gas Membrane Distillation Process

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ABSTRACT

Ammonia is a common contaminant in various effluents, including agricultural runoff, industrial discharges, and municipal wastewater. If released without proper treatment, ammonia can pose serious environmental threats, such as eutrophication and toxicity to aquatic life. At the same time, ammonia is a valuable raw material in modern industry, widely used in fertilizers, chemicals, and energy applications. Therefore, recovering ammonia from wastewater not only mitigates environmental harm but also provides significant economic advantages. Due to its high volatility in aqueous solutions, gaseous ammonia constitutes a significant portion of the total vapor in an ammonia aqueous solution. Through membrane distillation, ammonia can be effectively extracted to the permeate side, where its concentration can exceed that of the feed solution by several times. Moreover, the permeate typically contains only ammonia and water, free from the salts and impurities present in the feed stream. This study investigates the use of sweeping gas membrane distillation (SGMD) for ammonia recovery from aqueous solutions. Polyvinylidene fluoride (PVDF) hollow fiber membranes, fabricated via thermally induced phase separation and exhibiting a high water contact angle (>120º), were employed in the SGMD system. An ammonia aqueous solution was introduced to the shell side, while the sweeping gas flowed through lumen side to collect the permeate. The influence of key operational parameters—such as temperature and gas flow rate—on system performance was systematically evaluated. Under optimal conditions, the SGMD system successfully concentrated the ammonia solution from 5 wt% to over 20 wt%, with an ammonia recovery efficiency of 90%.

Keywords: *Membrane Distillation, Ammonia Recovery, PVDF Membrane*

Paper ID: A156

Three-Dimensional Visualization of Macrovoids Using X-Ray Microcomputed Tomography

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ABSTRACT

Asymmetric membranes are fabricated by non-solvent induced phase separation (NIPS) method. The membranes have finger-like anisotropic channels that enhance gas and liquid permeation, which are called macrovoids. Despite the importance on membrane permeation, only rough structural features of macrovoid have been discussed in literature according to the two-dimensional images obtained by SEM or an optical microscope. The key process parameters for the macrovoid formation on NIPS method have been empirically summarized. However, the formation mechanism of macrovoids is not fully understood and remains controversial because of the limitation of structural characterization. Here, we demonstrate a high-resolution X-ray microcomputed tomography (micro-CT) method with submicron-sized voxels as a three-dimensional structural characterization for the macrovoids in membrane sciences. The method visualized the microporous morphology clearly in three dimensions. By analyzing the 3D image using digital image analysis, the structural characteristics of the macrovoids could be quantitatively obtained. For example, we evaluated the changes in number density, size, and wall thickness of the macrovoids along the depth direction from the surface. This method allowed us to classify the types of macrovoids formed under different processing conditions based on their shape characteristics. Detailed structural information has provided a better understanding of the relationship between macrovoid structure and formation mechanisms.

Keywords: *Structural Characterization, X-ray Microcomputed Tomography (micro-CT), Asymmetric Membranes, Macrovoids, 3D Image*

Paper ID: A157

Ammonium Recovery from Filtrate Dewatered Digestive Fluid in Biomass Powerplant for Nitrogen-Circulating Society

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ABSTRACT

The construction of a nitrogen-recycling society by reducing the release of nitrogen compounds into the environment is an urgent issue from the perspective of planetary boundary [1]. The filtrate dewatered digestive fluid discharged from methane fermentation facilities (hereinafter referred to as “dewatered filtrate”) contains about 1000 to 2000 ppm of ammonia. If ammonia can be recovered from dewatered filtrate, it will contribute to the construction of a nitrogen-recycling society. In biomass power generation facilities using livestock biomass, which have been increasing in recent years, dewatered filtrate is reused as liquid fertilizer or detoxified at wastewater treatment facilities. However, the high transportation and treatment costs are problematic. Therefore, if ammonia can be efficiently recovered from dewatered filtrate, the wastewater treatment process can be made more energy efficient and less expensive. While ammonia concentration in membrane separation is expected to be a low-cost ammonia recovery method, it is essential to clean the filtrate by pretreatment. In particular, dewatered filtrate discharged from biomass power plants has a high concentration of suspended solids, and it is necessary to establish a cleaning method for membrane concentration. In this presentation, we report on our investigation of a purification method for dewatered filtrate discharged from a biogas power plant, and our attempt to concentrate the filtrate to 1 wt% ammonia by forward osmosis.

Keywords: *Forward Osmosis, Swage Concentration, Microfiltration, Coagulation Sedimentation*

Paper ID: A158

Thin-Film Nanocomposite Membrane Incorporated Ionic Liquid Modified Zeolitic Imidazolate Framework-8 for CO_2/CH_4 Separation

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ABSTRACT

Metal–organic frameworks (MOFs) possess adjustable properties that enable various modifications and enhancing their suitability for specific applications. In this study, zeolitic imidazolate framework-8 (ZIF-8) was synthesized and impregnated with ionic liquid 1-ethyl-1-methylpyrrolidinium dicyanamide [empyrr] [DCA] under varying IL loadings. The presence of $C{\equiv}N$ group observed after the modification indicates the successful impregnation of the ILs into the pores of ZIF-8. X-ray diffraction (XRD) pattern of modified ZIF-8 revealed that the crystal structure of ZIF-8 remained intact after the impregnation. The pure and modified ZIF-8s were then dispersed into a polysulfone (PSf) matrix, and the TFN membranes were prepared via phase inversion. A noticeable dispersion of IL@ZIF-8 particles was observed on the membrane morphology. As the IL loading increased, a corresponding rise in surface roughness was observed. The membranes were further subjected to pure CO_2 and CH_4 gas permeation experiments at 2 bar and 273K. CO_2 permeance and CO_2/CH_4 selectivity increased as a result of IL modified ZIF-8 incorporation, due to the increased gas permeation area and superior CO_2 solubility of IL. Results demonstrated that CO_2 permeance increased by 186% compared to pure ZIF-8 membrane, reaching 137 GPU at 10 wt% IL loading. CO_2/CH_4 selectivity increased to 66, marking a 128% enhancement compared to pure ZIF-8 membrane. The observed improvement indicates that IL modified ZIF-8 is worth to be explored as fillers in TFN membranes for CO_2/CH_4 seperation. Future research can explore optimization of IL loading to balance permeability and selectivity while ensuring membrane stability.

Keywords: *Metal Organic Framework, Thin-Film Nanocomposite, Ionic Liquid Impregnation, Carbon Capture*

Paper ID: A159

Directional Hollow-Channel Interface Engineered by Heterogeneous Wetting for High-Performance SiC Membranes

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ABSTRACT

Although SiC membranes offer robust hot gas filtration to drive energy savings and emission reductions in chemical industries, their performance is limited by interfacial mass transfer resistance, while their cost-effectiveness is constrained by high fabrication costs. Herein, a novel interfacial engineering strategy was developed to construct asymmetric SiC membranes with directionally aligned hollow channels at the membrane–support interface. By leveraging heterogeneous wettability between SiC particles and carbon pore formers, a localized infiltration barrier was induced during dip-coating, guiding the formation of low-resistance interfacial voids. These structures reduced interfacial flow resistance and increased gas permeance by 115% compared to conventional infiltration structures. Combined with a one-step co-sintering process, this approach yielded defect-free membranes with high permeance (521.8 $m^3 \cdot m^{-2} \cdot h^{-1} \cdot kPa^{-1}$) and 99.99% PM0.3 removal efficiency at 400 °C. The method also achieved a 35% reduction in processing time and 21% cost saving, demonstrating its potential for scalable, energy-efficient, and cost-effective hot gas filtration.

Keywords: *Directional Hollow Channel; Interfacial Engineering; Heterogeneous Wettability, SiC Membrane, Co-sintering, High-Temperature Filtration*

Paper ID: A160

Converting Nylon 6 Fabric to High-Performance Nylon/MWCNT Membranes via Screen Printing for Protein Recovery and Calcium Removal

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ABSTRACT

A thin-film nanocomposite membrane was developed by converting commercial nylon 6 fabric (mesh 500) using a screen-printing technique. The process involved a two-step preparation: (i) creating amino-enriched nylon 6 (Ny-NH2) fabric through hydrolysis-amidation; (ii) preparing the Ny-MWCNT membrane via screen-printing, capitalizing on a cross-linking reaction between carbonyl groups on carboxylated multi-walled carbon nanotubes (MWCNT-COOH) and amino groups on the Ny-NH2 fabric. Successful integration of MWCNT-COOH was verified using morphological analysis, FT-IR, and Raman spectroscopy. The membrane was evaluated for protein recovery from chitin production wastewater solutions, showing protein rejection ranging from 40 to 60% and Ca2+ rejection around 9%. Permeate flux was substantially affected by fouling, attributed to the adsorption and deposition of proteins and ions on the membrane surface and within capillaries, which progressively formed stable layers over operating time. The fouling phenomenon was described by the Hermia model, indicating an intermediate blocking mechanism. This mechanism was linked to higher protein concentrations and dissolved solid particles in the wastewater, which were larger than the pore diameter and settled on the membrane surface, creating multi-boundary layers.

Keywords: *Screen-Printing, Intermediate Blocking, Nylon-Mwnct Membrane, Calcium Remova;, Protein Recovery*

Paper ID: A161

Computational Fluid Dynamics Methods to Analyze CO_2 Capture Processes Aided by Catalysts in Membrane Gas–Solvent Contactors

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ABSTRACT

The utilization of catalyst-assisted CO_2 capture systems with membrane gas–solvent contactors show great potential for decreasing chemical absorption process energy requirements. The effectiveness of conventional solvent-based CO_2 capture techniques is limited by the substantial thermal input required for solvent regeneration. This research applies Computational Fluid Dynamics (CFD) methods to evaluate a new catalytic membrane system developed to improve CO_2 absorption. The design combines hydrophobic nanofiber membranes with dispersed mesoporous catalysts inside various concentration of monoethanolamine (MEA) solution. The catalytic membrane design enables a greater gas–liquid interfacial area and more sorption sites which leads to a significant reduction in regeneration temperature. CFD simulations demonstrate mass transfer performance improvements with absorption flux. The outcomes point to the ability of CFD modeling to lead the development and refinement of future catalytic systems for CO_2 capture.

Paper ID: A162

MOF Based Mixed Matrix Membranes via Dual-Spatial Confinement Strategy for Efficient Isobutanol Recovery

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ABSTRACT

Metal-organic framework (MOF)-based mixed-matrix membranes (MMMs) hold great promise for biofuel recovery. However, they are hampered by limitations such as low selectivity and poor dispersion. This study introduces a novel dual-spatial confinement strategy (D-SCS) for fabricating ionic liquid (IL)-loaded graphene oxide (GO)/MOF-polymer membranes. Through pore/surface confinement engineering, three innovative molecular selective transport channels were constructed within the MMMs. The layered structure of GO significantly improves the dispersion of MOF-808-ILs in the MMM matrix. By optimizing the type and content of ILs encapsulated within MOF pores, a balance was achieved between material hydrophobicity and free volume, which is conducive to isobutanol/water separation. Under the D-SCS approach, the fabricated membrane demonstrated a flux of 5050 g/m²·h and an isobutanol/water separation factor of 61.01 at 50°C. Additionally, Density Functional Theory (DFT), Grand Canonical Monte Carlo (GCMC), and Molecular Dynamics (MD) simulations were employed to elucidate the mechanisms underlying the selective adsorption and diffusion of isobutanol within the MMMs. This research not only lays a foundation for developing high-performance MMMs for efficient biofuel recovery but also highlights the potential of integrating pore encapsulation with surface confinement strategies to engineer molecular selective transport channels.

Keywords: *Isobutanol, Pervaporation, Graphene Oxide, Metal-Organic Framework, Ionic Liquid*

Paper ID: A163

Gas Permeation and Pervaporation Dehydration Characteristics of TiO_2-Based Organic-Inorganic Composite Membranes

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ABSTRACT

Separation processes in the chemical industry account for approximately 10–15% of global energy consumption, with distillation being the most widely used technique. However, conventional distillation systems are large, expensive, and highly energy-intensive [1]. Moreover, with the increasing demand for hydrogen as a clean energy carrier and reducing agent, the development of efficient hydrogen separation and purification technologies has become essential. Under these circumstances, ceramic membranes are gaining attention as promising alternatives due to their potential to reduce equipment size, energy consumption, and production costs, even under the harsh conditions typical of chemical processes. Titanium dioxide (TiO_2), known for its excellent thermal, chemical, and mechanical stability, has already been commercialized for applications such as nanofiltration and ultrafiltration membranes [2]. However, the dense crystalline structure of TiO_2 makes it difficult to control pore size at the sub-nanometer level, limiting its ability to achieve molecular-scale separation. This presentation introduces the material properties and separation performance of TiO_2-based composite membranes incorporating organic chelating ligands (OCLs), specifically acetylacetone (ACA), for hydrogen separation and water/alcohol pervaporation. TiO_2–SiO_2 composite membranes with ACA were synthesized and calcined at 500 °C in air, resulting in an average pore size of 0.68 nm. These membranes exhibited high water permeation flux and selectivity in the pervaporation of water/isopropanol mixtures, attributed to their relatively larger pore size and hydrophilic surface. Additionally, when calcined at 300 °C under nitrogen, the membranes exhibited molecular sieving performance suitable for gas separation applications. The introduction of OCLs enables precise control over pore size and surface hydrophilicity in TiO_2-based membranes, making them applicable to a wide range of organic solvent and gas separation processes with excellent resistance to chemical and thermal degradation. These robust ceramic membranes are expected to play a key role in advancing energy-efficient separation technologies across various chemical industry processes.

Keywords: *Pervaporation, Hydrogen, Titania, Silica, Chelate*

Paper ID: A164

Synthesis of Porous Cu@Carbon as Filler in Pebax-Based Mixed Matrix Membrane for Gas Separation

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ABSTRACT

Biogas is one of the renewable energy sources that can be used to reduce dependence on fossil fuels. However, the content of carbon dioxide (CO_2) and other impurity gases needs to be separated because they can reduce combustion efficiency and cause corrosion. One of the biogas purification technologies that is widely developed is membrane technology, as it has advantages in low energy consumption, ease of operation, and high efficiency. To improve the performance of gas separation, the approach through the manufacture of Mixed Matrix Membrane (MMM) is a solution that is in great demand, namely by combining polymers with inorganic materials as fillers. This study aims to synthesize a composite based on Pebax 1657 polymer with the addition of Cu-templated nitrogen-doped porous carbon fillers (Cu@NPC). Porous carbon is synthesized using sucrose as a source of carbon, triethylamine as a source of nitrogen, and $CuCl_2.2H_2O$ as a templating agent. The resulting Cu@NPC filler is then composed into a Pebax matrix with a concentration variation of 0.5; 1; and 1.5% wt. The success of filler and MMM synthesis is evidenced by the characterization of FTIR, XRD, SEM-EDX, and N_2 isothermal adsorption-desorption. The addition of Cu@NPC is expected to increase the permeability and selectivity of the membrane, through increasing porosity and affinity to CO_2 due to nitrogen doping. The test results will be compared against the Robeson limit to determine the effectiveness of performance improvements. This research is expected to contribute to the use of Cu@NPC as a filler for gas separation membranes.

Keywords: *Cu@NPC, PEBAX Polymer, Mixed Matrix Membrane, Gas Separation*

Paper ID: A165

Emerging Water Desalination Technologies: Challenges, Solutions, and Future Perspectives

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ABSTRACT

Water scarcity is an escalating global concern driven by increasing population, climate change, and industrialization. Desalination has emerged as a pivotal solution to address freshwater shortages, particularly in arid and semi-arid regions. This paper presents a comprehensive review of emerging desalination technologies, such as solar membrane distillation (SMD), electrothermal membrane distillation (EMD), capacitive deionizing membrane distillation (CDIMD), and flow electrode capacitive deionization (FCDI)—alongside conventional thermal and membrane-based systems. While reverse osmosis (RO) and multi-effect distillation (MED) dominate global applications, their high energy demands, fouling issues, and brine management challenges highlight the need for advanced alternatives. Emerging technologies demonstrate significant potential: SMD leverages photothermal materials for solar-driven efficiency, EMD reduces energy consumption through Joule heating, and hybrid systems like CDIMD integrate capacitive deionization with thermal processes to mitigate scaling. However, barriers such as intermittent energy supply, membrane degradation, high capital costs, and technological immaturity hinder widespread adoption. Solutions include nanostructured antifouling membranes, phase-change materials for energy buffering, and zero-liquid-discharge strategies for brine valorization. Future advancements hinge on smart materials, AI-driven optimization, and modular designs for decentralized use. Policy initiatives, such as subsidies for pilot projects and carbon credit incentives, are critical to accelerating commercialization. This study provides actionable insights for researchers, policymakers, and industries to advance sustainable, equitable water security through next-generation desalination technologies.

Keywords: *Desalination, Emerging technologies, Future Perspectives, Water Scarcity, Sustainable Technology*

Paper ID: A166

High-Temperature Reverse Osmosis and Molecular Separation with Robust Polyamide-Ceramic Membranes

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ABSTRACT

Polyamide (PA) thin-film composite (TFC) membranes are widely used for nanofiltration and reverse osmosis (RO) due to their high permeability and solute rejection. However, most commercial PA TFC membranes are recommended for operating temperature <45°C (Karami et al. 2020). In fact, water feeds with high temperature >50°C are common in the industries. The limited operating temperature range has constrained the applications of RO membranes. Herein, we aim to: (1) study the thermal stability of PA thin-films, (2) understand the limitations of commercial RO membranes at high temperature, and (3) develop robust PA-ceramic TFC membranes for high temperature RO (HT-RO). From the long-term study where PA-TFC membranes were immersed in hot water for a month, we found that PA thin-films showed good stability up to 75°C, but hydrolysis of polyamide bonds was observed at >80°C. We tested commercial PA-TFC for HT-RO at 70°C, and the membranes showed slight reduction of NaCl rejection (<95%) over time. Defects could have been generated in the PA layer as the polymeric substrates may not provide sufficient support at HT. We successfully fabricated PA-ceramic TFC membranes by synthesizing the PA layer on the inner surface of ceramic tubular membranes via interfacial polymerization. The composite membranes exhibited excellent thermal stability, maintaining high NaCl rejection (>95%) and steady water permeability (5-7 LMH/bar) during HT-RO at 70°C. However, we observed additional compaction of the polyamide layer at high temperature, which caused a significant drop in their permeability when being retested at room temperature. The ceramic substrates have provided a strong support at high temperature, and the highly stable PA-ceramic membranes have demonstrated huge potential for RO applications under more challenging conditions.

Keywords: *High-Temperature Reverse Osmosis (HT-RO), Ceramic Composite Membranes, Polyamide Thin-Film, Interfacial Polymerization*

Paper ID: A167

Green Fabrication of Hydrophilic PVDF Membranes for Effective Humic Acid Microfiltration

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ABSTRACT

The growing awareness of sustainability is driving a significant shift towards green membrane fabrication, with bio-based solvents emerging as a key focus for minimizing the environmental impact of membrane production. Despite this progress, the application of these sustainably produced membranes for humic acid removal remains significantly underexplored. Humic acid (HA), a significant component of natural organic matter (NOM), is particularly challenging in water treatment due to its inclination to produce harmful by-products during water disinfection processes. Recognizing the critical role of humic acid removal in ensuring clean and safe drinking water, further research in this area is urgently needed. The development of hydrophilic polyvinylidene fluoride (PVDF) membranes presents a promising approach for improving water treatment processes, particularly in removing humic acid (HA). This study explores the fabrication of PVDF microfiltration membranes using Cyrene™, a green solvent, via non-solvent induced phase separation (NIPS), incorporating polyethylene glycol (PEG) and polyvinylpyrrolidone (PVP) as hydrophilic additives. The resulting membranes were characterized for their morphology, surface hydrophilicity, mechanical properties, and antifouling performance. The findings demonstrate that the PEG-incorporated membranes exhibited markedly enhanced hydrophilicity, along with superior permeate flux and humic acid removal efficiency. Additionally, this formulation showed the lowest filtration resistance and maintained excellent stability over multiple filtration cycles, indicating strong potential for practical water treatment applications. In comparison, membranes modified with PVP developed increased pore sizes but were more susceptible to fouling and exhibited diminished mechanical integrity. These findings highlight the viability of Cyrene™ as an eco-friendly alternative solvent in membrane fabrication and the effectiveness of PEG in enhancing filtration performance, ultimately contributing to the advancement of sustainable membrane technology for water purification.

Keywords: *Cyrene, Membrane Fabrication, Hydrophilic Modification, Humic Acid Microfiltration*

Paper ID: A168

Critical Role of Ball Milling in Nano-Graphene Synthesis: From Micron-Scale Palm Kernel Shells to Uniform Nanoparticles

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ABSTRACT

The synthesis of high-quality graphene using biomass as the carbon precursor offers a sustainable approach for an eco-friendly alternative for advanced material development. This study explores the pivotal role of mechanical milling in reducing the particle size of palm kernel shell (PKS) derived graphene from micron-scale to nanometer dimensions while enhancing its structural properties. Graphene was synthesized by carbonizing palm kernel shell (PKS) at 500°C for 90 minutes, followed by milling the carbonized PKS using ball mill machine at varying durations (0 to 5 hours). The effects of milling time on particle size distribution, crystallinity and defect density were evaluated using Raman spectroscopy, X-ray diffraction (XRD) and particle size analysis. Raman analysis revealed that extended milling time reduced defect density and improved graphitic ordering which can be shown through the progressive decrease of I_D/I_G ratio with extended milling. XRD results confirmed enhanced crystallinity with prolonged milling while particle size analysis demonstrated a significant reduction in particle size and agglomeration, from micrometer scale (0-hour sample) to achieving nanoscale dimensions of graphene powder (5-hour sample). The study highlights the critical role of milling duration in optimizing the quality and uniformity of biomass-derived graphene as well as providing scalable and sustainable route for producing nanoscale graphene from agricultural waste. These findings underscore mechanical milling as an effective post-treatment strategy for tailoring graphene properties which makes it suitable for various applications such as energy storage, catalysis and nanocomposites.

Keywords: *Biomass-Derived Graphene, Palm Kernel Shell, Mechanical Milling, Particle Size Reduction, Nanoscale Materials.*

Paper ID: A169

Improved Molecular Selectivity of Ordered Polyamide Network Nanochannels Formed by Self-Aggregation of Porphyrins

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ABSTRACT

Organic solvent nanofiltration (OSN) is expected to efficiently recover solvents and purify special products at the nanometer scale (0.5–2 nm) in the pharmaceutical, food, and petrochemical industries. However, owing to problems such as swelling of the structure and reduced electrostatic interaction between the solute and the membrane surface in organic solvents, conventional polyamide (PA)-based nanofiltration membranes suffer from a significant decrease in separation efficiency. Therefore, the robustness of the nanochannels and precise pore control of the membrane are critical to achieving molecular separation in harsh solvents. It is possible to form a dense PA layer by the confined polymerization of amine and chloride monomers at a water–hexane interface based on the Schotten–Baumann reaction. The use of amine with units comprising rigid conjugated monomers is expected to simplify the fabrication, improve the connection continuity, and further regulate the structures to develop covalent organic frameworks-like networks. In this study, we report 5,10,15,20-tetrakis(4-aminophenyl)-21H,23H-porphyrin (TAPP)-based covalent organic networks membranes for preparing robust OSN membranes with enhanced selectivity as a step toward developing ideal topological membranes [1]. The vacuum-assisted interfacial polymerization (IP) method between a water phase and a hexane phase containing TAPP and acid chloride was designed to control the conformation of the conjugated TAPP and facilitate the transfer of the PA layer. To adjust the membrane structure, the acid-triggered protonation of TAPP was manipulated to improve solubility, further relieve the eclipse stack, and promote an offset stack, resulting in smaller pores. Feasible acyl chlorides were applied to finely tune the pore size to explore molecular separation dominated by the size-sieving effect. Furthermore, the robust network connections in the horizontal direction, and the designable interlayer bonds, endow the membranes with stability or reversibility when they operate in harsh solvents.

Keywords: *Porphyrin; Stacking Behavior, Covalent Organic Network, Organic Solvent Nanofiltration*

Paper ID: A170

PVA-MCC Reinforced Geopolymer Membranes: Balancing Pore Architecture and Mechanical Integrity for Selective Molecular Separation

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ABSTRACT

This study investigates the influence of polyvinyl alcohol (PVA) and microcrystalline cellulose (MCC) additives on the structural and functional performance of geopolymer membranes. PVA was employed as a pore-uniforming agent, while MCC served as a reinforcement material. Both additives were introduced at varying concentrations (0.4%, 0.6%, and 0.8% by weight relative to the geopolymer matrix). Hydrogen peroxide (H_2O_2) was utilized as a pore-forming agent at a fixed concentration of 2.5% of the total geopolymer mass. The resulting membranes were characterized in terms of surface morphology, mechanical strength, and separation efficiency for polyethylene glycol (PEG) molecules of specific molecular weights, with a focus on pore size distribution as the key determinant of performance. The results indicate that the optimized combination of PVA and MCC can significantly enhance membrane uniformity and mechanical robustness without compromising filtration efficiency. This study provides a promising route for tailoring geopolymer membranes with balanced density, mechanical integrity, and selective separation capabilities.

Keywords: *Geopolymer, MCC, Membrane, PVA*

Paper ID: A171

The Effect of H_2O_2 Addition on The Performance of Capkala Metakaolin-Based Geopolymer Membrane for Methylene Blue Separation

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ABSTRACT

Geopolymer membranes are membranes synthesized by mixing aluminosilicate with an alkaline activating solution. In this study, aluminosilicate was obtained from metakaolin, which was produced by calcining kaolin from Capkala. The geopolymer membrane was evaluated by varying the addition of H_2O_2 at concentrations of 2%, 2.5%, and 3% by total mass, and analyzing its effects on morphology, porosity, flexural strength, water absorption, and the filtration and adsorption performance of methylene blue. The membrane modification was done by adding 7% H_2O_2 as a pore-forming agent for the filtration of methylene blue. The reaction of H_2O_2 generates O_2 gas that creates pores during the hardening of the geopolymer. The resulting pore sizes were 147.2 μm for MG 3%, 112.8 μm for MG 2.5%, and 105 μm for MG 2%. MG 2% sample had better density and mechanical strength compared to MG 2.5% and MG 3%. Filtration results showed that MG 2% had the highest rejection percentage at 99.57%, while MG 3% had the lowest rejection percentage at 90.17%. Increasing the methylene blue concentration did not significantly reduce the rejection percentage but did decrease the solution flux due to fouling. The addition of H_2O_2 affected the number and size of the membrane pores, which impacted open pores, density, porosity, water absorption, and overall membrane performance.

Keywords: *Filtration, Geopolymer, Membrane, Methylene blue*

Paper ID: A172

Engineering Side-Chain Functionalized Polyvinylidene Fluoride-Based Membranes with Tunable Hydrophobicity for High-Performance Membrane Distillation

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ABSTRACT

Membrane distillation (MD) has emerged as a promising separation technology for desalination and industrial wastewater treatment due to its ability to achieve nearly complete rejection of non-volatile solutes. However, its widespread application is constrained by membrane wetting, fouling, and suboptimal module design that limit long-term efficiency and performance. In this study, we developed and evaluated a series of polyvinylidene fluoride (PVDF) based membranes, functionalized through side-chain grafting with a variety of alkyl, aromatic, and fluorinated moieties to enhance hydrophobicity, antifouling characteristics, and flux. Several functional groups including 1-bromodecane, 1-bromododecane, 1-bromohexadecane, trimethoxy silane, 4-methyl styrene, and 2,3,4,5,6-pentafluoro styrene were grafted onto the PVDF matrices using free-radical polymerization strategies. The modified membranes were characterized extensively using ATR-FTIR, ^{1}H NMR, SEM, AFM, and XPS to confirm successful grafting and to examine surface morphology, roughness, and chemical composition. The functionalization significantly improved membrane hydrophobicity, as evidenced by increased water contact angles and liquid entry pressures. Among the synthesized variants, the penta-fluorinated styrene (M-PFS) and long-chain alkyl (PVDF-g-GM-16C) membranes exhibited superior surface properties and porosity. The membrane performance was assessed using vacuum membrane distillation (VMD) for both saline solutions and dye-laden wastewater. The M-PFS membrane demonstrated enhanced flux (up to 36% higher than pristine PVDF) and consistently achieved >99.99% salt rejection across a wide salinity range. Similarly, the PVDF-g-GM-16C membrane achieved high permeate flux (21.24 L m^{-2} h^{-1}) and >99.25% rejection, along with excellent antifouling and regeneration behavior, maintaining performance over extended cycles. Long-term tests confirmed the thermal and operational stability of the membranes over 100 hours with minimal decline in performance. This integrated study highlights the synergistic effect of side-chain functionalization on enhancing membrane distillation performance. The results offer a scalable pathway for developing robust, high-flux, and fouling-resistant membranes tailored for challenging applications in desalination and industrial effluent treatment.

Keywords: *Membrane Distillation, Polyvinylidene Fluoride; Side Chain Grafting; Desalination.*

Ion Selective Membranes for Critical Resource Recovery

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ABSTRACT

The demand for lithium, driven by the development of electric vehicles, is expected to rise 600% by 2050, making sustainable fractionation of valuable ion from mixed streams essential (e.g., salt lake brine, spent lithium-ion battery leachates). The electrodialysis (ED) process with ion selective membranes (ISMs) is considered a promising solution for effective purification of lithium ions, but the currently available ISMs still face fundamental challenge towards achieving high precision/selectivity due to the intricate relationship of membrane parameters, particularly for ions with similar physiochemical properties. Thus, obtaining a deeper understanding of the membrane property – performance relationship and separation mechanisms is critical for rational membrane design. Thus, this work demonstrates several examples of in-house designed ion exchange membranes with superior properties promoting target ion transport. On one hand, selective ion exchange membranes with were designed via an ionic control method, which directed the formation of structurally order ion channels consisting of amine-based positively charged network. The membranes exhibited more homogenous morphology and enhanced stability in repeated separation experiments. The permselectivity of Li+/Mg2+ from a mixed solution reached 480, which was 2 orders of magnitude than that of commercial membranes. On the other hand, ISM with asymmetric ion channels was designed by incorporating 2D porous materials into the membrane matrix. By fine tuning the fabrication conditions (e.g., types and dosage of charged monomers), a series of ISMs were obtained with high selectivity towards Li+ (as compared to Mg2+) exceeding 1400, tailorable for both dilute and concentrated streams. Finally, the intricate interactions amongst different membrane properties are elucidated via transport modelling, which aims to provide guidance for designing future ion selective membranes for overcoming the permeability/selectivity trade-off. Addressing these knowledge gaps is expected to greatly advance the recovery of valuable ions from complex streams.

Keywords: *Ion Resource Recovery; Ion Selective Membranes (ISM); Permeability-Selectivity Trade-Off, Transport Mechanisms*

Paper ID: A174

Harnessing *Garcinia cymose f. pendula* Leaf Powder for Eco-Sustainable Chromium Biosorption

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ABSTRACT

The choice of an appropriate biosorbent for the removal of Chromium from the aqueous solution is demonstrated. Batch studies were adopted to investigate the effectiveness of *Garcinia cymose f. pendula* leave powder for the biosorption of chromium from aqueous solutions at an optimum pH 5, concentration 20 mg/L, adsorbent dosage 0.1 g and temperature 303 K, respectively, at an equilibrium agitation time of 60 min. Among the five isotherm models, Langmuir, Freundlich, Temkin, Redlich-Peterson and Dubinin–Radushkevich (D–R) were applied to analyze the fitness of the equilibrium data. Langmuir isotherm for chromium, with an average higher correlation coefficient of 0.9964, indicated the best fit to the experimental data, followed by Temkin, Freundlich, Dubinin–Radushkevich (D–R), and Redlich–Peterson models, respectively, suggesting monolayer adsorption onto a homogeneous surface as the dominant mechanism. The sorption process was found to be mostly a physisorption process, as witnessed from the apparent energy of adsorption. Overall, the outcomes evidenced that the model data were favorable in the removal of chromium and also confirmed that *Garcinia cymose f. pendula* could be utilized as an eco-friendly and cost-effective approach for the removal of chromium from aqueous solutions.

Keywords: *Chromium, Adsorption, Garcinia cymose f. pendula Leave Powder, Equilibrium Studies, Kinetic Studies, Physisorption*

Paper ID: A175

Improved Synthesis of Hollow Fiber SSZ-13 Zeolite Membranes for High-Pressure CO_2/CH_4 Separation

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ABSTRACT

High-silica CHA zeolite membranes are highly desired for noble gas separation [1] and natural gas upgrading because of their separation performance in combination with superior mechanical and chemical stability. Previously, we successfully synthesized SSZ-13 zeolite membranes on hollow fiber surfaces using the secondary growth method. These membranes demonstrated outstanding performance in separating CO_2/CH_4 and CO_2/N_2 mixtures [2]. However, the narrow synthesis conditions range significantly constrains scale-up preparation. Herein, we proposed a facile interzeolite conversion approach using FAU zeolite to prepare SSZ-13 zeolite seeds, featuring a shorter induction and a longer crystallization period of the membrane synthesis on hollow fiber substrates. The membrane thickness was constant at ~3 μm over a wide span of synthesis time (24 ~ 96 h), while the selectivity (separation efficiency) was easily improved by extending synthesis time without compromising permeance (throughput). At 0.2 MPa feed pressure and 303 K, the membranes showed an average CO_2 permeance of $(5.2 \pm 0.5) \times 10^{-7}$ $mol \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$ (1530 GPU), with an average CO_2/CH_4 mixture selectivity of 143 ± 7. Minimal defects ensure a high selectivity of 126 with a CO_2 permeation flux of 0.4 $mol \cdot m^{-2} \cdot s^{-1}$ at 6.1 MPa feed pressure, far surpassing requirements for industrial applications. The feasibility for successful scale-up of our approach was further demonstrated by the batch synthesis of 40 cm-long hollow fiber SSZ-13 zeolite membranes exhibiting CO_2/CH_4 mixture selectivity up to 400 (0.2 MPa feed pressure and 303 K) without using sweep gas.

Keywords: *Membranes, Gas Separation, Zeolites, Natural Gas, Carbon Dioxide*

Paper ID: A176

Rotary-actuated Hollow Fiber Membrane Contactor for Bubble-free Bioreactor Aeration

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ABSTRACT

Aeration typically contributes a significant portion of overall energy consumption in aerobic biological processes. The development of advanced aeration techniques may help to improve the performance and energy efficiency of biological processes with high aeration requirements. In this study, a rotary-actuated aeration device (RAAD) was fabricated based on hollow fiber membrane contactor and evaluated in terms of aeration efficiency under various operating conditions. The oxygen mass transfer coefficient of RAAD was found to be strongly dependent on rotation speed, but less affected by the flow rate of air supplied to RAAD. When tested in deionized water, the mass transfer coefficient of RAAD operated at rotation speed of 100 rpm was 5.9 h^{-1} when tested at 21 °C with air supply pressure less than 10 mbar. The aeration performance of the rotary-actuated aeration device was also tested in a lab-scale membrane bioreactor (MBR) with 2L working volume, which was operated for the cultivation of heterotrophic bacteria for 90 days. The effect of substituting common aeration stone with RAAD in MBR operation on membrane fouling and biomass quality was investigated. Fouling of hollow fiber membrane contactor on RAAD was suppressed as the turbulence created by the stirring effect of RAAD largely deterred the attachment of flocs. Compared to common aeration stone, RAAD can be driven with significantly lower air flow rate and pressure, which resulted in higher energy efficiency and could contribute to significant energy savings in bioreactor operation.

Keywords: *Bubble-Free, Bioreactor Aeration, Membrane Bioreactor, Membrane Fouling, Cell Cultivation*

Paper ID: A178

Janus Membrane for Simultaneous Water Purification and Power Generation

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ABSTRACT

The intricate water-energy nexus pinpoints the necessity of simultaneously managing both resources. The effective interaction between water movement and porous materials lies at the heart of membrane processes as well as hydrovoltaic technology. Herein, an innovative water-energy cogeneration system combining hydrovoltaic technology into membrane distillation processes is reported, leveraging hierarchically porous structures composed of polyaniline (PANI) and polydopamine (PDA)-modified carbon nanotubes (CNTs) nanofilaments on a commercial PVDF substrate. The heat-conductive CNTs network with the water-rich PDA, improves thermal efficiency, enhancing water production by 17.3% compared to bare PVDF. Synergistically enhanced by efficient ion transport within the PANI network, electron accumulation along the PANI-PDA-CNTs direction, and the conductive nanobridge effect of CNTs, a continuous and durable power density of 2.78 μW cm−2 is achieved in the commercially available membrane filtration process. This work provides an accessible approach to concurrently addressing water and energy challenges.

Paper ID: A179

Entrainer-Assisted Membrane Separation (EMS) Strategy for Efficient and Sustainable Purification Processes

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ABSTRACT

Efficient separation and purification of chemically similar compounds remain significant challenges in various industrial applications, particularly in biorefineries and ion recovery processes. The Entrainer-Assisted Membrane Separation (EMS) Strategy, inspired by azeotropic distillation, introduces selective binding agents to enhance separation performance by altering target molecules' effective size or charge. This present demonstrates the versatility and scalability of EMS strategies for the sustainable purification of ionic compounds (e.g., Lithium, Nickel, Organic acids, etc). Using innovative entrainers such as protonated polyethyleneimine (PEI)[1], poly(4-styrene sulfonic acid) (PSS)[2], and ionophore[3], this strategy achieves selective binding through electrostatic interactions, hydrogen bonding, or coordination chemistry. Key examples include the purification of organic acid, recovery of lithium ions from sodium-rich environments, and separation of nickel ions from brine solutions. By integrating EMS into membrane cascade systems, significant improvements in purity (up to 99.9%) and yield (exceeding 80%) were achieved, overcoming traditional limitations of nanofiltration and ultrafiltration. Techno-economic analyses revealed that the EMS reduces energy consumption by up to 50% compared to conventional ion exchange or distillation-based processes, with a return on investment (ROI) of less than one year in large-scale operations. Furthermore, entrainer regeneration and recyclability were validated across multiple cycles without performance degradation, emphasizing the sustainability of this approach. This work represents a paradigm shift toward scalable, energy-efficient, and sustainable membrane operations, providing innovative solutions for resource recovery and advanced separation technologies.

Keywords: *Entrainer Strategy, Membrane Cascade, Size Azeotropes, Process intensification, Ultrafiltration/Diafiltration*

Paper ID: A180

Nanoparticle-Modified Photocatalyst Membrane for the Removal of Contaminants of Emerging Concern (CECs)

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ABSTRACT

The increasing presence of contaminants of emerging concern (CECs) in wastewater due to broad use of various product, poses significant threats to human health and ecosystems. The characteristics of these components that persist in aquatic environments are challenging to be removed by using conventional treatment methods. Thus, to catalyse and promote sustainability, this paper reviews several hybrid and integrated method that demonstrate high efficiency in CECs removal. In pursuit of this objective, this study also introduces a novel system which is integration of nanoparticle-modified photocatalytic membranes with immobilized microalgae as an innovative and sustainable solution for CEC removal in wastewater. The incorporation of nanoparticle, serving as photocatalyst within hand-casted membrane will enhance photocatalytic activity to break down CECs and enable the integration of microalgae for effective bioremediation process. The inclusion of nanoparticles with suitable doping material allows the activation of photocatalyst with visible light which minimizes negative impacts on microalgae growth. This system runs at a reduced energy cost by employing visible light instead of ultraviolet light, while also facilitating the growth of algae. The focus of this review is also directed on system optimization, with particular attention to the selection of suitable membrane materials, nanoparticles, and microalgae, operating condition and the setup of the system. This optimized system expected to surpass single approached to achieve higher removal of variety of CECs components, including ibuprofen and phenethylamine. The suggested integrated system also conforms to the circular economy principle by supplying treated water devoid of CECs, suitable for non-potable uses, thus mitigating environmental effect. In conclusion, research into nature-based and advanced methods such immobilized microalgae and nanoparticle-modified photocatalytic membranes is crucial to promoting sustainable water treatment approaches. These technologies contribute considerably to meeting the Sustainable Development Goals 6: Water and Sanitation (SDG 6) by delivering effective, eco-friendly solutions for wastewater treatment.

Keywords: *Nanomodification, Photocatalyst Membrane, Contaminants of Emerging Concerns (CECs), Immobilized, Microalgae*

Paper ID: A181

Multi-layer PVDF Air Filters for Highly Efficient Electrostatic and Mechanical Removal of Fine Particulate Matter with Ultra-low Pressure Drop

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ABSTRACT

Electrospun nanofiber filters have attracted significant attention due to their high filtration efficiency for fine particles, mainly attributed to their small pore sizes and high specific surface areas. However, excessively reducing pore size or increasing filter thickness to improve filtration efficiency often results in a significant pressure drop and excessive energy consumption, creating a trade-off that limits practical applications. To overcome this issue, multilayer PVDF electrospun air filters were developed in this study with a hierarchical design integrating two distinct thin filtration layers: the S-layer, composed of ultrafine fibers forming a dense pore network, and the L-layer, made of relatively thicker fibers with larger pores. This structure aims to simultaneously achieve high filtration efficiency and low airflow resistance. In the multilayer PVDF filter, the S-layer mechanically intercepts larger particles (typically >100 nm) through inertial impaction and interception, while the L-layer captures smaller particles (<100 nm) primarily via electrostatic attraction, maintaining minimal pressure drop. The fabricated filter achieved high filtration efficiency corresponding to the HEPA 13 grade (99.95%) while maintaining a low-pressure drop of approximately 18 Pa against 300 nm particles. This strategic multilayer structure demonstrates significant potential as a highly efficient, low-resistance air purification solution for improving indoor air quality.

Keywords: *Electrospun Nanofiber Filter, Hierarchical Multilayer, Ultrafine Particle Removal, Electret-Based, Low-Pressure Drop Filter Design*

Paper ID: A182

Thin Film Composite Membrane from Cellulose Acetate-Polycaprolactone Incorporated with Rice Straw-Derived Carbon Quantum Dots for Forward Osmosis Desalination

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ABSTRACT

Rice straw-derived carbon quantum dots (CQDs) present significant potential in membrane fabrication because of its rich functional groups and sustainable synthesis due to the Philippines' abundant rice production. Hence, this study investigates the development of forward osmosis (FO) thin film composite membranes from cellulose acetate (CA) and polycaprolactone (PCL) incorporated with CQDs from rice straw. The CQDs were synthesized using a one-step thermal calcination technique and incorporated into CA-PCL membranes at varying concentrations of 0.01, 0.05, and 0.5 wt.%. These CQDs exhibited blue luminescence under UV light and mean particle size of 9.7 nm. UV-Vis spectroscopy and FTIR results indicate the presence of hydroxyl, carboxyl, and carbonyl functional groups. Incorporating 0.5 wt.% CQDs enhanced membrane properties: porosity increased to 56%, hydrophilicity improved with a contact angle decrease to 53°, and the mean pore radius reduced to 5.64 nm. FO performance was evaluated using distilled water and 17 mM NaCl as feed solutions, with 2 M NaCl as the draw solution. Using distilled water feed, the 0.5 wt.% CQD membrane exhibited the highest water flux (5.58 LMH) and lowest reverse salt flux (RSF) (10.78 GMH), outperforming the pristine CA-PCL membrane (1.38 LMH and 18.81 GMH). This indicates improved permeability without compromising selectivity. However, with 17 mM NaCl feed, the flux-selectivity trade-off became apparent. The 0.01 wt.% CQD membrane showed the highest salt rejection (97.43%) but the lowest flux (4.39 LMH). This suggests performance limitations under higher salinity. Overall, the findings highlight the potential of rice strawCQDs in enhancing CA-based membrane performance.

Keywords: *Forward Osmosis Membrane, Cellulose Acetate, Polycaprolactone, Carbon Quantum Dots, Rice Straw*

Paper ID: A183

Sustainable Fabrication of Robust Hydrophobic Membranes Using Green Solvent (Cyrene^{TM}) for Membrane Distillation (MD)

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ABSTRACT

Membrane Distillation (MD) is a thermally driven desalination process that offers high salt rejection and the ability to utilize low-grade heat. However, membrane wetting, fouling, and the widespread use of toxic solvents remain challenges to its broader implementation. This study aims to develop a robust and environmentally friendly hydrophobic membrane using polyvinylidene fluoride (PVDF) with Cyrene™, a green solvent, as a substitute for conventional hazardous solvents. To enhance membrane structure and performance, dolomite is incorporated as a natural bio filler. Membranes are fabricated via the non-solvent induced phase separation (NIPS) method. To evaluate membrane properties, the membrane will be characterized using instrumental material analysis such us FE-SEM, FTIR, water contact angle (WCA), liquid entry pressure (LEP), porosity, and pore size analysis. Thermogravimetric analysis (TGA) is conducted to assess the thermal stability of the composite membranes under MD operating temperatures. The novelty lies in the synergistic use of Cyrene™, PVDF, and surfactant-modified dolomite to achieve both high membrane performance and environmental sustainability. The expected outcome is a thermally stable, anti-wetting, and sustainable membrane suitable for long-term membrane distillation applications in saline water treatment.

Keywords: *Membrane Distillation, PVDF, Cyrene™, Dolomite, Thermal Stability*

Paper ID: A184

Entrainer-Assisted Membrane Separation (EMS) Strategy for Efficient and Sustainable Purification Processes

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ABSTRACT

Efficient separation and purification of chemically similar compounds remain significant challenges in various industrial applications, particularly in biorefineries and ion recovery processes. The Entrainer-Assisted Membrane Separation (EMS) Strategy, inspired by azeotropic distillation, introduces selective binding agents to enhance separation performance by altering target molecules' effective size or charge. This present demonstrates the versatility and scalability of EMS strategies for the sustainable purification of ionic compounds (e.g., Lithium, Nickel, Organic acids, etc). Using innovative entrainers such as protonated polyethyleneimine (PEI)[1], poly(4-styrene sulfonic acid) (PSS)[2], and ionophore[3], this strategy achieves selective binding through electrostatic interactions, hydrogen bonding, or coordination chemistry. Key examples include the purification of organic acid, recovery of lithium ions from sodium-rich environments, and separation of nickel ions from brine solutions. By integrating EMS into membrane cascade systems, significant improvements in purity (up to 99.9%) and yield (exceeding 80%) were achieved, overcoming traditional limitations of nanofiltration and ultrafiltration. Techno-economic analyses revealed that the EMS reduces energy consumption by up to 50% compared to conventional ion exchange or distillation-based processes, with a return on investment (ROI) of less than one year in large-scale operations. Furthermore, entrainer regeneration and recyclability were validated across multiple cycles without performance degradation, emphasizing the sustainability of this approach. This work represents a paradigm shift toward scalable, energy-efficient, and sustainable membrane operations, providing innovative solutions for resource recovery and advanced separation technologies.

Keywords: *Entrainer Strategy, Membrane Cascade, Size Azeotropes, Process Intensification, Ultrafiltration/Diafiltration*

Paper ID: A185

Enhancing Desalination Performance of Reverse Osmosis Thin-Film Composite Membranes Through Integration of MIL-101(Cr) Interlayer on Microfiltration Substrate

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ABSTRACT

The development of high-performance reverse osmosis (RO) membranes is essential to advance desalination technologies for sustainable freshwater supply. This study presents a novel modification of thin-film composite (TFC) membranes through the integration of a chromium-based metal-organic framework (MIL-101(Cr)) interlayer onto a microfiltration (MF) substrate. Functioning as a gutter layer, the MIL-101(Cr) interlayer will improve the substrate's surface hydrophilicity and porosity, providing an optimal interface for interfacial polymerization and enabling the formation of a thinner, more selective polyamide active layer. This design will facilitate enhanced water permeability while maintaining high salt rejection. Comprehensive characterization using FESEM, FTIR, AFM and contact angle analysis will confirm the successful integration of MIL-101(Cr) and its role in tuning membrane morphology. Performance evaluations in desalination applications will reveal significant improvements in water flux and NaCl rejection compared to conventional TFC membranes. This study will underscore the potential of MOF-based interlayers in advancing next-generation RO membranes for more efficient and sustainable desalination processes.

Keywords: *Thin-Film Composite, Metal-Organic Framework, Reverse Osmosis, Interlayer, Desalination.*

Paper ID: A186

Towards Low Fouling Ultrafiltration Membrane Using Natural Additives as Antifouling and Antimicrobial Agents

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ABSTRACT

Within the last two decades, ultrafiltration (UF) has been applied in wide range of industrial applications. Nevertheless, fouling caused by organic matters and microbial substances is still a serious problem during its application. One strategy to reduce fouling is to use low fouling UF membranes. This study focuses on the fabrication of low-fouling polyether sulfone UF membranes using natural additives as antifouling and antimicrobial agents. The natural additives used were chitosan, collagen and polyphenon from green tea. A series of membrane characterizations using scanning electron microscopy–energy-dispersive X-ray spectroscopy (SEM-EDX) mapping, Fourier transform infrared spectroscopy (FTIR), contact angle (CA) measurement and pure water flux (PWF) was performed. The antifouling performance was examined using bovine serum albumin and humic acid solution, whereas antibacterial performance was examined using *E. coli* and *S. mutans*. The addition of natural additives not only significantly increased PWF, but also increased the solute rejection and flux recovery. In addition, the membranes exhibited significant antibacterial properties.

Paper ID: A187

Engineering Polymeric Membranes for Water Reclamation: Addressing Emerging Contaminants and Fouling

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ABSTRACT

Advancements in membrane technology are critical for addressing the dual challenges of micropollutant removal and fouling control in water reclamation. This talk presents two strategies for engineering polymeric membranes to enhance municipal wastewater treatment. In the first approach, commercial nanofiltration (NF) membranes were surface-modified via redoxinitiated graft polymerization using oppositely charged methacrylate monomers. By tuning the monomer ratio (methacrylic acid:MOETMA = 1:9), the modified membranes achieved significantly higher rejection of carbamazepine (CBZ)—a persistent pharmaceutical pollutant— reaching 87% compared to 47% for the pristine membrane, with a concurrent 15% increase in pure water permeance and improved fouling resistance. In the second approach, polyacrylonitrile (PAN) membranes were blended with 2 wt% polyethylene glycol (PEG-1000), resulting in a morphological transition to a more hydrophilic, spongy structure. These membranes exhibited enhanced antifouling performance, with flux recovery exceeding 80% after long-term cycling with real wastewater, and consistently high rejection (>99%) of model foulants such as BSA. Together, these approaches highlight the potential of molecular-level membrane engineering to improve the selectivity, permeability, and durability of polymeric membranes for sustainable wastewater reuse.

Keywords: *Polymeric Nanofiltration Membranes, Graft Polymerization, Pharmaceutical Micropollutants, Fouling Mitigation, Water Reclamation*

Paper ID: A188

Fabrication of Modified Zeolite-Infused Polysulfone Mixed Matrix Hollow Fiber Membranes for Water Remediation

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ABSTRACT

Increased population in the last decade demands the requirement of new industries for fulfilling their daily needs. Many industries like metallurgy, textile, paper and dye industries produce large quantities of toxic effluents causing the pollution of soil and water resources, finally it may severely damage our environment and becomes a threaten to human life. Therefore industries must treat their effluents before discharging it to the water bodies and lands. Membrane technology holds a central position in numerous separation and purification procedures, and recent advancements in nanoscience have paved the way for augmenting membrane efficiency. High surface per volume compared with flat sheet membrane, makes hollow fiber membrane excellent choice for water refinement applications. This abstract offers an overview of polysulfone composite hollow fiber membranes with nano additives, highlighting their characterization and potential application in dye rejection studies. The phase inversion technique was adopted to form well-defined nanocomposite HF membranes with enhanced structural and functional properties. Detailed characterization techniques provide insight into the morphology and chemical properties. SEM, AFM, EDX, water uptake, contact angle, zeta potential, MWCO studies, water permeability, antifouling capabilities and rejection experiments (dye and heavy metal) were carried out. The integration of nano additives upgraded the effectiveness of the novel membrane in eliminating the dyes RO16 and Crystal violet as well as the heavy metals Pb and Cd. The findings indicated that the additives have great potential to improve membrane properties while maintaining their rejection capabilities intact. The results of such studies will be discussed in this paper.

Keywords: *Membranes, Dye Rejection, Heavy Metals, Nanocomposite, Polysulfone*

Paper ID: A189

Impact of Lab-scale Hollow Fiber Membranes Configuration and Presence of Heavy Hydrocarbon towards Membrane Performance for Natural Gas Separation from CO2

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ABSTRACT

Polymeric membrane-based gas separation continues to gain momentum in the energy sector, particularly for applications such as natural gas purification. Traditionally, the performance of hollow fiber membranes is assessed at the laboratory scale using single-loop cell configurations to evaluate gas permeability and selectivity. Although this method is cost-effective for initial screening, it often results in performance discrepancies when the fiber count and gas flow rate are below optimal levels. These inconsistencies are primarily attributed to the limited number of fibers and the relatively small membrane surface area used during lab-scale evaluations. To address these limitations, this study introduces an improved testing setup employing a series configured loop cell system. By connecting two loop cells in series, the total membrane surface area is significantly increased, providing a more realistic operational environment and enhancing experimental flexibility. Comparative experiments demonstrate that the binary loop cell configuration improved gas separation performance compared to the conventional single loop setup. Notably, this approach enables a more representative assessment of membrane behaviour under conditions closer to optimal, thereby narrowing the gap between lab findings and the actual fibers performance. Moreover, the study reveals that the presence of heavy hydrocarbons has a substantial impact on membrane efficiency, particularly in terms of CO_2 permeability and CO_2/CH_4 separation selectivity. These effects underscore the importance of robust pretreatment strategies and the careful selection of membrane materials when designing systems for natural gas processing. Overall, the proposed testing method offers a promising advancement in membrane evaluation techniques, supporting the development of more scalable and reliable gas separation technologies for industrial applications.

Keywords: *Hollow Fiber Membrane, Fiber Counts, Heavy Hydrocarbons, CO2/CH4 Separation, Performance Evaluation*

Paper ID: A190

Strategy For the Construction of Thin-Layer Composite Nanofiltration Membranes for Lithium and Magnesium Separation

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ABSTRACT

The lithium in salt lake brine accounts for 60% of the world’s total lithium reserves, and there are also abundant magnesium resources. The development of efficient lithium and magnesium separation technology for salt lake brine is a key issue in alleviating the current shortage of strategic industrial salt resources. Thin-film composite (TFC) nanofiltration membrane separation technology is one of the effective ways to achieve lithium and magnesium separation. This report focuses on the strategy for the construction of thin-film composite (TFC) nanofiltration membranes for lithium and magnesium separation, proposing four strategies including trace metal ion doping, surface modification, construction of interfacial polymerization regulator, and structure design of new interfacial polymerization monomer. New types of TFC nanofiltration membranes are therefore constructed, and lithium ion selective separation performance is investigated. The simultaneous improvement of water permeability and lithium separation selectivity of the nanofiltration membrane is achieved, effectively breaking the “trade-off” effect between permeability and selectivity. Molecular dynamics simulations are used to assist in the analyses, elucidating the selective lithium separation mechanism and the dominant role played by the Donnan effect from the aspects of monomer diffusion behavior during interfacial polymerization, the influence of monomer structure design on free volume, transport behavior of water molecules, and the different transport behaviors of lithium and magnesium ions within the skin layer. The nanofiltration membrane separation technologies developed based on the above strategies have significant implications for the industrial lithium and magnesium selective separation.

Keywords: *Nanofiltration, Lithium and Magnesium Separation, Construction Strategy, Interfacial Polymerization, Molecular Dynamics Simulations*

Paper ID: A191

Smart Design of 2D Nanomaterials for Next-Generation Water Treatment

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ABSTRACT

Engineering two-dimensional (2D) nanomaterials plays a pivotal role in advancing membrane technology for water treatment. This presentation will highlight key strategies for tailoring 2D materials—such as noble metals, MXenes, metal-organic frameworks (MOFs), layered double hydroxides (LDHs), and graphene—to enhance performance in nanofiltration, solar stills, and membrane distillation. The relationship between their unique physicochemical properties, rational design, and water treatment efficiency will be discussed through both experimental data and computational simulations. Additionally, a novel integration of aerosol jet 3D printing for fabricating graphene-based 2D materials into membrane systems will be introduced as a future-forward solution.

Keywords: *Nanotechnology, 2D Nanomaterials, Water Treatment*

Paper ID: A193

Design and Fabrication of CO2 Separation Membranes

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ABSTRACT

The separation and capture of carbon dioxide (CO2) is of great significance in natural gas purification and CO2 emission reduction. Compared to traditional amine absorption methods, CO2 membrane separation technology has advantages such as low energy consumption, high efficiency, small footprint, low pollution, and ease of integration, which has shown good industrial application prospect and receives increasingly widespread attention. However, there are two main challenges of CO2 membrane separation technology: (1) the tradeoff between CO2 separation permeability and selectivity of traditional membrane materials, so-called the upper bound of separation performance, restrict the development of membrane separation technology; (2) under high CO2 feed pressures, polymer chain segments swell and plasticize, resulting in a sharp decline of gas selectivity and loss of separation performance. In response to the aforementioned bottlenecks in CO2 membrane separation technology, this study started from molecular design to regulate the formation of membrane structures, break the upper bounds of traditional membrane materials for CO2 separation, and improve the CO2 plasticization resistance of the membranes. This research is expected to be applied to important fields of CO2 separation such as natural gas purification and CO2 capture.

Keywords: *CO2 Capture, Membrane Separation, Upper Bounds, Plasticization Resistance*

Paper ID: A194

Tailoring Heteroatom-Doped Carbon Fibers for Microbial Electrochemical Systems: A Review on N-S Electrochemical Impact

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ABSTRACT

The implementation of Nitrogen and Sulphur (N-S) co-doping of carbon fibres have emerged as a promising material for electrochemical systems such as Microbial Fuel Cell (MFC). This is mainly due to its enhanced electronic conductivity, catalytic activity, and surface reactivity. The incorporation of heteroatoms into carbon matrices modifies the electronic structure that creates active sites which will significantly improve the charge transfer and electrocatalytic performance. Novel carbon materials often suffer from limited functionality, but co-doping introduces synergistics effects that enhance both pseudocapacitance and oxygen reduction reaction (ORR) activity. The fabrication of N-S co-doped carbon fibres typically involves precursor selection—such as polyacrylonitrile (PAN) or biomass, followed by thermal treatments like pyrolysis or chemical vapor deposition (CVD) in the presence of N and S sources, such as thiourea or ammonium persulphate. Advanced techniques like electrospinning are also employed to create fibrous structures with high surface areas before doping. Studies have demonstrated that N-S co-doped carbon fibres exhibit superior electrochemical performance, with increased specific capacitance (up to 450 F/g) and improved ORR onset potentials due to the combined effects of pyrrolic-N, pyridinic-N, and thiophenic-S configurations of the N-S chemical structure. In addition to that, these materials show excellent stability in harsh electrochemical environments, such as when using wastewater in the system. Overall, the tunability of N-S doping ratios and the scalability of synthesis methods make these materials highly versatile for next-generation energy storage and conversion technologies, offering a sustainable alternative to precious metal-based catalysts which also combines the cost-effectiveness with high performance for diverse electrochemical applications.

Keywords: *Microbial Fuel Cell, Carbon Fibres, Electrocatalytic Performance, ORR, Sustainable Alternative.*

Paper ID: A195

Hydrothermal Coating of MnO_2 on Ni/YSZ Membranes for Electrochemical Degradation of Tannins and Lignin

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ABSTRACT

Recalcitrant organic pollutants, such as tannin and lignin are difficult to degrade and have become a major focus in environmental research. Electrocatalytic oxidation using electrocatalyst-incorporated filtration membranes has shown promise but requires further optimisation to enhance performance. This study investigates the electrochemical properties of reduced nickel/yttria-stabilised zirconia (Ni/YSZ) single-layer hollow fibre membranes hydrothermally coated with manganese (IV) oxide (MnO_2). Coating conditions were varied using different concentrations of potassium permanganate, $KMnO_4$ solution (0.05, 0.1, 0.15 M), hydrothermal durations (4, 5, 6 hours), and temperatures (100, 150, 200 °C), based on the Taguchi method to obtain optimised membrane showing highest conductivity and electrochemical surface area. Membrane characterisation was further conducted using microscopy, SEM-EDX, water contact angle measurements, water flux analysis, cyclic voltammetry (CV), and electrochemical impedance spectroscopy (EIS). The membranes were tested with a lignin and tannic acid mixture at varying concentrations to evaluate degradation performance over time. Feed, retentate, and filtrate samples were analysed using UV-Vis spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, and total organic carbon (TOC) analysis to elucidate degradation mechanisms. Results revealed that $KMnO_4$ concentration, hydrothermal time, and temperature significantly influenced the morphology and electrochemical performance of the MnO_2 coating. Optimal conditions enhanced charge transfer and radical generation (•OH and •H), as confirmed by electrochemical and degradation analyses. This study provides insights into the optimal MnO_2 coating parameters on Ni/YSZ membranes, demonstrating their potential for effective electrocatalytic degradation of recalcitrant organic pollutants in environmental applications.

Keywords: *MnO_2-coated Ni/YSZ Membrane, Electrocatalytic Degradation, Hydrothermal Coating, Tannin and Lignin Degradation, Electrochemical Characterisation*

Paper ID: A196

Zero-Sintering Geopolymer Membranes from Palm Oil Fuel Ash: A Green Solution for Industrial Wastewater Treatment

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ABSTRACT

Industrial wastewater treatment remains a global environmental priority, particularly in regions where agriculture and processing industries contribute to water pollution and solid waste generation. Conventional membrane technologies such as polymeric and sintered ceramic membranes are widely used but present notable drawbacks, including high production costs, energy-intensive fabrication, and limited sustainability. In this context, geopolymer membranes fabricated from palm oil fuel ash (POFA) through a zero-sintering process have emerged as a promising, eco-friendly alternative. This review explores the potential of POFA-based geopolymer membranes as a green solution for industrial wastewater treatment. POFA, a highly abundant byproduct of the palm oil industry, is rich in reactive silica and alumina, making it suitable for geopolymerization through alkali activation. By avoiding the high-temperature sintering typically required in ceramic membrane production, this method significantly reduces energy consumption and environmental impact. The resulting membranes can be engineered to exhibit desirable porosity, chemical stability, and pollutant rejection capabilities. Recent studies have demonstrated that these membranes are capable of removing dyes, organic matter, and suspended solids from various effluent sources. Moreover, the use of POFA valorizes waste material that would otherwise contribute to landfilling or air pollution through incineration. Despite the promising results, challenges remain in optimizing membrane structure, improving long-term stability, and scaling production for industrial applications. This review highlights current advancements, identifies critical knowledge gaps, and proposes future research directions to enable practical deployment. POFA-based geopolymer membranes represent a convergence of waste valorization, green chemistry, and membrane innovation—offering a viable pathway toward sustainable wastewater management, especially in palm-oil-producing nations. Keywords: Geopolymer membrane, palm oil fuel ash (POFA), alkali activation, zero-sintering, green materials, industrial effluent, membrane technology

Paper ID: A197

Lithium Recovery from Seawater Desalination Brines using Ion-Sieve Electrospun Nanofibrous Membranes: The Role of Nanofiber Design

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ABSTRACT

The increasing demand for lithium (Li) necessitates sustainable extraction from alternative sources such as desalination brines. This study developed and evaluated electrospun nanofibrous membranes with lithium ion-sieves, $H_{1.6}Mn_{1.6}O_4$ (HMO) and H_2TiO_3 (HTO), for lithium recovery from seawater reverse osmosis (SWRO) brines. Three distinct nanofiber morphologies, namely – direct-blend, mesoporous, and electrospray – were fabricated to optimize adsorbent distribution and accessibility. Mesoporous membranes enhanced adsorption by creating accessible pores via sacrificial polymer elution, achieving 13.5% capacity increase over powder adsorbents. Electrospray membranes, despite maximizing adsorbent surface exposure, showed a 25.6% capacity reduction due to particle agglomeration. Static tests demonstrated HTO's higher lithium selectivity, but slower kinetics compared to HMO. Dynamic experiments revealed mesoporous HMO/PAN membranes as optimal, achieving an 82.7-fold lithium enrichment (from 0.34 to 28.11 mg L^{-1}) and a dynamic capacity of 2.11 ± 0.16 mg g^{-1} over six cycles. Mesoporous HMO/PAN membranes were able to concentrate 3.7 times more lithium in the first cycle compared to the HMO packed bed configuration (7.78 mg L^{-1} eluted compared to 2.12 mg L^{-1}). High separation factors (4198 for Na^+, 4131 for Mg^{2+}, 1829 for Ca^{2+}, and 1113 for K^+) underscored exceptional selectivity of the ion-sieve embedded membranes. Continuous adsorption-desorption tests confirmed the membranes' robustness and reusability. These results demonstrate the critical role of nanofiber design in optimizing adsorption capacity, selectivity, and kinetics, enabling scalable lithium recovery from desalination brines.

Keywords: *Lithium Recovery, Electrospun Membranes, Nanofibers, Desalination Brine, Lithium Ion-Sieves*

Paper ID: A198

Biomimetic Interface Functionalization of Antifouling and Catalytic Cleaning Membranes

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ABSTRACT

Pressure-driven membrane processes play increasingly critical roles in energy-efficient wastewater treatments, and they significantly tie into water and energy sustainability. Membrane fouling, induced by contaminant adsorption at the membrane/aqueous solution interface, restricts the efficacious and lasting operation of membrane modules and equipment. Thus, membrane antifouling strategies have been a subject of intense research. Ex situ cleaning, requiring removal of membrane modules from operation, is commonly applied, but represents a significant economic and productivity cost. Therein, catalytic cleaning membranes offer tremendous promise for mitigating fouling by virtue of efficient environment-stimulated foulant repulsion and degradation. However, there remains a grand challenge in constructing energy-efficient catalytic cleaning membranes, especially on the basis of the widely used hydrophobic polymeric membranes. Natural systems evolved from prebiotic chemistry or bio-adhesion offer a glimpse of creative solutions. Herein, some mediated mineralization method are reported for universally engineering a superhydrophilic hierarchical nanocoating to endow hydrophobic polymeric membranes with exceptional catalytic cleaning ability. Hydrogen peroxide catalytically triggered in-situ cleaning of the mineralized membrane and enabled operando flux recovery. The mineralized membrane demonstrate active catalytic antifouling coupled with passive hydration antifouling. Electron density differences derived from the precursor interaction during mediated mineralization unveiled detailed structures. This work paves the way to construct multifunctional engineered materials for energy-efficient water treatment as well as for diverse promising applications in catalysis, solar steam generation, and beyond.

Keywords: *Membrane Separation, Membrane Fouling, Antifouling, Membrane Regeneration.*

Paper ID: A199

Investigating the Impact of TFC Membrane Structure and Compaction on Performance in Hypersaline Brine Desalination via High-Pressure Reverse Osmosis

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ABSTRACT

Recent works on high-pressure reverse osmosis (HPRO, applied pressure $\Delta P \geq 120$ bar) seek to understand the impact of compaction on thin-film composite (TFC) polyamide membranes. However, previous studies have primarily focused on commercial membranes to identify key traits for HPRO operation, leaving a gap in guidance on how to fabricate resilient TFC membranes, particularly in terms of the support and polyamide selective layers. In this work, we synthesized four types of TFC membranes with customized support and polyamide structures to determine the optimal composite design for HPRO operation. Our results indicate that a TFC membrane with a dense polyamide layer (featuring low protuberances and a high degree of crosslinking), synthesized atop a sponge-like support layer (17 wt% Polysulfone), exhibits greater resistance to compaction (denoted as TFC-17-L$_{protub}$). In SWRO test (ΔP: 55 bar, 35 g/L NaCl feed), the TFC-17-L$_{protub}$ membrane demonstrated a water permeability of 0.80 $Lm^{-2}h^{-1}bar^{-1}$ with 99.2% salt rejection. This performance decreased to 0.39 $Lm^{-2}h^{-1}bar^{-1}$ with 98.6% salt rejection during the desalination of hypersaline brine via HPRO (ΔP: 150 bar, 70 g/L NaCl feed). Post-compaction analysis showed a compression of the support layer's surface, with a 28% reduction in pore diameter and a 54% decrease in cross-sectional thickness. In contrast, the polyamide surface morphology and cross-sectional height remained unchanged at approximately 190 nm. This study enhances the understanding of the compaction behavior of TFC membranes under high pressure and explores the potential benefits of incorporating an HPRO stage in the context of SWRO brine management.

Keywords: *Thin-Film Composite (TFC) Membrane Compaction, Phase Inversion, Interfacial Polymerization, High-Pressure Reverse Osmosis (HPRO), SWRO Brine Management*

Paper ID: A200

Graphene Oxide Framework Membranes Constructed via Confined Polymerization for Ion Separations

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ABSTRACT

Lamellar membranes constructed from two-dimensional graphene oxide (GO) nanosheets demonstrate exceptional separation potential, yet their applications for precision and durable ion sieving remains challenging because of hydration-induced structural distortion. Herein, we present the reverse diffusion and confined polymerization strategy to weave highly ionized polyamide (PA) networks that thread throughout laminated GO nanosheets to sew up GO membranes for enhanced ion sieving and reinforce mechanical architecture. We demonstrate the gradient distribution of amine monomers across GO membranes, combined with reverse-diffusing acyl chloride monomers, enables controlled growth of ionic PA networks throughout the membrane. The in situ-formed PA networks patch the non-selective interspace to enhance the ion selectivity while interlocking adjacent GO nanosheets and strengthening substrate immobilization through mechanically interfacial anchoring effects. The resultant polyamide within GO (PA-w-GO) membrane showcases superior robustness, and exhibits superiority in the water permeability and ion selectivity, outperforming the contemporary GO membranes towards sustainable ion-sieving applications.

Keywords: *Nanofiltration, Graphene Oxide, Confined Polymerization*

Paper ID: A201

Superamphiphobic Hollow Fiber Membrane for Blood Oxygenation Application: An In-Vivo Animal Trial Result

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ABSTRACT

Extracorporeal membrane oxygenation (ECMO) provides critical heart-lung support but is constrained by blood coagulation during prolonged use. Commercial polypropylene (PP) and poly(methyl pentene) (PMP) membranes demonstrate low biocompatibility due to protein adsorption, which triggers clotting. This study evaluates three innovative surface modifications—superhydrophobic, superamphiphobic, and tethered liquid perfluorocarbon (TLP) coatings—to enhance hemocompatibility. While superhydrophobic membranes effectively repel water, superamphiphobic surfaces, utilizing perfluorocarbon-silane coatings, repel both water and oil but present bioaccumulation risks. TLP coatings reduce protein adsorption but experience issues with mobile liquid depletion. To assess in vivo performance, a superamphiphobic hollow fiber module was tested in a blood oxygenation experiment, showing no clot formation after the experiment. However, due to the relatively small size of the membrane module compared to the tested animal, the in vivo results showed limited oxygenation performance. This work identifies promising strategies for developing long-term non-toxic ECMO membranes with improved hemocompatibility.

Keywords: Superamphiphobic Membrane, Superhydrophobic Membrane, Extracorporeal Membrane Oxygenation, Artificial Lung, Blood Oxygenation.

Paper ID: A202

Sustainable Membrane Fabrication with Support-Free Interfacial Polymerization on Bio-Based Materials

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ABSTRACT

With sustainability at its core, this research focuses on replacing traditional fossil-based nonwoven backings and porous membranes, such as those made from polyester, polysulfone, polyethersulfone, and polyimide, with bioderived materials. Inspired by the previous work of Kim et al. [ref], the porous support layer was fabricated using a cellulose membrane, while the bottom-most layer was prepared from Hanji – Korean traditional paper. Hanji, known for its high tensile strength, outstanding durability, and resistance in organic solvents, emerged as an excellent candidate for use as a substrate in thin-film composite (TFC) membrane preparation. By utilizing entirely bioderived and bio-recyclable components including solvents, nonwoven supports, and the porous membrane, this study demonstrates a significant leap toward sustainability in membrane fabrication.The fabricated membranes exhibited remarkable solvent resistance, making them suitable for organic solvent nanofiltration (OSN) applications. Surface and structural properties of cellulose acetate (CA) and cellulose membranes were characterized using scanning electron microscopy (SEM), Fourier-transform infrared (FTIR) spectroscopy, Atomic force microscopy (AFM), and contact angle measurements. Nanofiltration experiments, conducted with a cross-flow system, evaluated the permeance and selectivity of the as-prepared membranes using feed solutions of poly(propylene glycol) (PPG) with molecular weights ranging from 400 to 1,000 g/mol in various organic solvents. The results highlight the viability of bioderived membranes for OSN applications, presenting a sustainable and environmentally friendly alternative to conventional membranes while maintaining high performance under challenging conditions.

Keywords: *Cellulose; Solvent Resistance; Thin-Film Composite Membrane*

Paper ID: A203

Enhancing Waste-to-Energy Gasification Process with Membrane-Based Oxygen-Enriched Gas

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ABSTRACT

Oxygen (O_2) separation membrane technology presents a compelling alternative to pressure swing adsorption and cryogenic distillation for the production of oxygen-enriched gas (OEG) from atmospheric air. The approach is particularly advantageous for generating medium-purity gas streams with O_2 concentration of 30% to 45%, offering improved energy efficiency and cost-effectiveness over conventional technologies. This presentation outlines our advancements in the development and scale-up of hollow fiber membranes for oxygen separation, with the objective of enhancing thermal conversion processes. In our initial work, we employed defect-free, integrally skinned asymmetric hollow fiber membranes fabricated from Matrimid® 5218 polyimide to achieve an OEG with O_2 purity of 45%. These membranes were successfully scaled up to 2-inch modules for municipal solid waste (MSW) gasification to support waste-to-energy conversion. Our results showed that membrane-based OEG generated syngas with a lower heating value (LHV), which was 70% higher than that of conventional air gasification. Process simulations further confirmed better energy efficiency using membrane-based separation for OEG production in the medium-purity regime [1]. However, the use of OEG in gasification also presents challenges, which include localized overheating and elevated nitrogen oxide emissions. To address these issues, we investigated flue gas recirculation (FGR) as a mitigation strategy. The combination of membrane-based OEG and FGR still saw a syngas LHV improvement of up to 44% over air gasification. In addition, the carbon conversion efficiency was enhanced by 22% as compared to OEG gasification without FGR [2]. In our subsequent work, we report the development of a thin-film composite (TFC) hollow fiber membrane for oxygen separation and their translation into a containerized modular unit. This system was successfully deployed to produce OEG with O_2 purity of 30% to support MSW slagging gasification at our test-bedding facility, further strengthening the commercial readiness of membrane-based OEG technology in the waste-to-energy sector.

Keywords: *Hollow Fiber Membrane; Gas Separation; Thin-Film Composite Membrane; Gasification; Waste-to-Energy Conversion*

Paper ID: A204

Rotary-actuated Hollow Fiber Membrane Contactor for Bubble-free Bioreactor Aeration

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ABSTRACT

Aeration typically contributes a significant portion of overall energy consumption in aerobic biological processes. The development of advanced aeration techniques may help to improve the performance and energy efficiency of biological processes with high aeration requirements. In this study, a rotary-actuated aeration device (RAAD) was fabricated based on hollow fiber membrane contactor and evaluated in terms of aeration efficiency under various operating conditions. The oxygen mass transfer coefficient of RAAD was found to be strongly dependent on rotation speed, but less affected by the flow rate of air supplied to RAAD. When tested in deionized water, the mass transfer coefficient of RAAD operated at rotation speed of 100 rpm was 5.9 h^{-1} when tested at 21 °C with air supply pressure less than 10 mbar. The aeration performance of the rotary-actuated aeration device was also tested in a lab-scale membrane bioreactor (MBR) with 2L working volume, which was operated for the cultivation of heterotrophic bacteria for 90 days. The effect of substituting common aeration stone with RAAD in MBR operation on membrane fouling and biomass quality was investigated. Fouling of hollow fiber membrane contactor on RAAD was suppressed as the turbulence created by the stirring effect of RAAD largely deterred the attachment of flocs. Compared to common aeration stone, RAAD can be driven with significantly lower air flow rate and pressure, which resulted in higher energy efficiency and could contribute to significant energy savings in bioreactor operation.

Keywords: *Bubble-Free Bioreactor Aeration; Membrane Bioreactor; Membrane Fouling;Cell Cultivation*

Paper ID: A205

Extrinsically Microporous Polymer Membranes Derived from Thermally Cross-linked Perfluorinated Aryl-Ether-Free Polymers for Gas Separation

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ABSTRACT

Conventional microporous polymers, such as polymers of intrinsic microporosity (PIMs), rely on rigid, contorted molecular backbones to create intrinsic micropores. While they exhibit high gas permeability, their performance is often compromised by physical aging and plasticization under high pressures of condensable gases. Here, we present extrinsically microporous polymer membranes (EMPMs) as a new class of microporous membranes, fabricated from perfluorinated ary-ether-free aromatic polymers via defluorination-induced thermal cross-linking. This process generates permanent interconnected micropores, increases intersegmental distances, and unprecedentedly enhances gas permeability. Additionally, the rigid cross-linked network enhances resistance against plasticization and maintains sufficient micropore volume even after aging. Furthermore, EMP hollow fiber membranes prepared via dip-coating deliver a CO_2 permeance of 2,174 GPU and CO_2/N_2 selectivity of 30 at -20 °C, highlighting their industrial potential. This study establishes a scalable method for fabricating high-performance microporous polymeric membranes with exceptional stability for sustainable energy and environmental applications.

Keywords: *Gas Separation, Ary-Ether-Free Aromatic Polymer, Microporous Polymer, Cross-Linking*

Optimized Preparation of Alginate/Nanocellulose/Polypyrrole Composite Hydrogel via In-Situ Polymerization for High-Efficiency Solar Water Desalination and Purification

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ABSTRACT

In the field of solar steam generation, hydrogels with interfacial evaporation configurations stand as a promising candidate for solar evaporators. Hydrogel-based photothermal materials provide excellent hydration channels for supplying water to the evaporative layer due to their porous structure and hydrophilic nature. This work proposes a facile and in-situ fabrication of the typical alginate-calcium hydrogel with incorporation of cellulose nanocrystals (CNC) and polypyrrole (PPy) as an effective photothermal material. A robust and systematic statistical tool for the design of experiments (DOE) called Taguchi's method was employed to optimize processing conditions to achieve a maximum output. The optimized hydrogel composite demonstrates an excellent evaporation rates of 1.47 kg m^{-2} h^{-1} under 1 sun and 2.81 kg m^{-2} h^{-1} under 2 sun, which are approximately 1.4 times better after optimization, as well as an efficiency of 91.3% is observed under 1 sun illumination. Integrating CNC and PPy into the SA-Ca hydrogel has improved its porosity and hydrophilicity. Additionally, the optimized hydrogel revealed an excellent removal of salts, hardness, dyes, and heavy metal contaminants.

Keywords: *Sodium Alginate Hydrogel, Cellulose Nanocrystal, Polypyrrole, Taguchi Method, Solar Desalination, Wastewater Purification.*

A Modern and Integrated System to Remove Sulphur Dioxide, Carbon Dioxide and Nitrogen Dioxide from Acid Rain by MFM-300 (Al) with the Aim to Increase Water Security

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ABSTRACT

This research investigates the application of metal-organic framework MFM-300(Al) as an innovative solution for rainwater purification through the selective adsorption of atmospheric pollutants. Acid rain, primarily caused by sulfur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen dioxide (NO_2) from industrial emissions and vehicle exhaust, poses significant environmental challenges globally. Our study demonstrates that MFM-300(Al) effectively captures these pollutants from rainwater through a specialized adsorption device. The MFM-300(Al) framework exhibits remarkable stability under hydrothermal conditions and thermal resilience up to 600°C, making it suitable for practical environmental applications despite synthesis challenges and reduced surface area observed in BET analysis. Our device operates through a systematic process: pollutant absorption, automatic sealing, purified water discharge through a porous membrane, and material regeneration via steam treatment to restore adsorption capacity. BET analysis confirms the material's significant adsorption capabilities for all three-target pollutants. The process variables were carefully controlled, with temperature and pressure identified as key factors affecting both MFM-300(Al) formation and gas adsorption efficiency. The thermogravimetric analysis further validates the material's thermal stability under operating conditions. Future development will focus on optimizing manufacturing processes for enhanced purity and efficiency, investigating environmental variable impacts on adsorption performance, testing in diverse environments, and scaling up for broader applications. The potential for 3D-printed prototypes offers promising avenues for cost-effective deployment. This research contributes to sustainable water management strategies by providing an efficient method to mitigate acid rain effects, with implications for both environmental protection and public health improvement in industrialized regions.

Keywords: *Metal Organic Framework, Membrane Technology, Chitosan Polymer, Water Desalination, Casting Device, Hydrophilicity*

Design and Fabrication of CO2 Separation Membranes

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ABSTRACT

The separation and capture of carbon dioxide (CO2) is of great significance in natural gas purification and CO2 emission reduction. Compared to traditional amine absorption methods, CO2 membrane separation technology has advantages such as low energy consumption, high efficiency, small footprint, low pollution, and ease of integration, which has shown good industrial application prospect and receives increasingly widespread attention. However, there are two main challenges of CO2 membrane separation technology: (1) the tradeoff between CO2 separation permeability and selectivity of traditional membrane materials, so-called the upper bound of separation performance, restrict the development of membrane separation technology; (2) under high CO2 feed pressures, polymer chain segments swell and plasticize, resulting in a sharp decline of gas selectivity and loss of separation performance. In response to the aforementioned bottlenecks in CO2 membrane separation technology, this study started from molecular design to regulate the formation of membrane structures, break the upper bounds of traditional membrane materials for CO2 separation, and improve the CO2 plasticization resistance of the membranes. This research is expected to be applied to important fields of CO2 separation such as natural gas purification and CO2 capture.

Keywords: *CO2 Capture, Membrane Separation, Upper Bounds, Plasticization Resistance*

Mechanism, Impacts and Mitigation Strategies of Carbon Deposition in Solid Oxide Fuel Cell: A Short Perspective

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ABSTRACT

Carbon deposition or coking remains a critical issue affecting the durability and efficiency of solid oxide fuel cells (SOFC) when operating on hydrocarbon fuels such as methane and syngas. This review summarizes an experimental investigation on the formation mechanisms of carbon deposition on Ni-based anodes in different operating conditions. Additionally, various technique including scanning electron microscopy (SEM) were highlighted to monitor and characterise the initial phase of carbon deposition on the anode utilising methane and syngas fuels. To determine which conditions were most prone to coking, the effects of several parameters, such as temperature, steam-to-carbon ratio, and current load, were discuss in details. In addition, several mitigation strategies were also deliberated, including steam reforming as well as alternative anode material whereby it can enhance both cell stability and performance. This review aims to give a practical insight into operational guidelines and material design for enhancing the carbon tolerance of SOFC systems in real-world applications.

Keywords: *SOFC, Carbon Coking, Hydrocarbons, Carbon Mitigation, Fuel Cell*

Blocking of Carboxyl Groups in Polyamide Reverse Osmosis Membranes for Antifouling Performance during Treating Industrial Wastewater

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ABSTRACT

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 1-3 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 4.5 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.

Keywords: Reverse osmosis, Polyamide, Fouling, Grafting, Interfacial Polymerization

Paper ID: A211

Proton Exchange Membranes with Enhanced Proton Conductivity via π–π Stacking Interactions for High-Temperature Fuel Cells

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ABSTRACT

High-temperature proton exchange membranes (HT-PEMs) are pivotal for advancing fuel cell technologies, yet they often grapple with challenges like acid leaching and diminished proton conductivity under anhydrous conditions. To surmount these hurdles, we have engineered a novel class of HT-PEMs that leverage π–π stacking interactions to bolster proton transport pathways and membrane stability. By integrating aromatic-rich polymer backbones with strategically positioned π-conjugated units, these membranes establish robust supramolecular networks conducive to efficient proton conduction. This innovative approach underscores the potential of π–π stacking interactions in enhancing the performance and durability of HT-PEMs, marking a significant stride toward the practical deployment of high-temperature fuel cells.

Keywords: *Proton Exchange Membrane*, π–π *Stacking Interactions, High Temperature Fuel Cell*

Paper ID: A213

Removal of Nuclides from Radioactive Wastewater using Nanofiltration Membrane

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ABSTRACT

Nuclear-fouled power plants produce a large quantity of radioactive wastewater that can not be directly discharged into the environment due to its harmfulness and also difficulties to eliminate. Therefore, the water quality control for nuclear power station will be concerned. This study focuses on the insight into the understanding of the removal of targeted nuclides as radioactive compounds from wastewater using nanofiltration (NF). NF membrane performance was examined with respect to permeate flux and rejection of cesium (Cs), and strontium(Sr). The influences of surfactants and PAH on the removal efficiency were also studied. The experiments were conducted in cross flow filtration mode operated in acidic and alkaline conditions.The best result revealed that the rejection of Cs (molecular weight 168 g/mole) nearly approached 99.9% in various condition pH levels.

Keywords: *Nuclear Power Plants, Nanofiltration, Radioactive Wastewater, Ph Levels, Relative Flux*

Paper ID: A214

Preparation and Characterization of Activated Carbon Derived from Coffee Waste as Potential Electrode in Electrochemical Process

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ABSTRACT

Among various carbon-based electrodes in electrochemical applications, activated carbon has been one of the most used materials due to its good wettability, porous characteristics, high surface area, good conductivity, low cost, and simple production process. Recent studies have explored the potential of natural sources to synthesize activated carbon (AC) through carbonization and chemical activation. Carbonization helps in enriching the carbon content and creating an initial porosity, while chemical activation enhances the pore structure. Phosphoric acid (H_3PO_4) was reported to be a poor activating agent compared with an alkaline agent such as potassium hydroxide (KOH). However, optimization on the concentration of H_3PO_4 is still underexplored. Here we show the preparation and characterization of AC prepared from coffee waste through carbonization and chemical activation using different concentrations of H_3PO_4. The SEM result revealed that AC impregnated with 50% H_3PO_4 produced a more robust surface morphology and possesses more well-developed, well-defined pore walls compared with 30% and 80% H_3PO_4. Meanwhile the BET/BJH result showed that 30% H_3PO_4 has a specific surface area of 783.7344 m^2/g and pore volume of 0.237490 cm^3/g, which is slightly higher than the specific surface area (610.9487 m^2/g) and pore volume (0.295928 cm^3/g) of AC impregnated with 50% H_3PO_4. Besides that, the results obtained are also significantly higher compared with previous reports that uses similar combination of materials and chemicals. These results prove that the concentration of H_3PO_4 does affect the effectiveness of the activating agent and should be considered when optimizing the effectiveness.

Keywords: *Activated Carbon, Coffee Waste, Phosphoric Acid, Anode Electrode, Electrochemical Applications*

Paper ID: A215

Effect of Operating Pressure on Membrane Separation Efficiency for Methane Enrichment in Renewable Natural Gas Production

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ABSTRACT

As part of Malaysia's push for cleaner energy under the National Energy Transition Roadmap (NETR), renewable natural gas (RNG) is emerging as a promising alternative to reduce fossil fuel use. A key source of RNG is biogas from organic waste, which can be purified using membrane technology to produce high-quality methane (CH_4). In this process, operating pressure significantly affects methane purity, making it a vital factor in improving RNG output for use in the national grid and other applications. This study aims to evaluate the impact of operating pressure on CH_4 purity in a two-stage hollow fibre membrane system using polyimide membrane material, with a focus on optimizing CO_2 removal. Prior to separation, crude biogas is cleaned by removing moisture and hydrogen sulphide. Operating pressure of 8 to 16 bar were applied to the first-stage membrane to evaluate their effect on CH_4 purity during membrane separation. The pre-treated gas, comprising 55–65% CH_4 and 35–45% CO_2, enters the first-stage membrane unit for initial CH_4 purification. The retentate is then fed into the second-stage membrane for further removal of CO_2. The results indicate that at lower operating pressure of 8 bar, the purity of CH_4 achieved is 81%. At 14 bar, the CO_2 purity increases to 85% and reaches 97% at 16 bar, demonstrating that higher operating pressure significantly enhances CO_2 permeation due to its greater solubility and diffusivity in the polyimide membrane. This progressive increase aligns with the flux equation, where an increased membrane pressure difference promotes CO_2 permeation, thereby enriching CH_4 concentration in the retentate stream. Achieving up to 97% CH_4 purity meets grid specifications, highlighting the need to optimize operating pressure for energy-efficient membrane-based RNG production.

Keywords: *Renewable Natural Gas (RNG), Biogas Purification, Membrane Separation, Polymeric Hollow Fibre Membrane, Pressure Driven Membrane, And Pipeline-Grade Natural Gas.*

Paper ID: A216

Time-Evolved Growth of Polyamide Nanofilms and Their Structure-Performance Relationship: Mechanistic Insights and Implications for Membrane Synthesis

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ABSTRACT

The separation performance of a thin film composite (TFC) membranes is governed by its polyamide film. Unfortunately, the growth of this critical film during interfacial polymerization (IP) has not been fully understood. In this study, we investigate the evolution of fully-aromatic and semi-aromatic polyamide nanofilms at the aqueous/organic interface over time. Different film growth has been observed for these two kinds of films. For the fully-aromatic film, its thickness remaining largely constant (~15 nm) for the IP reaction time ranging from 0.5 to 60 min, the density of the polyamide nanofilm increased from 1.25 to 1.36 g cm^{-3} due to the continued reaction between diffused m-phenylenediamine and dangling acyl chloride groups within the formed polyamide film. This continued growth of the polyamide nanofilm led to a simultaneous increase in its crosslinking degree (from 50.1 to 94.3%) and the healing of nanosized defects, resulting in a greatly enhanced rejection of 99.2% for NaCl without sacrificing water permeance. In contrast, for semi-aromatic polyamide film, we revealed a two-stage growth kinetics, with the film growth rate in the later stage (7.0 nm min^{-1}) one order of magnitude slower than the initial rate (68.2 nm min^{-1}) as a result of reduced availability of piperazine monomers. This two-stage growth mechanism led to an asymmetric film structure, with compelling characterization results (i.e., crosslinking degree, film density, and pore size) showing that the newly formed polyamide under the reduced PIP availability was much looser than the incipient film. We demonstrated that such asymmetric structure had profound impact on the separation performance of the resulting nanofiltration membrane through mechanisms such as internal concentration polarization and gutter effect. The mechanistic insights into the growth-structure-performance relationship of polyamide films could guide the synthesis of high-performance TFC membranes.

Keywords: *Polyamide Film, Growth Kinetics, Film Structure, Separation Performance*

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P012	Kueir-Rarn Lee Polyphenol-assisted layer-by-layer cross-linking of sulfonated polyethyleneimine for highly selective pervaporation dehydration of butanol
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P023	**Ke Shi** Construction of hydrazide COFs membranes and their application in rare-metal ion separation
P024	慧 金 Microporous forward osmosis membrane with vertically aligned 2D nanosheets for exceptional permselectivity
P025	**Nan Ma** Loose polyester nanofiltration membrane designed with hydroxyl-ammonium for efficient dye/salt separation
P026	**Wan Syarizawani Wan Chik** Enhancing desalination performance of reverse osmosis thin-film composite membranes through integration of MIL-101(Cr) interlayer on microfiltration substrate
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	Precise pore structure regulation of polyethersulfone (PES) hollow fiber membranes and its application in the purification of biological products and virus filtration
P029	**Jana Floreková** Advanced magnetic-responsive mixed matrix membranes (MMMs) for CO_2 capture and gas separation
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P046	**JinWon Seo** Interfacial polymerization of MPN/MOF-801-P composite polyamide membranes on PES flat sheets for water treatment
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P076	**Changseog Oh** Remote operation and field demonstration of a pilot-scale MCDI system in Malaysia
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P090	**Chia Ming Liew** Photothermal rice husk char-based omniphobic dual-layer hollow fiber membrane for POME reclamation via membrane distillation
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P093	**Hellen Julian** Removal of microplastic in polluted water by membrane distillation
P094	**Titik Istirokhatun** Removal of nuclides from radioactive wastewater using nanofiltration membrane
P095	**Sakanishi W** Effect of main chain structure on gas transport properties of thermally rearranged polybenzoxazole copolymers

Paper ID: P001

Development of Bipolar Membranes with Increased Hydrophilicity and Catalytic Activity by Leveraging the Physicochemical and Structural Characteristics of Montmorillonite

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ABSTRACT

Bipolar membrane water electrolysis (BPMWE) is a technology that is distinctly different from conventional water dissociation, utilizing electrodes that can split water into H^+ and OH^- at a potential of approximately 0.8 V without any gas formation. However, 2D interface BPMs, where two ion exchange membranes are combined in a planar geometry, have increased membrane thickness and limited interface area, leading to problems such as dehydration, delamination at the interface during water dissociation, and high overpotentials. In order to overcome these weaknesses, 3D junction BPMs with extended interpenetrating interfaces were fabricated by means of single and dual electrospinning. Furthermore, Montmorillonite (MMT) catalysts were uniformly introduced into the 3D interfaces by air-spray. The 3D BPMs with dispersed MMT catalysts at optimised conditions were labelled 3D-x, where x is the amount of catalyst (x mg/cm^2). 3D-1.0 demonstrated the best performance across the I-V curve. Specifically, the transmembrane voltage (TMV) measured at 100 mA/cm^2 (U_{100}) for 3D-1.0 (0.83 V) was decreased by 24.5% and 28.0% compared to the U_{100} for 2D-0 (3.39 V) and 3D-0 (2.96 V) without catalyst, respectively. To evaluate stability at high current densities, the percentage change in TMV of 3D-1.0 (1.2%) measured before and after a 5-hour exposure at 1000 mA/cm^2 showed little change compared to FBM (34.0%). In the long-term stability of BPMs operated at U_{100} for 100 h, the increase in TMV of 3D-1.0 (1.2%) was lower than that of 2D (18.6%) and FBM (6.6%). The BPMs were evaluated for acid and base production by bipolar membrane electrodialysis (BMED) at U_{100} for 2h. Based on this, the current efficiency and energy consumption of the BPMs were derived and it was found that 3D-1.0 (5.65 kWh/kg) was better than the FBM (6.13 kWh/kg) in terms of energy consumption.

Keywords: *Bipolar Membrane; Water Dissociation; Electrospinning; 3D Junction; Montmorillonite*

Paper ID: P002

Highly Oxidation-resistant Polysulfonate-Ester Nanofiltration Membranes for Recycling of Waste Solutions from the Semiconductor Industry

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ABSTRACT

Waste solutions from the semiconductor industry contain high levels of oxidants such as hydrogen peroxide used for wafer surface etching and cleaning. Conventional polyamide (PA) nanofiltration (NF) membranes are widely employed for industrial wastewater treatment due to their superior separation performance (Lee et al. 2023). However, polyamide NF membranes are susceptible to oxidative degradation induced by hydrogen peroxide, and thus, their uses in the recycling of semiconductor waste solutions are limited (Cheng et al. 2023). In this study, we report a novel molecular-level design to fabricate polysulfonate-ester (PSE) NF membranes with enhanced oxidation-resistance via interfacial polymerization (IP) of phenoxide and sulfonyl chloride monomers, followed by end-capping treatment. Three different types of end-capping agents were used to convert residual hydroxyl groups in the PSE matrix into chemically-inert terminal groups. We found that end-capping treatment imparts the chemical stability and steric hindrance to the polymer structure, playing a key role to mitigate membrane degradation by oxidative attack. Performance stability of the PSE NF membranes was evaluated in terms of water permeability and salt (Na2SO4) rejection for 7 days under exposure to 1 wt% hydrogen peroxide. Our results demonstrate that the PSE NF membranes end-capped with sulfonyl terminal group have a stronger resistance toward oxidative attack by hydrogen peroxide than PA NF membranes, offering a promising solution to address the challenges of recovering valuable oxidizing agents from harsh semiconductor waste solutions.

Keywords: *Interfacial Polymerization, Nanofiltration Membrane, Oxidation-Resistance, Semiconductor Waste Solutions*

Paper ID: P003

Defect Engineering of MOF-808 Incorporated in Mixed Matrix Membranes for CO_2 Capture

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ABSTRACT

Carbon capture has emerged as a critical strategy in mitigating the escalating threat of global warming. Mixed matrix membranes (MMMs) incorporating metal-organic frameworks (MOFs) have attracted considerable attention due to their superior gas separation performance. Among various MOFs, MOF-808 is particularly notable for its exceptional stability and environmentally synthesis process. In this study, MOF-808 was synthesized with varying modulator loadings, which significantly influenced its structural properties. A drying-free method was employed to incorporate MOF-808 into a Pebax polymer matrix, ensuring uniform dispersion. The incorporation of MOF-808 into the Pebax matrix enhanced CO_2 permeability and CO_2/N_2 selectivity, achieving values of 142 Barrer and 77, respectively. Additionally, the membranes can be processed via dip-coating, enabling scalable module fabrication. This technique allows the formation of uniform thin-film layers on hollow fiber supports, facilitating industrial application. Notably, the fabrication process avoided toxic solvents, presenting a sustainable approach for developing high-performance MMMs for efficient CO_2 capture.

Keywords: *MOF-808, Modulator, CO_2/N_2 Separation, Green Process*

Paper ID: P004

Fabrication and Characterization of Nanoparticle Enhanced High-Permeability Hollow Fiber RO Membranes

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ABSTRACT

In this study, we addressed the low water permeability of conventional RO membranes by integrating nanoparticles during interfacial polymerization. Optimal conditions for forming a polyamide selective layer on polysulfone hollow fiber membranes were determined by evaluating the effects of aqueous and organic solution circulation cycles and nitrogen purging duration. TFN membranes were then produced by incorporating ZnO, SiO_2, ZrO_2, and GO nanoparticles into the trimesoyl chloride organic solution at concentrations ranging from 0.03 to 0.07 w/v%. Membranes with 0.05 w/v% nanoparticles exhibited a stable ridge-and-valley surface structure. In particular, those containing 0.05 w/v% SiO_2 showed the lowest water contact angle, which promoted efficient water transport. As a result, these membranes achieved a maximum water permeability of 8.4 LMH/bar, along with 82.4% NaCl and 96.6% $MgSO_4$ rejection rates.

Keywords: *Hollow Fiber Membrane, Reverse Osmosis, Thin Film Nanocomposite, Interfacial Polymerization, Nanoparticle.*

Paper ID: P005

Porous Catalytic Bipolar Membrane Derived from Ether-Free Polymer for the Enhancement of Water Splitting Performance and Chemical Stability

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ABSTRACT

Water electrolysis presents a promising avenue for sustainable energy production, leveraging abundant water resources and offering carbon neutrality. Bipolar membranes (BPM), particularly facilitating *in-situ* H^+/OH^- generation, have gained significant attention. In other words, BPM electrolyzers exhibit the capability to maintain a steady-state pH gradient as a critical attribute for optimizing electrode reaction kinetics. However, there are some persisting challenges such as high overpotentials, mass transfer limitations, and chemical instability. This study addresses these issues by fabricating BPMs incorporating porous γ-Fe_2O_3 catalysts within a 3D structural junction through dual electrospinning of ether-free polymers. The synergistic integration of the catalyst and the 3D junction notably enhances water dissociation kinetics via interlayer interlocking. Furthermore, the utilization of poly (terphenyl alkylene)-derived ion exchange membranes enhances chemical stability under corrosive environments. The optimized catalytic 3D-BPM (3D-E-45) exhibited a water dissociation voltage of 0.68 V and a transmembrane voltage U_{100} of 0.76 V at 100 mA.cm^{-2}, representing a substantial reduction compared to the catalyst-free 3D-E-0 BPM with a U_{100} of 3.13 V. The engineered membrane demonstrated exceptional durability and robust resistance to interface delamination under high current density conditions, as evidenced by sustained operation for over 200 h at 100 mA cm^{-2} and maintaining interface integrity after 5 hours of exposure at the current density of 1000 mA cm^{-2}. These findings highlight the beneficial synergistic effects of the porous catalyst and 3D junction on water dissociation efficiency, positioning 3D-E-45 BPM as a viable candidate for electrolysis applications, including acid-base generation and green hydrogen production.

Keywords: *Ether-Free Polymer, Electrospinning, γ-Fe_2O_3 Catalyst, Water Splitting, Bipolar Membrane Electrodialysis*

Paper ID: P006

Advanced Polydopamine-Assisted Immobilization of Lanthanum-EDTA Metalorganic Frameworks onto Polysulfone Membrane for Adsorptive Filtration of Lead

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ABSTRACT

Water pollution is a global issue, exacerbated by both natural and anthropogenic activities that release pollutants to the environment. Specifically, heavy metals in water resources have become a critical challenge due to their toxicity and bioaccumulation. Thus, advancement in water treatment technologies has become crucial to prevent their detrimental consequences and to ensure clean, efficient water in the future. Adsorptive membrane filtration has become a feasible alternative due to its easy use, affordability, and higher efficiency. In this study, a novel Lanthanum-EDTA metal-organic framework (La-EDTA MOF) was synthesized, followed by dopamine coating to form a polydopamine MOF composite (PDA@La-EDTA). During batch adsorption, both pristine and composite MOFs demonstrated pseudo-second-order kinetics (R^2= 0.99 and 0.98), and the composite MOF achieved nearly double Pb^{2+} ion removal efficiency compared to the pristine MOF. Both also adhered to Langmuir adsorption isotherm models (R^2= 0.992 and 0.997) achieving maximum adsorption capacities of 233 and 358 mg/g, respectively. Inspired by this, varying amounts (i.e., 25, 50, and 100 mg) of the as-synthesized La-MOF were embedded onto the polysulfone membrane via dopamine coating. Dopamine coating enabled simultaneous functionalization of MOF and membrane surface along with MOF surface anchoring. The resulting membranes were evaluated for morphology, porosity, hydrophilicity, permeability, and filtration tests. The membrane PSF/PDA/M_{50} achieved up to 94.7% rejection of Pb^{2+} ions (~1.8 times higher than that of the PSF membrane) with a pure water flux of 100 LMH, balancing high pollutant removal with nominally reduced flux. This higher rejection result was achieved by size exclusion, Donnan effect, and polar functionalities (-COOH, -OH, and -NH_2) from the MOF and PDA, proving the potential of PDA@MOF hybrid membrane as a highly effective solution for mitigating lead contamination during water treatment.

Keywords: *Metal Organic Frameworks, Lanthanum, La-EDTA, Polydopamine, Adsorptive Membrane Filtration.*

Paper ID: P007

Comparing Block and Random Copolymers for All-Polymeric Thin Film Composite Membranes for CO2 Capture: Experimental and Computational Approach

ABSTRACT

Additive-free, high-performance all-polymeric thin-film composite (TFC) membranes were developed for CO_2 capture, with emphasis on the structural and functional comparison between block and random copolymers. These copolymers (PTF) were composed of hydrophobic poly(2,2,2-trifluoroethyl methacrylate) (PTFEMA) and CO_2-philic poly(oxyethylene methacrylate) (POEM) segments. The random copolymer, synthesized via free-radical polymerization, exhibited a disordered morphology, while the block copolymer, synthesized through reversible addition-fragmentation chain transfer (RAFT) polymerization, formed a well-ordered, hexagonally packed cylindrical structure, indicating microphase separation. Molecular dynamics simulations revealed strong affinity between CO_2 and the POEM segments in both copolymers, whereas PTFEMA showed minimal gas interaction. Both copolymers demonstrated comparable CO_2 permeance, attributed to similar diffusivity and solubility. However, the block copolymer significantly reduced N_2 transport, leading to nearly fourfold improvement in CO_2/N_2 selectivity. This enhanced selectivity was further supported by a lower mean squared displacement of N_2 within the block structure. Notably, the PTF block copolymer outperformed the commercial Pebax membrane, achieving CO_2 capture performance that exceeds industrial benchmarks. These findings suggest that single-matrix block copolymers present a scalable and efficient alternative to mixed-matrix membranes for advanced gas separation applications.

Keywords: CO_2 *Capture, Block Copolymer, Thin-Film Composite Membrane, Gas Separation, Molecular Dynamics Simulation*

Paper ID: P008

Innovative Methods to Improve and Optimize Reverse Osmosis Membranes with Hydrophilic Additives

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ABSTRACT

Reverse osmosis (RO) membranes play an essential role in desalination and water treatment, yet their performance can be significantly improved through the strategic incorporation of hydrophilic additives during interfacial polymerization. In this study, we introduced various hydrophilic additives into the polyamide layer and optimized both curing temperature and curing time to enhance water permeability and salt rejection. Scanning electron microscopy (SEM) revealed that a uniform "ridge-and-valley" polyamide layer had formed on the support substrate. Moreover, contact angle measurements demonstrated that the membrane prepared with EHD exhibited the highest degree of hydrophilicity among all tested samples. Extending the curing time led to increased mechanical strength in the polyamide layer, indicating that longer curing durations promote further crosslinking and structural stability. Additionally, we employed a mixture of p-toluenesulfonic acid (p-TSA) and 1,3-dimethyl-2-imidazolidinone (DMI) for an optimal curing process at 70°C for three minutes. Under these conditions, the "DMI-3" membrane achieved remarkable salt rejection rates of 97.78% for NaCl and 98.7% for $MgSO_4$, alongside a water flux of 3.31 L/(m²·h·bar). These results represent a significant performance improvement over the control membrane without additives, highlighting the benefits of hydrophilic additive incorporation. Overall, this study underscores the importance of selecting suitable hydrophilic additives and refining processing parameters in the fabrication of high performance RO membranes. By systematically optimizing additive incorporation, curing temperature, and curing time, we have demonstrated a viable route toward producing robust membranes with enhanced water permeability and salt rejection efficiency.

Keywords: *Reverse Osmosis Membrane, Thin Film Composite, Interfacial Polymerization, Polyamide, Hydrophilic Additive*

Paper ID: P009

The Effect of Solution Flow Rate on Selective Layer Formation for Improved Dye Separation in Hollow Fiber Membranes

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ABSTRACT

Separation technologies are essential across multiple sectors, such as food manufacturing, petrochemical processing, and pharmaceuticals, particularly for eliminating large molecules like dyes. While thin-film composite membranes typically employ a polyamide layer for separation purposes, creating a selective polyamide layer on hollow fiber (HF) membranes remains a significant challenge. This study explores the fabrication of polyamide-based HF membranes via interfacial polymerization, involving the circulation of both aqueous and organic solutions. By adjusting the flow rates of these solutions, the research investigates the effect on dye rejection performance, membrane structure, polyamide layer thickness, mechanical properties, and surface hydrophilicity. All membranes developed in this study demonstrated consistent congo red rejection exceeding 98%, with the highest methyl orange rejection observed at around 92%. The best-performing membranes were obtained using an aqueous flow rate of 180 ml/min and an organic flow rate of 220 ml/min. These membranes also showed high ethanol permeance, with congo red rejection reaching 99.75% and methyl orange rejection at 91.68%. Moreover, their performance indicates potential suitability for reverse osmosis applications, especially in salt removal.

Keywords: *Hollow Fiber, Water Treatment, Selective Layer*

Paper ID: P010

Studies of the Structural and Gas Separation Properties of Polybenzimidazole/Polyetherimide Blend Membranes

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ABSTRACT

Polymer blending for gas separation has been extensively discussed in the literature. A highly efficient gas separation membrane was fabricated by combining polybenzimidazole (PBI) with the commercial polyetherimide polymer EXTEM, representing a significant advancement in CO_2 capture technology. The miscibility and molecular interaction between EXTEM and PBI for various blend compositions were investigated. FTIR analysis of the polymer blend membranes revealed noticeable shifts in absorption bands of the functional group, indicating potential intermolecular interactions between the PBI and EXTEM polymer components. We evaluated the variations in the glass transition temperature (Tg) between the virgin membrane and the blend films through thermogravimetric analysis (TGA), differential scanning calorimetry (DSC) and dynamic mechanical analysis (DMA). The membranes' separation performance of the membranes has been assessed for H_2, CO_2, and N_2, gases. All results will be thoroughly discussed in this presentation.

Keywords: *Polybenzimidazole, Blend Membranes, Gas Separation.*

Paper ID: P011

Effect of Carbon Quantum Dots Modification on Oil/Water Separation of Cellulose Acetate Tubular Membrane

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ABSTRACT

The highly hydrophilic membrane surface can reduce the absorption of oil droplets and improve the antifouling properties during the oil/water separation operations. In this study, the oil-water separation performance of cellulose acetate (CA) tubular membranes with/without grafting of carbon quantum dots (CQDs) was investigated. The non-solvent induced phase separation process (NIPS) prepared CA tubular membrane was modified by grafting CQDs on the surfaces with N, N'-diisopropylcarbodiimide (DIC), followed by zwitterionization the CQDs. The results showed that the zwitterionic CQDs modified CA tubular membrane achieved oil rejection of 99.6%, with the flux recovery ratio to 96.9%, and the total fouling rate reduced to 33.4%.

Keywords: *Zwitterionization, Cellulose Acetate, Carbon Quantum Dots, Tubular Membrane*

Paper ID: P012

Polyphenol-Assisted Layer-by-Layer Cross-linking of Sulfonated Polyethyleneimine for Highly Selective Pervaporation Dehydration of Butanol

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ABSTRACT

Pervaporation (PV) has emerged as a highly promising approach for the dehydration of butanol, offering energy-efficient separation capabilities. In this work, we present a novel composite membrane fabricated via covalent layer-by-layer assembly of sulfonated polyethyleneimine (SPEI) and tannic acid (TA) for enhanced butanol dehydration. Sulfonic acid groups were introduced into polyethyleneimine (PEI) through chemical modification with 1,3-propanesultone, yielding SPEI with improved hydrophilicity. This functional polymer was then sequentially deposited onto a hydrolyzed polyacrylonitrile (mPAN) support using a polyphenol-based self-assembly strategy to construct a dense, water-affinitive selective layer. Extensive physicochemical characterization confirmed the successful incorporation of SPEI and TA, resulting in improved surface wettability and a well-structured membrane morphology. Pervaporation testing revealed that the incorporation of SPEI significantly boosted membrane performance. The optimized $(SPEI_1/TA)_{1.5}$ membrane achieved a high permeation flux of 623.45 $g{\cdot}m^{-2}{\cdot}h^{-1}$ and a water concentration in the permeate of 99.5 wt.%, with separation factor and pervaporation separation index (PSI) values approximately 8 and 10 times greater, respectively, than those of the unmodified $(PEI_1/TA)_{1.5}$ membrane. These superior results are primarily attributed to the strong polar affinity between sulfonic acid groups and water molecules, which facilitates selective water transport. Overall, the developed membranes effectively overcome the azeotropic constraint of n-butanol/water mixtures, underscoring their strong potential for sustainable and efficient industrial dehydration processes.

Keywords: *Pervaporation, Tannic Acid, Sulfonated Polyethyleneimine, Layer-by-Layer, Butano*

Paper ID: P013

Fabrication and Application of Mono-Valent Ion Selective Membranes Modified by MXene

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ABSTRACT

Monovalent ion-selective ion-exchange membranes (IEMs) are key materials used in various electro-membrane processes for saltwater desalination, wastewater treatment, and the separation and recovery of specific ions. In this study, MXene, a layered 2D nanomaterial with hydrophilic surface functional groups, was employed as a membrane surface modification material to selectively separate monovalent ions from a solution containing a mixture of monovalent and multivalent ions. It was anticipated that MXene could effectively control ion-selective transport by modulating the interlayer distance and surface properties. In particular, novel composite IEMs were fabricated by optimizing the dispersibility and rheological properties of the MXene solution, adjusting the coating conditions, and applying an electric field as a post-treatment process. The fabricated composite IEMs were systematically characterized using various physical and electrochemical analyses. The results confirmed that both monovalent ion selectivity and ion conductivity of the membranes could be simultaneously improved by optimizing the arrangement and surface condition of the MXene materials introduced on the membrane surface. Furthermore, the performance of the prepared membranes was validated by applying them to various electro-membrane processes such as water-splitting electrodialysis and reverse electrodialysis. This work was supported by the NRF grants (NRF-2022M3C1A3081178) and the ME and KEITI's 2024 green convergence professional manpower training support project.

Keywords: *Monovalent Ion-Selective Ion-Exchange Membranes, Electro-Membrane Processes, MXene, Surface Modification, Electric Field*

Paper ID: P014

Fabrication and Characterization of Asymmetric Bipolar Membranes Incorporating Mxene Catalyst

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ABSTRACT

A bipolar membrane (BPM), composed of laminated cation-exchange and anion-exchange layers, is a specialized ion-exchange membrane capable of dissociating water molecules into hydrogen and hydroxide ions under a strong electric field. BPMs have been utilized in various electro-membrane processes, such as bipolar membrane electrodialysis (BMED) for producing acids and bases from salt solutions, as well as in water electrolysis for hydrogen production. The water-splitting performance of BPMs is influenced by the characteristics of the bipolar junction and the properties of the ion-exchange layers. In this study, BPMs were fabricated using ion-exchange layers with varying compositions and thicknesses, and their characteristics were analyzed to determine the optimal fabrication conditions for maximizing water-splitting performance. Additionally, MXene was introduced at the bipolar junction to evaluate its effectiveness as a water-splitting catalyst. As a result, an asymmetric BPM with enhanced water-splitting characteristics was successfully fabricated by comprehensively optimizing both the bipolar junction and the ion-exchange layers. The fabricated BPMs were systematically characterized through various physical and electrochemical analyses, and their performance was validated through application in electro-membrane processes such as BMED and direct seawater electrolysis. This work was supported by the NRF grants (NRF-2022M3C1A3081178) and the ME and KEITI's 2024 green convergence professional manpower training support project.

Keywords: *Bipolar Membrane, Bipolar Membrane Electrodialysis, Bipolar Junction, MXene, Asymmetric BPMs*

Paper ID: P015

Resource Recovery from Industrial Wastewater via Electrochemical Ion-Exchange Membrane Technology

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ABSTRACT

This study addresses the challenge of managing high-conductivity wastewater generated from the regeneration of 2B3T resin towers in ultrapure water (UPW) systems, widely used in semiconductor manufacturing. Resin units remove cations and anions such as Ca^{2+}, Mg^{2+}, silicates, and sulfates. Upon saturation, regeneration with 5 wt% HCl and NaOH is required, producing approximately 50 tons of wastewater per 1,000 tons of UPW. Conventional neutralization methods result in elevated effluent conductivity (~50,000 μS/cm), limiting water recovery rates and complicating regulatory compliance. To overcome these challenges, an electro-driven ion-exchange membrane technology was developed to recover and concentrate acid and alkali from the regeneration waste streams. The system integrates cation-exchange membranes (CEMs), anion-exchange membranes (AEMs), and monovalent selective membranes to achieve efficient ion separation and water dissociation with low energy consumption. Using optimized configurations, the technology successfully recovered up to 50% of the ionic content, producing 5 wt% HCl and NaOH solutions with purities exceeding 95%. The recovered chemicals are reused in the resin regeneration process, creating a closed-loop cycle that significantly reduces chemical consumption, wastewater conductivity, and operational costs. Preliminary results indicate a 50% reduction in wastewater generation, a 33% decrease in chemical procurement costs, and a 20% reduction in carbon emissions (Scope 3). This approach offers a scalable and sustainable solution for resource circulation and low-carbon manufacturing in the semiconductor industry.

Keywords: *Resource Recovery from Industrial Wastewater; Acid and Alkali Recycling for Ion Exchange Resin Towers, Ion Exchange Membranes, Conductivity Reduction, Net-Zero Discharge*

Paper ID: P016

Development of CPVC/P(MEA-co-styrene) Blend Microfiltration Membranes using NIPS Method

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ABSTRACT

In our previous study, we successfully developed low-fouling microfiltration membranes by blending poly(vinylidene fluoride) (PVDF) with poly(2-methoxyethyl acrylate) (PMEA) [1,2]. However, in the development of microfiltration membranes, the replacement of PVDF with other polymers has been expected. Chlorinated polyvinyl chloride (CPVC) was used in this study. The compatibility of CPVC and PMEA is not good, and only 1 wt% PMEA can be blended with 15 wt% CPVC. Furthermore, when an aqueous solution containing 1000 ppm BSA was filtered through the CPVC/PMEA blend membrane, the flux reduced by 35%. Therefore, we aimed to develop new microfiltration membranes with improved low-fouling properties by increasing the amounts of low-fouling units in the blend membranes. Copolymers of MEA and styrene were prepared by changing the composition of MEA and styrene monomers. N,N-dimethylacetamide was used as a solvent to prepare transparent dope solution, and membrane formation was performed by the non-solvent induced phase separation (NIPS) method. The low-fouling properties of the prepared non-blended and blend membranes were evaluated by filtration tests of aqueous solution containing BSA. The higher the percentage of styrene in the copolymer, the better the compatibility with CPVC, but the higher the percentage of styrene, the lower the low-fouling property of the membrane. When the molar ratio of MEA to styrene in the copolymer was 87:13, the copolymer that could be blended with 15 wt% CPVC increased to 4 wt%. The filtration test using this membrane showed that the flux only reduced by 20%. These results indicated that the CPVC/P (MEA-co-styrene) blend membranes suppressed protein adsorption to the membrane surface and effectively inhibited fouling against BSA.

Keywords: *Poly(2-methoxyethyl acrylate), Styrene, CPVC, Fouling, NIPS*

Paper ID: P017

Zwitterionic Membranes and Biomedical Applications

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ABSTRACT

This poster presentation summarizes our laboratory's advancements in interface and membrane functionalization using zwitterionic biomaterials. We discuss the design of zwitterionic polymers and copolymers, such as sulfobetaine-based, carboxybetaine-based, or phosphobetaine-based materials, and the strategies employed for surface/membrane functionalization, including coating, grafting, or in situ modification. Emphasis is placed on the crucial role of zwitterionic membranes in key medical applications. Our research primarily focuses on leukodepletion technology, which significantly enhances transfusion safety, disease prevention, and medical efficiency. Through collaborative efforts with our research team and students, we have developed a range of products and methods related to leukodepletion technology. These achievements have garnered widespread recognition in academia and have substantial societal impact, particularly in improving healthcare outcomes. Furthermore, our research extends to disease diagnostics, where we have developed microfiltration technology to enhance the accuracy of disease detection by purifying blood samples directly. This has significant implications for early disease detection and treatment, potentially saving lives. Additionally, our work encompasses disease treatment applications. We have developed blood platelet purification and concentration filtration products that play a crucial role in treating conditions like arthritis, improving treatment efficacy, and reducing patient discomfort. This contributes to enhancing overall quality of life and health outcomes. Finally, we discuss potential future directions, including molecular design, functionalization processes, and applications. Our research underscores the importance of zwitterionic biomaterials in advancing medical technologies and improving patient care.

Keywords: *Zwitterionic Membranes, Phase Inversion, Surface Grafting, Bioseparation, Medical Applications*

Paper ID: P018

Highly Loaded Prussian Blue Mixed Matrix Membrane for Salt-tolerant Solar Catalytic Oxidation

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ABSTRACT

Dispersing metal-organic framework (MOF) fillers within matrix polymeric membranes is essential for enhancing their availability, processability, and performance, yet hampered by serious agglomeration. Herein, we synthesize a novel Prussian Blue mixed matrix membrane for solar catalytic oxidation. Micro-scaled Prussian Blue microspheres are coated with Polyvinyl pyrrolidone-Vinyltriethoxysilane (PVP-VTES) crosslinked network to enhance the dispersed stability in the organic solution. The loading of modified Prussian Blue (mPB) fillers in Polyvinylidene fluoride (PVDF) matrix membrane could reach 40%. The PB mixed matrix membrane shows enhanced hydrophilicity, water permeance, and excellent photothermal conversion capability. The membrane exhibits a sustainable tetracycline (TC) removal (>96%) under solar irradiation in the presence of high salinity (e.g. NaCl, NaAC, and NaHCO3). The photothermal effect facilitates peroxymonosulfate activation for reactive oxygen species efficient generation (1O2/•OH/SO4•-), resulting in instantaneous catalytic removal rate, multi-salt tolerance, and sustainable pollutants removal. The reported technique could potentially address interface challenges in mixed matrix membranes and can be extrapolated to the development of other fillers, achieving superior performance in membranes for water remediation.

Keywords: *Highly Dispersive, Metal Organic Frameworks, Polymer Network, Solar Catalytic Membrane, Saline Organic Wastewater*

Paper ID: P019

Diffusion Mediated Tips for Preparing PVDF Membranes with Enhanced Separation Performances

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ABSTRACT

Thermally induced phase separation (TIPS) process is an appealing method for preparing poly(vinylidene fluoride) (PVDF) membranes for separation. In this work, we developed a diffusion mediated thermally induced phase separation (d-TIPS) to prepare PVDF membranes with great molecules separation performances. We investigated the thermodynamics of ternary polymer solutions including PVDF, caprolactam (CPL), and Polyethylene glycol (PEG). We controlled liquid-liquid phase separation and the CPL diffusion by adjusting the addition of PEG and molecular weight to modulate the evolution of morphology from spherulitic to bicontinuous structure. We used high molecular weight PEG to modulate the thermodynamics process to undergo a liquid–liquid phase separation process, leading to a membrane structure transition from spherulitic to bi-continuous morphology. The addition of high molecular weight PEG modulates the diffusion of CPL along with the thermally induced phase separation, causing the skin layer to become thin and porous. Moreover, the surface enrichment of PEG enhanced membrane hydrophilicity. The prepared membrane exhibited narrow pore size distribution, enhanced tensile strength, high permeability, and high rejection to protein molecules. More importantly, the membrane achieved a great protein rejection capability for BSA and BFG. This diffusion mediated thermally induced phase separation approach holds broad prospects for fine-structured membranes in the separation, concentration, and purification processes necessary for biomedicine production, that shows the great potential of PVDF membranes in macromolecules separation.

Keyword:*Poly(vinylidene fluoride) membranes,Diffusion Mediated Thermally Induced Phase Separation, Liquid Phase Separation, Molecules Separation*

Paper ID: P020

Aluminum MOF 303–PES Composite Ultrafiltration Membranes: A Strategy for Improved Permeability and Antifouling

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ABSTRACT:

The performance of ultrafiltration membranes in water and wastewater treatment is often limited by the trade-off between selectivity, permeability, and fouling resistance. In this study, we addressed these challenges by incorporating metal–organic framework (MOF) 303 into polyether sulfone (PES) ultrafiltration membranes. Composite PES-MOF 303 membranes with varying MOF 303 concentrations (0.25–1.0 wt%) were fabricated via phase inversion. The optimized membranes—PES$_{12.5\text{-}0.5}$, PES$_{15\text{-}0.5}$, and PES$_{17.5\text{-}0.75}$—demonstrated significant enhancements in pure water flux, increasing by 36.13 % (455.62 ± 4.16 LMH), 37.83 % (301.1 ± 35.48 LMH), and 117.8 % (162.96 ± 6.82 LMH), respectively, compared to unmodified PES membranes. BSA protein rejection also improved by 20.76 % (59.75 ± 5.97 %) and 16.23 % (89.45 ± 2.17 %), with PES$_{17.5\text{-}0.75}$ achieving a rejection rate of 94.24 %. Notably, PES17.5-0.75 exhibited a 200 % reduction in protein adsorption and achieved over 85 % flux recovery, indicating excellent fouling resistance. These improvements are attributed to increased surface roughness, enhanced hydrophilicity, and a more negative surface charge due to MOF 303 incorporation. Furthermore, the membranes maintained high stability with minimal MOF 303 leaching in harsh acidic and basic environments and efficiently removed various contaminants, such as arsenate, chromate, fluoride, Congo red, and methyl orange, from water matrix. These results provide new insights into the development of high-performance PES-MOF 303 composite membranes for advanced water and wastewater treatment applications.

Keywords: *Ultrafiltration, MOF-composite membrane, Antifouling, Permeability-selectivity*

Paper ID: P021

Thin-Film Composite Electro-Nanofiltration Membrane for One-Step and Efficient Fractionation of Dyes and Salts In High-Salinity Textile Wastewater

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ABSTRACT

The key to achieve sustainable treatment of high-salinity dye-containing wastewater is effective fractionation of dyes and salts. In this study, a thin-film composite electro-nanofiltration membrane was successfully fabricated by co-deposition of levodopa and ε-polylysine onto a porous ultrafiltration membrane substrate. With the co-deposition of the polylevodopa/ε-polylysine composite coating on the substrate membrane, the surface properties were significantly regulated, resulting in decreased pore size, reduced surface negative charge density and lower specific electric resistance, thus enhancing their ion transfer and dye/salt fractionation efficacy. Specifically, the fabricated LDP-4 membrane (molecular weight cut-off of 408 Da) with a 4-h co-deposition experienced a 99.12% reactive orange 16 dye rejection and 10.15% NaCl rejection, indicating an impressive selectivity between dyes and salts. Additionally, the LDP-4 electro-nanofiltration membrane as anion conducting membrane exhibited a fast and efficient electro-driven transfer of Cl- ions. Notably, under an electric field, the fabricated LDP-4 electro-nanofiltration membrane can efficiently fractionate NaCl from the reactive orange 16/NaCl mixed solution, achieving a 98.89% desalination efficiency and 99.79% dye recovery. Furthermore, the LDP-4 membrane demonstrated remarkable anti-fouling property and long-term stability over an 8-cycle electro-nanofiltration operation. Therefore, the electro-nanofiltration membranes fabricated by co-deposition of levodopa and ε-polylysine show a promising potential in sustainable resource recovery from high-salinity dye-containing wastewater.

Keywords: *Electro-Nanofiltration Membrane, High-Salinity Wastewater, Co-Deposition, Dopamine-Based Modification, Resource Recovery*

Paper ID: P022

Catalyst Engineering for the Multilayer Porous Graphene Synthesis

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ABSTRACT

Despite the superb membrane performances that porous graphene promises, there is wide room for improving the porous graphene formation process. As its two significant pillars are the synthesis of graphene and the formation of pores in it, the process for securing both aspects can take dual avenues: top-down & bottom-up methods. The top-down method, which separates graphene synthesis and perforation, normally detaches carbon atoms from the graphitic lattice by energetic collision after graphene synthesis. Well-controlled post-synthesis perforation can create sub-nm-wide pores in graphene, though a slight miscue could lead to a defective structure at a larger scale. On the other hand, the bottom-up method is based on the idea of synthesizing porous graphene directly without including post-perforation. Designing a catalyst to synthesize graphene in the selected area, excluding where the pores should be, is crucial. Only a few studies have demonstrated the bottom-up porous graphene synthesis. Furthermore, the mechanical vulnerability of handling single-layer porous graphene has been disrupting its practical application. Interestingly, porous graphene can maintain the ultimate permeation even at increased thickness, depending on the aspect ratio. Such layer tolerance suggests employment of the multilayer structure rather than the vulnerable single-layer counterpart. Here, we introduce advanced catalyst engineering to synthesize multilayer porous graphene via the bottom-up method. Catalyst engineering consists of material selection, catalyst taming, and crystallinity alignment. The unprecedented Ni/Ag catalyst provides multilayer porous graphene with an average pore size of less than 20 nm and a pore density of 10^{10} cm^{-2}. As-synthesized multilayer porous graphene is promising as a high-performance membrane in filtration, breathable membranes, etc.

Keywords: *Porous graphene, Chemical Vapor Deposition, Bottom-up Synthesis, Catalyst Engineering, Crystallinity Alignment*

Paper ID: P023

Construction of Hydrazide COFs Membranes and Their Application in Rare-Metal Ion Separation

ABSTRACT

Rare metal (RMs), prized for their high mechanical strength, exceptional corrosion resistance, and superior catalytic activity, have seen surging demand across critical fields such as new energy. However, the increasing scarcity of resources and the environmental and operational limitations of traditional metallurgical extraction methods pose significant challenges. Membrane separation technology stands out as a promising alternative due to its environmental sustainability and operational efficiency. Despite this, conventional membrane materials are hindered by the "trade-off" effect between permeability and selectivity, which limits their overall performance.This study delves into the application of hydrazide covalent organic framework (COFs) membranes for the separation of rare-metal ions, aiming to address these challenges. Four distinct COF membranes, varying in oxygen-group density, were synthesized via interfacial polymerization using 135-benzene-trimethylhydrazide and formaldehyde derivatives with differing hydroxyl group functionalities. Advanced characterization techniques, including PXRD and GIWAXS, were employed to elucidate the structural properties of the membranes. Our research systematically explored the influence of acid concentration and film-formation time on the nucleation, growth, and crystallization of the COF membranes. Through these investigations, we identified an optimal acid concentration range that maximizes membrane crystallinity. Performance evaluation revealed that the BTCH-TP membrane demonstrated exceptional selectivity for cesium and uranyl ions, achieving a selectivity coefficient of up to 230. Notably, high-valence cations exhibited significantly reduced permeation rates, highlighting the membrane's high selectivity and efficiency. These findings underscore the potential of hydrazide COFs membranes as high-performance materials for rare-metal ion separation. By offering a novel approach to address the limitations of traditional separation methods, this work not only advances the field of membrane separation technology but also holds great promise for fostering the sustainable development of industries reliant on rare-metal resources.

Keywords: *Covalent Organic Framework Membrane, Rare metals, Ion Selective Separation, Hydroxyl Functionalization*

Paper ID: P024

Microporous Forward Osmosis Membrane with Vertically Aligned 2D Nanosheets for Exceptional Permselectivity

ABSTRACT

Conventional thin-film composite polyamide forward osmosis (FO) membranes suffer from the permeability-selectivity trade-off inherent to solution-diffusion mechanisms. This study breaks this limitation by designing a sandwich microporous FO membrane featuring vertically aligned nanosheets as a key functional layer, simultaneously achieving high water flux and ultra-low reverse salt flux. The membrane architecture comprises: (i) a hydrophilic polyethersulfone (PES) support, (ii) an intermediate hydrophobic layer of vertically oriented nanosheets creating nanobubble-enriched air gaps, and (iii) an electrospun polyacrylonitrile (PAN) protective layer. The 2D nanosheet array provides threefold permselectivity enhancement: (1) hydrophobic nanochannels inhibit salt ion diffusion, (2) electrostatic repulsion from nanosheet surfaces rejects dissolved ions, and (3) size exclusion through precisely controlled interlayer spacing. The hydrophilic PAN top layer further stabilizes the hydrophobic interface under hydrodynamic flow. Remarkably, this design achieves a record-low reverse salt flux of 2.8*10-4g m^{-2} h^{-1} with concurrent high water flux (46.8 LMH), representing a 5.7-fold improvement in permselectivity ratio compared to conventional TFC-FO membranes. Long-term testing demonstrates stable performance over 1,300 minutes of continuous operation, showcasing exceptional potential for energy-efficient desalination and zero-liquid-discharge systems.

Paper ID: P025

Loose Polyester Nanofiltration Membrane Designed with Hydroxyl-Ammonium for Efficient Dye/Salt Separation

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ABSTRACT

The Efficient dye/salt separation poses a great challenge to nanofiltration (NF) membrane technology in the desalting sector of the dye synthesis industry. In this study, we fabricated a novel loose polyester NF membrane via an interfacial polymerization method using "hydroxyl-ammonium" biquaternary diethanolamine (MDET) and trimesoyl chloride. The molecular design of MDET provides a loose crosslinking network, showing high rejection of dyes and the passage of monovalent salt/divalent salt ions in the dye solution, exhibiting exceptional filtration efficiency with high selectivity. Furthermore, the membrane exhibits excellent operational stability for over 100 h, demonstrating superior antifouling properties and high resistance to chlorine. This study provides new insights into the role of dyes and mono- and divalent ions in desalination processes related to the dye synthesis industry.

Keywords: *Polyester Nanofiltration Membrane, Monomer Design, Inorganic Salts, Dye Separation, Loose Network*

Paper ID: P026

Tailored Heterogeneity in SPEEK Membranes for Advanced Blue Energy Harvesting

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ABSTRACT

Reverse electrodialysis (RED) has emerged as a promising renewable energy technology that harnesses osmotic power from salinity differences via selective ion transport membranes. Conventional polymeric membranes often suffer from suboptimal power generation due to poorly defined ionic pathways. To address this limitation, we develop a novel heterogeneous sulfonated poly(ether ether ketone) (H-SPEEK) membrane engineered through solvent-induced phase separation, exhibiting an exceptionally high surface charge density of -10.8 C m^{-2}. The unique phase-separated architecture of H-SPEEK not only amplifies its anionic charge but also improves hydrophilicity, enabling accelerated ion mobility. Under extreme salinity gradients (50-fold, $CaCl_2$), it maintains a robust performance of 12.0 W m^{-2}. This breakthrough is attributed to the membrane's optimized nanochannels and ion diode characteristics, which promote selective cation conduction while mitigating polarization losses. The innovative design of heterogeneous SPEEK membranes opens new avenues for high-efficiency blue energy conversion.

Keywords: *Osmotic Energy Conversion, Ion Selectivity, Ion Flux, Ion Exchange Membrane*

Paper ID: P027

Synthesis of Self-Standing Fluorine-Substituted Covalent Organic Framework Membrane via Homogeneous Solvothermal Method

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ABSTRACT

Membrane technology plays an indispensable role in promoting sustainable social development due to its significant effectiveness in addressing energy crises, water shortages, environmental pollution, and achieving carbon neutrality. The advantages of membrane technology lie in its low energy consumption, ease of operation and environmental friendliness. However, traditional membrane materials have problems such as non-uniform pore size, uneven pore size distribution and the trade-off between permeability and selectivity. To fully unleash the application potential of membrane technology, it is urgently necessary to develop new high-performance membrane materials. Covalent organic framework (COFs) are a new type of multifunctional membrane material with attracted widespread attention due to its high adjustability, ordered crystal pore structure, high porosity and excellent stability. Based on network chemistry, the modular nature of COFs enables it to precisely regulate the network dimension, optimize porosity and introduce functional groups at the molecular level. This feature creates numerous opportunities for designing various hierarchical topological structures and different chemical functions of nanochannels in COFs membranes. However, COFs often exists in powder form, and the insolubility and non-fusibility of COFs powder further restrict its processing and film formation. The existing COFs membrane preparation techniques, such as interfacial polymerization method and vacuum filtration membrane formation method, have problems such as poor crystallinity, limited diffusion and weak binding to the substrate. Therefore, our work focus on developing new methods for preparing COFs membranes to obtain a series of functionally oriented COFs membranes. It is of great significance for giving full play to the inherent advantages of COFs to solve existing energy, environmental, chemical and other problems, as well as promoting the innovative development of the next generation of efficient separation membrane materials.

Paper ID: P028

Precise Pore Structure Regulation of Polyethersulfone (PES) Hollow Fiber Membranes and Its Application in The Purification of Biological Products and Virus Filtration

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ABSTRACT

With the intensification of population aging and social concern for life and health, the demand for PES membranes in the medical field is increasing. However, there are still some drawbacks exist during the current application of PES hollow fiber membranes: the main disadvantage is poor selective separation, poor pressure stability and susceptibility to contamination. We prepared a novel PES ultrafiltration hollow fiber with "hour-glass' like spongy micropore-structure via vapor and liquid induced phase separation (V-LIPS) technique. This structure endows the membrane with excellent mechanical properties and pressure resistance stability. The high humidity environment induced the uniform distribution of hydrophilic components from the inner surface to the outer surface, ensured the high hydrophilicity of the membrane surface and cross-section, and effectively guaranteed the high anti-pollution performance of the membrane during the separation of biological feed solutions. The obtained membrane with a pore size of 100 nm showed excellent separation properties for protein purification with high rejection of 98% to collagen. The prepared membrane with a mean pore size of 20nm exhibited robust virus filtering performance of MVM LRV>4, and high recovery performance of mAb >95%.

Keywords: *Polyethersulfone Hollow Fiber Membrane, Phase Separation, Antifouling, Virus Filtration*

Paper ID: P029

Advanced Magnetic-Responsive Mixed Matrix Membranes (MMMs) for CO_2 Capture and Gas Separation

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ABSTRACT

Tackling the escalating threat of climate change demands innovative solutions, and CO_2 capture technologies are at the forefront. With their precision and adaptability, membrane-based systems redefine how we approach emissions reduction. Particularly, the fusion of polymers with inorganic fillers in mixed matrix membranes unlocks unparalleled potential for selective and efficient CO_2 separation, paving the way for cleaner industries and a sustainable future. This study explores the potential of amine-functionalized UiO-66-NH_2 MOFs combined with magnetic $MnFe_2O_4$ nanoparticles (MNPs) within a Pebax-based membrane system. The synergistic effects of these components significantly improve gas transport properties, focusing on enhanced CO_2 separation and incorporating MNPs at 5, 10, 15, and 20 wt.% within the polymer matrix resulted in a remarkable improvement in permeability and selectivity. For example, CO_2 permeability increased from 71 Barrer in the pristine Pebax membrane to 245 Barrer in the membrane containing 20 wt.% of MNPs. Concurrently, CO_2/N_2 selectivity increased from 43.6 to 73.26, and CO_2/CH_4 selectivity increased from 18.2 to 21.0. Observed enhancements were achieved through the controlled alignment of nanoparticles under an external magnetic field, which mitigated aggregation and sedimentation issues and optimized their dispersion within the matrix. Including $MnFe_2O_4$ as the magnetic component also provided additional advantages, such as forming ordered nanoparticle arrays that enhanced gas diffusion pathways. This approach resulted in membranes that surpassed the Robeson upper bound for CO_2/CH_4, CO_2/N_2, and O_2/N_2 separations and demonstrated exceptional stability and performance in gas separation applications. Our results underline the potential of MMMs incorporating UiO-66-NH_2 and $MnFe_2O_4$ as a scalable and efficient solution for industrial CO_2 capture and other gas separation processes, offering a blend of superior selectivity, permeability, and robustness and providing valuable insights for future research and industrial applications.

Keywords: *Post-Combustion CO_2 Capture, Mixed Matrix Membranes, Metal-Organic Framework Nanoparticles, Gas Separation Efficiency*

Paper ID: P030

Development of Thin-film nano composite Hollow Fiber Membranes for CO_2 Separation Using a MOF-COP Composite on Porous Substrate

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ABSTRACT

While the global warming due to CO_2 has become a keen concern, the purpose of this study was to separate CO_2 using thin film nano composite (TFNC) hollow fiber membranes. TFNC hollow fiber membrane. TFNC hollow fiber membrane was manufactured into a porous PES substrate by using additional equipment (heat and pressure) when spinning the hollow fiber membrane to obtain high permeability. The spun hollow fiber membrane used an interfacial polymerization method to obtain high permeability and selectivity through thin films and nanoparticles. Among various nanoparticles, metal organic framework (MOF) and covalent organic polymer (COP) complex were synthesized and fixed on the PES substrate to reduce agglomeration and improve nano-particle distribution. Furthermore, optimization was derived based on variations in MOF-COP complex nanoparticle concentration.

Keyword: *Gas Separation, Hollow Fiber Membrane, Interfacial Polymerization, Mixed Matrix Membrane, Nano Particle.*

Paper ID: P032

Investigation of Interaction Between Organic Solvent and High-Performance Go/hBN Organic Solvent Nanofiltration Membrane

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ABSTRACT

Organic solvents are essential in various industries, yet their low reuse rates present significant environmental and economic challenges. Organic solvent nanofiltration (OSN) provides a more energy-efficient purification method than conventional thermal processes. However, most polymer membranes are susceptible to degradation in harsh solvent conditions, highlighting the need for chemically robust alternatives.In this study, a composite membrane was fabricated by depositing a high amount of hexagonal boron nitride (hBN) nanosheets onto a nylon substrate, with graphene oxide (GO) acting as a spacer to enhance its structural stability. The membrane's performance was systematically evaluated under two conditions: moist and thermally treated, and five different solvents: acetone, methanol, DMF, ethanol, and NMP. Positive and negatively charged dyes such as methylene blue, methyl orange, crystal violet, and acid blue 25 were used to assess rejection rates. Also, the rejection rates of the membrane were tested and compared based on the molecular size. The thermally treated GO/hBN membrane exhibited high acetone permeability (1,187 LMH/bar), while the moist GO/hBN membrane achieved over 90% rejection of methylene blue across five solvents. To demonstrate the impressive mechanism of the GO/hBN membrane, the solvation behavior of organic dyes was also investigated. Using the Hansen solubility parameter and properties of solvents such as protic/aprotic character, viscosity, and polarity, the transport of organic dyes in the OSN process was analysed.

Keywords: *Organic Solvent Nanofiltration, Boron Nitride, Graphene Oxide, Solvation, Hydrogen Bonding*

Paper ID: P033

Solvent-free Polyester TFC Membrane Fabrication for Saline Water Recovery

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ABSTRACT

The rapid expansion of industrial processes such as textile and petrochemical generate a large volume of saline wastewater that offers opportunity for valorisation through saline water recovery, which can be potentially reuse in industrial processes. While thin film composite (TFC) nanofiltration (NF) membranes have emerged as a promising technology for saline water recovery, the usage of large amounts of organic solvent and unsustainable amine-based monomers during membrane manufacturing remains a major concern. Thus, a greener approach to prepare TFC membranes based on solvent-free trimesoyl chloride (TMC) monomer vaporization using sugar-based glucose as the aqueous monomer is presented in this work. By exploring various synthesis parameters, the optimized PE TFC membrane (PE VIP-0.60) can be developed at a glucose concentration of 5 wt% and NaOH concentration of 0.05 wt% at a contact time of 30 min. Our findings revealed that thinner and looser PE structure contributes to the improvement in pure water permeability (PWP) of PE VIP-0.60 membrane by 11 times as compared to the conventional PA TFC membrane (PA VIP-0.60), recording 28.27 L/m^2.h.bar. Most importantly, PE VIP-0.60 membrane achieved stable performance during the 8-h filtration of synthetic textile effluent and produced water, achieving >99% rejection of contaminants (i.e., Rose Bengal dye and crude oil) while recovering >83% of saline water. In addition, PE VIP-0.60 membrane also showed outstanding chlorine resistance after immersion in sodium hypochlorite (NaClO) solution for 24 h, preserving at least 90% of the original permeability while exhibiting no significant difference in organic solute rejection.

Keywords: *Thin Film Composite, Nanofiltration, Polyester, Saline Water*

Paper ID: P034

PPO-Based Ion Exchange Membranes with Distinct Functional Groups for Bioelectrochemical Systems: A Comparative Study of Sulfonated and Quaternized Types in MFC and MEC Modes

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ABSTRACT

Microbial Electrolysis Cells (MECs) and Microbial Fuel Cells (MFCs) are types of bioelectrochemical systems (BESs) that utilize microbial catalysts to convert the chemical energy contained in organic wastewater into into hydrogen gas and electricity, respectively. In this study, PPO-based ion exchange membranes fabricated in the laboratory were compared with commercial membranes for application in MFC and MEC systems. Five membranes, including two fabricated membranes (SPPO and QPPO) and three commercial membranes, were evaluated based on their physicochemical and electrochemical properties, and their performances in MFC and MEC systems were assessed. The SPPO membrane achieved Coulombic efficiencies (CE) of 53.4% in MFCs and 75.2% in MECs, while the QPPO membrane showed CEs of 58.4% and 56.0%, respectively. Hydrogen recovery efficiencies in MECs were 23.4% for SPPO and 29.2% for QPPO. Compared to commercial membranes, the fabricated membranes exhibited competitive performance in real systems, suggesting the potential for low-cost, high-efficiency membrane development.

Keywords: *Ion Exchange Membrane, Water Treatment, Poly(2,6-dimethyl-1,4-phenylene oxide), Microbial Fuel Cell (MFC), Microbial Electrolysis Cell(MEC)*

Paper ID: P035

MFI Zeolite Membrane Reactor for Enhanced and Stable Para-Xylene Production from Transalkylation of Toluene with 1, 2, 4-Trimethylbenzene

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ABSTRACT

Transalkylation of toluene (TL) with 1, 2, 4-trimethylbenzene (1, 2, 4-TMB) is a significant reaction to produce high-value para-xylene (PX). It is difficult to achieve good as well as stable PX production in the conventional fixed-bed reactor (FBR) because of simultaneous side reactions and coking formation. A PX-selective MFI zeolite membrane was synthesized by the two-stage varing-temperature method and used to develop a membrane reactor (MR) for the transalkylation reaction intensification. The PX selectivity and yield was obviously enhanced in the MR compared to the PBR due to the selective removal of PX through the membrane. When the reaction temperature, WHSV and helium sweep gas flow rate were 350°C, 0.6 h^{-1} and 45 ml/min, the PX selectivity and yield of PX were 17%, 9.1% in MR while those were 8.3% and 7.5% in PBR. Moreover, the PX yield in MR was more stable than that in PBR. The TG and XPS analysis results also confirmed that the amount of coking deposition in catalysts was less in MR than in PBR.

Keywords: *Tansalkylation; Toluene, Para-Xylene, Membrane Reactor, MFI Zeolite membrane*

Paper ID: P037

Fabrication and Performance Enhancement of Pd–Ru Hollow Fiber Membranes Supported on γ-Al_2O_3 Modified α-Al_2O_3 for High-Temperature Hydrogen Separation

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ABSTRACT

In this study, α-Al_2O_3 hollow fiber membrane (HFM) supports were coated with a γ-Al_2O_3 layer, and Pd and Pd-Ru hydrogen separation membranes were fabricated via electroless plating. The γ-Al_2O_3 coating effectively reduced the surface roughness and controlled the pore structure of the HFM, providing an optimized substrate for subsequent metal deposition. Pd and Pd-Ru alloy membranes were successfully deposited onto the coated supports, and their microstructures and gas permeation properties were systematically evaluated. Single hydrogen permeation tests conducted at 450°C revealed that the Pd-Ru membrane exhibited approximately 1.8 times higher hydrogen flux compared to the Pd membrane, attributed to lattice distortion induced by Ru addition and enhanced hydrogen solubility and diffusivity. In mixed gas permeation experiments using a H_2:N_2 = 3:1 feed ratio, the Pd-Ru membrane maintained a high hydrogen selectivity with α values exceeding 1600 across various feed flow rates. Although increasing the feed flow rate resulted in higher hydrogen permeance and a slight increase in permeate hydrogen concentration due to reduced concentration polarization and nitrogen permeation, the hydrogen recovery decreased, leading to a gradual decline in selectivity. These results demonstrate that the combined strategy of γ-Al_2O_3 surface modification and Pd-Ru alloying significantly improves the hydrogen permeation performance and selectivity of hollow fiber membrane-based systems. The Pd-Ru membranes developed in this study show strong potential for application in high-temperature hydrogen production and purification processes, such as ammonia decomposition.

Keywords: *Ceramic Substrate, Electroless Plating, Pd alloy, Hydrogen Purification, Hydrogen Membranes*

Paper ID: P038

Fabrication and Performance Evaluation of P84 Polyimide Hollow Fiber Membranes for Organic Solvent Nanofiltration

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ABSTRACT

This study presents the fabrication and systematic optimization of single-layer polyimide (P84®) hollow fiber membranes for organic solvent nanofiltration (OSN) via the phase inversion technique. Critical spinning parameters-including polymer content, bore liquid composition, dope and bore flow rates, and air gap-were systematically varied to assess their impact on membrane morphology and filtration performance. Field emission scanning electron microscopy (FESEM) confirmed that the optimized membranes exhibited a defect-free, integrally skinned asymmetric (ISA) structure with a dense selective layer, which is essential for achieving high selectivity and mechanical robustness. In ethanol-based OSN performance tests, the P84 hollow fiber membranes achieved Orange G dye (452.37 g/mol) rejection rates of 85% and a permeance of 10 $L\cdot m^{-2}\cdot h^{-1}\cdot bar^{-1}$ indicating efficient solvent utilization and strong potential for industrial process integration. These findings underscore the importance of precise control over spinning parameters to tailor membrane structure and optimize performance in organic solvent systems. The combination of high dye rejection, excellent permeance, and robust mechanical properties positions these P84-based hollow fiber membranes as promising candidates for advanced OSN applications, such as solvent recovery, dye purification, and pharmaceutical processing, and provides valuable insights into the design and optimization of polyimide hollow fiber membranes for efficient and sustainable organic solvent nanofiltration.

Keywords: *Polyimide, Hollow Fiber Membrane, Organic Solvent Nanofiltration(OSN), Phase Inversion, Integrally Skin Asymmetric(ISA)*

Paper ID: P039

Theoretical Evaluation of Li Ion Conductivity in Single Ion Conductive Polymers

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ABSTRACT

Polymer electrolyte is a key material for solid-state battery which has the advantage of easy interface with cathodes and anodes and low manufacturing cost. [1]. Among them, single ion-conducting polymers (SICPE) are promising battery materials that exhibit high cation transfusion rates. Computational chemistry, which allows microscopic analysis of ionic conduction mechanisms, is an effective way to explore new materials. One of the computational methods is the molecular dynamics (MD) method, which has advantages such as theoretical screening, but conventional methods have not evaluated the electric field dependence. In this study, the ionic conductivity was estimated by simulating ion diffusion enhanced by the non-equilibrium MD method with an external electric field to evaluate the electric field dependence of ion diffusion. As a computational model, a unit cell was constructed with 11 different SICPE polymer structures as a single pentameric chain. In addition, a bulk model of the electrolyte was created by NPT ensemble MD simulations at 298 K. Ion diffusion was obtained by non-equilibrium MD simulation with an electric field applied in one direction. When the electric field strength was varied from 0.1 to 0.4 V/Å, the ionic conductivity increased in proportion to the electric field strength. By extrapolating the electric field strength to 0, the dependence of ion diffusion on the electric field during actual battery use was evaluated. The ionic conductivity calculated at this time was estimated within an error range of 10 times the experimental value for several polymers. At an electric field strength of 0.3 V/Å, the displacement of Li was temporarily stagnant, greatly displaced, and then stagnant again, indicating that the behaviour of the hopping mechanism is reproduced. This study shows that NEMD allows us to estimate an ionic conductivity in various SICPE with considering the effect of the electric field dependence of the actual battery.

Keywords: *Molecular Dynamics, All-Solid-State Battery, Polymer Electrolyte*

Paper ID: P040

Black TiO_2-Coated Hollow Fiber Membranes for Efficient Photocatalytic Removal of Ammonia Gas

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ABSTRACT

Improving indoor air quality remains a pressing public health challenge, particularly due to the limited efficiency of current photocatalytic membranes under visible light. In this study, we propose an innovative solution by incorporating nitrogen-doped black TiO_2 (BT550) onto α-Al_2O_3 hollow fiber membranes to enhance photocatalytic performance under visible light conditions. Nitrogen doping induced key structural modifications, such as the formation of oxygen vacancies and Ti^{3+} species, which effectively broadened the visible light absorption range and improved charge separation efficiency. These modifications enabled the BT550 membrane, prepared by calcination at 550 °C, to exhibit markedly superior ammonia removal efficiency compared to conventional TiO_2 membranes. In particular, the BT550 membrane (BT550M) demonstrated significantly enhanced photocatalytic performance compared to the air-calcined TiO_2 membrane at the same temperature (T550M). Under optimal conditions and at a flow rate of 10 sccm, BT550M achieved ammonia removal efficiencies of up to 97.0% under UV light and 82.8% under visible light. Furthermore, long-term stability tests confirmed the durability of BT550M, with sustained removal efficiencies ranging from 95.6% to 97.1% under UV and from 81.3% to 83.1% under visible light over a continuous six-day operation. These results underscore the practical potential of nitrogen-doped black TiO_2 membranes—particularly BT550M—as a highly effective and durable solution for continuous indoor air purification, especially in the removal of toxic ammonia gases.

Keywords: *Black TiO_2, Nitrogen Doping, Photocatalytic Membrane, Ammonia Removal, Visible Light Activation.*

Paper ID: P041

Optimization of NiHCF-based Mixed Matrix Membranes for CO2 Separation: Structural, Adsorption, and Feature Importance Analysis via Machine Learning

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ABSTRACT

Achieving carbon neutrality requires the selective separation and removal of carbon dioxide from various mixed gas streams, including exhaust gases, natural gas. Membrane technology has been increasingly recognized for its advantages, such as low energy consumption and cost-effectiveness, compared to conventional separation methods including distillation, cryogenic processes and adsorption. However, most polymer-based membranes have the drawback of a trade-off between performance and efficiency. To overcome this, many studies have focused on mixed matrix membranes, where inorganic and organic fillers are added to improve the properties of the polymer. Additives with excellent selective adsorption properties for carbon dioxide, such as zeolites and MOFs, have attracted considerable attention. Among them, NiHCF, a Prussian Blue Analogue (PBA), is based on an inorganic crystalline structure, rather than a MOF framework, and has garnered attention as a promising material for commercialization due to its excellent synthesis ease, low manufacturing cost, and good adsorption performance. In this study, we evaluated the structural and adsorption characteristics of NiHCF synthesized under various conditions and applied it to polymer-based mixed matrix membranes for carbon dioxide separation performance analysis. Additionally, a Random Forest model was used to train the entire dataset, after which the importance of each synthesis condition factor was assessed. Based on this, optimization conditions were derived by focusing on the most important factors, and the optimal synthesis conditions were proposed.

Keywords: *Gas Separation Membranes, Prussian Blue Analogues(PBAS), Mixed Matrix Membranes(MMMS), Carbon Dioxide Separation, Machine Learning-Based Optimization*

Paper ID: P042

Removal of Arsenic (III) Ions Using Carboxymethyl Cellulose-Enhanced Ultrafiltration as Bio-sorbent in Comparisons to FAST Simulation Study

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ABSTRACT

Arsenic contamination in wastewater is a major environmental concern due to its toxicity and persistence. Conventional treatment methods often generate excessive sludge and require high chemical addition. This study explores the use of carboxymethyl cellulose (CMC) as a bio-sorbent in an ultrafiltration system to remove arsenic (III) ions which can reduces sludge production. CMC act as a biosorbent facilitates the complexation of arsenic ions into macromolecular structures, which are effectively retained on a polysulfone (PSf) membrane surface. The optimization of key operating parameter, including pH, polymer concentration, and arsenic feed concentration was using Response Surface Methodology (RSM) with a Box–Behnken design. The results demonstrate that under optimal conditions pH 2, CMC concentration 5 mg/L, and arsenic concentration 50 mg/L, an arsenic removal efficiency of up to 90.41% was achieved. Scanning Electron Microscopy (SEM) analysis of the PSf membrane post-filtration confirmed the adsorption of arsenic onto the CMC layer. Thus, a comparative analysis was performed using the Fixed-bed Adsorption Simulation Tool (FAST) to evaluate the influence of contact time, initial ion concentration, and adsorbent dosage, further supporting the experimental data. This study highlights the potential of unmodified CMC as an effective, low-cost bio-sorbent for As(III) removal in PEUF systems.

Keywords: *Arsenic, Carboxymethyl Cellulose, Adsorption, Bio-Sorbent, Simulation Study, Wastewater*

Paper ID: P043

Interface Reconstruction of Polyamide Nanolayers Enabled by Bidentate Ammonium Modification for Precise Li^+/Mg^{2+} Separation

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ABSTRACT

To address the growing demand for lithium extraction from salt lake brines and overcome the limitations of conventional nanofiltration (NF) membranes with low lithium permeability, we report a novel and practical post-modification strategy for fabricating high-performance NF membranes. This method involves non-aqueous solvent-induced swelling and rearrangement of the polyamide (PA) layer, followed by deep grafting of a newly designed bidentate quaternary ammonium salts - 1,4-bis(3-aminopropyl)pyrazine-1,4-diium (QP). The modification facilitates the formation of a nearly neutral surface charge and a uniform pore structure in the separation layer, significantly enhancing membrane performance. As a result, the modified membrane exhibits a twofold increase in water flux compared to the pristine PA membrane, while maintaining excellent magnesium-lithium selectivity. Importantly, it achieves a high magnesium-lithium separation factor of 50, offering a promising and scalable solution for efficient lithium recovery from complex brine systems.

Keywords: *Li^+/Mg^{2+} Separation, Nanofiltration, Quaternary Ammonium Salt*

Paper ID: P044

Self-Standing Covalent Organic Framework Membranes as a Protective Layer for Membrane Distillation

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ABSTRACT

Membrane distillation (MD) is a promising technology for desalination and wastewater treatment, but its application is often hindered by membrane fouling, wetting and scaling. To improve MD membrane durability, many methods (e. g. Superhydrophobic or hydrophilic modification) have been studied, but few membrane achieved simultaneously resistance to fouling, wetting and scalling. Meanwhile, improving the water vapor flux and cyclical stability remain challenges for MD application. In this work, a sulfonic acid-functionalized covalent organic frameworks (COFs) was fabricated and applied as a protective layer on commercial hydrophobic polyvinylidene difluoride (PVDF) membranes for membrane distillation (MD). Benefiting from the well-defined, ordered channels of the COF structure, the COF-PVDF membrane retains the vapor flux of the original hydrophobic support. The dense COF layer significantly enhances the liquid entry pressure (LEP), achieving fivefold increase in wetting resistance compared to pristine PVDF membranes. Moreover, the high density of sulfonic acid groups of COF layer imparts membrane excellent anti-scaling performance, enabling continuous MD process for over 24 h, which is threefold increase than that of pristine PVDF membrane. Due to the hydrophilicity of COF layer, the membrane showed an enhanced anti-fouling performance remaining 24 h MD process compared with the 4 h MD process of pristine PVDF. Furthermore, the COF-PVDF membrane maintained stable MD process for 3 cycles of operation (24 h for a cycle) with low surface tension feed solution.

Keywords: *Membrane Distillation, Covalent Organic Framework, Wetting, Fouling, Scalling*

Paper ID: P045

Facile Strategy to Improve Li^+/Mg^{2+} Selectivity in Nanofiltration Membranes via Amine-Polymer Additive Engineering

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ABSTRACT

Direct lithium extraction (DLE) from brine offers a more efficient and environmentally friendly alternative to traditional evaporation-based methods, yet effective Li^+/Mg^{2+} separation remains a key challenge due to the high Mg^{2+} concentration in natural salt lakes. Nanofiltration (NF) membranes, particularly those based on polyamide (PA) layers formed via interfacial polymerization (IP), are promising for lithium enrichment owing to their ability to selectively reject multivalent cations. However, conventional NF membranes prepared using piperazine (PIP) suffer from low Li^+/Mg^{2+} selectivity due to excessive negative surface charge and a trade-off between membrane permeance and selectivity. In this study, we report the incorporation of polyallylamine (PAA), an amine-rich polymer, into the aqueous PIP solution as an additive during the IP process to enhance lithium separation performance. PAA not only introduces additional positive charges into the PA network, improving Mg^{2+} rejection via the Donnan effect, but also alters monomer diffusion, leading to a crumpled PA morphology that contributes to water permeance. The resulting optimal membrane exhibited a high water permeance of 12.1 L m^{-2} h^{-1} bar^{-1}, a low LiCl rejection of 12.6 %, and significantly enhanced the rejection of $MgCl_2$ from 18.8 % to 94.7 %. Furthermore, a two-stage NF process using the optimized membrane effectively concentrated lithium from simulated salt lake brine, highlighting the potential of this strategy for practical DLE applications.

Keywords: A*mine-Polymer Additive Engineering, Interfacial Polymerization, Nanofiltration Membrane, Lithium Extraction.*

Paper ID: P046

Evaluation of CO_2 Separation Property of a Module with Facilitated Transport Hollow Fiber Membranes

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ABSTRACT

Facilitated transport membranes (FTMs) have high CO2 permeance and CO2/N2 permselectivity under optimal conditions. However, CO2 permeance of FTMs depends on CO2 partial pressure and humidity. Predicting performance of FTMs modules is difficult because feed gas composition continuously changes in module due to selective permeation of CO2 and water vapor. In this study, we developed a performance prediction model of FTM modules by considering changes in feed gas composition. We evaluated FTM's CO_2 and water vapor permeances using feed gases with various gas compositions. From the data, we developed an empirical equation to estimate CO_2 and water vapor permeances of FTMs under wide CO_2 partial pressure and humidity. The equation was combined with gas-transport equation to calculate each gas component permeation in a small section of the module. The mass-transport calculation was performed from inlet to outlet of the module. In each calculation, CO_2 and water vapor permeances were estimated from the empirical equation and used for the mass-transfer calculation in each section. By the calculation, molar flow rate of each gas component including that at the outlet was determined. We fabricated FTM modules with various packing densities of hollow-fiber-based FTMs and evaluated the performance by sweep and vacuum methods. CO_2 mole fraction of permeated gas exhausted from the module was compared with the estimated value by our established module-performance evaluation model. As a result, when packing density of the FTMs was low, estimated results agreed with experimental results. Conversely, when the packing density was high, CO_2 mole fraction in the exhausted gas was smaller than the estimated value. This would be due to drift gas flow in permeated side. Based on these results, it is expected that the developed FTM-module-performance estimation model could provide a design guideline of the module structure for optimizing the performance of FTM modules.

Keywords: CO_2 *Separation, Facilitated Transport, Hollow Fiber, Membrane Module, Mathematical Model*

Paper ID: P047

Polyethylenimine-Based Polymaide Membranes for Efficient Organic Solvent Reverse Osmosis

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ABSTRACT

Organic solvent reverse osmosis (OSRO) has gained extensive attention for Angstrom-scale separation of solvent mixtures without phase change using. However, traditional polyamide (PA) RO membranes face limitations of inefficient perm-selectivity due to depth heterogeneity of the PA layer, e.g., non-uniform pore size distribution. Here, it is demonstrated that the nanoscale homogeneity of PA thin film composite membranes can be achieved via quasi-saturated monolayer surfactant-assembly regulated interfacial polymerization (QSARIP). The self-assembly of polyethyleneimine (PEI) and sodium dodecyl sulfate (SDS) via hydrogen bonding and electrostatic interactions enhances interfacial diffusion and promotes uniform PEI monomer distribution at the water/n-hexane interface during interfacial polymerization, yielding PA layers with more uniform nanopores than those formed via conventional IP process. Concurrently, the self-assembled network competitively suppresses SDS micellization, thereby increasing the SDS molecular requirement for critical monolayer formation at the interface. Various characterization techniques elucidate in detail the underlying molecular mechanism by which the monolayer surfactant at interface confines and regulates the distribution and diffusion of amine monomers and interfacial properties of the water-oil interface and thus tunes the nanoscale homogeneity of the polyamide layer. The resulting PA membranes by QSARIP, featuring thin, smooth, dense, and structurally uniform selective layers, exhibit a ~31.7% improvement in toluene rejection and enhanced stability under high-pressure filtration, enabling highly efficient OSRO. This work offers valuable insights into the structural tunability of polyamide membranes toward precision separation of solvent mixtures.

Keywords: *Polyamide Membrane, Polyethyleneimine, Surfactant Self-Assembly, Organic Solvent Reverse Osmosis*

Paper ID: P048

Re-Entrant Structural Design on Hydrophobic Membranes to Enhance Anti-Wetting Performance in Membrane Distillation

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ABSTRACT

Membrane distillation (MD) has emerged as a promising thermally driven separation technology for seawater desalination and wastewater treatment. However, its practical application remains constrained by membrane wetting and scaling, particularly under the influence of low surface tension contaminants and inorganic scaling. In this study, we introduce a straightforward and effective one-step dip-coating method to modify hierarchical polyvinylidene fluoride (PVDF) membranes with the low surface energy fluoropolymer AF2400. A spontaneous interface phase separation phenomenon induced by alcohol pretreatment facilitates the formation of a re-entrant surface structure during the coating process. This strategy enables the precise construction of a dual-scale surface structure, retaining the original hierarchical roughness while introducing a secondary re-entrant structure. The modified membranes exhibited enhanced resistance to both wetting and scaling. The synergistic effect of hierarchical morphology and engineered surface chemistry contributed to improved membrane robustness and long-term performance. These results highlight a scalable and effective route to fabricating advanced MD membranes with robust anti-wetting and anti-fouling performance.

Keywords: *Secondary Structure, Re-Entrant Layer; Wetting Resistance; Scaling Resistance; Membrane Distillation*

Paper ID: P049

Forward Osmosis Process for Organic/SO42- Selective Concentration in Sewage

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ABSTRACT

In recent years, methane fermentation has been attempted for effective utilization of sewage. Methane fermentation is a process to produce methane from organics by microorganisms. In general, the concentration of organics in sewage is very low (TOC is 50 mg/L), and the organics in sewage needs to be concentrated to make methane fermentation more efficient (TOC is more than 1500 mg/L). Therefore, the organics must be concentrated more than 30 times. However, the usual concentration method consumes large amounts of energy, and such a high concentration of SO42- ions in 30 times-concentrated sewage inhibits methane fermentation [1]. Therefore, we focused on the forward osmosis (FO) process. FO process is an energy-saving process, and it has been reported that target substances can be selectively concentrated by controlling the pore size of the membrane [2]. However, conventional nanofiltration membranes with “negatively charged surfaces” repel SO42- ions, and methane fermentation of sewage concentrated by negatively charged membranes is inhibited by SO42- ions. In this study, we focused on nanofiltration membranes with “positively charged surfaces” to permeate SO42- ions. The nanofiltration membrane with a positively charged surface was fabricated by an interfacial polymerization method. The SO42- ion rejection of the conventional nanofiltration membrane with a negative surface (PIP-TMC) was 95%, whereas that of the nanofiltration membrane with a positive surface (PEI-TMC) was reduced to 40%. These results indicate that nanofiltration membranes with positively charged surfaces are effective in concentrating sewage for methane fermentation. Furthermore, sewage was concentrated by the FO process using these membranes. The results showed that the SO42-recovery ratio of PEI-TMC membrane was 0.83 while that of PIP-TMC membrane was 0.93.

Keywords: *Forward Osmosis, Nanofiltration, Methane Fermentation, Selective Concentration*

Paper ID: P050

Effect of the Support of Silicalite-1 Membrane on Ethanol/Water Separation Performance

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ABSTRACT

The demand of bioethanol is rapidly growing. The substantial energy consumption in azeotropic distillation during purification of bioethanol is a significant issue. Membrane separation has attracted attention as an alternative technology to azeotropic distillation. This study focuses on zeolite as membrane material because of its high thermal, mechanical, and chemical resistances. Since ethanol has a lower latent heat of vaporization than that of water, use Ethanol-selective membranes in pervaporation is expected to reduce energy consumption. Therefore, silicalite-1 membrane with ethanol-selectivity based on the hydrophobicity have been widely studied. However, its separation performance remain insufficient. In this study, two types of supports were used for membrane synthesis, α-Al_2O_3 and SiC, support. Silicalite-1 membranes were synthesized on these supports by a secondary growth method using seed crystals. Ethanol/water separation performance was evaluated by pervaporation under conditions of ethanol/water = 10/90 wt% at 323 K. The ethanol flux and separation factor on silicalite-1 membrane on the α-Al_2O_3 support were 24.7×10^{-4} mol m^{-2} s^{-1} and 16.8, respectively. The membrane prepared on SiC support showed a flux of 35.9×10^{-4} mol m^{-2} s^{-1} with a separation factor of 68.0. As a result, the ethanol/water separation performance was notably enhabced on the SiC support. In comparison to the α-Al_2O_3 support, the SiC support has a small thermal expansion coefficient, which is predicted to prevent crack formation during calcination. In addition, the absence of Al is thought to expected to impede Al dissolution from the support during membrane synthesis. The factors mentioned above may contribute to the high separation performance of silicalite-1 membrane on SiC support.

Keywords: *Zeolite, Membrane, Pervaporation, Ethanol/Water Separation, SiC Support*

Paper ID: P051

Solar Driven MXene/MoS_2 Photothermal Membrane Distillation for Seawater Desalination

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ABSTRACT

Seawater desalination is becoming more important as freshwater resources are strained by climate change, population growth, and industrial use. Photothermal membrane distillation (MD) is a promising method that uses solar energy to purify water, offering a cleaner and more energy-efficient alternative to traditional methods. However, current membranes often have low vapor flow, poor light absorption, and weak long-term stability. To improve this, MXene-MoS_2/PVDF hollow fiber membranes were created by coating PVDF fibers with MXene, MoS_2, or a mix of both. This combines the benefits of MXene's strong heat response with MoS_2's good light absorption. The membranes were tested using XRD, BET, FTIR, and particle size analysis, confirming they had a porous structure, large surface area, and strong light-absorbing properties. When tested with saltwater, the MoS_2 membrane showed the highest flux at 15 kg/m²h, while the MXene-MoS_2 composite reached 9 kg/m²h. At a higher feed temperature of 80°C, the composite membrane performed much better, reaching 36.5 kg/m²h with over 99.9% salt rejection. These results show that MXene-MoS_2 membranes have strong potential for solar-powered desalination, especially at high temperatures. Further work is needed to improve the material design and scale up production for long-term, practical use in clean water technologies.

Keywords: *Photothermal, Membrane Distillation, MXene, MoS_2, Desalination*

Paper ID: P052

Molecular Dynamics Study on the Transport Mechanisms of Organic Solvent Mixtures in Ceramic Nanopores

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ABSTRACT

In the chemical industries, distillation remains the primary method for separation and purification of many chemicals such as organic solvents. However, due to the high energy cost, membrane separation has garnered attention as a more energy-efficient alternative technology [1]. Particularly, inorganic membranes generally outperform organic membranes in terms of solvent resistance, pressure resistance, and the thermal stability etc. making them promise for organic solvent separation. Nonetheless, reports suggest that organic solvents exhibit a peculiar permeation phenomenon in the nanopores of inorganic membranes, deviating from the Hagen-Poiseuille rule [2]. Additionally, permeability changes between single-component and mixed-component systems have been observed [3]. Despite these findings, a quantitative evaluation of these permeation phenomena in porous inorganic membranes is lacking. Therefore, the objective for this study is to conduct nano-scale simulations using porous inorganic virtual membranes for organic solvent mixtures, aiming to elucidate the permeation mechanisms. BIOVIA's Materials Studio® served as the computational software for this experiment. Methanol, toluene, and hexane were chosen as organic solvents. TiO2 virtual membranes with pores of 1.2, 1.9, 2.6 nm in diameter with the modification of -OH groups in surface were fabricated. A total of 12 different models, including single-component and two-component systems, were created using the universal force field. Diffusion simulations were conducted to investigate the behavior of solvent in nanopore. As a result, because of the geometric condition of the molecule and interaction between solvent and surface of the membrane, it was observed that the solvent had a limited diffusivity in nanopore and the viscosity for solvent increased from the bulk value. Also, from toluene/methanol mixture system simulation, it was observed that the diffusivity increase of toluene and diffusivity decrease of methanol. This was because the relative difference of the affinity to the pore surface, these two solvents were separated into two phases in pore.

Keywords: MD *Simulation, Ceramic Membrane, Organic Solvent Nanofiltration*

Paper ID: P053

Gas Permeation Characteristics and Hydrothermal Stability of Microporous TiO_2-Al_2O_3-double Chelating Ligand (bi-OCL) Composite Membranes for Hydrogen Separation

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ABSTRACT

SiO_2 membranes are gas separation membranes with high permeance and selectivity, but their performance degrades under hydrothermal treatment conditions. Therefore, we focused on TiO_2 which has excellent stability, and Al_2O_3 which is used as a support material. However, both materials are crystalline materials, and it is difficult to control the pore size effective for gas separation. In a previous study, it was reported that the addition of an organic chelating ligand (OCL) to a TiO_2 and SiO_2 composite material can suppress crystallization of TiO_2 while maintaining high permeance and selectivity. In this study, we investigated the amount of acetylacetone (ACA) which coordinates to TiO_2, and diethanolamine (DEA) which contributes to pore control, to fabricate TiO_2-Al_2O_3-OCL composite membrane with high H_2 permeance and high H_2/CH_4 selectivity. Polymer sols were prepared using Ti alkoxide, Al alkoxide, ACA, and DEA by the sol-gel method, and the amount added was controlled by the molar ratio of OCL to metal alkoxide. After coating the prepared sol, the membrane was formed by firing at 300°C under nitrogen atmosphere. The membrane performance was evaluated by a pure gas permeation test, and hydrothermal stability was confirmed by comparing the performance before and after low-humidity treatment. As a result, for the Ti:Al:ACA:DEA = 1:1:2:2 membrane, the H_2 permeance was slightly low at 1.5×10^{-7} mol/m²-s-Pa, but the H_2/CH_4 selectivity was improved. This is thought to be due to the formation of a TiO_2-Al_2O_3 network effective for gas separation due to the increase in ACA addition, and furthermore, the grain boundaries were occluded by DEA addition. XRD measurements of Ti:Al:ACA:DEA = 1:1:2:2 gel powder confirmed that the amorphous structure was maintained before and after hydrothermal treatment, suggesting the hydrothermal stability of the membrane.

Keywords: *Gas Membrane , Sol-Gel Method, OCL , Hydrothermal Stability*

Paper ID: P054

Modeling of Rejection of Neutral Organic Compound in RO

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ABSTRACT

Reverse Osmosis (RO) membranes are widely used for seawater purification due to their high salt rejection. However, the rejection of neutral organic compounds(NOC) in RO is generally insufficient, and the physicochemical mechanisms of the rejection are still not fully understood. The solute's dissolved state in such membranes could be analyzed using non-equilibrium molecular dynamics. It has been pointed out that changes in the number of hydrogen bonds between solute and solvent during permeation affect the membrane's rejection performance. However, the detail permeation mechanism of the NOC in RO remain unclear. Therefore, this study uses molecular dynamics (MD) simulations to investigate the NOC penetrating the interior of the RO membrane. The relationship between solute stability and rejection in the RO membrane is discussed using MD simulations. As an aromatic polyamide, m-phenylenediamine and trimesoyl chloride were used as a model. Hydrated membrane model consisting of 32 chains of MPD16-TMC11, water, and some solute molecules (NaCl, ethanol, methanol, urea,1-propanol, 2-propanol) were modeled. The water content in the membrane models was varied from 10 to 30 wt%. Each membrane structure was stabilized using MD until the density became constant. The energy stability of the solutes in RO was discussed using the free energy of solute(*E*SFm). *E*SFm was calculated using the Bennett Acceptance Ratio (BAR) method [1]. With the increase in water content, *E*SFm showed an increasing trend for almost solutes, but only NaCl exhibited a decreasing trend. This suggests a correlation between the rejection and *E*SFm. Furthermore, when comparing the *E*SFw in aqueous solution, it was found that the solutes are relatively more stable in aqueous solution. By comparing the stability in the membrane and in aqueous solution, it is shown that there is a good correlation between the free energy and experimentally reported rejection.

Keywords: *Reverse Osmosis Membranes, Molecular Dynamics, Polyamide*

Paper ID: P055

Fabrication of ZnCoFe LDH Incorporated PES Hollow Fiber Ultrafiltration Membrane for the Separation of Agrochemicals and Textile Dyes from Wastewater

ABSTRACT

The contamination of water bodies with agrochemicals and textile dyes poses a significant challenge to environmental integrity. In this work, ZnCoFe layered double hydroxide (LDH) was synthesized by co-precipitation method with a molar ratio of 2:2:1 of nitrates of Zn, Co, and Fe metals. For the first time, ZnCoFe LDH incorporated hollow fiber membranes were fabricated and employed for the separation of hazardous agrochemicals and dyes from waste water. Incorporation of hydrophilic ZnCoFe LDH into the polyether sulfone (PES) membranes improved its pure water flux from 91.03 $Lm^{-2}h^{-1}$ to 143.25 $Lm^{-2}h^{-1}$. The MLZ-2 membrane revealed a good antifouling nature with flux recovery ratio of 64.18 %. The optimized membrane (MLZ-2) exhibited 90.9 % and 47.1 % rejection of chlorpyrifos and 2,4-dichlorophenoxy acetic acid respectively while neat membrane showed 78.8 % and 22.7 %. In case of dyes, the MLZ-2 showed rejection of 99.1 % for Crystal Violet and 83.2 % for Reactive Orange 16, whereas the values for pristine membrane were 79.8 % and 74.9 % respectively. Therefore, the ZnCoFe LDH-PES hollow fiber membranes can potentially be used for removal of agrochemicals and textile dyes from wastewater.

Paper ID: P056

Impact of Trace Light Hydrocarbons in CO_2/CH_4 Mixtures through Zoelite Membrane

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ABSTRACT

Eight-membered ring zeolites are expected to exhibit high CO_2 selectivity in CO_2/CH_4 mixtures. However, trace amounts of light hydrocarbons present in natural gas can degrade CO_2 separation performance [1]. Therefore, understanding the mechanism by which light hydrocarbons hinder CO_2 permeation is essential. However, conventional molecular dynamics (MD) methods have difficulty simulating the permeation of gas mixtures with large differences in diffusion coefficients, such as CO_2 and light hydrocarbons. In this study, the Dynamic Monte Carlo (DyMC) method, which allows efficient time evolution calculations, was used to simulate permeation of mixture gas in CHA membranes. A membrane model was constructed based on the pure silica CHA-type zeolite crystal structure, and light hydrocarbons were adsorbed using Grand Canonical Monte Carlo simulations. The adsorption-dependent self-diffusion coefficients were then calculated using MD simulations. Site information from the crystal structure was used to construct a lattice model representing the porous structure, and hopping constants (k) for gas molecules moving between adsorption sites were determined for DyMC calculations. DyMC simulations were conducted for two different gas mixture systems: a binary CO_2/CH_4 mixture (1:1) and a ternary mixture with 1%-C_3H_8 added. The results showed that the addition of C_3H_8 reduced the permeation of CO_2 and CH_4 by 78.8% and 78.5%, respectively. Additionally, during the permeation simulation, the number of gas molecules within the membrane decreased for CO_2 in proportion to the number of C_3H_8 molecules present, whereas CH_4 remained unaffected by C_3H_8. The CO_2 separation factor decreased by 1% in the presence of C_3H_8 from 24.8 of CO_2/CH_4 binary system. The reason why C_3H_8 affected CO_2 permeation is that CO_2 is most strongly adsorbed species in the zeolite's crystalline, and thus competition of C_3H_8 adsorption decreases the amount of CO_2 adsorption, resalting in the decrease of CO_2 permeation.

Keywords: *CO_2 Separation, Zeolite Membrane, Molecular Dynamics, Dynamic Monte Carlo*

Paper ID: P057

Interfacial Polymerized Covalent Organic Frameworks-Polyamide Composite Membranes for Pervaporation Dehydration of Biobutanol

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ABSTRACT

Pervaporation has a potential to combine with or substitute for the conventional separation processes for the dehydration and purification of biobutanol because of its cost saving, energy saving and environmental protection. In this study, a series of covalent organic framework (COF)-polyamide (PA) composite membranes were fabricated via in-situ interfacial polymerization by p-phenylenediamine (Pa) and 2,4,6-trihydroxybenzene-1,3,5-tricarbaldehyde (Tp) coupled with acyl chloride monomers. These composite membranes were applied for the pervaporation separation of n-butanol aqueous solutions. Attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy to analyze the chemical structure of membranes, field emission scanning electron microscopy (FE-SEM) to observe the surface and cross-sectional morphologies of membrane, atomic force microscopy (AFM) to measure the membrane surface roughness, and water contact angle (WCA) measurements to evaluate the hydrophilicity of membrane. It is expected that directly connecting COF to the interfacial polymerized polyamide backbone can not only promote their compatibility and anti-swelling but also increase the hydrophilicity of selective layer, resulting in an improvement in the operation stability and separation performance of composite membrane.

Keywords: *Covalent Organic Framework, Polyamide, Composite Membrane, Interfacial Polymerization, Pervaporation*

Paper ID: P058

A Membrane-Based Immunosensor Enabling High Antifouling Properties and Sensitive Molecular Recognition

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ABSTRACT

The fouling of non-targeted biomolecules on sensing surfaces, which can cause a reduction in sensing performance, is a severe problem in immunosensing platforms. The incorporation of hydrophilic polymers on sensing surfaces is effective against antifouling. However, such an approach can reduce the density of the capture antibody, resulting in a decrease in sensitivity and signal output. Previously, we developed a membrane-based immunosensor that uses the submicron-scaled pores of track-etched porous membranes for molecular recognition [1]. This sensor achieved a high signal output through the accumulation of the capture antibody in the pores and utilizing analytes permeation. The potential of this sensor was demonstrated via the detection of the inflammatory marker interleukin-6 (IL-6) in a model buffer, and a limit of detection (LOD) of 4.5 pg/mL was obtained [2]. This sensor should be endowed with antifouling properties to inhibit fouling in practical diagnoses using biological samples, such as serum and saliva. The pores have a large surface area per space and can maintain high antibody density while introducing antifouling polymers. Thus, the potential to achieve both antifouling properties and high sensitivity exists.

Here, both high sensitivity and antifouling properties were achieved using a porous-membrane-based immunosensor. The ideal ratio of the receptor/antifouling moiety was estimated from numerical modeling. The high sensitivity and antifouling properties of the designed sensor were demonstrated via the detection test of interleukin-6 (IL-6). The proposed sensor exhibited excellent antifouling and high sensitivity with LOD of 4.8 and 1.2 pg/mL in artificial saliva and serum, respectively [3]. The study findings highlight the potential of membrane-based sensors for practical diagnoses.

Keywords: *Porous membrane, Immunosensor, Antifouling, Numerical modeling, Interleukin-6*

Paper ID: P059

Permselective Performance of ChA Membranes for Vapor Separation

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ABSTRACT

CHA-type zeolite has 8-membered ring and is used as membrane material for separation of water and gases. While, recently, H2O/CO2 separation by ZSM-5 membrane is reported for CCUS [1], its separation performance for H2O/CO2 should be further improved. In this study, permselective performance of CHA-type zeolite membranes for water vapor was evaluated. The relationships between vapor adsorption behavior and permselective performance were examined. SAPO-34 (CHA-type zeolite) membrane was synthesized on α-alumina tubular support by a secondary growth method. The performance of SAPO-34 membrane was evaluated by the separation tests for H2O/CO2 and H2O/H2 mixtures at 473 K, varying the H2O mole ratio from 0.1 to 0.9. In addition, the compactness of membrane was evaluated by H2O/isopropyl alcohol (IPA) separation test. H2O/IPA separation factor of SAPO-34 membrane was 170. Since the molecular size of IPA is larger than the size of micropores of SAPO-34 membranes, the SAPO-34 membrane has size exclusion ability based on a molecular sieving effect. In contrast, the membrane showed low selectivities of about 3 for H2O/CO2 and less than unity for H2O/H2 respectively. In hydrophilic zeolite membranes, it is expected that preferential adsorption of H2O molecules in the micropores narrows spaces and may inhibit the permeation of CO2 and H2. Our results suggested that H2O molecules were not preferentially adsorbed in the micropores, or even if H2O molecules are adsorbed, CO2 and H2 molecules permeation was not inhibited. Adsorption properties of SAPO-34 membranes for H2O, CO2, H2 should be studied to understand the relationships between vapor adsorption behavior and permeation separation performance of SAPO-34 membranes.

Keywords: SAPO-34 *Membrane, Vapor Separation*

Paper ID: P060

Molecular Simulations for Investigating Gas Adsorption and Diffusion in Metal-Organic Frameworks

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ABSTRACT

Amid escalating global concerns over climate change, carbon capture has emerged as a critical strategy for reducing greenhouse gas emissions. Metal–Organic Frameworks (MOFs), a class of crystalline porous materials composed of metal ions coordinated to organic ligands, have garnered significant attention due to their tunable pore structures, high surface areas, and chemical versatility, making them promising candidates for gas separation applications. This study focuses on the molecular simulation-based design of mixed-linker derivatives of MOF-303 to predict their potential performance in CO_2/N_2 separation. Monte Carlo (MC) and Molecular Dynamics (MD) simulations were utilized to evaluate the adsorption capacities and self-diffusion coefficients of CO_2 and N_2 within various framework configurations, from which gas separation selectivity was determined. Moreover, the effect of gas loading on diffusion behavior was systematically investigated, enabling the development of a predictive molecular-scale model for assessing the separation performance of different mixed-linker MOF-303 structures. The ultimate objective is to identify high-performance candidates exhibiting both high selectivity and permeability for CO_2/N_2 separation, contributing to the advancement of efficient carbon capture technologies.

Keywords: *Gas Separation, Molecular Simulation*

Paper ID: P062

Development of Fluorine-Free Anionic Polymer Electrolyte Membranes using Aromatic Hydrocarbon Polymers by Radiation-Induced Graft Polymerization and their Alkaline Resistance

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ABSTRACT

The development of polymer electrolyte membranes is indispensable for solid polymer fuel cells. To make a desired membrane, we have reported a promising radiation-induced graft polymerization (RGP) method in that it shows great advantages such as low-cost fabrication and imparting new functionality by graft polymers to commercially available substrate polymer films with excellent mechanical/thermal properties. Among various substrate polymers, poly (ether ether ketone) (PEEK) is regarded as one of the most promising hydrocarbon polymer for the long life-time operation requirement of fuel cells due to its excellent mechanical stability and high gas barrier property at high temperature. However, graft polymerization on PEEK substrate is rather difficult. We have extensively investigated irradiation and graft polymerization conditions in order to obtain PEEK-based polymer electrolyte membranes with well-balanced properties. In this work, we will report the synthesis and property of PEEK-based anion-exchange membrane (PEEK-AEMs), durability test in KOH solution, and the fuel cell performance with PEEK-AEM.

Keywords: *Radiation-Induced Graft Polymerization, Poly (Ether Ether Ketone), Anion-Exchange Membrane.*

Paper ID: P063

Bipolar Membranes Incorporating a Three-Dimensional Junction and ZSM-5 to Enhance Structural Stability and Water-Splitting Efficiency

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ABSTRACT

To suppress global warming caused by carbon dioxide in rapidly growing modern society that utilizes oil as main energy source, we have researched how to split water using a bipolar membrane (BPM). To utilize BPMs, it is necessary to address overpotential and structural instability that arise during the water dissociation process. ZSM-5 (Zeolite) was used to solve the overpotential, and a three-dimensional membrane (3D-BPM) was fabricated to solve the structural instability. The 3D- BPM is made of a cation exchange membrane, an anion exchange membrane, and a junction layer. The junction layer consists of entangled cation-exchange and anion-exchange nanofibers, both containing catalysts (ZSM-5). It was confirmed that the transmembrane voltage of 3D-1.33 (0.88 V) was about 14.6% lower than that of commercially available FBM (1.04 V) at U_{100}. In addition, a long-term stability test and a high current density test were conducted to confirm the structural stability. For the long-term stability test, the TMV of the FBM and the TMV of 3D-1.33 were checked by exposing the fabricated membrane to 100mA/cm^2 for 100h. The TMV increased by about 9% for FBM and 5.5% for 3D-1.33, indicating that a 3D-BPM is more stable than a 2D-BPM (FBM). In addition, the High current density test confirmed the TMV of U_{100} after exposure to 1000mA/cm^2 for 5h. While the TMV of FBM increased by 26.7%, the TMV of 3D-1.33 increased by 2.13%. Thus, the BPM was fabricated with structural stability while reducing overpotential. Lastly, the BMED process was tested for acid-base production for commercial use. The focus was on current efficiency and energy consumption. It was found that 3D-1.33 (92.5%, 6.54 kWh) and FBM (96.7%, 6.19 kWh) had comparable values.

Keywords: *Bipolar Membrane, Water Splitting, ZSM-5, Catalyst, 3D Junction*

Paper ID: P064

Methods for Fouling Mitigation in Membrane Distillation

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ABSTRACT

Membrane distillation (MD) is a thermal driven technology, which shows a great potential for desalination, water treatment and wastewater treatment. However, fouling is a complicated issue, which affects the overall performance of MD process. Membrane fouling is an intricate challenge and is associated with the accumulation of any superfluous material such as organic matter, particulate matter, microorganism on the membrane surface or inside the membrane's pores. The factors for fouling depend on the membrane properties, feed characteristics, foulant behavior, and operational parameters. This study outlined an inclusive analysis of MD membrane fouling subtypes, along with its attributed cleaning and controlling methods as well as characterization and monitoring techniques. It was recorded for inorganic fouling specifically induced by calcium carbonate ($CaCO_3$), can efficiently eradicate by rinsing direct contact membrane distillation (DCMD) module membrane with 2-5 wt% of hydrochloric acid (HCL) solution. Furthermore, fouling was considerably minimized for optimum conditions of minimum feed flow rate of 0.5 m/s and operating temperature below 60 to 70 ℃. The strong adhering property of silica can cause a huge decrement in permeate flux up to 60 to 70 %. In contrast, humic acid cause organic fouling, can easily removed by rinsing with 0.08 to 0.1 M of NaOH solution with clean water. It was concluded for operating condition 20 to 40 ℃ and the concentration up to 0.5 to 1% by weight and solution pH of 7.4 does not shows any fouling phenomena for bovine serum albumin (BSA). While MD membrane fouling remains a complex issue for practical world application, addressing the issues by implementing a contemporary method such as membrane surface modification, self-cleaning of membrane, antifouling coating, real-time fouling monitoring, feed pretreatment nanocomposite membrane fabrication. This study also curated efficacy of these methodologies enabling the appropriate selection of techniques refined for MD processes.

Keywords: *Membrane Fouling, Types of Fouling, Controlling and Monitoring Technology, Real-Time Fouling Monitoring.*

Paper ID: P065

Interfacial Polymerization of MPN/MOF-801-P Composite Polyamide Membranes on PES Flat Sheets for Water Treatment

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ABSTRACT

The development of high-performance water treatment membranes is essential for the efficient removal of organic contaminants, dyes, and pharmaceutical residues from industrial and municipal wastewater. In this study, polyethersulfone (PES) flat sheet membranes were coated with a metal-phenolic network (MPN), and MOF-801-P was incorporated at concentrations of 0.02, 0.04, 0.06, and 0.08 wt% during interfacial polymerization to fabricate composite polyamide membranes. MPD (m-phenylenediamine) and TMC (trimesoyl chloride) were used as aqueous and organic phase monomers, respectively, in the interfacial polymerization process. The structural and surface properties of the fabricated membranes were evaluated using scanning electron microscopy (SEM), contact angle measurement, and Fourier-transform infrared spectroscopy (FT-IR). The separation performance was evaluated using a series of dyes and pharmaceuticals with varying molecular sizes and charges, including Neutral Red, Methylene Blue, Tetracycline, and Rose Bengal. SEM images revealed changes in the pore structure and uniform formation of the polyamide selective layer upon MOF-801-P incorporation, Increasing the MOF-801-P content enhanced the pore structure and hydrophilicity of the polyamide selective layer, achieving optimal performance at 0.06 wt%. At this concentration, the membrane demonstrated water superior treatment capabilities, exhibiting over 96% rejection for all tested dyes spanning a wide range of molecular sizes (288–1018 Da).

Keywords: *Polyethersulfone(PES), Metal-Phenolic Network(MPN), MOF-801-P, Interfacial Polymerization, Water Treatment Membrane*

Paper ID: P066

Polyacrylonitrile Hollow Fiber Membranes: Synthesis Parameter Optimization for Post-Combustion CO2 Separation from Flue Gas

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ABSTRACT

CO2 separation is a key strategy for mitigating the impacts of climate change caused by greenhouse gas emissions. Efficient separation technologies are essential for the effective removal of CO2 from flue gases, enabling broader deployment in industrial applications. Membrane-based gas separation offers advantages over conventional methods due to its compactness, energy efficiency, and cost-effectiveness. Among these, polymeric membranes in hollow fiber configurations—currently at technology readiness levels (TRL) 6–7—are promising candidates for post-combustion CO2 capture from fossil fuel-based flue gases. As per the literature reports on this topic, their performance is often limited by the trade-off between permeability and selectivity, influenced by factors such as membrane material, structure, transmembrane pressure, and thickness. This study presents the synthesis and optimisation of scalable, high-performance polyacrylonitrile (PAN) hollow fiber membranes for CO2 separation. Scanning electron microscopy revealed morphology changes with varying synthesis parameters, and all membranes exhibited finger-like structures with thermal stability up to 300 °C. Gas separation performance was evaluated using both pure and mixed gases, with a CO2/N2 molar ratio of 15/85 employed to simulate realistic flue gas conditions. The membranes demonstrated high CO2 permeability, ranging from 59,542.2 to 79,412.9 Barrer for pure gases and 1,731.3 to 50,155.5 Barrer for mixed gases. CO2/N2 selectivity ranged from 3.4 to 4.2 for pure gases and 2.4 to 12.3 for mixed gases. Furthermore, the membranes retained stable performance after one week of continuous exposure, confirming their potential for practical CO2 separation applications.

Keywords: *Polyacrylonitrile, Hollow Fiber Membrane; Flue Gas Treatment; CO2 Separation; CO2/N2 Selectivity.*

Paper ID: P067

The Feasibility of using Palm Oil Fuel Ash (POFA) as a Potential Membrane Supporter for Microbial Fuel Cell Application in Comparison with Montmorillonite clay (MMT) Membrane

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ABSTRACT

The integration of waste-derived materials in membrane technology is gaining traction due to their low cost, mechanical strength, and contribution to long-term membrane stability. This approach reduces production and disposal costs while enhancing sustainability. Hence, this study aims to explore the usage of waste material which is Palm oil fuel ash (POFA) as a membrane for microbial fuel cell application and Montmorillonite (MMT) clay membrane as a control. Pure POFA and MMT membrane was prepared using phase inversion technique and sintered at 1150 °C with 4 mm thickness. In addition to that, both membranes were coated hydrothermally with sodium dodecyl sulphate (SDS) (MMT-SDS and POFA-SDS) using hydrothermal technique to investigate the fouling properties. The ion elution test showed gradual decrease of ion content (cations and anions) among which MMT showed significant reduction for over three-day period compared to POFA membrane. This finding aligned with the cation exchange capacity (CEC), where POFA showed higher CEC at 0.913 meq/g and MMT at 0.674 meq/g. However, POFA membrane possess high membrane resistance of 26.86 Ω, while MMT's resistance was profoundly low at 3.04 Ω. With regards to the MFC application using sewage as a substrate, both POFA and MMT membranes have shown a maximum current density of 5 A/m^2 at anode. POFA coated with SDS has shown the highest current density of 25 A/m^2. This finding proves the potential energy generation of POFA membrane. On the other hand, SDS coated MMT membrane (1.28E+07 cell/mL) and SDS coated POFA membrane (1.75E+07 cell/mL) have recorded lower attachment of microbes compared to the concentration of microbes present in the sewage (3.75E+07 cell/mL). This finding highlights the anti-biofouling properties of the coated membrane for long term MFC performance. Hence, pure POFA and coated POFA have potential to perform as a membrane supporter for MFC application. However, the cathode potential was not performed due to membrane damage and water leakage in MFC set up. This limitation could influence the overall current density, making the data insufficient to draw definitive conclusions.

Keywords: *Ceramic Membrane, Microbial Fuel Cell, Current Density, Membrane Biofouling, Ion Exchange Capacity*

Paper ID: P068

Protein-Incorporated Filtration Membrane for Urea Removal in Portable Peritoneal Dialysis Applications

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ABSTRACT

The mechanism of urea removal in dialysis treatments for kidney failure patients typically involves either urease conversion, direct urea adsorption, or oxidative methods. However, these methodologies could not achieve complete urea removal, making it unsuitable for portability purposes. In this work, a filtration membrane targeting enhanced water selectivity and permeation is developed with a support and an active layer. The active layer responsible for urea rejection is incorporated with aquaporin proteins. The proteins were stabilized using a silica encapsulation method developed previously. The aquaporins within the filtration membrane act as a passive and highly selective water transport channel, allowing enhanced flux permeation while maintaining high urea rejection. The membrane performance was then benchmarked against commercial membranes in terms of flux permeability and urea rejection using a mixture of salt and urea solution. Structural analysis of the stabilized aquaporins and the aquaporin-incorporated membranes were conducted using AFM and SEM, respectively. The biomimetic membranes recorded a 20% increase in terms of flux while improving NaCl and urea rejection from 92 to 97% and 68 to 76%, respectively. The findings of this work provided insight into the application of filtration membranes to dialysis applications.

Keywords: *Aquaporin; Membrane, Dialysis, Polymer, Flux, Rejection, Urea*

Paper ID: P069

Dynamic Covalent Chemistry Enabled Closed-Loop Recycling of Thermally Modified Polymer Membrane

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ABSTRACT

The increasing demand for sustainable solutions to oil-water separation and end-of-life membrane disposal has prompted the development of recyclable membrane technologies. In this study, we present an innovative approach to fabricating closed-loop, recyclable nanofibrous membranes (RFMs) utilising reversible covalent networks based on the Diels–Alder reaction. A methacrylate-based copolymer was synthesised via free radical polymerisation, combining hydrophobic monomers for enhanced separation performance, with furan-functionalised monomers for recyclability. This copolymer was electrospun into a porous substrate and crosslinked with bismaleimide crosslinkers to form a dynamic covalent network. By incorporating post-thermal modification to the nanofibrous membrane, the hydrophobicity and the membrane porosity can be optimised. The resulting RFM exhibited outstanding oil-water separation capabilities, achieving pure oil flux of up to 1,187 LMH with separation efficiency up to 99% in water-oil emulsions, as demonstrated in tests with dichloromethane and other oils. Notably, the RFMs maintained structural and chemical stability after two recycling cycles, with recycled membranes retaining fluxes of 474–1,187 LMH and efficiencies of 98.8–99.5%. Thermal and mechanical characterisations confirmed the great stability of the membranes, with the Diels–Alder reaction enabling depolymerisation and reformation of the network without causing significant degradation. Additionally, the RFMs were recycled the third time, maintaining the fluxes (752 LMH to 823 LMH) from the previous generation with a slight decrease in separation efficiency in dichloromethane-water emulsion separation (98.3% to 97%). By integrating dynamic covalent chemistry with scalable fabrication methods, RFMs represent a transformative step toward circular economy in oil-water separation and broader wastewater treatment and resource recovery.

Keywords: *Diels-Alder Chemistry, Circular Economy, Oil/water Separation, Electrospinning, Sustainable Membrane*

Paper ID: P070

Terahertz Conductivity of Free-Standing 3D Covalent Organic Framework Membranes Fabricated via Triple-Layer-Dual Interfacial Approach

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ABSTRACT

Processable covalent organic framework membranes (COFMs) are emerging as a potential class of semiconducting materials for device applications. Despite extensive exploration of two-dimensional (2D) COFMs, the fabrication of crystalline, self-standing three-dimensional (3D) COFMs poses significant challenges. In this work, we have developed a unique time and solvent-efficient triple-layer-dual interfacial (TLDI) approach for the simultaneous synthesis of two 3D COFMs from a single system by deliberately choosing a system of three immiscible solvents with varying specific gravities. The mechanical robustness of the synthesized 3D COFMs, essential for potential applications, has been assessed using the nanoindentation technique. Besides, for the first time, the optical conductivity of these free-standing 3D COFMs is analyzed using terahertz (THz) spectroscopy in transmission mode to investigate the ground-state charge carrier properties. Interestingly, these membranes show excellent transmittance (>70%) at THz frequencies with very high intrinsic THz conductivities (70-100 S/m). The evaluated scattering time and plasma frequency of the free carriers of the COFMs are highly promising for future applications in optoelectronic devices in THz frequencies.

Keywords: *Covalent Organic Framework, Membrane, Terahertz, Conductivity*

Paper ID: P071

Mathematical Modelling of CO_2/CH_4 Separation Through High-Permeable Hollow Fiber DD3R Zeolite Membranes

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ABSTRACT

Hollow fiber DD3R (HF-DD3R) zeolite membranes represent a promising material for CO_2 capture from natural gas, and devoting to its permeance promotion becomes an attractive topic in recent. Whereas, the external resistances including concentration polarization and lumen resistance, may be also pronounced in such high-permeable systems, thereby changing the matched feeding conditions with membrane area. To reveal this variation, a modified two-dimensional (2-D) mathematical model with distributed parameters was established to describe the CO_2/CH_4 separation process, where the distributed pressure drops, as well as the external resistances induced by concentration polarization (ECP) and lumen resistance (ELR) were explicitly considered. Compared to the classical one-dimensional (1-D) model with lumped parameters, the predicted CO_2 permeance by our model showed better agreement with the experimental data under the same conditions. The distributions of trans-membrane resistances were examined in terms of relative pressure drop (RPD), where the external resistances resulted in a remarkable loss of pressure drop (arrived to 42%) in the high-permeable membrane with a membrane thickness of 0.5 μm, primarily attributed to the stronger bulk flow towards to the membrane surface. Furthermore, the external resistances significantly inhibited the CO_2 removal efficiency at different $X_{\text{CH4, retentate}}$ for the membrane. Finally, the decreased passage area achieved by adjusting the membrane packing density and the module diameter could also promote the convection mass transfer in the shell side, leading to the improved CO_2 removal efficiency. The established 2-D mathematical model serves as a valuable tool for elucidating the CO_2/CH_4 separation behaviors in the high-permeable HF-DD3R zeolite membrane, which could be also extended to other zeolite membrane materials.

Keywords: CO_2 *Separation, Zeolite Membrane, Mass Transfer, Mathematical Modelling*

Paper ID: P073

Engineering and Scale-Up of Pervaporation Membrane with an Intermediate Layer

Jie Li

ABSTRACT

The fabrication and scale-up of pervaporation composite membranes are often challenged by pore penetration into the microporous substrate. We present an innovative composite membrane featuring an intermediate poly(ether block amide) (PEBA) layer formed at a liquid-liquid interface, which effectively mitigates pore penetration and creates a uniform surface for deposition of the top selective layer. A polydimethylsiloxane (PDMS) separation layer was developed with precise control through dynamic monitoring of the membrane solution spreading droplets, optimizing the PDMS spreading thermodynamic and kinetic parameters involved. SEM analysis confirmed the dense top-layer structure of the PDMS-PEBA/polytetrafluoroethylene (PTFE) membrane, with controllable thicknesses of individual layers. The appropriate thicknesses for the PEBA and PDMS layers were investigated through both the resistance model analysis and pervaporation test results. Based on this trilayer structure, a 600 cm^2 PDMS-PEBA/PTFE membrane was successfully scaled up, achieving a separation factor of 22.4 and a flux of 1.9 $kg \cdot m^{-2} \cdot h^{-1}$ for concentrating n-butanol (60℃, 1 wt.% n-butanol/water). To enhance the pervaporation performance, PDMS@COFTpBd-F (fluorinated triformylphloroglucinol-benzidine covalent organic framework)-PEBA/PTFE mixed matrix membranes was also fabricated. The introduction of 0.05 wt% TpBd-F was demonstrated to enhance the PDMS spreading coefficient by 60%. The interfacial regulation and particle synergistic optimization mechanisms established in this study provided theoretical and technical foundations for scale-up fabrication of high-performance butanol-permselective pervaporation membranes.

Keywords: *PDMS-PEBA, COF, Intermediate Layer, Scale-up, Pervaporation*

Paper ID: P074

Chelation-Driven In-Situ Growth of Uniform Palladium Nanoparticles in Polythiosemicarbazide Membranes for Catalytic Water Treatment

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ABSTRACT

The integration of catalytic function into membrane systems offers a compelling route for simultaneous pollutant removal and degradation in water treatment. However, traditional catalytic membranes often suffer from uneven nanoparticle distribution, agglomeration, and metal leaching, limiting their practical viability. In this study, we present a chelation-driven strategy for fabricating high-performance catalytic membranes by in-situ growth of palladium nanoparticles (PdNPs) within a polythiosemicarbazide (PTSC) matrix. The PTSC polymer contains a single chelation site per monomeric unit, enabling strong coordination with Pd^{2+} ions and facilitating their controlled reduction into uniformly dispersed PdNPs with an average diameter of 2.3 nm, without the use of stabilizers or surfactants. Membranes were fabricated via nonsolvent-induced phase separation, forming a porous asymmetric structure with high water permeability and mechanical integrity. FTIR analysis revealed characteristic shifts—such as the disappearance of the C=S band, formation of C=N, and emergence of C–S stretching vibrations—confirming metal coordination with palladium. The in-situ reduction resulted in PdNPs uniformly distributed across the membrane cross-section, as confirmed by TEM and EDX mapping. Chelation-based confinement prevented agglomeration and ensured excellent nanoparticle retention, with no detectable Pd leaching under dynamic testing. Despite low Pd loading (1 wt%), the membrane exhibited strong catalytic activity. The reduction of 4-nitrophenol showed a k_{app} of 0.029 min^{-1} under dynamic operation, while batch conditions reached a k_{app} of 0.0061 min^{-1} . This improvement is attributed to convective flow through the Pd-loaded membrane matrix, which increases contact between the active sites and reactants while minimizing diffusion limitations. While catalytic degradation was successfully demonstrated in this study, future work should focus on achieving simultaneous pollutant breakdown and selective separation of intermediate or by-product species to fully realize the integrated potential of membrane-based catalytic systems.

Paper ID: P075

Binary-Halogen Doped BSCF Oxide Provides a Highly Oxygen Permeable Membrane

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ABSTRACT

Oxygen permeability is the primary requirement for mixed ionic electronic conductor (MIEC) membranes. Halogen doping enhances the permeability of MIEC membranes [1,2]. Various halogens (F, Cl, and I) affect the performance of perovskite oxides differently, owing to variations in electronegativity, ionic radius, and other properties [3,4,5,6]. In this work, an F and Cl co-doping strategy was proposed to improve perovskite oxygen permeation. A series of $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}Cl_xF_{0.1-x}$ materials were synthesized by the solid phase reaction method, and the impact of binary halogen doping on the crystal structure and oxygen permeability performance was systematically studied. Oxygen permeability tests suggested that the $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}Cl_{0.06}F_{0.04}$ disk membrane had good performance of 2.95±0.046 $mL\cdot min^{-1}\cdot cm^{-2}$, confirming the benefits of the binary halogen-doped strategy. This improved performance results from the F and Cl co-doping, which enhances the oxygen vacancy concentration compared to $Ba_{0.5}Sr_{0.5}Co_{0.8}Fe_{0.2}O_{3-\delta}$ materials, lowers the average metal-oxygen bond energy, and increases electrical conductivity. These results suggest that the binary halogen-doping strategy offers significant progress in the development of high-performance MIEC materials and potentially provides a new basis for the application of MIEC membranes.

Keywords: *Oxygen Permeable Membrane, Perovskite Oxide, Binary Halogen, Co-Doping*

Paper ID: P076

Remote Operation and Field Demonstration of a Pilot-Scale MCDI System in Malaysia

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ABSTRACT

This study presents the remote operation and field demonstration of a pilot-scale Membrane Capacitive Deionization (MCDI) system installed in Malaysia. The system was developed as part of a technology localization initiative to deliver decentralized and energy-efficient water treatment solutions in areas with limited resources and infrastructure. The MCDI unit is located at a testbed site and is fully operated and monitored from South Korea through a real-time control platform. This configuration enables remote adjustment of operational parameters, automated fault detection, and continuous performance monitoring, minimizing the need for on-site management. Emphasis is placed on the technical feasibility, stability, and reliability of long-distance, cross-border system operation. The results highlight the effectiveness of remote operation in maintaining system performance and ensuring operational continuity under real field conditions. Additionally, the pilot project demonstrates the adaptability of MCDI for various site conditions and its potential for integration into smart, modular water treatment systems. The findings suggest that MCDI, when combined with digital control technologies, offers a practical and scalable solution for decentralized water supply in underserved or geographically isolated communities.

Keywords: *Decentralized Water Treatment, MCDI (Membrane Capacitive Deionization), Pilot-scale, Remote Operation, Testbed*

Paper ID: P077

Construction of Bionic Enzyme Gas Channels on the Surface of PMP Hollow Fiber Membrane for Rapid CO2 Removal in ECCO2R System

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ABSTRACT

The extracorporeal carbon dioxide removal (ECCO2R) system is a life-support technique that has been shown to facilitate a protective ventilation strategy. When the lung disease cannot remove carbon dioxide (CO2) in time, resulting in CO2 retention, ECCO2R is used to remove the excess CO2.As the key component of the artificial lung, the gas transport performance of the membrane determines the CO2 removal capacity of the membrane lung, which should present high CO2 selectivity to increase the efficient CO2removalrate.At present, the most widely used gas-blood exchange membrane is the poly (4-methyl-1-pentene)(PMP) hollow fiber membrane. Our team has achieved the large-scale preparation of PMP hollow fiber membranes and solved the problems that gas-blood exchange membranes are prone to plasma leakage [1] and thrombosis [2].In this study, a biomimetic metalloenzyme, ZIF-8-NH2,was prepared to mimic the function of carbonic anhydrase(CA).The pore in ZIF-8-NH2was constructed to act as gas channel, in order to enhance the CO2/O2selectivity. The ZIF-8-NH2/Pebax, which has functions similar to those of CA and gas channel (AQP1),was coated on the surface of PMP membranes to fabricate the composite membrane. The results confirmed that the CO2/O2selectivity of the ZIF-8-NH2/Pebax composite membrane was 7.4, which was 7.5 times higher than that of the original PMP membrane. The protein adsorption and thrombin time were 35.5 % lower and 34.4 % higher than those of PMP membrane, respectively. These results demonstrated that the prepared composite membrane possessed good blood compatibility. Additionally, an *in-vitro* blood circulation device was established to comparatively evaluate the hemocompatibility and CO2 removal efficiency of PMP and the composite membrane modules under dynamic blood flow.

关键词：*ECCO2R, ZIF-8-NH2, Bionic Enzyme, Gas Channel, CO2 Removal*

Paper ID: P078

The dual effects of the integrated heat exchange membrane distillation module: near-surface heating, and turbulence promoting

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ABSTRACT

The typical membrane distillation (MD) shows severe temperature polarization in the actual process, which may lead to a 50% to 80% reduction in water vapor mass transfer [1]. In addition, during the MD process, it was found that the high salinity of the feed liquid and other complex components could cause corrosion of the heat pipes in ordinary metal heat exchangers. In response to the problems existing in the above-mentioned research, we combined the polymer heat exchanger with the membrane distillation module and designed an integrated heat exchange membrane distillation (IHEMD) module, achieving simultaneous heating and distillation within one module. This IHEMD module utilizes heat exchange hollow fibers to achieve near-surface heating, and promotes turbulence through the grid-like arrangement of the hollow fibers, enhances fluid flow, and reduces the deposition of pollutants. We systematically studied each operating condition and the improvement degree of temperature difference polarization was measured by comparing the outlet temperature of the feed liquid, it was found that the outlet temperature was higher than the inlet in IHEMD module, which is lower than inlet in conventional MD module. In addition, it was also investigated that compared with the conventional module, this design has a good performance in resisting pollutant deposition in the treating mixed solutions containing inorganic and organic substances of the same concentration. Compared with the ordinary MD module, the flux was increased by approximately 90% under the same experimental conditions. In IHEMD module, both liquid and gas can pass through the polymer hollow fiber membrane for heat exchanging, which can utilize the heat in the factory wastewater and waste gas, avoid the corrosion of the metal heat exchanger by high-salt solutions, and largely solve the energy consumption problem of membrane distillation.

Paper ID: P079

An Atomistical Investigation of CO2/CH4 Adsorption by Matrimid/ZIF-8 based Mixed Matrix Membranes through Molecular Simulation

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ABSTRACT

Polymeric membranes are economically preferred than the other conventional membranes in the industrial gas separation application, but the selectivity-permeability trade-off often limits their performance [1], [2]. Inorganic membranes offer gas separation performance but are hindered by costly and complex fabrication, limiting large scale usage. Hence, many researchers fabricated mixed matrix membranes (MMMs) combining polymers and inorganic fillers, which offered improvements in processability, flexibility, thermal stability, and gas separation performance [1]. Despite promising experimental results, atomistic-level comprehension of MMMs, especially for the fillers of intrinsic nanopores remained limited [3], [4]. Fillers like zeolite-imidazole frameworks (ZIFs), despite their elevated molecular sieving property, facile synthesis with good polymeric-filler compatibility [5], [6], [7] were yet to be explored computationally. Hence, this research aimed to develop a validated computational framework that investigate the CO2/CH4 gas separation of Matrimid/ZIF-8 based MMMs across different ZIF-8 weight loadings. The Material Studio software and the Dreiding force field were used throughout the simulation process. The physical properties (density, fractional free volume, d-spacing, binding energy) and the gaseous adsorption of the membranes were also studied throughout the research. Results showed that the pristine materials (ZIF-8 and Matrimid) and the MMMs also show minimal deviation across all loadings. The addition of ZIF-8 at 10 wt.% stabilised the membrane system, indicated by an increase in the binding energy, but an increase in the weight loading destabilised it. Nonetheless, a rise in the weight loading improved the gas adsorption due to the increase in the adsorption sites within the membrane structure. In summary, this research has presented a comprehensive framework that provides insights for ZIF-8-based membranes.

Keywords: *Mixed Matrix Membrane, Molecular Dynamics Simulation, CO2/CH4 separation, Matrimid, Zeolite Imidazole Framework (ZIF-8) (up to 5 keywords)*

Paper ID: P080

Preparation and Mass Transfer Mechanism Study of Polyvinylidene Fluoride Piezoelectric Membrane

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ABSTRACT

Piezoelectric poly(vinylidene fluoride) (PVDF) membrane, with its outstanding voltage output, mechanical robustness, and tunable structure, hold a significant potential for addressing global water and energy shortages. Piezoelectric PVDF membranes show growing promise for mitigating fouling in solid-liquid separation processes, as evidenced by recent advances. Zhang et al. (2022, 10.1021/acs.est.2c05359) demonstrated the efficacy of integrated phase separation and mild polarization using NaCl-induced ion-dipole interactions,where in-situ surface potential (ζ) generation reduced fouling through charge repulsion. Complementarily, Chen et al. (2019, 10.1016/j.seppur.2018.12.082) established that applied vibration (1601 Hz) from pre-poled PVDF membranes enhanced permeate flux by 87 ± 3% during kaolin suspension filtration. Here, we developed a high-performance piezoelectric PVDF membrane via a two-step approach combining nonsolvent-induced phase separation (NIPS) and high-electric-field polarization, leveraging ion-dipole interactions between LiCl and PVDF chains. The optimized membrane exhibited exceptional polarizability, achieving a maximum piezoelectric coefficient (d33) of up to 20 pC·N-1, outstanding mechanical stability, enhanced β-phase crystallinity orientation, and a more negative surface zeta potential (with a maximum shift from -39 mV to -55 mV). Underwater acoustic response and mechano-electrical tests revealed strong correlations between d33 and energy conversion efficiency, demonstrating both enhanced response above 80 kHz and maximum output voltage, current, and charge reaching 73.7%, 71.9%, and 77.6% of commercial PVDF film, respectively. Notably, the membrane demonstrated superior separation performance for humic acid (90.7% rejection), bovine serum albumin (100%), dextrans (71.3 kDa MWCO), and real surface water (>77% rejection),coupled with high flux recovery rates (90% for HA, 71.1% for surface water) and dominated by reversible fouling resistance. This study provides the first systematic evaluation of d33-dependent energy conversion and separation performance in pure PVDF membranes, offering a promising strategy for simultaneous water treatment and energy recovery, with broad implications for sustainable resource management.

Paper ID: P081

High-Performance Polyamide Nanofiltration Membrane via MXene Confined Regulation for Lithium Extraction from Salt-Lake Brines

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ABSTRACT

Development of cost-effective materials and technologies for lithium extraction in salt-lake brines is of great importance to meeting rising lithium demands. Nanofiltration (NF) process is a feasible solution, however, it has commonly had operational problems such as low permeability. In this study, an MXene-regulated interfacial polymerization (MRIP) method was developed for fabrication of high-performance polyethyleneimine (PEI)-based polyamide (PA) NF membrane. The MXene nanosheets tiled at the water-oil interface, by which a spatio-temporal confinement effect was created; such structure could nicely regulate diffusion of monomers and precisely control PA nanofilm. The MXene-regulated membrane (PA@M) had thinner thickness, larger pore size, and better hydrophilicity. As a result, the permeance of PA@M membrane was significantly increased by more than 300%. Moreover, the membrane had outstanding cation selectivity with >98% rejection for Mg^{2+} and <20% rejection for Li^{+}. Meanwhile, the selectivity factor of Li^{+}/Mg^{2+} reached 31.5. Furthermore, a two-stage nanofiltration process by the membrane could reduce the Mg^{2+}/Li^{+} ratio from 40 to 0.45, suggesting greater suitability of membrane for lithium extraction. The MRIP method offers a promising strategy and method for development of high-performance PA-NF membranes for resource recovery and water purification applications.

Keyword: *Nanofiltration, Mxene, Confined Interfacial Polymerization, Polyethyleneimine, Lithium Extraction*

Paper ID: P082

Development of ZIF-8/Biopolymer Hybrid Membranes for Selective Removal of Heavy Metals from Aqueous Solutions

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ABSTRACT

A novel eco-friendly hybrid membrane system was successfully developed by integrating zeolitic imidazolate framework-8 (ZIF-8) metal–organic frameworks with a biodegradable polymeric matrix composed of alginate and chitosan. The membrane fabrication process involved a layer-by-layer casting technique followed by ionic crosslinking using calcium ions, which significantly enhanced the mechanical strength and structural stability of the composite. The selection of alginate, known for its hydrophilicity and gel-forming properties, combined with chitosan, a cationic biopolymer rich in amino and hydroxyl functional groups, provided an ideal platform for efficient MOF immobilization and synergistic metal ion binding. The homogenous dispersion of ZIF-8 within the polymer network contributed to increased surface area and porosity, facilitating improved sorption and permeation characteristics. Comprehensive characterization using scanning electron microscopy (SEM) and Fourier-transform infrared spectroscopy (FTIR) confirmed the successful integration of ZIF-8 and preservation of the hybrid structure. The membrane displayed high chemical stability across a broad pH range (pH 3–9) and retained its sorption capacity over multiple regeneration cycles, demonstrating strong reusability. These findings highlight the potential of alginate–chitosan–MOF hybrid membranes as sustainable, selective, and cost-effective sorbents for the efficient removal of heavy metals and emerging contaminants from wastewater.

Keywords: *Metal Organic Framework, Biopolymer, Membrane, Water Purification*

Paper ID: P083

Fabrication of High Permeance Hollow Fiber Nanofiltration Membrane with Enhanced Organic Micropollutant Rejection for Drinking Water Treatment

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ABSTRACT

To enhance the permeance-selectivity trade-off in hollow fiber membranes, a novel vacuum-assisted interfacial polymerization method was employed to prepare nanofiltration (NF) membranes on polyacrylonitrile (PAN) support layers. Sodium bicarbonate ($NaHCO_3$) was utilized as a foaming agent during the polymerization process, resulting in a unique stripe-like morphology on the polyamide active layer. This modification significantly improved the pure water flux of the NF membrane, increasing it from approximately 18 L m^{-2} h^{-1} bar^{-1} for the control membrane to 34 L m^{-2} h^{-1} bar^{-1} for the modified NF membrane (NF-1) while maintaining a high salt rejection. Based on the membrane characterization results, the foaming agent is believed to role in formation of the stripe-like morphology. The surface roughness was found to be inthe range of 15.6 ± 3.6 to 19.0 ± 4.8 nm,as observed by AFM.TEM revealed a thinner polyamide layer, indicating that sodium bicarbonate acted as an inhibitor for IP reaction. The modified NF-1 membrane was then applied for the removal of per- and polyfluoroalkyl substances (PFAS) such as PFBA, PFBS, GENX, PFOA, and PFOS from drinking water. Results showed that the NF-1 membrane exhibited higher selectivity for calcium ions over PFAS compared to the control NF-0 membrane, making it a promising candidate for PFAS removal applications. This study demonstrates the potential of using a simple and effective approach to enhance membrane performance while maintaining or improving selective separation properties for contaminants like PFAS.

Keywords*: Hollow Fiber, Nanofiltration, Sodium Bicarbonate, Per-And Polyfluoroalkyl Substances, Drinking Water*

Paper ID: P084

Fabrication of PSS-MOF-303/rGO Membranes for Effective Separation of Rare Metal Ions

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ABSTRACT

In this study, MOF-303/reduced graphene oxide (MOF-303/rGO) nanofiltration membranes were successfully prepared using the polyelectrolyte sodium polystyrene sulfonate (PSSNa) as a dispersing agent. This PSS-assisted strategy promotes a more uniform dispersion of MOF-303 within the rGO membrane, thereby enhancing its structural stability during membrane separation. The fabricated membranes demonstrate exceptional performance in the selective separation of rare earth elements (lanthanum) and radioactive contaminants (Strontium). A detailed investigation of the separation mechanism revealed that size sieving and electrostatic interactions are the primary factors driving selectivity. Compared to rGO membranes, the PSS-MOF-303/rGO membrane exhibits approximately four times higher water permeance while achieving a modest improvement in selectivity. Furthermore, the PSS-MOF-303/rGO membrane maintains excellent separation performance under varying pressures, different feed concentrations, diverse La/Sr mass ratios, and long-term stability tests. These findings highlight the potential of PSS-MOF-303/rGO membranes for the efficient separation of rare earth ions from radioactive wastewater.

Keywords: *Reduced graphene oxide; MOF-303; Selective separation; Lanthanum*

Paper ID: P085

Design of Nanostructured Porous Membranes *via* Block Copolymer Self-Assembly for Advanced Separation Applications

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ABSTRACT

Block copolymers (BCPs) have emerged as versatile templating agents for the fabrication of nanostructured membranes with precisely tunable pore sizes and morphologies. In this study, we report the preparation of porous membranes through the self-assembly of amphiphilic BCPs under controlled conditions, followed by selective removal of one block to generate well-defined porosity. The influence of solvent choice, annealing strategies, and BCP composition on the phase separation and pore architecture was systematically investigated. Membrane structures were characterized using SEM, AFM, etc. techniques to elucidate the domain organization and continuity of the porous network. This work demonstrates the potential of block copolymer-based design as a scalable platform for creating next-generation membranes with tailor-made functionality and structure.

Keywords: *Membrane, Block Copolymer, Self-Assembly*

Paper ID: P086

Compressed Air Backwash for Increased Recovery Rate and Enhanced Fouling Control

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ABSTRACT

Membrane fouling remains the principal limitation to the long-term performance of ultrafiltration (UF) systems, leading to flux decline and elevated energy consumption [1]. Backwashing, reversing permeate flow through the membrane, is typically employed to restore membrane permeability, but conventional methods using membrane permeate sacrifice water recovery and offer limited foulant removal [2]. Therefore, we explore an innovative alternative using compressed air to reverse the permeate flow from the lumen to the shell of the inside-out membrane module installed in a pilot-scale UF plant. In this pilot-scale study, we compared a conventional permeate backwash (30 kPa for 100 s) with a compressed air backwash (50 kPa for 60 s), in which compressed air was used to force the remaining permeate in the membrane lumen toward the shell side. Both were operated at a flux of 47.8 L/m^2-h. The compressed air backwash strategy achieved a mean recovery rate of 97.8 %, a 3.3 % improvement over the 94.5 % recovery of the conventional method. Crucially, this increase in recovery did not compromise cleaning efficacy at all. Moreover, specific UV absorbance (SUVA) analysis of the cleaning-in-place effluent showed a higher conventional backwash SUVA of 3.95 L/mg-cm versus 2.86 L/mg-cm for the compressed air method, indicating that the latter removed more hydrophobic organic foulants during the periodic backwash. The transmembrane pressure profiles were comparable between the two approaches, averaging approximately 36.8 kPa for the conventional method and 36.1 kPa for the compressed air backwash. This indicates that fouling control remained stable and effective, even with reduced permeate consumption in the compressed air backwash system. Implementing this backwash strategy can enhance overall system efficiency and reduce water losses. Additional work should evaluate the effects of varying pressures under different operating conditions and assess long-term impacts.

Keywords: *Backwash, Compressed Air, Membrane Cleaning, Ultrafiltration, Water Recovery*

Paper ID: P087

Flow-Electrode Capacitive Deionization for Phosphorus Removal from Secondary Wastewater Effluent

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ABSTRACT

In response to climate change and the growing need for carbon neutrality, the water treatment industry is seeking energy-efficient and sustainable solutions. Electrochemical water treatment technologies, particularly Flow-Electrode Capacitive Deionization (FCDI), are gaining attention for their potential to overcome limitations of conventional CDI systems by enabling continuous operation and selective ion removal [1, 2]. This study explores the effectiveness of FCDI in removing total phosphorus from synthetic secondary effluent, simulating municipal wastewater conditions. Batch experiments were conducted under varying current densities (0–2.2 mA/cm^2), with adjustments to key parameters such as current density, activated carbon type, residence time, and chemical oxygen demand (COD) concentration. Results showed that phosphorus removal efficiency significantly improved at current densities above 1.1 mA/cm^2. While higher current densities increased power usage, total energy consumption decreased due to reduced reaction time, highlighting the importance of current density in optimizing both reaction kinetics and energy efficiency. The performance also depended on the activated carbon type and the feed COD concentration. Activated carbon (type A) achieved better phosphorus removal under moderate COD levels (10–30 mg/L) but declined at 50 mg/L, whereas another activated carbon (type B) showed a decline with increasing COD. To understand these differences, further analysis is underway on carbon material properties, such as surface charge, moisture content, and pore structure, using dry weight comparison, thermogravimetric analysis, and porosimetry. In addition, long-term monitoring of electrode and membrane fouling is further explored to develop effective cleaning protocols and maintenance schedules. Overall, this study demonstrates the feasibility of using FCDI for phosphorus removal from secondary effluent and provides insights into optimizing operational conditions. These findings support the development of more sustainable and efficient electrochemical water treatment systems.

Keywords: *Activated Carbon, Current Density, Electrochemical Water Treatment, Flow-Electrode Capacitive Deionization, Phosphorus Removal*

Paper ID: P088

Enhancing Conductivity and Alkaline Stability of Poly(Aryl Piperidinium) Anion Exchange Membrane for Fuel Cells by Grafting Side-Chain Type Piperidinium

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ABSTRACT

As a critical component of anion exchange membrane fuel cells (AEMFCs), anion exchange membranes (AEMs) must simultaneously achieve high conductivity and excellent alkaline stability. This study presents an innovative strategy for enhancing both properties through the incorporation of side-chain piperidinium into poly(aryl piperidinium) polymers containing backbone piperidinium groups. The resulting dual-piperidinium AEMs demonstrated remarkable performance improvements, achieving an exceptional hydroxide conductivity of 167.5 mS cm^{-1} at 30°C with a low activation energy for OH^- transport. These enhancements stem from both increased ion exchange capacity (IEC) and the formation of efficient ion transport channels. Combined theoretical calculations and experimental investigations revealed that the side-chain piperidinium groups, being spatially separated from the polymer backbone, exhibit superior alkaline stability compared to backbone piperidinium moieties, as evidenced by their higher Hofmann elimination energy barrier. The membranes delivered an outstanding peak power density of 1.38 W cm^{-2} and demonstrated stable operation over 50 hours at 0.6 A cm^{-2}.

Paper ID: P089

Enhanced CO_2 Separation Using CNT-Reinforced Cellulose Triacetate Membranes with High Ionic Liquid Loading

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ABSTRACT

In recent years, carbon-based materials, such as carbon nanotubes and carbon molecular sieves, have gained substantial interest as additives for gas separation membranes due to their exceptional properties, including high permeability, thermal and chemical stability, and good processability.[1, 2] Their integration consistently enhances gas transport performance and durability in mixed-matrix and hybrid membrane systems.[3] In this study, we report on the synergistic integration of single-walled carbon nanotubes (CNTs) into CO_2-selective cellulose triacetate (CTA) membranes containing high loadings of ionic liquids (ILs). For CO_2-selective membranes, CNTs were used as supports for vacuum filtration of a CTA solution containing 1-ethyl-3-methylimidazolium dicyanamide (EMIM-DCA). The resulting hybrid membranes were characterized using single-gas permeation measurements with an integral permeameter and a constant-volume cell. Notably, the CNT-CTA membrane containing 50 wt.% EMIM-DCA exhibited a significant improvement in both gas permeability and ideal selectivity compared to the pristine materials, surpassing the Robeson 2008 upper bound for the CO_2/N_2 gas pair. Membranes containing EMIM-DCA showed increasing CO_2 permeability with rising IL content while maintaining stable CO_2/CH_4 selectivity and improved CO_2/N_2 selectivity. A comprehensive suite of analytical techniques, including TGA, FTIR, XPS, confocal surface imaging (CSI), SEM-EDX, ICP-MS, and CHN analysis, was employed to assess thermal behavior, morphology, elemental composition, and IL distribution. These analyses provided critical insight into the relationships between IL content, membrane structure, and functional performance.

Keywords: CO_2 *Separation, Mixed Matrix Membranes, Ionic Liquid, Gas Separation Efficiency*

Paper ID: P090

Photothermal Rice Husk Char-Based Omniphobic Dual-Layer Hollow Fiber Membrane for POME Reclamation via Membrane Distillation

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ABSTRACT

This study presents a novel photothermal omniphobic hollow fiber membrane (POM) integrating rice husk-derived biochar (RHC) for energy-efficient palm oil mill effluent (POME) reclamation via membrane distillation (MD). The dual-layer membrane combines RHC-enhanced photothermal conversion with omniphobicity achieved through solvent etching and fluorosilanes grafting, exhibiting exceptional broadband absorption (<20% reflectance, 250–1100 nm), rapid surface heating (121% temperature rise at 0.5 kW/m^2), and fouling resistance (water/oil contact angles: 125.2±2.2°/105.9±2.0°; liquid entry pressure: 4.17±0.12 bar). In direct contact MD (DCMD) tests using synthetic and real POME, the POM demonstrated superior performance over conventional membranes, achieving stable fluxes of 12.68–14.25 kg/m^2·h (conventional heating) and 3.82–4.58 kg/m^2·h (solar-driven), with temperature polarization factor (TPF) of 93.9–96.7% (vs. 84.0–85.6% for pristine membranes) due to localized photothermal activation via RHC's lattice vibrations. Energy efficiency metrics revealed a 38.7–42.5% energy gain, 66.5–79.8% solar utilization efficiency, and 63.4–65.4% reduction in specific thermal energy consumption (STEC; minimum: 963 kWh/m^3). The gained output ratio (GOR) increased fivefold under irradiation, underscoring the system's energy sustainability. Remarkably, permeate quality met stringent standards, with >95% BOD removal and >98% rejection of COD, NH_3-N, and TSS, while oil, color, and turbidity were reduced by >99%. This work advances waste-to-resource strategies by leveraging agricultural waste-derived photothermal materials and omniphobic engineering, offering a scalable solution for low-carbon POME treatment.

Keywords: *Photothermal Membrane Distillation, Omniphobic Membrane, Palm Oil Mill Effluent, Synthetic Wastewater, Temperature Polarization*

Paper ID: P091

Janus PAN-PCA-PTFE Membrane with Bidirectional Selectivity for Enhanced Oil/Water Emulsion Separation

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ABSTRACT

Membrane fouling, particularly when treating feed solutions containing organic solvents with low surface tension and contaminating oils, poses a significant challenge in membrane distillation (MD). While coating a hydrophilic polymer layer onto hydrophobic membranes (e.g., PTFE) can mitigate fouling, a fundamental conflict often exists between achieving strong adhesive stability and maintaining effective antifouling performance at the hydrophilic-hydrophobic interface. To address this, this study introduces adhesive protocatechuic acid (PCA) as an intermediate layer. Utilizing a simple dip-coating method, polyacrylonitrile (PAN) was uniformly coated onto a polytetrafluoroethylene (PTFE) membrane surface. This approach presents a novel strategy for constructing a robust, adhesive hydrophilic layer on the membrane, ingeniously integrating high adhesion strength, exceptional anti-oil fouling capability, an ultrathin thickness (ensuring high flux), and good durability. Through sequential deposition of PCA/PAN, a hierarchical distribution—from the PTFE substrate towards the surface—of adhesive PCA and hydrophilic PAN was achieved, successfully fabricating a PAN-PCA-PTFE composite membrane. Within this structure, the intermediate PCA layer ensures strong adhesion between PAN and PTFE, while the outermost PAN layer confers superior antifouling properties without compromising high permeate flux. The resulting PAN-PCA-PTFE membrane demonstrated superhydrophilicity, excellent resistance to fouling by various oils, and good mechanical wear resistance in direct contact membrane distillation (DCMD) tests. This membrane achieved highly efficient and stable separation of surfactant-stabilized oil-in-water emulsions and crude oil/water mixtures. This work provides a novel and effective design strategy for developing antifouling separation membranes suitable for complex oily wastewater treatment in practical applications.

Keywords: *Adhesive Interlayer、Anti-oil-fouling、Layer-by-Layer Deposition, Oil/Water Separation、Superhydrophilic Membrane*

Paper ID: P092

Impact Of Trace Light Hydrocarbons in CO_2/CH_4 Mixtures through Zeolite Membrane

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ABSTRACT

Eight-membered ring zeolites are expected to exhibit high CO_2 selectivity in CO_2/CH_4 mixtures. However, trace amounts of light hydrocarbons present in natural gas can degrade CO_2 separation performance [1]. Therefore, understanding the mechanism by which light hydrocarbons hinder CO_2 permeation is essential. However, conventional molecular dynamics (MD) methods have difficulty simulating the permeation of gas mixtures with large differences in diffusion coefficients, such as CO_2 and light hydrocarbons. In this study, the Dynamic Monte Carlo (DyMC) method, which allows efficient time evolution calculations, was used to simulate permeation of mixture gas in CHA membranes. A membrane model was constructed based on the pure silica CHA-type zeolite crystal structure, and light hydrocarbons were adsorbed using Grand Canonical Monte Carlo simulations. The adsorption-dependent self-diffusion coefficients were then calculated using MD simulations. Site information from the crystal structure was used to construct a lattice model representing the porous structure, and hopping constants (k) for gas molecules moving between adsorption sites were determined for DyMC calculations. DyMC simulations were conducted for two different gas mixture systems: a binary CO_2/CH_4 mixture (1:1) and a ternary mixture with 1%-C_3H_8 added. The results showed that the addition of C_3H_8 reduced the permeation of CO_2 and CH_4 by 78.8% and 78.5%, respectively. Additionally, during the permeation simulation, the number of gas molecules within the membrane decreased for CO_2 in proportion to the number of C_3H_8 molecules present, whereas CH_4 remained unaffected by C_3H_8. The CO_2 separation factor decreased by 1% in the presence of C_3H_8 from 24.8 of CO_2/CH_4 binary system. The reason why C_3H_8 affected CO_2 permeation is that CO_2 is most strongly adsorbed species in the zeolite's crystalline, and thus competition of C_3H_8 adsorption decreases the amount of CO_2 adsorption, resalting in the decrease of CO_2 permeation.

Keywords: *CO_2 separation, Zeolite Membrane, Molecular Dynamics, Dynamic Monte Carlo*

Paper ID: P093

Removal of Microplastic in Polluted Water by Membrane Distillation

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The presence of microplastics (MP) in aquatic ecosystems worldwide has become a stressful issue in the last decade. It is emphasized that the amount of MP is positively correlated with the plastic waste in a region, can be accumulated in living organisms, and poses a negative impact on the health of ecosystems. In the treatment of wastewater and drinking water, membrane technology has been appointed as the most effective and promising technology to remove MP. In general, pressure-driven membranes, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, have been extensively studied to remove the MP. However, the removal of MP cannot reach 100%, despite the significantly smaller membrane pores than the microplastics size. In most cases, the remaining MP in the permeate streams consists of fiber-shaped MP, showing an indication that MP can pass the membranes longitudinally. The application of another membrane technology that prohibits the convective flow of water is necessary. Membrane distillation (MD) involves a hydrophobic membrane that passes through water vapor, instead of water. This approach theoretically allows for 100% rejection of MP. In this research, polluted river water was used as the feed. Various MPs, such as PVC, PE, and PS, were detected in the feed. Treatment using MD was able to remove most of the MPs. Fouling occurrence during MD was prominent; however, straightforward pretreatment by filtration successfully reduced the fouling propensity.

Keywords: *Microplastic, Membrane Distillation, Fouling, Water Treatment*

Paper ID: P094

Removal of Nuclides from Radioactive Wastewater using Nanofiltration Membrane

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ABSTRACT

Nuclear-fouled power plants produce a large quantity of radioactive wastewater that can not be directly discharged into the environment due to its harmfulness and also difficulties to eliminate. Therefore, the water quality control for nuclear power station will be concerned. This study focuses on the insight into the understanding of the removal of targeted nuclides as radioactive compounds from wastewater using nanofiltration (NF). NF membrane performance was examined with respect to permeate flux and rejection of cesium (Cs), and strontium(Sr). The influences of surfactants and PAH on the removal efficiency were also studied. The experiments were conducted in cross flow filtration mode operated in acidic and alkaline conditions.The best result revealed that the rejection of Cs (molecular weight 168 g/mole) nearly approached 99.9% in various condition pH levels.

Keywords: *Nuclear Power Plants, Nanofiltration, Radioactive Wastewater, pH Levels, Relative Flux*

Paper ID: P095

Effect of Main Chain Structure on Gas Transport Properties of Thermally Rearranged Polybenzoxazole Copolymers

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ABSTRACT

Thermally rearranged polybenzoxazole copolymers (TR-PBOs) were prepared by thermal rearrangement of poly(*o*-hydroxy imide)s and exhibited high gas permeability, which was attributed to their high fractional free volume (FFV) [1]. It has also been reported that thermally rearranged polybenzoxazole copolymers (TR-*co*PBOs) with fluorene ring moieties introduced into the main chain exhibited greatly enhanced gas permeability at certain copolymerization compositions [2][3]. It is believed that the partial introduction of the fluorene ring moiety into TR-*co*PBOs causes steric repulsion and suppression of molecular chain packing, resulting in the specific increase in gas permeability. In this presentation, we focus on the specific gas permeability enhancement in TR-*co*PBOs with a fluorene ring moiety in the main chain. The effect of the main chain structures on the specific gas permeability was evaluated with a single gas. A series of TR-*co*PBOs without fluorene ring moieties were synthesized by polycondensation of three types of hydroxydiamine monomers (2,2'-bis(3-amino-4-hydroxyphenyl)hexafluoropropane (6FAHP), 3,3'-dihydroxybenzidine (HAB), and 2,2-bis(3-amino-4-hydroxyphenyl)propane (APA)) with dianhydrides in various molar ratios. As a result, TR-coPBOs without fluorene ring moieties, as well as TR-coPBOs with the moieties, showed specific gas permeability enhancement. Among the TR-coPBOs without the moieties, those with trifluoromethyl groups in the polymer backbone showed 2141 Barrer in gas permeabilities that were 2.4 times higher than the calculated value at the specific copolymer composition, while those with methyl groups had gas permeabilities as calculated. The gas separation performance using CO2/N2 mixed gas in TR-*co*PBOs with fluorene ring moiety in the main chain will be discussed.

Keywords: *Polybenzoxazole, Copolymer, Thermal rearrangement*

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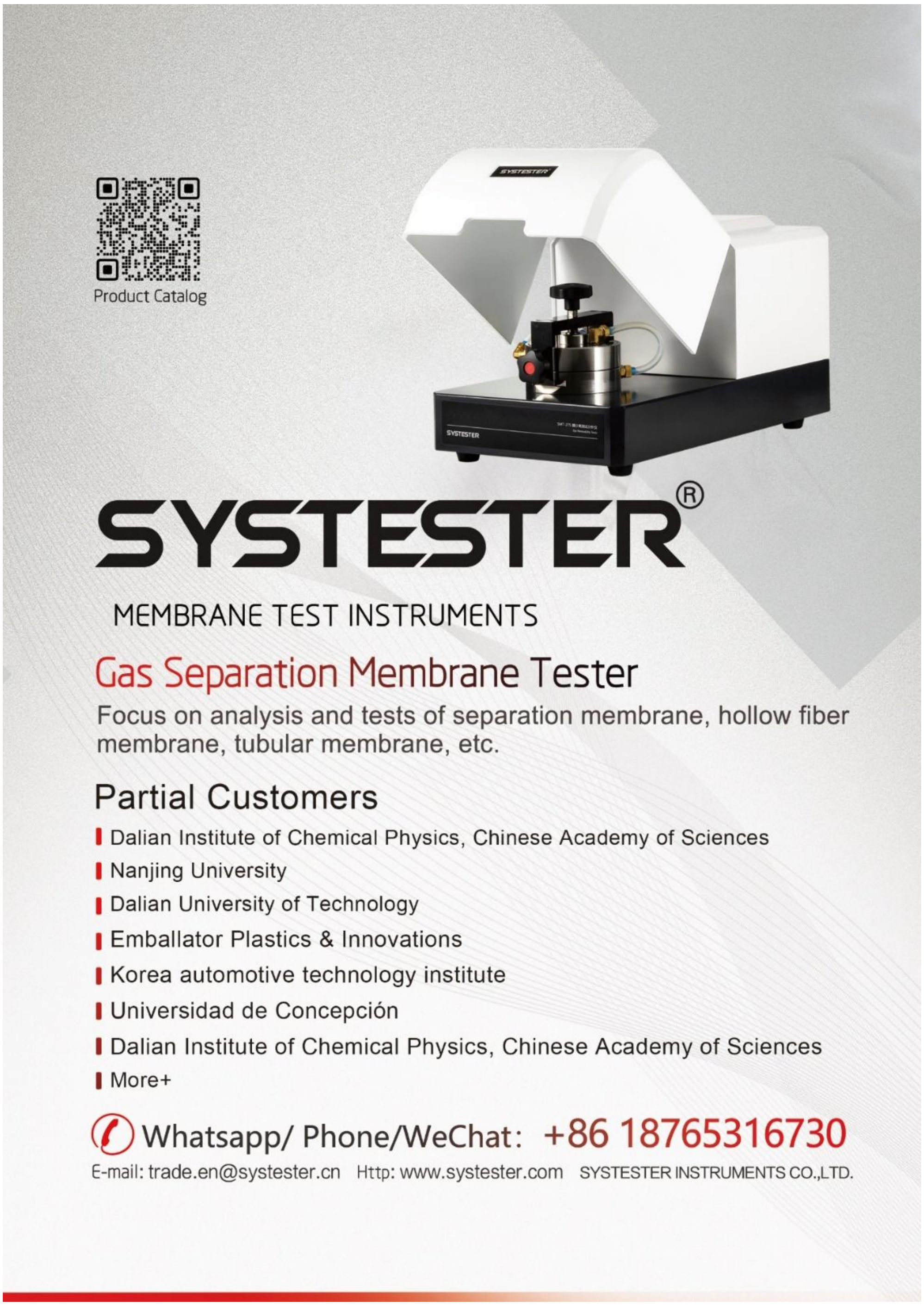

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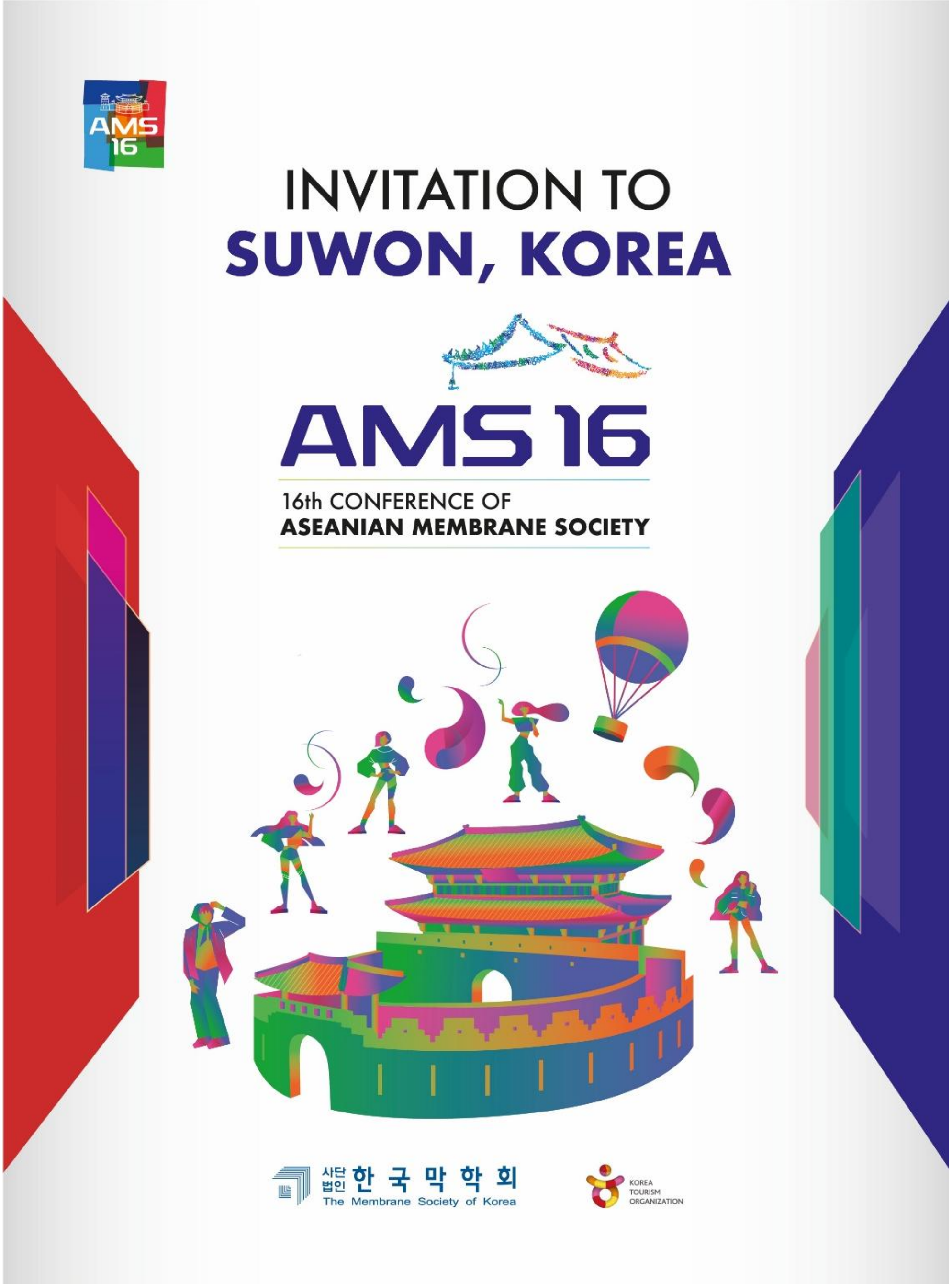

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