



October 4–7, 2026 ● Prague

MELPRO 2026

**International conference focused on
membrane and electromembrane processes,
where industrial leaders and world-class
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BOOK OF ABSTRACTS

Organized by CZECH MEMBRANE PLATFORM
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Book of Abstracts, MELPRO Conference, 2026

Edited by Czech Membrane Platform & AMCA

Published by Czech Membrane Platform in 2026

Abstracts, except for their headings, are published without editing.

ISBN 978-80-909640-4-4

ISSN 2694-8958

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ISBN 978-80-909640-4-4



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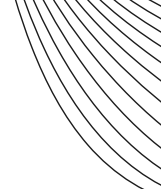


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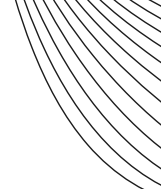
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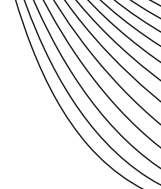
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PREFACE

Dear Colleagues, Ladies and Gentlemen,

On behalf of the **Czech Membrane Platform**, it is our distinct pleasure to welcome you to the seventh international conference **MELPRO 2026**, a premier event dedicated to the advancement of membrane and electromembrane processes across research, development, and industrial applications. Following the highly successful integration of our previous edition into **EUROMEMBRANE 2024** in Prague – which significantly enhanced the international visibility of the MELPRO series – we are delighted to return to our independent format and continue building upon this long-standing tradition.

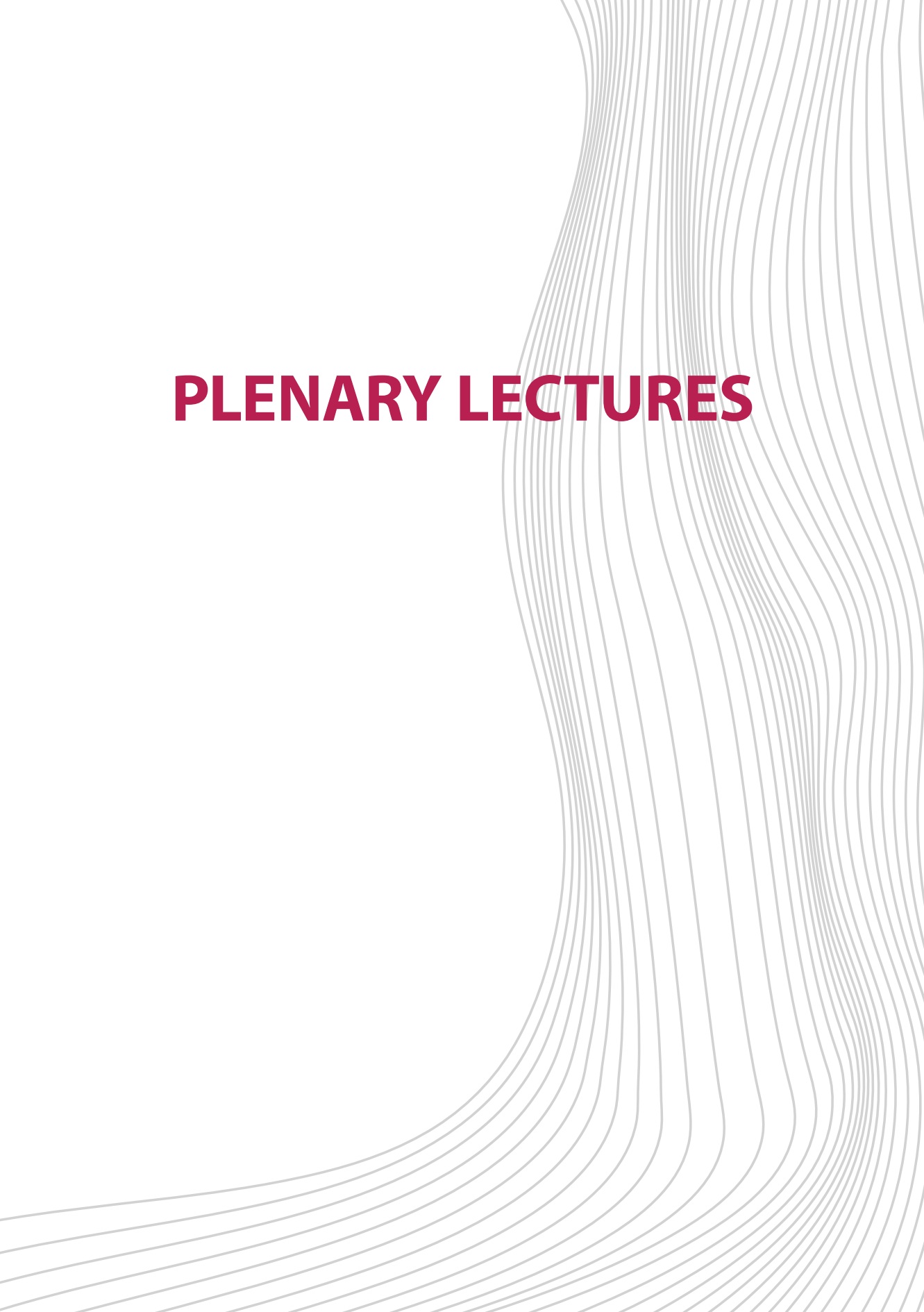
The MELPRO conferences have consistently served as a vital forum where experts from academia, industry, and research institutions gather to exchange knowledge, debate novel ideas, and explore emerging trends in membrane science. Following the virtual edition in 2020 and the exceptional joint event in 2024, we are thrilled to welcome you once again in person. We believe that nothing can truly replace the value of direct interaction, spontaneous informal discussions, and the vibrant atmosphere that face-to-face meetings uniquely provide.

This year's contributions are organized into six key thematic areas, spanning from Pressure-driven and osmotic membrane processes to New trends in membrane applications. As with previous editions, a particularly strong representation can be found in the field of Novel membrane materials. Each session offers valuable insights and reflects the diversity, innovation, and growing importance of membrane technologies in addressing today's pressing environmental and industrial challenges.

We trust that **MELPRO 2026** will provide you with an inspiring scientific programme, fruitful discussions, and excellent opportunities for new professional collaborations. We wish you a pleasant and memorable stay in Prague, and we are confident that this year's conference will exceed your expectations. Thank you for being a part of this journey, and we look forward to welcoming you to future MELPRO meetings.

Czech Membrane Platform

PLENARY LECTURES

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INSIGHTS INTO THE ADSORPTION- AND PHASE BEHAVIOUR OF FLUIDS IN NANOPOROUS MATERIALS: TOWARDS AN ADVANCED TEXTURAL AND SURFACE CHARACTERIZATION

M. Thommes

Institute of Separation Science & Technology, Department of Chemical and Biological Engineering, Friedrich-Alexander University, Erlangen-Nürnberg (FAU)

Abstract: Nanoporous materials (e.g. carbons, zeolites, metal organic framework materials, ordered and hierarchically structured meso-macroporous oxides etc.) have been the subject of extensive research targeted towards a wide range of applications because of their unique textural properties (e.g., increased surface area and the ability to customize the pore size and pore size distribution). In addition, unique nano-confinement effects including shifts in the phase diagram of pore fluids and altered thermophysical properties can be observed. In order to utilize effects of nano-confinement in various application areas (e.g., separation, catalysis, gas-energy storage) a detailed understanding of the interplay between effective fluid-fluid and fluid-(pore) wall interactions on the one hand and the effects of confined pore space and pore geometry/pore network on the other hand is required.

Within this context, we discuss important aspects associated with the adsorption-, phase- and wetting behavior of fluids in nanoporous materials and link these with recent advances in the development and application of advanced and novel adsorption methodologies for assessing key aspects of (i) their pore network characteristics (e.g., pore connectivity, characteristic parameters correlated with of pore network disorder/restrictions), and (ii) pore surface properties (e.g., hydrophobicity/hydrophilicity).

SEEING THE INVISIBLE: MOLECULAR SIMULATIONS REDEFINING MEMBRANE OPERATIONS

E. Tocci

Institute on Membrane Technology, National Research Council of Italy (CNR-ITM), Via P.
Bucci 17/C, 87036 Rende (CS), Italy

Abstract: Membrane processes are increasingly challenged to achieve higher separation efficiency under stringent energy and material constraints. Transport phenomena govern their performance at nanoscales and at dynamic interfaces, where molecular interactions within confined environments remain largely inaccessible to experimental observation. Molecular simulations provide a unique framework for accessing these scales, enabling direct analysis of transport pathways, interfacial phenomena, and dynamic molecular rearrangements that determine separation performance. Beyond their traditional interpretative role, simulations are increasingly enabling the quantification of mechanisms governing selectivity, transport anomalies, and interfacial processes such as nucleation and crystallization at membrane surfaces. When integrated with experimental studies, multiscale modeling, and machine learning approaches, molecular simulations establish quantitative links between molecular behavior and macroscopic process performance. This integration is driving a transition from empirically optimized systems to predictive, rationally designed membrane processes. In this perspective, molecular-level phenomena are no longer hidden variables but become actionable parameters for process design, opening new opportunities for the development of more efficient and sustainable separation technologies. When combined with experimental studies, multiscale modeling, and machine learning, molecular simulations enable the transition from empirically optimized systems to rationally designed, predictive membrane processes. Seeing the invisible is therefore not only a matter of understanding, but a prerequisite for predictive membrane process design.

SCALABLE AND INTEGRATED MEMBRANE PROCESSES FOR INDUSTRIAL RESOURCE RECOVERY

M. Bobák¹, L. Šeda¹, M. Grošík¹

¹MemBrain s.r.o., Pod Vinicí 87, 471 27 Stráž pod Ralskem, Czech Republic
(marek.bobak@membrain.cz, www.membrain.cz)

Abstract: Industrial operations generate large volumes of saline wastewaters and by-products that are costly to manage and often lead to the loss of valuable resources. This plenary lecture presents an integrated membrane-based technology platform that converts such streams into marketable products — including high-purity solid salts, regenerated chemicals, and reusable water — while substantially reducing energy demand and residual waste. The work is focused on commercial applications with measurable economic benefits and resource recovery within a circular economy framework.

Presented will be a newly developed process that builds on the well-known ability of electrodialysis to concentrate aqueous solutions and integrates this effect into a membrane-based route for the recovery of sparingly soluble salts, without reliance on chemical additives or energy-intensive evaporation. The approach enables recovery of target salts as a high-purity product, with substantially improved energy efficiency and environmental performance compared to conventional alternatives, while also generating a reusable water stream suitable for minimal or near-zero liquid discharge concepts. Laboratory and pilot-scale validation demonstrate a step-change reduction in energy consumption and operating costs compared to conventional thermal or chemical routes, with ongoing pilot operation under real industrial conditions confirming scalability and robustness.

Beyond this flagship technology, the lecture will summarize key results in membrane-based recovery of salts and chemicals from industrial wastewaters, including electrodialysis with bipolar membranes (EDBM) for on-site regeneration of acids and bases from spent ion-exchange streams. These solutions close chemical loops, significantly reduce waste volumes, and are currently being piloted in industrial environments. Together, the presented results outline a coherent pathway from membrane research through pilot validation to industrial deployment and commercialization, delivering tangible environmental and economic advantages for water-, energy-, and chemical-intensive industries.

DEMONSTRATING THE POTENTIAL OF MOLECULAR-LEVEL ENGINEERING FOR THE PREPARATION OF HIGHLY EFFICIENT COMPOSITE MATERIALS FOR TARGETED GAS SEPARATIONS

S. Ashtiani¹, J. Schneider¹, J. Florečová¹, D. Gardenö¹, Z. Sofer², K. Friess¹

¹Department of Physical Chemistry, University of Chemistry and Technology Prague, Technická 5, Prague 6 16628, Czech Republic

²Department of Inorganic Chemistry, University of Chemistry and Technology Prague, Technická 5, Prague 6 166 28, Czech Republic

Abstract: Since 2020, our research group has been developing an innovative molecular engineering (MLE) concept for the fabrication of efficient mixed matrix membranes (MMM) for gas separation with targeted nanoparticles. The concept enables precise control of additive properties and their deposition, thereby eliminating the common weaknesses of material MMMs, such as randomness, phase separation, aggregation, and additive sedimentation. In general, MLE enables the targeted development of nanostructured MMMs for fabricating highly efficient membrane separation materials with tailored morphology and surface properties.

In the initial phase, we developed multifunctional magnetic nanoparticles (SMNPs) from metal-organic framework (MOF) UiO-66, decorated with $\text{Co}_{0.5}\text{Ni}_{0.5}\text{FeCrO}_4$ spinels, which were directly grown on oxidized single-walled carbon nanotubes (SWCNTs) and graphene oxide (GO) monolayers¹. Subsequently, a single-crystal magnetically responsive core-shell MOF UiO-66-NH₂ grafted with magnetic nanoparticles was prepared and exhibited magnetic-stimulus-responsive behavior. This material was used for controlled deposition in polymethyl methacrylate (PMMA)-based MMMs. The controlled deposition of the MOF yielded excellent permeability and H₂/CO₂ selectivity, exceeding the Robeson upper limit of 2008 compared to PMMA+MOF MMMs without controlled magnetic deposition². We further synthesized a channel layer of zeolite-imidazole framework (ZIF-8) nanoparticles on a free-standing, chemically modified single-walled carbon nanotube (SWCNT) membrane via chemical bonding. The SWCNT-ZIF-8 composite support was sprayed with a thick hydrophobic PDMS layer, and the resulting composite membrane exhibited improved mechanical and thermal stability, as well as excellent performance in CO₂/N₂ gas separation and C₃ olefin/paraffin vapor separation.³

Another example is the multifunctional 2D-MXene-based nanocomposite, in which CoFe₂O₄ nanoparticles are grafted onto Ti₃C₂T_x sheets and aligned in a polyethersulfone (PES) matrix via magnetic-field-assisted deposition. The resulting films synergistically combine structural organization with high stability, magnetic sensitivity, and exceptional sorption capacity. In addition, the material exhibits excellent gas separation performance, with an O₂ permeability of 67 Barrer and an

O₂/N₂ selectivity of 11.5, which exceeds the upper limit of Robeson theory across the temperature range from 298 to 350 K and at inlet pressures of 0.1 to 2 bar.⁴

In addition to the above examples, the lecture will present further examples demonstrating the MLE concept's ability to prepare highly efficient MMM separation materials from common polymers and with minimal nanoparticle content (< 10 wt.%). The above findings underscore the potential of the MLE concept to achieve simultaneous increases in permeability and selectivity for various gas pairs, thereby moving to the upper-right corner of the Robeson diagrams and potentially guaranteeing both performance and cost for successful use in industrial applications.

Keywords: Gas separation, Mixed matrix membranes, Molecular engineering, O₂/N₂ separation, Magnetic field, Chemical bonding, gas sorption

Acknowledgements: This research was supported by a project of the Grant Agency of the Czech Republic (grant no. 24-11041S) and a specific research grant of the University of Chemistry and Technology in Prague IGA no. A1_FCHI_2025_001 and 2026.

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INTERFACIAL POLYMERIZATION: NEW CHEMISTRIES, SYNTHESIS AND ADVANCED CHARACTERIZATION

S. P. Nunes

King Abdullah University of Science and Technology (KAUST)

Abstract: Interfacial polymerization has been one of the most successful methods of large-scale membrane fabrication with application in desalination and nanofiltration. The flexibility of the method enables a rich variety of approaches and exploration of monomers and reactions that could extend the applications to more challenging separations and minimize the limitations of the current membranes. Examples of membranes for reverse osmosis and nanofiltration developed in our research group will be presented. Among them are membranes based on macrocycles such as amino-functionalized cyclodextrin, crown ether and other monomers. The influence of pre-assembly of monomers on the membrane formation and performance will be discussed. The morphology of interfacial polymerized layers is complex. To fully understand the membrane formation and transport and be able to propose new approaches, we have been working at the frontier of the currently available methods of morphological characterization. We apply advanced methods of high-resolution transmission electron microscopy and synchrotron x-ray ptychography, with the objective of resolving sub-nanometer structures or providing information in water, closer to the operation conditions.

KEYNOTE LECTURES

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MEMBRANE DISTILLATION BEYOND DESALINATION: WHERE CAN THE TECHNOLOGY DELIVER REAL VALUE?

G. Viano¹, C. Quist-Jensen², A. Ali^{1*}

¹AAU Energy, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg Øst, Denmark

²Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg Øst, Denmark

Abstract: Membrane distillation (MD) has emerged as a promising thermally driven separation technology capable of producing high-quality water from highly saline, contaminated, and difficult-to-treat streams. However, despite decades of research and significant technological advancements, commercialization of MD has remained limited. This gap between apparent progress and industrial adoption highlights the need for a realistic reassessment of where MD can create real value and what barriers continue to hinder its commercial deployment.

This presentation draws on knowledge and experience gained from our three ongoing EU-funded projects, including [CORNERSTONE](#), [MELODIZER](#), and [SpurUP](#), to critically evaluate application domains where unique characteristics of MD can provide a clear technological and economic benefit. Attention is given to industrial wastewater treatment and resource recovery applications where significant quantities of low-grade heat are available but remain underutilized. The technology is especially attractive in applications requiring exceptionally high-quality water, such as the production of ultrapure water for green hydrogen production through water electrolysis.

At the same time, the presentation emphasizes that the availability of waste heat alone does not guarantee process viability. A comprehensive assessment of the overall energy footprint remains essential. In particular, electrical energy consumption associated with pumping and auxiliary equipment, as well as the often-overlooked cooling requirements of MD systems, can significantly influence both process performance and economic competitiveness. These factors must be systematically integrated into technology assessments and scale-up strategies.

The presentation concludes that the future success of MD lies in targeting applications where its unique strengths align with real industrial needs. The greatest opportunities exist where low-grade heat is abundant, water quality requirements are stringent, wastewater streams are challenging to treat, and integrated water-energy solutions generate additional value. By directing research, development, and commercialization efforts toward these high-impact niches, MD can move beyond its status as a promising laboratory technology to become a practical and economically viable solution for advanced water treatment and resource recovery applications.

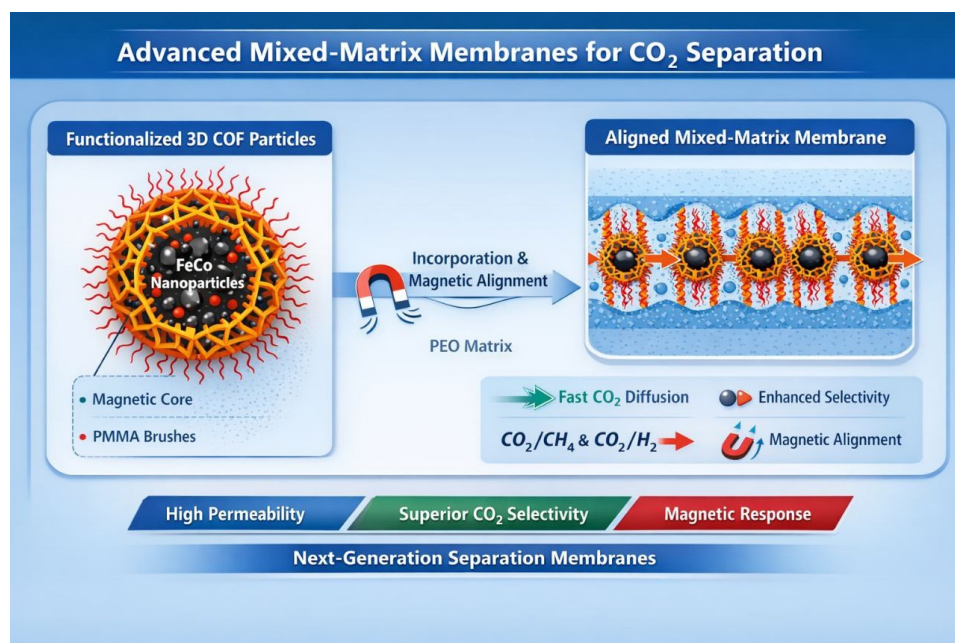
Acknowledgements: This work was funded by the European Union Horizon Europe Program under grant agreement numbers 101091915 (acronym “MEloDIZER”), 101072449 (acronym “CORNERSTONE”) and 101239566 (acronym “SpurUp”).

SYNERGISTIC MAGNETIC ALIGNMENT AND POLYMER-BRUSH FUNCTIONALIZATION IN 3D COF MIXED-MATRIX MEMBRANES FOR EFFICIENT CO₂/H₂ AND CO₂/CH₄ SEPARATION

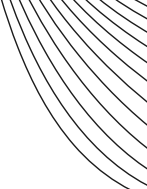
S. Ashtiani¹, P. Izak^{1,2}, K. Friess¹

¹Department of Physical Chemistry, University of Chemistry and Technology Prague, Technická 5, Prague 6, 16628 Czech Republic

²Institute of Chemical Process Fundamentals of the Czech Academy of Sciences, Rozvojová 135, 165 00 Prague 6, Czech Republic



Abstract: We report a high-performance mixed-matrix membrane (MMM) for efficient CO₂/CH₄ and CO₂/H₂ separation, achieved by integrating magnetically responsive three-dimensional covalent organic frameworks (3D COFs) functionalized with polymer brushes into a poly(ethylene oxide) (PEO) matrix. The 3D COF scaffold, prepared via Schiff-base condensation of tetrahedral amine and aldehyde monomers, provides a robust, isotropic microporous network featuring interconnected transport channels. To improve filler–matrix compatibility and impart CO₂-selective affinity, poly(methyl methacrylate) (PMMA) brushes were covalently grafted onto the COF surfaces through surface-initiated polymerization. These brushes enhance interfacial adhesion with the PEO phase suppressing non-selective voids at high loadings and create confined domains that boost CO₂ solubility via favourable interactions.



Incorporation of magnetic FeCo nanoparticles within the COF pores enables external magnetic-field alignment during solvent evaporation casting, yielding oriented filler structures with minimized diffusion tortuosity. This hierarchical design synergistically overcomes the permeability–selectivity trade-off: magnetic alignment establishes low-resistance pathways for enhanced permeance, while brush functionalization selectively augments CO₂ solubility and diffusivity in pore-confined regions, improving ideal selectivities for both gas pairs without compromising flux. Brush-mediated interfacial rigidification further eliminates defects, preserving selectivity at elevated filler contents.

Gas permeation data reveal substantially higher CO₂ permeability and CO₂/H₂ and CO₂/CH₄ selectivities compared to neat PEO, surpassing the 2008 Robeson upper bound. Structural integrity is confirmed by PXRD, TEM, SEM, and XPS, demonstrating retained COF crystallinity, uniform brush coverage, homogeneous dispersion, and effective alignment. This modular approach leveraging 3D COF topology, tailored brush chemistry, and magnetic organization establishes a versatile platform for advanced, energy-efficient polymeric gas separation membranes that exceed conventional material limits.

Keywords: COF, MLE, Polymer brush, MMM, Magnetic

Acknowledgement

The authors are grateful for support from the Czech Science Foundation (GAČR 24-11041S) and GAČR 24-10288S.

MIXED MATRIX MEMBRANES WITH TAILORED POROUS FILLERS FOR ENHANCED GAS SEPARATION AND CO₂

M. Carta^{1,2,3}, C. Grazia Bezzu¹, A. Al Ruwaili¹, M. Taddei⁴, M. Lessi⁴, F. Nerli⁴, A. Fuoco³, M. Vaccaro³, C. Rizzuto³, J.C. Jansen³

¹Department of Chemistry, Swansea University, Faculty of Science and Engineering, Singleton Park, Swansea, SA28PP, UK.

²Instituto de Síntesis Química y Catálisis Homogénea, CSIC-Universidad de Zaragoza, C/Pedro Cerbuna 12, Facultad de Ciencias, Zaragoza 50009, Spain

³Institute on Membrane Technology “Enrico Drioli”, National Research Council of Italy (CNR-ITM), via P. Bucci 17/C, Rende (CS), 87036, Italy

⁴Department of Chemistry and Industrial Chemistry, University of Pisa, via G. Moruzzi 13, 56124 Pisa, Italy.

Abstract: The development of energy-efficient processes for gas separation and carbon dioxide (CO₂) valorisation is a central challenge in the transition toward low-carbon industrial systems. Among emerging technologies, mixed matrix membranes (MMMs) represent a highly promising approach due to their ability to combine polymer processability with the superior transport and sorption properties of porous fillers. In this work, we report the systematic design of MMMs based on different classes of porous materials, including metal-organic frameworks (MOFs) and porous organic Polymers (i.e. PIMs and hypercrosslinked polymers), with tailored pore structures and surface functionalities. Particular attention is devoted to optimizing polymer-filler interactions to minimize non-selective interfacial voids and enhance molecular sieving effects. The influence of filler loading, particle size, and chemical functionalization on membrane morphology and transport properties is critically analysed using SEM, FTIR and sorption techniques. Gas permeation experiments are performed with CO₂/N₂ for the potential in carbon capture and H₂/N₂ and O₂/N₂ to better test the enhanced molecular sieving. Selected MMMs exhibit significantly enhanced performance, approaching or exceeding Robeson upper bounds. The improved performance is attributed to synergistic effects between preferential CO₂ adsorption and controlled diffusion pathways within the hybrid structure.

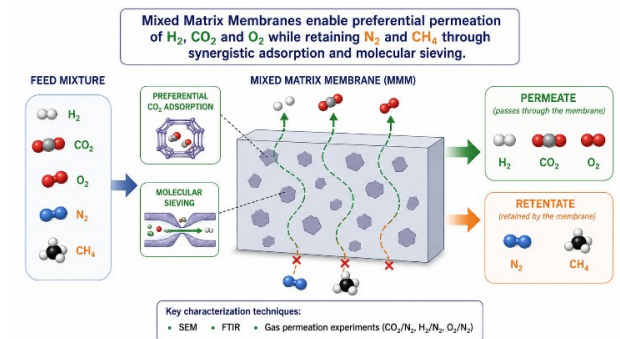


Figure 1. Conceptual cartoon illustrating the main topics of the presentation.

RESEARCH AND INDUSTRIALIZATION OF ADVANCED MEMBRANES FOR GAS-LIQUID SEPARATION

Z. L. Cui

State Key Laboratory of Materials-oriented Chemical Engineering, College of Chemical Engineering, Nanjing Tech University, Nanjing 210009, China (zcui@njtech.edu.cn)

Abstract: Efficient removal of dissolved gases is critical for industries ranging from semiconductor manufacturing to pharmaceutical production and extracorporeal blood treatment, where even trace gases compromise process quality. Membrane contactors offer a compact, chemical-free alternative to conventional degassing, yet their full potential demands systematic integration of material design, fabrication, module engineering, and surface functionalization.

We established a green thermally induced phase separation (TIPS) platform using acetyl tributyl citrate (ATBC) for both poly-4-methyl-1-pentene (PMP) and polypropylene (PP) membranes. Their distinct formation mechanisms were elucidated by correlating quench conditions, polymer concentration, and diluent composition with membrane morphology and transport properties, yielding material-specific fabrication protocols.

Building on optimized hollow fiber membranes, we progressed to the module level, where fiber packing density and flow configuration were engineered to maximize mass transfer. The integrated contactors were validated across multiple applications: dissolved oxygen in semiconductor ultrapure water was reduced to ~ 1 ppb; ink degassing achieved < 3 ppm¹; and NH_4^+ -N in medical wastewater was reduced from 13,900 to 390 ppm (94.50% removal) under horizontal countercurrent flow².

To overcome membrane wetting, the principal durability bottleneck, fluorine-containing coatings (Hyflon AD[®] and fluorinated nano-SiO₂) were applied to PP membranes, improving long-term stability and raising NH_4^+ -N removal to 98.94% (1,040 to 10 ppm) in aggressive streams. Extending the platform to biomedical applications, PMP membranes were evaluated for CO₂ removal in extracorporeal membrane oxygenation (ECMO), with surface modifications enhancing hemocompatibility and suppressing plasma leakage³.

This systematic platform, spanning green fabrication, module engineering, and surface functionalization, has been industrialized through spin-off company Jiangsu IKMO High-tech Co., Ltd. Deployed in semiconductor manufacturing and exceeding the most stringent industry standards, the technology establishes membrane degassing as a scalable, high-precision solution for critical industries.

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EMERGING INDUSTRIAL APPLICATIONS OF ELECTROMEMBRANE PROCESSES

T. Dornik

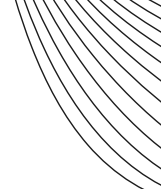
MEGA a.s., Pod Vinicí 87, 471 27 Stráž pod Ralskem, Czech Republic (www.mega.cz)

Abstract: Electromembrane processes — electrodialysis (ED), electrodialysis reversal (EDR), electrodeionization (EDI) and electrodialysis with bipolar membranes (EDBM) — are established in brackish water desalination and in the production of ultrapure water. Over the past decade the centre of industrial interest has shifted from desalination as such towards the separation, concentration, and conversion of ions as a route to recovering water, salts and reagents from streams previously handled as waste. This contribution reviews the applications emerging from that shift and the process characteristics behind them.

Three drivers are examined. Discharge limits on salinity, sulphate and chloride are tightening across jurisdictions, so that dilution has ceased to be a defensible compliance strategy. Acid and caustic prices follow energy markets, which makes on-site regeneration of reagents a hedge rather than merely an environmental measure. And water scarcity, together with decarbonisation commitments, favours unit operations driven by electricity rather than by heat since electricity can be supplied from renewable sources.

The applications are grouped by the function the membrane stack performs in the flowsheet. Concentration duties place ED or EDR ahead of evaporation in zero and minimal liquid discharge schemes, in water recovery from mine and tailings waters, and in the post-treatment of reverse osmosis reject, where the absence of an osmotic pressure limit allows brines to be taken beyond the reach of hydraulically driven processes. Conversion duties rest on the bipolar membrane, which dissociates water into H^+ and OH^- so that a spent salt stream returns to service as its corresponding acid and base: regeneration of ion-exchange eluates, caustic recovery in textile dyeing, valorisation of process brines, and the electrical regeneration of alkaline absorbents in carbon capture, where avoiding thermal stripping is the principal motivation. Purification and product duties cover EDI for electrolyser feed water in green hydrogen and for rinse water in semiconductor manufacture, and electrodialysis metathesis for lithium, in which separation and reaction are combined in a single stack.

Common to these cases is that feasibility is governed by the ionic composition of the feed rather than by its nominal salinity: scaling species, organic load and temperature determine the pretreatment train, the attainable concentration, and the specific energy consumption. The contribution closes with the limitations that still constrain deployment — current efficiency and co-ion leakage at high concentration, membrane lifetime under aggressive cleaning, and the transfer of laboratory performance to industrial scale.



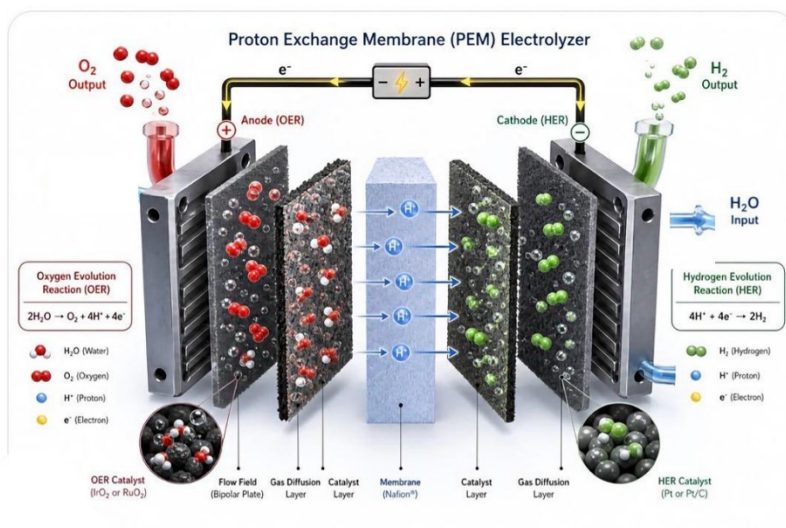
H₂ PRODUCTION BY MEANS OF MINIATURIZED PEM ELECTROLYZERS FOR SPACE APPLICATIONS

E. Esposito¹, A. Minotti², E. Fontananova¹, M. Longo¹, J. C. Jansen¹, A. Figoli¹

¹Institute on Membrane Technology "Enrico Drioli" – National Research Council (CNR-ITM), Via P. Bucci 17/c, 87036 Rende (CS), Italy

²MIPRONS srl, Via Lauri 32, 00037, Segni (RM)

Abstract: Hydrogen produced by proton exchange membrane (PEM) water electrolysis represents a promising solution for future space propulsion systems, offering a clean and efficient energy vector. This work presents the development and optimization of a miniaturized PEM electrolyser based on a membrane active area of 36cm² and compact dimensions.



The study focuses on the influence of operating conditions and cell components on the electrochemical performance, with particular attention to the reduction of energy losses and the improvement of overall efficiency. Hydrogen production rates of about 0.02 g min⁻¹ were achieved, while optimization of clamping pressure, gas diffusion layers, and cell-stack configurations allowed energy efficiency values close to 80%, meeting the target requirements for aerospace applications.

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DOUBLE ACTIVE MEMBRANES FOR A SUSTAINABLE CO₂ CYCLE: THE DAM4CO₂ PROJECT

A. Fuoco, and the DAM4CO₂ consortium

National Research Council of Italy (CNR-ITM and CNR-ICCOM); National Interuniversity Consortium of Materials Science and Technology (INSTM, UniTO, UniPI, UniPG); Universitat Politècnica de València (UPV); Swansea University; The University of Edinburgh; Me-Sep; Primalchit Solutions; Instituto de Síntesis Química y Catálisis Homogénea, CSIC-Universidad de Zaragoza

Abstract: DAM4CO₂ is an EIC Pathfinder project that aims to develop an innovative membrane technology for the integrated capture and photocatalytic conversion of CO₂ into C₄₊ hydrocarbons, enabling the production of renewable fuels.^{1,2} The project addresses the limitations of conventional membrane systems through the design of Double Active Membranes (DAMs), which combine a durable and highly selective CO₂ separation layer with a photocatalytic layer capable of driving, in a single integrated process, the Reverse Water-Gas Shift (RWGS) reaction and Fischer-Tropsch Synthesis (FTS). This approach enables the direct conversion of captured CO₂ into higher-value C₄₊ molecules. This presentation will introduce the vision and objectives of the DAM4CO₂ project, provide an overview of the consortium and its multidisciplinary expertise, and highlight the main scientific and technological achievements obtained to date. In addition, the presentation will briefly showcase the activities of the EIC Portfolio on CO₂ and Nitrogen Management and Valorisation, emphasizing synergies and collaborative opportunities within the portfolio.³

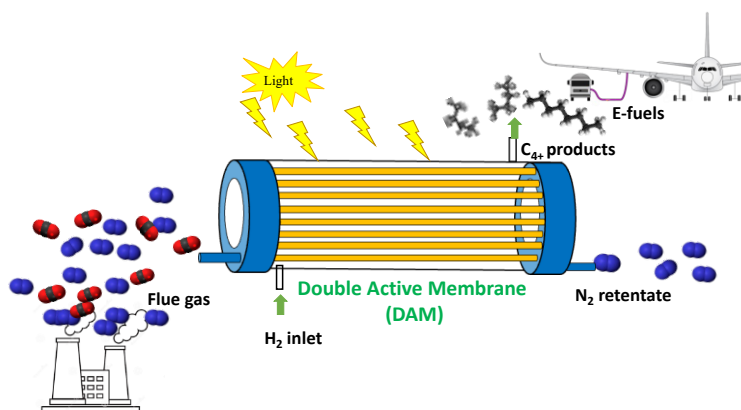


Figure 1 Graphical Abstract of the DAM4CO₂ project

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BEYOND PASSIVE BARRIERS: TUNING WATER VAPOR TRANSPORT THROUGH MEMBRANE MORPHOLOGY FOR SELECTIVE AMMONIA RECOVERY

E. Guillen-Burrieza^{1*}, M. Prado-Padín¹, H. Bazargan Harandi¹,
L. García-Fernández², C. García-Payo², M. Khayet²

¹Chemical Engineering Department, Polytechnic University of Catalonia, BarcelonaTECH,
C/Eduard Maristany 10-14, 08930 Barcelona, Spain (elena.guillen@upc.edu)

²Department of Structure of Matter, Thermal Physics and Electronics, Faculty of Physics,
University Complutense of Madrid, Avda. Complutense s/n, 28040 Madrid, Spain

Abstract: The selective recovery of ammonia from liquid waste streams remains a key challenge in resource recovery, particularly for producing a gaseous product suitable for valorization as a fuel or chemical feedstock. Vacuum membrane distillation (VMD) is a promising approach, as membrane distillation (MD) systems have demonstrated robust operation in wastewater treatment and relatively high ammonia fluxes [1], which may enable lower capital costs compared to alternative technologies. However, the application of vacuum provides a continuous driving force for water vapor transport across the membrane. As a result, the recovered ammonia stream is typically “wet,” containing significant co-transported water vapor, which reduces product quality and limits downstream applications [2]. Therefore, reducing water vapor permeation while maintaining ammonia transport is a critical objective for improving process selectivity.

Building upon previous work by the authors [3], which developed a model linking membrane morphology to ammonia flux and selectivity, this study experimentally examines the role of morphology under realistic casting and VMD conditions. PVDF membranes with similar pore size and thickness were fabricated using different NIPS casting conditions (e.g., solvent system, polymer concentration, drying time) to tailor morphology while keeping nominal structural parameters comparable.

The prepared membranes exhibited distinct morphological characteristics, particularly with respect to structural asymmetry of their cross-section. Relative to a symmetric commercial PVDF membrane (Amersham™ Hybond™ SEQ 0.2 PVDF, Cytiva, USA) of comparable pore size and thickness, the developed membranes achieved up to 78% higher ammonia/water vapor selectivity at relatively low ammonia feed concentrations (i.e., 2 g NH₃/l). The results demonstrate the strong dependence of separation performance on membrane morphology, with asymmetric structures comprising a thin selective skin layer and a sponge-like porous core showing the highest selectivity effectively suppressing water vapor transport while sustaining ammonia permeation (maximum selectivity of 6.0% at 10–11 mbar TMP vs. 3.4% for the commercial membrane).

Although membranes in MD are often regarded as passive barriers enabling evaporation while remaining non-selective to volatile mixtures, this work demonstrates that membrane morphology can impart measurable selectivity effects. This morphology-dependent transport behavior can be leveraged to tune membrane selectivity, opening opportunities for targeted separation of volatile species. By linking casting conditions directly to specific morphological features and performance outcomes, the study further advances the rational design of membranes for selective ammonia recovery. Ongoing statistical analysis (ANOVA) will enable correlation of casting conditions with resulting morphological features, and of morphological features with membrane performance (Figure 1).

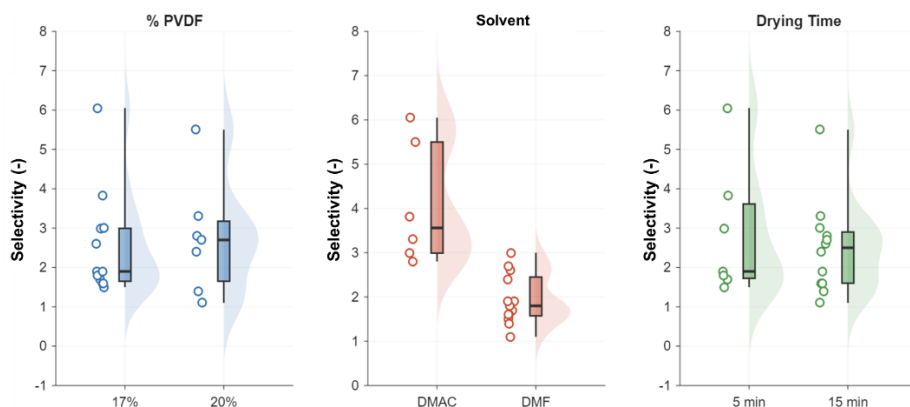


Figure 1. Preliminary ANOVA results showing the distribution of ammonia/water vapor selectivity for the prepared membranes as a function of key fabrication parameters: polymer content (% PVDF), solvent type (DMAC vs DMF), and drying time (5 vs 15 min), highlighting the influence of casting conditions on membrane performance.

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PIEZO DIALYSIS USING CHARGED MOSAIC MEMBRANES TOWARD NEXT-GENERATION DESALINATION TECHNOLOGY

M. Higa^{1,2,3}, H. Yoshida², S. Isikawa², S. Sawada⁴, H. Koshikawa⁴,
T. Yamaki⁴, M. Higa^{*1,2}

¹Blue Energy center for SGE Technology (BEST), Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan

²Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan

³School of Materials and Chemical Technology, Institute of Science Tokyo, 2-12-1, Ookayama, Meguro-ku, Tokyo 152-8550, Japan

⁴National Institutes for Quantum Science and Technology, 1233 Watanuki-machi, Takasaki, Gunma 370-1292, Japan

Abstract: Global water scarcity has become an urgent challenge, creating strong demand for efficient and sustainable desalination technologies. Among emerging membrane-based approaches, Charged Mosaic Membranes (CMM) have attracted attention due to their unique structure, in which negatively and positively charged layers are arranged in parallel through the membrane thickness and penetrate both membrane surfaces [1]. This structure generates a circulating current inside [1] and exhibits electrolyte permselectivity and desalination capability; hence, it is expected to be applied to desalination for drinking water and separation and concentration in the food and pharmaceutical fields. Under piezo dialysis, CMMs preferentially transport electrolytes far less abundant than water, offering the potential for significantly lower energy consumption than conventional reverse osmosis (RO) membranes.

Although many fabrication methods for CMMs have been proposed, conventional CMMs suffer from weak interfacial bonding between oppositely charged layers, causing water leakage under piezo dialysis and limiting practical application. In this study, we developed a high-strength CMM using an ion beam-induced ion track grafting polymerization method (IB-CMM [2]). The base membrane was irradiated to form latent tracks. In IB-CMM, ion channels are introduced through covalent bonding, which significantly enhances the interfacial strength between the oppositely charged layers.

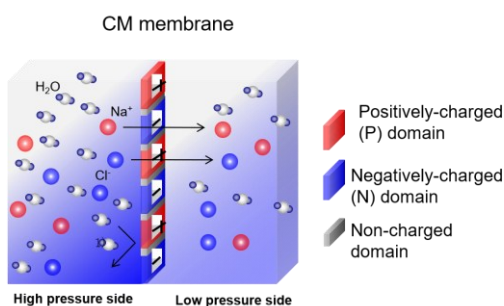


Fig.1 Schematic diagram of the charged structure and principle of electrolyte permselectivity of a charged mosaic membrane.

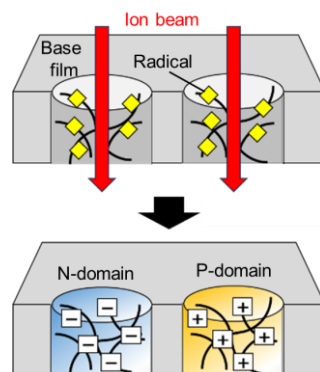


Fig. 2 Preparation process of a CM membrane by ion track graft polymerization (One step method) .

As a base material, ETFE was irradiated with a heavy ion beam with 310 MeV ⁸⁴Kr to generate radicals that initiate the polymerization of Ethyl p-styrenesulfonate monomers to form negatively-charged channels. Next the base material was irradiated again to form positively-charged channels by grafting chloromethylstyrene monomers and by quaternizing with trimethylamine [3]. The ion transport properties of the IB-CMM were evaluated by water permeation measurements, diffusion dialysis, and piezo dialysis.

Structural observation using TEM and EDX confirmed the IB-CMM had nano-order of positively- and negatively- charged channels. IB-CMM showed negative osmosis in water permeation measurements. Piezo dialysis desalination performance was evaluated using NaCl solutions (500–6000 ppm) under applied pressures of 0.5–3.0 MPa. IB-CMM exhibited clear desalination behavior, achieving desalination rates approximately 3–50 times higher than conventional CMMs while maintaining water permeability comparable to a commercial RO membrane. Further improvements in desalination performance are expected through membrane thinning and optimization of fabrication conditions.

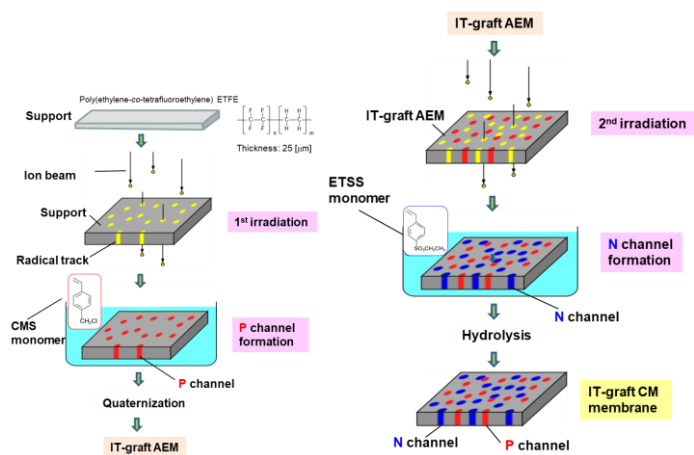


Fig. 3 Preparation process of a CM membrane by ion track graft polymerization (Two step method) .

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OPERATIONAL PERFORMANCE OF A MINIMAL LIQUID DISCHARGE SYSTEM FOR DAIRY WASTEWATER RECLAMATION

D. Horňák, M. Procházková, V. Miklas and M. Vondra

Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic
(david.hornak1@vut.cz)

Abstract: The dairy sector is a major consumer of freshwater and a significant source of wastewater, with dairy plants in EU-27 countries generating an estimated 192.5 million m³ of wastewater annually¹ Minimal Liquid Discharge (MLD) technologies offer the potential to recover up to 95% of this water² yet their broader deployment remains limited by technological complexity, energy demand, and challenges in managing both the produced concentrate and membrane fouling.

This contribution builds upon previous research³ describing an MLD system in which dairy wastewater is treated by microfiltration (MF) and reverse osmosis (RO) to recover reusable water, while the retentates from both stages are concentrated in an agitated vacuum evaporator (AGEV), and the final concentrate is processed by anaerobic digestion (AD) for energy recovery. Extending that work, the present study introduces and experimentally validates a distillate recycle stream, in which the AGEV distillate is returned to the RO feed to enhance permeate quality (Figure 1).

The aim of this work is to evaluate the operational performance of the system under optimized conditions established through prior techno-economic assessment, with particular attention to the hydraulic stability of the membrane stages and the quality of the reclaimed water. The MF stage was operated with periodic hydraulic backwashing to mitigate fouling, while the RO stage was tested under intensified operating conditions to enhance permeate flux. The physico-chemical and microbiological quality of the reclaimed water was assessed against the requirements for agricultural reuse defined in EU Regulation 2020/741.

The results confirm the high removal efficiency (>95%) of the MLD system across all monitored water quality parameters and demonstrate that the optimized operating regime substantially improves the hydraulic performance and operational stability of the membrane processes. The integration of the distillate recycle stream further improved the quality of the final reclaimed water (see Table 1). The permeability of the MF increased from 10.8 l/m²·h·bar to 58 l/m²·h·bar, while the permeability of the RO process increased from 1.0 to 2.0 l/m²·h·bar. Microbiological analysis revealed that the RO permeate did not meet the hygienic requirements for safe water reuse; a final UV disinfection step is therefore proposed to ensure the microbiological safety of the reclaimed water and to establish the MLD system as a robust solution for sustainable water reclamation in the dairy industry.

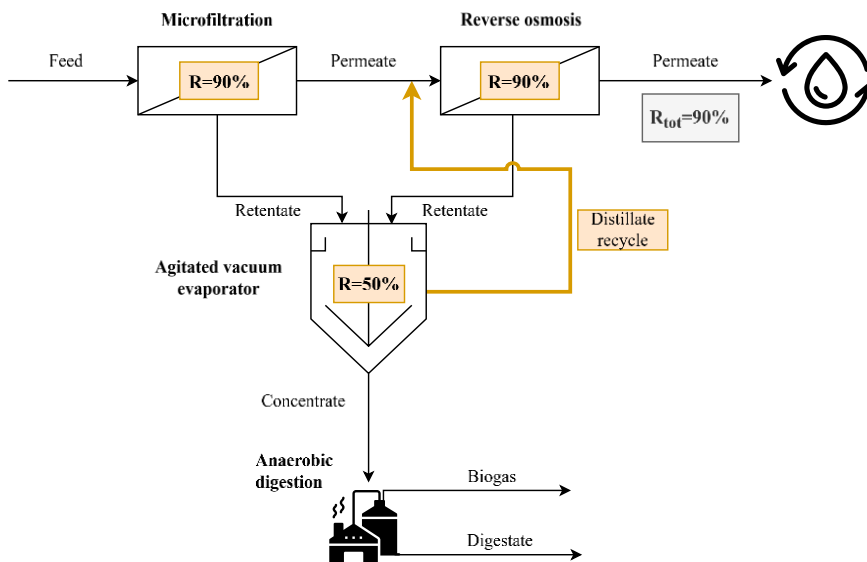


Figure 1 Scheme of the proposed MLD system with targeted water recovery rates

Table 1 Comparison of RO permeates water quality

Water quality parameters	Feed water	RO permeate (without distillate recycle)	RO permeate (with distillate recycle)
pH [-]	5.3	6.3	6.4
EC [$\mu\text{S}/\text{cm}$]	5,540	184	133
COD [mg/L]	4,320	66	66
BOD [mg/L]	1,920	18.7	11.5
TSS [mg/L]	1,080	<2	<2
NH ₄ -N [mg/L]	12.2	0.2	0.1
TN [mg/L]	155	6.6	3.8
TP [mg/L]	29.3	0.5	0.2

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PHOTOCHROMIC PROBES FOR MODULATING GAS PERMEABILITY IN POLYMERIC MEMBRANES

J.C. Jansen, M. Macchione, E. Drioli, M. Longo, F. Saeed, E. Bonyadi, S. Capizzano, E. Esposito, A. Fuoco, M. Monteleone, E. Tocci.

Consiglio Nazionale delle Ricerche, Istituto per la Tecnologia delle Membrane “Enrico Drioli” (CNR-ITM), Via P. Bucci 17/C, 87036 Rende (CS), Italy.
(johannescarolus.jansen@cnr.it).

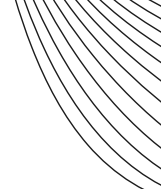
Abstract: Photochromic probes such as azobenzene and stilbene derivatives have been used to probe the free volume elements^{1,2} and sense the glass transition³ and physical aging phenomena⁴ in polymers. One of the basic assumptions of successful probing of the polymer matrix is that the matrix itself is not affected by the probe. Remarkably, we found that some probes may radically change the gas permeability in membrane materials such as the perfluorinated glassy polymer Hyflon® AD60X. For instance, photochromic switching of the azobenzene probe from the cis- to the trans-configuration leads to a radical increase in CO₂ permeability and simultaneous increase in CO₂/CH₄ ideal selectivity, and time lag measurements reveal that the change is mainly a result of an increase of CO₂ solubility. This process is largely reversible and alternating irradiation with UV and visible light to switch from the trans- to the cis-configuration and back makes the membrane performance jump from one side to of the 1991 upper bound the other for CO₂/CH₄.

In this work we extend the preliminary single gas permeation measurements and off-line switching, to mixed gases and to online switching of the probes in a specially designed cross-flow cell with quartz window. We will discuss the effect of the polymer and probe type, as well as the switching conditions, such as light intensity, wavelength, and duration of the irradiation. Furthermore, experimental results will be supported with molecular modelling studies.

Acknowledgements: This work has received funding from the European Union’s Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101168776 (PhotoBrane).

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ENGINEERING COMPACTION-RESISTANT REVERSE OSMOSIS MEMBRANES FOR HYPERSALINE BRINE DESALINATION: FROM FUNDAMENTAL COMPACTION MECHANISMS TO HIGH-PRESSURE RO APPLICATIONS

Y.J. Lim, N. Nadzri, Q. Xue, Y. Liang, C. Li, K. Goh, R. Wang

Singapore Membrane Technology Center, Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore (yujie.lim@ntu.edu.sg)

Abstract: Minimum liquid discharge (MLD) is increasingly recognized as a key objective for sustainable seawater desalination, requiring technologies capable of concentrating reverse osmosis (RO) brines beyond the limits of conventional seawater RO (SWRO). High-pressure reverse osmosis (HPRO), operating at pressures exceeding 120 bar, offers a lower-energy alternative to thermal brine concentration processes. However, membrane compaction under extreme hydraulic pressures remains a major barrier to widespread implementation. This work presents a comprehensive investigation into membrane compaction, membrane design, and process performance for hypersaline brine desalination using HPRO. Commercial thin-film composite (TFC) membranes were first evaluated under HPRO conditions using synthetic SWRO brine ($70 \text{ g L}^{-1} \text{ NaCl}$) at pressures up to 200 bar (Ref. [1]). Structural characterization revealed significant densification of both support and polyamide layers, resulting in irreversible permeability losses. Mechanical analysis identified support-layer tensile strength and Young's modulus as critical parameters governing resistance to compaction. Building upon these findings, custom TFC membranes with tailored support and polyamide architectures were fabricated to establish design principles for HPRO operation (Ref. [2]). A membrane comprising a sponge-like polysulfone support and a highly crosslinked, low-protuberance polyamide layer exhibited the greatest structural stability, maintaining 98.6% salt rejection and a water permeability of $0.39 \text{ L m}^{-2} \text{ h}^{-1} \text{ bar}^{-1}$ under HPRO conditions despite substantial support compression. To assess the practical value of improved membrane properties, module-scale simulations were performed (Ref. [3]). Increasing membrane permeability from 0.45 to $1.35 \text{ L m}^{-2} \text{ h}^{-1} \text{ bar}^{-1}$ was predicted to reduce specific energy consumption by up to 23% or decrease pressure-vessel requirements by 62% for an HPRO system operating at 50% recovery. Experimental evaluation of twelve state-of-the-art RO membranes under hypersaline conditions demonstrated water permeabilities ranging from 0.34 – $0.87 \text{ L m}^{-2} \text{ h}^{-1} \text{ bar}^{-1}$ while maintaining 98.7–99.6% salt rejection. To further enhance HPRO performance, MXene-interlayered thin-film nanocomposite (TFNi-MXene) membranes were developed using a scalable brush-coating process (Ref. [4]). The optimized membrane exhibited 17% higher permeability than a TFC control under SWRO conditions while maintaining high salt rejection and improved resistance to compaction during HPRO operation. Module-scale simulations predicted an 8.3% reduction in energy consumption, and five-day testing with real SWRO brine

confirmed stable operation with $40 \text{ L m}^{-2} \text{ h}^{-1}$ flux and 98.8% solute rejection. Collectively, these results establish a framework for designing next-generation HPRO membranes and demonstrate the potential of HPRO as an enabling technology for brine minimization, minimum liquid discharge, and sustainable desalination.

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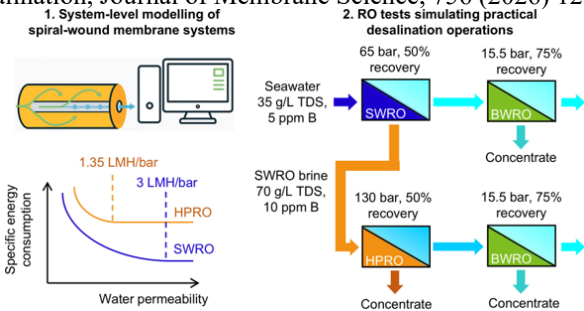


Figure 1. Quantifying the potential of high-performance RO membranes with module-scale modelling and experimental evaluation.

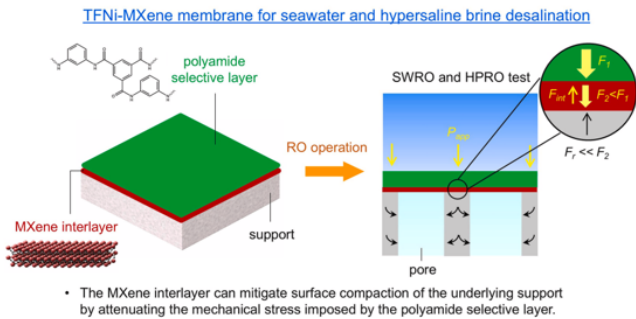


Figure 2. MXene interlayered thin-film nanocomposite HPRO membrane.

NATURE-INSPIRED BIOCATALYTIC MEMBRANES: A SCALABLE SYSTEM FOR SUSTAINABLE PROCESS INTENSIFICATION

R. Mazzei, L. Giorno

National Research Council, Institute on Membrane Technology “Enrico Drioli,” CNR-ITM,
University of Calabria, via P. Bucci, 17/C, 87036 Rende (Cosenza), Italy

The authors did not consent to the publication of this abstract.

ELECTRICALLY CONDUCTING MEMBRANES FOR AMMONIA RECOVERY AND FOULING CONTROL IN WASTEWATER TREATMENT

A. Ronen, S. Qi

Zuckerberg Institute for Water Research, Ben-Gurion University of the Negev, Sde Boker Campus, Midreshet Ben-Gurion 8499000, Israel

Abstract: Electrochemical membrane stripping (EMS) offers a compact alternative to conventional biological nitrogen removal, yet practical implementation remains limited by chemical dependency on external alkalinity addition and susceptibility of hydrophobic membranes to organic fouling and biofouling. This work presents hydrophobic CNT-based electrically conducting membranes (CNT-ECMs) as a unified platform addressing both challenges through two complementary DC-polarization driven applications.

For ammonia recovery, cathodic polarization simultaneously elevated interfacial pH, shifting the ammonium-ammonia equilibrium toward the volatile form, and drove electromigration of ammonium ions toward the membrane surface, producing a threefold increase in interfacial free ammonia concentration. The system achieved 88% recovery at $37 \pm 1.45 \text{ g m}^{-2} \text{ d}^{-1}$ (Fig. 1a) with a specific energy consumption of $2.0 \pm 0.15 \text{ kWh kg}^{-1} \text{ N}$, outperforming conventional pH-driven stripping by 33.5% and maintaining stable flux over 72 h under real municipal wastewater conditions¹.

For fouling control, DC polarization substantially reduced organic fouling and biofouling of the hydrophobic CNT-ECM during treatment of real secondary effluents (Fig. 1b), through electrochemical generation of reactive oxygen species and potential-driven surface charge modulation, as confirmed by flux measurements, SEM, and confocal microscopy. Together, these results establish CNT-ECMs as an electrochemical membrane platform capable of simultaneously intensifying ammonia recovery and controlling fouling without chemical addition.

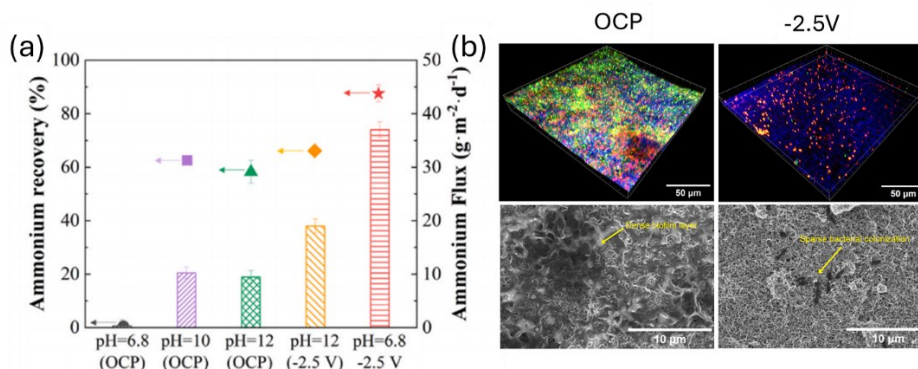


Figure 1. (a) Ammonia recovery flux as a function of pH and applied potential, highlighting the role of electromigration in the EMS system⁽¹⁾; (b) membrane surface with and without DC polarization showing electrochemical mitigation of biofouling.

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INVESTIGATION OF LAYER-BY-LAYER COATED NANOFILTRATION MEMBRANES FOR OLIGOSACCHARIDE CONCENTRATION FROM FERMENTATION BROTH

C. Sander^{1,2}, C. Milimonka¹, M. Wessling^{1,2}

¹RWTH Aachen University, Aachener Verfahrenstechnik-Chemical Process Engineering, Forckenbeckstraße 51, 52074 Aachen, Germany

²DWI - Leibniz Institute for Interactive Materials e.V., Forckenbeckstraße 50, 52074 Aachen, Germany

Abstract: Oligosaccharides produced through microbial fermentation represent valuable biomolecules with significant commercial importance, particularly in pharmaceutical, food, and biotechnology industries. However, separating and purifying them from complex fermentation broths poses considerable technical challenges due to metabolic by-products and impurities like proteins, heavy metals, trace elements, and salts. Conventional purification methods like activated carbon adsorption and ion exchange chromatography generate significant waste, incur high costs, and have limitations in efficiency and yield in comparison to nanofiltration (NF) membrane processes. Since fermentation broth composition varies with the organism used and its medium requirements and therefore the separation task, a precise adjustment of the membrane properties is favorable. Layer-by-Layer coatings (LbL) with polyelectrolytes enable the production of NF-membranes with tailored separation properties.

This work investigates the separation of an oligosaccharide with a molecular weight of about 500 g/mol from fermentation broth using layer-by-layer coated membranes. Therefore, the polyelectrolyte (PE) system poly(sodium 4-

styrenesulfonate) (PSS) and poly(diallyldimethylammonium chloride) (PDADMAC) was coated onto an ultrafiltration (UF) hollow fiber support membrane. The effect of the additive salts MgSO_4 and Na_2SO_4 in the coating solution on the Oligosaccharide retention has been compared to no addition of salt. Furthermore, the effect of an even and uneven number of layers on the oligosaccharide retention has been investigated.

The membranes coated without salt in the coating solution resulted in an Oligosaccharide retention of 93%. The addition of Na_2SO_4 to the coating solution increased the retention to 97%, while the addition of MgSO_4 further enhanced the retention to 99%. An uneven number of layers – with PDADMAC being the final layer - resulted in a more significant decrease of the permeability during the fermentation broth experiment in comparison to the PSS terminated membranes, regardless of salt addition to the coating solution.

PILOT-SCALE CLOSED-LOOP DIALYSIS AND ELECTRODIALYSIS PROCESS FOR BIOSURFACTANT RECOVERY

X. Vecino^{1,2*}, J.M. Cruz^{1,2}, B. Pérez-Cid^{2,3}, A.B. Moldes^{1,2}, J.L. Cortina⁴, M. Reig⁴

¹Dpto de Enxeñaría Química, Escola de Enxeñaría Industrial, Universidade de Vigo, Campus As Lagoas-Marcosende, 36310 Vigo, Spain. (xanel.vecino@uvigo.gal)

²CINTECX, Universidade de Vigo, EQ10, Campus As Lagoas-Marcosende, 36310 Vigo, Spain.

³Dpto de Química Analítica e Alimentaria, Facultade de Química, Universidade de Vigo, Campus As Lagoas-Marcosende, 36310 Vigo, Spain.

⁴Chemical Engineering Dept and CCEM Barcelona, Escola d'Enginyeria de Barcelona Est, Universitat Politècnica de Catalunya, Av. Eduard Maristany 16, Campus Diagonal-Besòs, Barcelona 08019, Spain.

Abstract: Corn steep water (CSW) is a major byproduct of the corn wet milling industry rich in biosurfactants (BS). The recovery of these valuable compounds is essential for promoting industrial circularity and environmental sustainability. This study presents a technical comparison between diffusion dialysis (DD) and electrodialysis (ED) in a closed-loop configuration for the recovery of biosurfactants from CSW at pilot scale. Centrifuged CSW (1.5 L) was pumped to the DD unit at 0.56 L/hm² and counter current Milli-Q water (4.5 L) at 1.12 L/hm², with 929 cm² of regenerated cellulose membranes (6-8 kDa). Optimal DD conditions required adjusting the feed pH to 6.5 to enhance the diffusion of deprotonated organic acids, with processing times reaching up to 72 h. In contrast, ED was tested using a constant flow rate of 35 L/h, completing the purification in 8 h using 6 cell pairs (64 cm² each) of standard ion-exchange membranes. The optimal ED performance was achieved at the natural pH of CSW (4.5), which also minimized the risk of microbial contamination. Regarding the characteristics of the obtained extracts, both processes successfully purified BS by removing ionic impurities and organic acids. The ED extract reduced the surface tension at 54.9 mN/m with a critical micelle concentration (CMC) of 0.18 g/L, a 3.5-fold improvement over raw CSW. DD yielded a slightly lower CMC of 0.14 g/L, attributed to the retention of ionic high-molecular-weight compounds (m/z 950 and 1156) with surfactant activity, that may partially migrate through ED membranes. Both BS extracts demonstrated exceptional wettability, with contact angles of 14.2° for ED and 10.7° for DD. While DD represents a sustainable, solvent-free alternative based on biocompatible cellulose membranes, ED provides a faster desalination, due to the electrical driving force, and its synthetic ion-exchange membranes exhibit enhanced resistance to microbial degradation. This work supports the advancement of these technologies from laboratory validation towards TRL 5.

Acknowledgments: This study was supported by the project ED431F 2023/17 (Xunta de Galicia) and by the project CNS2025-166045 (MICIU/AEI /10.13039/501100011033). X. Vecino acknowledges the grant RYC2021-030966-I (MCIN/AEI/10.13039/501100011033 and “NextGenerationEU/PRTR”).

MACHINE LEARNING-BASED FOULING PREDICTION IN ELECTRODIALYSIS UNDER DYNAMIC CURRENT DENSITY PROFILES

F. Volpe, G. Battaglia, A. Cipollina, G. Micale, A. Tamburini

Università degli Studi di Palermo, Dipartimento di Ingegneria, Viale delle Scienze, 90128
Palermo, Italy (francesco.volpe03@unipa.it)

Abstract: Electrodialysis (ED) is an ion-exchange membrane (IEM)-based separation technology in which an external electric field drives a selective ion transport through anion- and cation-exchange membranes (AEMs and CEMs, respectively), enabling concentration and dilution of feed solutions. This technology, thanks to its high selectivity, energy efficiency, and low chemical consumption, has been widely adopted in several applications, e.g., desalination, wastewater treatment, resource recovery, food processing, and stream purification¹. However, membrane fouling remains a major challenge for ED, as process performance and operational stability are compromised by fouling phenomena that increase membrane resistance and pressure drop while deteriorating membrane properties².

Although membrane fouling has been extensively investigated^{2,3}, reliable models for its prediction and control in ED, particularly under time-varying operating conditions, are still lacking. To address this gap and support the development of advanced control tools for ED systems, this work investigates the application of machine learning (ML)-based models to predict fouling evolution under dynamic current density profiles, i.e., current density varying within the same experiment, thereby extending the use of ML approaches beyond the steady operating conditions explored in previous studies³ to the fluctuating operating conditions encountered in industrial applications and integrated energy systems⁴.

The modelling activities were guided by an extensive experimental campaign with synthetic saline solutions containing humic acid (HA). The experiments were conducted in a 10×10 cm² ED unit equipped with Fujifilm Type 10 AEMs and CEMs. An aqueous solution of 0.1 M NaCl and 1 g/L HA was employed as feed solution. The HA concentration was effective in inducing rapid fouling phenomena, as required for this work.

A total of 25 experiments were performed, with flow velocity ranging from 0.7 to 1.0 cm/s and current density ranging from 100 to 200 A/m², including step changes in current density within each experiment. The stack voltage was recorded over time and used as the target variable for model training, validation, and testing.

Several ML architectures, including Long Short-Term Memory (LSTM), Random Forest (RF), and Temporal Fusion Transformer (TFT), were investigated to identify the most suitable model for capturing the temporal fouling evolution. ML models were implemented in a Python environment exploiting PyTorch, Keras, and scikit-

learn libraries. The experiments were split into training (~75%) and test (~25%) sets. Hyperparameters were optimized through the Optuna algorithm, enabling an efficient exploration of the hyperparameter space. A systematic grid search was performed to assess the influence of the input and output sequence lengths on model performance.

The RF model exhibited the best predictive performance on both the training and test datasets. The predictions accurately reproduced the experimental evolution of the stack voltage over time, including the transient response following the imposed current density step changes.

Figure 1 shows a comparison between RF model predictions and the experimental voltage curves for one experiment from the training dataset (Figure 1a) and one from the test dataset (Figure 1b), along with the respective current density profile.

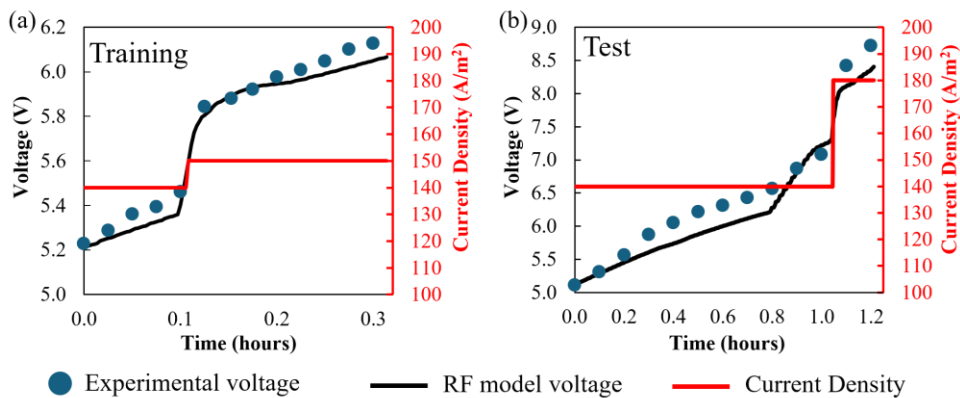


Figure 1. Time series of stack voltage predicted by the RF model (black line) and measured experimentally (points) for (a) an experiment from the training dataset (flow velocity: 1.0 cm/s; current density: 140-150 A/m²) and (b) an experiment from the test dataset (flow velocity: 0.7 cm/s; current density: 140-180 A/m²). The red line represents the current density profile associated with each experiment.

The best-performing model, i.e., the RF model, was subsequently employed to predict fouling evolution under dynamic current profiles not investigated experimentally, enabling a systematic investigation of ED performance over a broader range of current density step changes. Figure 2 illustrates the predicted stack voltage response for three distinct current density step changes at a flow velocity of 1.0 cm/s.

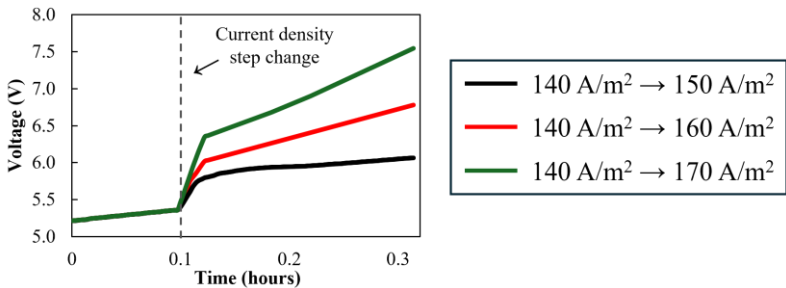


Figure 2. RF model predictions of stack voltage evolution under three dynamic current density profiles at a flow velocity of 1.0 cm/s. The 140-150 A/m² profile corresponds to the one showed in Figure 1a. The dashed vertical line marks the current density step change.

The developed ML model will be used to develop a surrogate model for rapid productivity estimation, offering a computationally efficient tool for the evaluation of multiple operating scenarios, optimization, predictive control, and process design.

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ARE HUGE SALINITY-GRADIENT POWER DENSITIES REPORTED FOR TINY-AREA MEMBRANES ($< 0.03 \text{ mm}^2$) UP-SCALABLE TO MUCH LARGER MEMBRANE AREAS?

A. Yaroshchuk^{1,2}

¹ICREA, pg. L. Companys, 08010 Barcelona, Spain (andriy.yaroshchuk@upc.edu)

²Department of Chemical Engineering, Polytechnic University of Catalonia, Barcelona Tech, av. Diagonal 647, 08028 Barcelona, Spain

Abstract: In recent literature, difficulties of wide-spread application of salinity-gradient (or “osmotic”) energy via reverse electrodialysis (RED) have been repeatedly assigned to insufficient permeances (and/or perm-selectivities) of conventional ion-exchange membrane materials. In response to this speculation, a frenetic search for “more permeable” ion-permselective materials has been unleashed in recent couple of years (>300 publications in 3 years). Very high power densities (as compared to the conventional RED configurations) have often been reported. However, in an overwhelming majority of these studies, membranes of extremely small areas (typically $< 0.03 \text{ mm}^2$) were used. Some studies attempted to extend these impressive results to larger membrane areas but the observed power densities were invariably much smaller (often by orders of magnitude). Notably, the studies used a single-membrane configuration with remote reversible electrodes. At first glance, it is unclear how partial short-circuit conditions could be implemented in this case. This communication will show that the reason is the hemi-spherical conductance pattern occurring with tiny-area membranes. Due to it, external electrical resistances can be strongly reduced. External diffusion resistances can be made smaller than in RED configurations, too, although making the effect of this really noticeable would require still much smaller membrane areas.

A simple new analytical model of voltage-retarded diffusion currents will be used to show that without external mass-transfer limitations, power densities can be very high even for conventional ion-exchange membranes. It will also demonstrate what makes membranes of larger areas perform much worse as well as highlight the perils of incorrect handling of electrode voltage differences as a possible source of anomalously-high power densities reported in some studies.

In summary, the power densities reported for tiny-area membranes do not necessarily require “fancy” novel membrane materials. The principal reason for the typically modest performance of “conventional” RED are fundamental mass-transfer limitations outside the membrane. They are very difficult to overcome, so for large-scale applications, the answer to the title question is “No.” Nonetheless, there may be niche applications (like powering micro-sensors) where very small currents could be sufficient and salinity-gradient power could be an option.

CONTRIBUTED TALKS

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DESIGN OF GREEN CATION EXCHANGE MEMBRANES FOR SUSTAINABLE ELECTROCHEMICAL DESALINATION

R. Abu Alwan^{1,2}, N. Hilal², D. Johnson²

¹Chemical and Biomolecular Engineering Department, New York University, Tandon School of Engineering, Brooklyn, NY 11201, USA

²NYUAD Water Research Center, New York University Abu Dhabi, P.O. Box 129188, Abu Dhabi, United Arab Emirates (ra4006@nyu.edu)

Abstract: In an era of ever-growing anthropogenic activity and climate change, the quest for secure, reliable, and clean water has become a defining scientific imperative. The heavy reliance on conventional desalination technologies, which are energy-intensive, expensive, and unsustainable, underscores the need for innovative solutions to address one of the largest problems facing humankind. Meanwhile, navigating emerging sustainability concerns requires adopting green processing and engineering practices. To address this, we develop green and sustainable membranes as active gates for enhancing a newer generation of electrochemical desalination processes called membrane capacitive deionization (MCDI). Through a comprehensive multi-criteria design framework emphasizing desalination performance, energy efficiency, and an eco-friendly synthesis approach, the resulting system is grounded in bio-based polymers, benign chemistries, and a scalable, low-footprint design.

MCDI is an emerging low-voltage electrochemical desalination technology for brackish water treatment; however, its wider implementation remains limited by the cost, resistance, durability, and sustainability of ion-exchange membranes.^{1,2} In particular, commercial membranes often rely on synthetic or fluorinated ionomers, while many laboratory-scale alternatives require harsh solvents or complex functionalization.³ Herein, we report a green cation-exchange membrane (CEM) platform based on poly(vinyl alcohol) (PVA) and carboxymethyl cellulose (CMC), fabricated by aqueous solvent casting and thermally activated crosslinking. The membrane design exploits PVA as a mechanically stable film-forming matrix and CMC as a renewable polyanionic component providing fixed carboxylate groups for cation-selective transport.

A series of PVA–CMC membranes with varied polymer ratios and crosslinking chemistries was prepared and evaluated through a combination of structural, chemical, electrochemical, and desalination performance analyses. Morphological characterization revealed dense, homogeneous membrane structures, while spectroscopic analysis supported the formation of crosslinked PVA–CMC networks containing carboxylate-rich functional groups. Electrochemical impedance screening was used to identify membranes with favorable ion-transport behavior and sufficient mechanical integrity for cell assembly. When incorporated into the MCDI configuration, the optimized membrane, which combines fixed-charge density,

hydrophilicity, low resistance, and mechanical durability, achieved more effective conductivity decline during adsorption (i.e., higher desalination capacity) and stable regeneration behavior across repeated desalination cycles, compared with conventional CDI operation and commercial membrane-based controls, as shown in Figure 1. These trends indicate that the hydrophilic polyanionic matrix can support selective cation transport while remaining compatible with activated-carbon MCDI electrodes.

Overall, this study demonstrates the potential of water-processable PVA–CMC membranes as sustainable cation-exchange layers for electrochemical desalination. By combining renewable polymer chemistry, non-toxic crosslinking, and practical MCDI integration, the work provides a material-design pathway toward greener membrane platforms for next-generation ion-selective water treatment technologies.

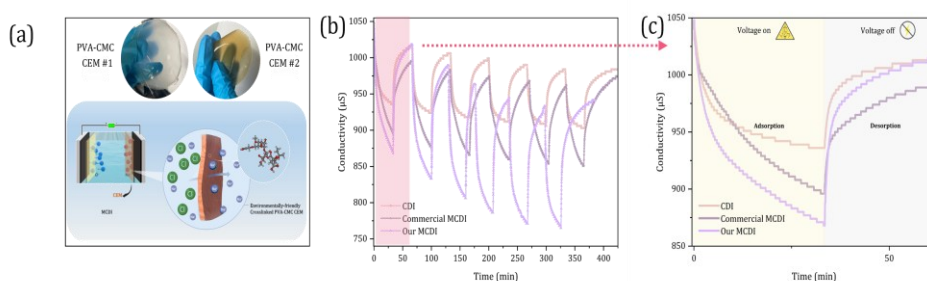


Figure 1. Green PVA-CMC CEMs and their MCDI performance: (a) fabricated membranes and conceptual integration into the MCDI architecture; (b) cyclic conductivity response of CDI, commercial MCDI, and our optimized PVA-CMC CEM; (c) representative adsorption/desorption conductivity profiles during the first cycle of operation.

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SELF-HEALING HYDROGELS TO ENHANCE PERFORMANCE IN PROTON EXCHANGE MEMBRANE

A. S. Ahmad Zabidi¹, N. Adrus^{1,2}, M.H.D. Othman^{1,3}

¹Department of Chemical Engineering, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

²IJN-UTM Cardiovascular Engineering Centre, Institute of Human Centered Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

³Advanced Membrane Technology Research Centre (AMTEC), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

(nadia@utm.my)

Abstract: Self-healing hydrogel has been extensively researched, especially in electrochemical devices such as supercapacitors and fuel cells, due to its performance as an electrolyte and electrode. However, in fuel cell applications, the proton exchange membrane has always been the choice, as the industrialized NafionTM has better chemical stability. In previous studies, there have been attempts to use self-healing hydrogel as an electrolyte, but most research still depends on NafionTM as the base polymer. Hence, this study focuses on exploring the self-healing hydrogel based on a combination of functionalized chitosan and oxidized sodium alginate (OSA). The functionalized chitosan used in this study includes: carboxyethyl chitosan (CEC) with varying acrylic acid (0.5-2.0) ml and sulfonated chitosan (sCs) with varying 1,3-propane sultone (0.5-2.0) g. Both functionalized chitosan derivatives were combined with OSA in order to form a reversible hydrogel network through a Schiff base interaction. The degree of carboxyethylation and sulfonation was investigated using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). Then, both functionalized chitosan hydrogels were evaluated to determine the most suitable self-healing performance for advanced hydrogel applications.

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PERVAPORATION-SUPPORTED VALORIZATION OF FUSEL OIL

S. Akkol, W. Kujawski

Faculty of Chemistry, Nicolaus Copernicus University in Toruń, 7 Gagarina Street, 87-100 Toruń, Poland

Abstract: Fusel oil is a complex by-product formed during bioethanol fermentation and is mainly composed of higher alcohols, including isoamyl alcohol, isobutanol, propanol, and residual ethanol, together with water and other minor organic compounds. Although it has traditionally been considered a low-value side stream, fusel oil represents a promising renewable feedstock for the production of value-added chemicals, particularly esters used as flavoring agents, fragrances, green solvents, and biolubricants^{1,2}. However, its direct valorization is limited by its variable composition and relatively high water content, which commonly ranges between 5 and 20 wt.%³. The presence of water is especially critical because it forms azeotropes with the alcohol components, making the distillation stage energy-intensive and insufficient for competent recovery of individual pure alcohols⁴.

This study presents an integrated route for fusel oil valorization based on membrane-based dehydration, fractional distillation, and subsequent valorization. Fusel oil samples obtained from various Polish distilleries were first characterized to determine their alcohol composition and water content. Hydrophilic pervaporation was then applied as an intensified dehydration step prior to downstream fractionation. The experiments were performed using a commercial PERVAP 4100 polymeric membrane supplied by Deltamem AG. The process was carried out at 60°C under vacuum conditions. Ceramic membranes supplied by Pervatech were also included in the study as a comparative membrane for evaluating material-dependent separation behavior and process applicability.

The polymeric pervaporation experiments demonstrated effective water removal from fusel oil streams with different initial water contents. In a representative experiment, the water content was reduced from approximately 18 wt.% to below 2 wt.%. In a second fusel oil stream with lower initial water content, dehydration from 4.6 wt.% to below 2 wt.% was also easily achieved. These results confirm that hydrophilic pervaporation can efficiently decrease the water content of fusel oil to a level suitable for further processing. Since pervaporation is not limited by vapor–liquid equilibrium, it provides a practical approach for overcoming azeotrope-related separation difficulties in alcohol-rich mixtures⁵.

After membrane dehydration, the obtained low-water fusel oil stream was directed to fractional distillation to obtain fractions. This sequence emphasizes the effectiveness of a hybrid process. The recovered alcohol fractions, particularly isoamyl alcohol-rich streams, are suitable precursors for esterification reactions. Esterification enables the conversion of fusel oil-derived alcohols into high-value products such as isoamyl

acetate, isoamyl butyrate and isoamyl oleate, which are relevant for flavor, fragrance, solvent and biolubricant applications^{2,6}.

Overall, the results demonstrate that pervaporation is a key enabling step in the valorization of fusel oil. By reducing water content to desired amount, the process improves the suitability of fusel oil for subsequent fractionation and chemical upgrading. The proposed membrane-assisted route supports the transformation of fusel oil from a low-value by-product into a valuable and renewable source of industrially relevant chemicals within a circular biorefinery framework.

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NANOFILTRATION AS AN ENERGY-EFFICIENT ALTERNATIVE TO BRACKISH WATER REVERSE OSMOSIS FOR IRRIGATION-GRADE WATER PRODUCTION IN QATAR

F. Alafifi, K. Mahmoud

Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Doha, Qatar

Abstract: Brackish groundwater is the primary available water source for agricultural operations across Qatar, yet its elevated salinity renders it unsuitable for direct irrigation without prior treatment. Conventional brackish water reverse osmosis (BWRO) has been widely adopted for such applications; however, it routinely reduces salinity beyond what irrigation standards require, incurring unnecessary energy expenditure in the process. This study proposes nanofiltration (NF) as a more appropriate and energy-efficient alternative to BWRO for producing irrigation-grade water ($\text{TDS} < 500 \text{ mg/L}$) in agricultural settings. The central argument is one of treatment trade-off: BWRO reduces salinity well below irrigation requirements, whereas NF targets only the threshold needed, operating at lower transmembrane pressures and substantially reduced energy consumption. Simulations based on local brackish feed water conditions estimate a specific energy consumption of 0.59 kWh/m^3 for NF, compared to 1.14 kWh/m^3 for BWRO, representing a reduction of approximately 48% in energy demand. To validate these computational findings, bench-scale experiments were conducted to directly compare the performance of NF and RO membranes, including an assessment of fouling potential under representative feed water conditions. Experimental results provide practical insight into membrane selection, operational longevity, and system reliability for brackish water desalination in agricultural contexts. This work demonstrates that selecting the appropriate level of treatment, rather than the maximum technically achievable, is central to sustainable and efficient water resource management in water-scarce agricultural environments such as Qatar.

MODULE-SCALE REPURPOSING OF END-OF-LIFE RO MEMBRANES THROUGH IN-SITU BIO-INSPIRED SURFACE ENGINEERING

A. Alkhouzaam, M. Khraisheh

College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar

Abstract: The expanding use of membrane technologies in desalination and water treatment has resulted in a growing number of discarded end-of-life (EoL) reverse osmosis (RO) membrane elements, with nearly two million modules estimated to be disposed of annually¹. Developing scalable repurposing strategies is therefore essential to reduce membrane waste, recover material value, and support circular resource utilization in membrane-based separation processes².

In this work, we present a module-scale in-situ transformation approach for repurposing spiral-wound RO membrane modules without disassembly. A dedicated coating system was designed and developed to enable controlled chemical deposition within the intact spiral-wound architecture. The approach employs bio-inspired polydopamine (PDA)-based coatings formed through dopamine self-polymerization under mild aqueous conditions, allowing functional modification of the membrane surface while preserving the structural integrity of the module. Compared with disassembly-based recycling or conventional chemical transformation routes, this strategy offers a more practical and environmentally friendly pathway for extending membrane service life.

Coating distribution and uniformity across the membrane envelope were evaluated using advanced characterization techniques, confirming effective deposition throughout the module. By adjusting coating parameters, including deposition time and reagent concentration, the separation performance of the repurposed membranes could be systematically tuned, enabling transformation of EoL RO modules into nanofiltration- or ultrafiltration-type membranes with customizable permeability and selectivity.

The repurposed modules demonstrated stable operation, improved fouling resistance, and promising performance when treating challenging wastewater streams. This module-scale in-situ repurposing strategy eliminates membrane disassembly, reduces chemical and material consumption, and minimizes membrane waste. Overall, the proposed approach provides a scalable and environmentally responsible framework for extending the lifecycle of spiral-wound membranes while advancing circular economy principles in membrane-based separation and purification technologies.

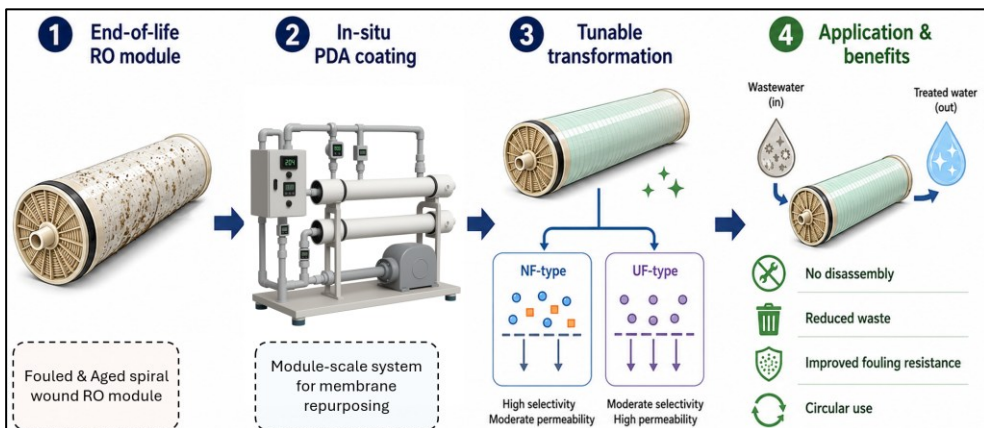


Figure 1: Schematic illustration of the in-situ repurposing of end-of-life RO modules.

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EARLY-STAGE LIFE CYCLE ASSESSMENT OF NOVEL NANOFILTRATION MEMBRANE MANUFACTURING METHODS FOR SUSTAINABLE SCALE-UP

P. Almendras Flores^{1,2}, A. Arun², J. de Grooth², R.G.H. Lammertink¹

¹Department of Membrane Science and Technology, University of Twente, De Horst 2, 7522 LW Enschede, The Netherlands

²NX Filtration B.V., Haaksbergerstraat 95, 7554 PA Hengelo, The Netherlands

(pablo.almendras@utwente.nl - p.almendras@NXfiltration.com)

Abstract: As water scarcity becomes more severe, membranes have emerged as an alternative technology for water treatment and purification, acting as a selective barrier that allows to water pass while retaining contaminants. Nanofiltration (NF) membranes, in particular, are designed to remove small organic molecules and multivalent ions. Hollow fiber (HF) NF membranes offer advantages such as higher packing density, lower operating pressure, and reduced fouling tendency, thereby reducing pretreatment requirements. However, their manufacturing process relies heavily on the use of fossil-based raw materials and solvents¹. In order to address this issue, novel alternative fabrication techniques have emerged in recent years, although they are still in early development stages.

The manufacturing process of a HF-NF membrane module can be divided into four main steps: *fiber support fabrication*, *selective layer formation*, *fibers drying*, and *module assembly*. A porous membrane fiber is produced in the first step via phase inversion. Non-solvent Induced Phase Separation (NIPS) is the most commonly used technique, and relies typically on the use of toxic organic fossil-based solvents. Aqueous Phase Separation (APS) an emerging technology demonstrated only at laboratory scale, represents a full water-based alternative^{2,3}. On the next step, a selective nanolayer is formed commonly through Interfacial Polymerization (IP), a well-studied process that also relies on organic solvents. The Layer-by-Layer (LbL) approach, has gained relevance as an alternative coating technique that only relies on water-based chemistry⁴. Since drying and module assembly are required in all cases, the comparison focused on the first two steps.

Therefore, Life Cycle Assessment (LCA) was combined with process modelling to assess the environmental impacts at industrial scale of novel fabrication techniques, evaluate their scalability potential, and compare them with conventional technologies. The functional unit (FU) for the analysis was defined as 1000 m² of membrane produced, and a cradle-to-gate approach was used.

A process model was developed on Python to estimate material and energy flows for all process units and steps. Environmental impacts were estimated using the *LCA for Experts* software and the *ReCiPe 2016* impact assessment method. The results are presented in Figure 1.

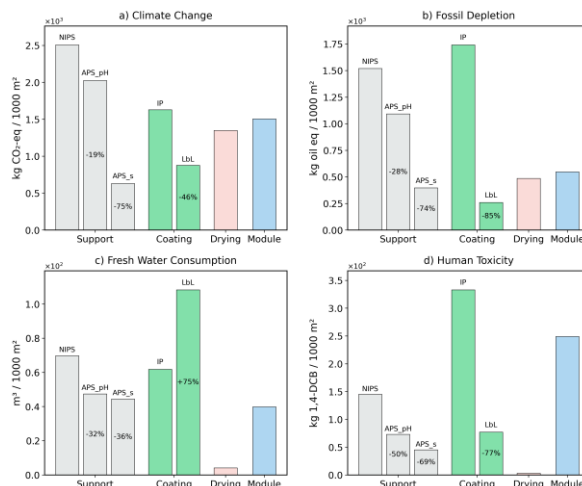


Figure 1. Environmental impacts per 1000 m² of HF-NF membrane modules for four process steps, evaluated in terms of a) Climate Change (CC), b) Fossil Depletion (FD), c) Fresh Water Consumption (FWC) and d) Human Toxicity (HT).

For the *support fabrication* step, the conventional NIPS process was compared with two APS variants, pH-induced (APS_pH) and salinity-induced (APS_s). All studied categories showed lower impacts for APS, with APS_s achieving the greatest reductions. For the *selective layer formation* step, the LbL technology outperformed IP in most categories, reducing climate change, fossil depletion and human toxicity impacts, although at the expense of higher freshwater consumption. Due to its high energy demand, the *fibers drying* step contributed substantially to climate change and fossil depletion, while the *module assembly* step showed significant impacts across all categories because of the raw materials and energy requirements.

Overall, APS and LbL demonstrated the potential to reduce the environmental impacts of HF-NF membrane manufacturing. However, freshwater consumption remains an important trade-off, particularly for LbL, highlighting the need for further process optimization. Hotspot and sensitivity analyses identified the main impact drivers, helping researchers and manufacturers target improvement areas and move towards more sustainable membrane production.

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Disclosure: This work is part of the Bio-GENTLE Project (Grant Agreement No. 101119963) funded by the European Union's Marie Skłodowska-Curie Actions under the Horizon Europe programme.

RECOVERY OF LITHIUM AND BORON FROM LITHIUM TETRABORATE SOLUTION WITH BIPOLAR MEMBRANE ELECTRODIALYSIS: EFFECT OF MEMBRANE TRIPLET NUMBER

E. Altıok¹, P. Çamcı¹, K. Bostancı^{1,2,3}, M. Arda², N. Kabay¹

¹Chemical Engineering Department, Ege University, Bornova, İzmir, 35100, Türkiye

²Chemistry Department, Ege University, Bornova, İzmir, 35100, Türkiye

³Mining Technology Programme, Torbalı Vocational Ege University School, Dokuz Eylül University, Torbalı, İzmir, Türkiye

(esra.altiok@ege.edu.tr, pelinsucamci0@gmail.com, kamil.bostanci@deu.edu.tr, musserref.arda@ege.edu.tr, nalan.kabay@ege.edu.tr)

Abstract: The growing demand for rechargeable batteries and the rapid expansion of electric vehicles and renewable energy technologies have led to a significant increase in global lithium consumption. Consequently, the demand for lithium is expected to continue rising in the coming years. However, conventional lithium production routes alone are unlikely to satisfy future needs, highlighting the importance of developing alternative lithium recovery technologies^{1,2,3}.

In addition to conventional lithium resources, boron mining wastewaters have attracted increasing attention as potential secondary lithium resources. Lithium may coexist with boron in boron-bearing mineral deposits and can therefore be present in waste streams generated during boron mining and mineral processing. Consequently, the simultaneous recovery of lithium and boron from these wastewaters offers an opportunity for sustainable resource utilization while reducing environmental impacts. In this context, electromembrane processes have emerged as attractive alternatives owing to their high efficiency and their ability to selectively recover valuable ions with reduced chemical consumption⁴.

Bipolar membrane electrodialysis (BMED) is an advanced electromembrane technology that integrates conventional electrodialysis (ED) with bipolar membranes. A typical BMED stack consists of repeating membrane triplets, each comprising one bipolar membrane (BPM), one anion exchange membrane (AEM), and one cation exchange membrane (CEM). Under an applied electric field, ions are transported through ion exchange membranes while water is simultaneously dissociated into hydrogen and hydroxide ions within the bipolar membrane. This unique feature enables the direct conversion of salts into their corresponding acid and base streams. Therefore, unlike conventional (ED), BMED serves not only as a separation process but also as a chemical conversion process. This unique capability makes BMED particularly attractive for the simultaneous recovery of lithium and boron, enabling the production of lithium hydroxide and boric acid from lithium borate-containing solutions⁵.

In this study, the effect of membrane triplet number on lithium and boron recovery from the lithium tetraborate solution with BMED was investigated. Experiments were carried out using a laboratory-scale MEGA EDBM-Z/4×10-0.8 BMED system equipped with RALEX bipolar, RALEX CMH-PES, and RALEX AMH-PES membranes as BPM, CEM, and AEM, respectively. The BMED system was operated using three membrane stack configurations consisting of 5, 7, and 10 membrane triplets. A feed solution containing approximately 250 mg B/L (corresponding to 80 mg Li/L) was prepared by dissolving lithium tetraborate pentahydrate ($\text{Li}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) in ultrapure water. The acid and base compartments were filled with 0.003 M HCl and 0.003 M NaOH, respectively, while 0.1 M NaOH was used as the electrode rinse solution. Experiments were performed at a constant voltage of 20 V for 120 min. Lithium and boron concentrations were determined using atomic absorption spectroscopy (AAS; Shimadzu AA-7000) and inductively coupled plasma optical emission spectroscopy (ICP-OES; Perkin Elmer Avio 200), while pH and conductivity were monitored throughout the experiments.

The experimental results demonstrated that membrane triplet number significantly influenced the overall performance of the BMED system. Lithium removal exceeded 99% in all membrane configurations, whereas lithium recovery strongly depended on membrane triplet number. The highest lithium recovery was achieved with the 5-triplet configuration (78%), followed by the 7-triplet (55%) and 10-triplet (32%) systems. Boron removal remained within approximately 50–60%, while boron recovery exhibited greater variation. Overall, the findings indicate that reducing membrane triplet number improves lithium recovery and represents a promising strategy for optimizing BMED performance.

Acknowledgements

The authors acknowledge the financial support provided by the Ege University Scientific Research Projects Coordination Unit (Project No. FM-ADP-2024-32715). The authors also gratefully acknowledge A. Çelik, E. Köken, N. Erzine, and Y. Yılmaz for their contributions to the experimental studies.

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RECOVERY OF IMIDAZOLIUM BASED IONIC LIQUIDS FROM WASTEWATERS BY ELECTRODIALYSIS METHOD

D. Babilas-Krzyżowska^{1*}, J. Chromikova², M. Heliova², K. Bartel¹, J. Botor¹, A. Milewski¹, A. Mielańczyk¹, S. Ruczka¹, P. Dydo¹

¹Silesian University of Technology, Faculty of Chemistry, Gliwice, Poland

²Technical University of Ostrava, Ostrava-Poruba, Czech Republic

*dorota.babilas@polsl.pl

Abstract: Ionic liquids (ILs) are class of compounds consisted of organic cations and inorganic or organic anions. One of the most popular group of ILs are the imidazolium based ILs. This group of ILs exhibits water solubility, biodegradability, chemical and thermal stability, as well as broad electrochemical windows¹. Imidazolium based ILs are widely used as solvents in chemical synthesis and for the pretreatment of lignocellulosic biomass. However, the applications of ILs in large-scale requires the developments of their recovery and recycling methods². One of the promising methods of the ILs recovery from aqueous solutions and wastewater is electrodialysis (ED). ED constitutes an electromembrane separation technique wherein an applied electrical potential gradient allows for the selective transport of ionic species across the ion-exchange membranes and separating them from neutral compounds or aqueous solutions³. Therefore, the aim of this work was to examine the efficiency of the selected imidazolium based ILs recovery from aqueous solutions by electrodialysis method. This research utilized three imidazolium based ILs: 1-ethyl-3-methylimidazolium chloride ([Emim]Cl), *N,N*-dibutylimidazolium chloride ([BBim]Cl), 1-methyl-3-octylimidazolium chloride ([Omim]Cl). Also, the chemical stability of the recovered ILs, and the characteristics of the tested ion-exchange membranes (IEMs) before and after ED were determined. Moreover, the effect of the IL's alkyl chain length on their recovery effectiveness was discussed.

The recovery of selected imidazolium based ILs ([Emim]Cl, [BBim]Cl, [Omim]Cl) was carried out using an EDR-Z/10-0.8 module (MemBrain, Czech Republic) with an effective single membrane area of 64 cm². There were 5 pairs of the IEMs. The IEMs used in this work were the heterogeneous AM(H)–CM(H) (Ralex, Czech Republic), and AMA–AMC (Ionsep, China). Research included a series of experiments on the influence of operating parameters, such as IL concentration, applied voltage per membrane pair, and linear flow velocity on the ED performance. The concentrations of imidazolium based ILs in diluate and concentrate solutions were analyzed using a UV-VIS spectrophotometer (Shimadzu UV-2700i, Japan). The surface morphology of IEMs before and after ED were investigated by scanning electron microscopy (SEM, FlexSEM 1000 II VP-SEM, Hitachi, Japan). The wettability of the membranes used in the experiments were examined using an optical contact angle goniometer. In addition, the X-ray photoelectron spectroscopy (XPS) experiments of the membrane samples before and after ED were carried out. The

chemical stability of the recovered ILs was determined by ^1H Nuclear Magnetic Resonance (^1H NMR).

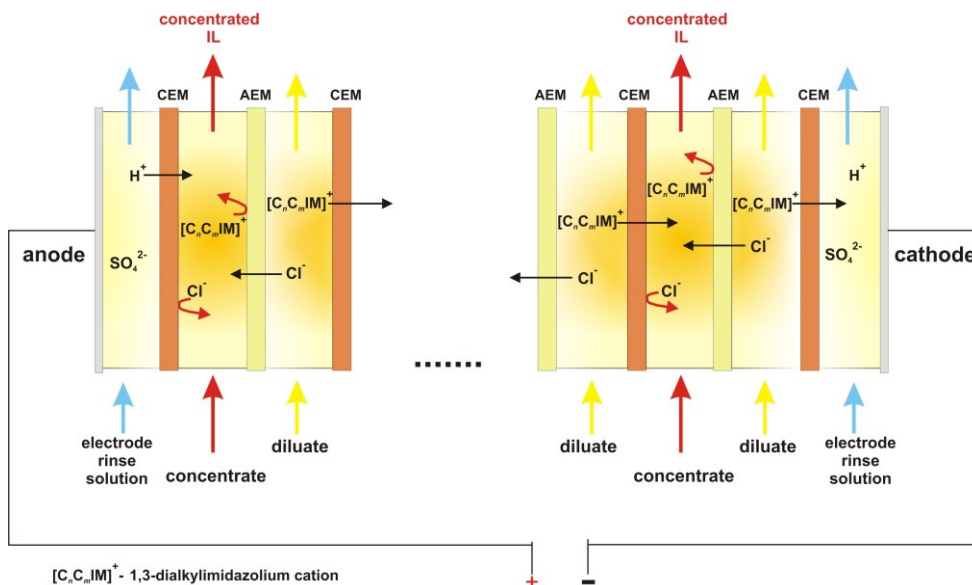


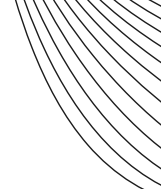
Figure 1. Schematic representation of the ED stack for ILs recovery.

It was found that the investigated imidazolium based ILs concentration, applied voltage drop, and linear flow velocity had influence on the selected ILs recovery by ED method. The ILs recovery and concentration degree increased with increasing IL concentration in the initial diluate solution. Moreover, the highest ED efficiency was obtained when a 2 V electric potential per one membrane pair was applied, using a 2 cm/s linear flow velocity. Under these conditions, the ILs recovery reached above 80%. The effectiveness of ILs recovery also strongly depended on the treated IL's alkyl chain length. As the alkyl chain length increases, the ILs recovery decreases. In addition, it was observed that, the surface morphology and chemical structure of the IEMs after ED was not differ significantly in comparison to the pristine IEMs. It was also confirmed that the recovered ILs had the same structure as the fresh solution of ILs. ^1H NMR analysis proved the absence of ILs degradation products in the concentrate solutions after ED. Therefore, the recovered ILs were stable and could be reused. The findings summarized here indicate that, the ED allows for the effective ILs recovery from aqueous solutions.

Acknowledgements: This work was supported by the National Science Centre, Poland, under research Project No.: 2021/43/D/ST8/02776, and partially by the internal grant of Silesian University of Technology, Poland (BK_2026 no. 04/010/BK_26/1120).

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HOT SEPARATION OF HYDROGEN AND BENZYL TOLUENE

N. Bachhuber¹, T. van Gestel², R. Stöber¹, M. Geißelbrecht³, P. Wasserscheid^{1,3,4}, W. Meulenberg²

¹Forschungszentrum Jülich, Institute for a Sustainable Hydrogen Economy (IHE-3), An der deutschen Welle 7a, 52428 Jülich, Germany

²Forschungszentrum Jülich, Institute of Energy Materials and Devices (IMD-2), Wilhelm-Johnen-Straße, 52428 Jülich, Germany

³Forschungszentrum Jülich, Helmholtz-Institute Erlangen-Nürnberg for Renewable Energy (IET-2), Cauerstraße 1, 91058 Erlangen, Germany

⁴Lehrstuhl für Chemische Reaktionstechnik (CRT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Egerlandstraße 3, 91058 Erlangen, Germany

Abstract: The transition from fossil-based energy systems toward sustainable and renewable energy technologies has significantly increased the demand for efficient large-scale energy storage solutions. Due to the intermittent behavior of sustainable energy production methods such as solar and wind, the intermediate conversion of energy to another energy carrier has become impactful. Besides battery storage systems, the production of hydrogen via electrolysis during low demand/high generation scenarios has attracted growing interest. Hydrogen at ambient conditions suffers from a low volumetric energy density where chemical hydrogen carriers including methanol, ammonia, dimethyl ether and liquid organic hydrogen carrier (LOHC) have increasing volumetric energy density. These chemical hydrogen carriers enable long and safe storage periods, high volumetric energy densities, the utilization of the existing infrastructure and recyclability compared to traditional pressurized or cryogenic hydrogen storage solutions. One promising LOHC carrier is represented by the benzyltoluene (H0-BT)/perhydro-benzyltoluene (H12-BT) pair.¹ Hydrogen is bound to H0-BT in an exothermic hydrogenation reaction, while hydrogen release proceeds via endothermic dehydrogenation (see Figure 1). In both reactions the LOHC compounds are preferably present in liquid state as liquid phase catalysis offers advantages, such as better heat transfer to/from the catalyst, higher catalyst productivities and lower deactivation rates.^{2,3}

However, especially during the endothermic dehydrogenation reaction, Hx-BT evaporates at least partly due to the increasing hydrogen partial pressure in typical fixed bed reactors.² To tackle this challenge, we have developed a membrane reactor as a new approach for H12-BT dehydrogenation reactor with integrated hot hydrogen removal. The membrane that was utilized for this separation is an in-house fabricated, bio-inspired, carbon molecular sieving membrane.

Our setup enabled us to study hydrogen release from H12-BT and simultaneous hydrogen separation at 273 °C.

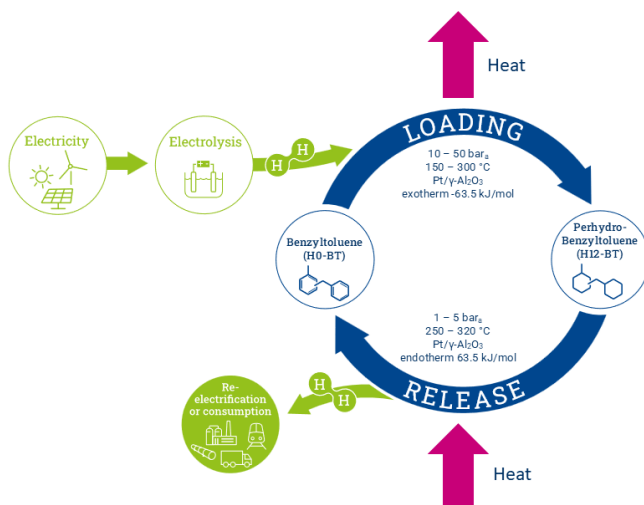


Figure 2: Principle of Liquid organic hydrogen carrier.

Under these conditions a stable H_2 permeance of close to $1500 \text{ l}_n \text{ m}^{-2} \text{ h}^{-1} \text{ bar}^{-1}$ ($\triangleq 1.71 \cdot 10^{-7} \text{ mol m}^{-2} \text{ s}^{-1} \text{ Pa}^{-1}$) was observed after a slight increase over the first 240 h of the experiment (see Figure 2). The separation factor required ca. 240 h to reach its steady-state value of 3500 but remained constant for the rest of the experiment (total experiment time: 900 h). At steady-state, the measured H12-BT concentration in the permeate was 104 ppm, corresponding to a hydrogen purity of 99.988 %. A planned shutdown period of three weeks did not result in any measurable change in hydrogen permeance or separation factor, demonstrating the operational stability of the system under the investigated conditions.

Overall, our experiments demonstrate that hot hydrogen separation from a product gas mixture from H12-BT dehydrogenation is possible with high hydrogen flux, excellent separation selectivity and operational robustness.

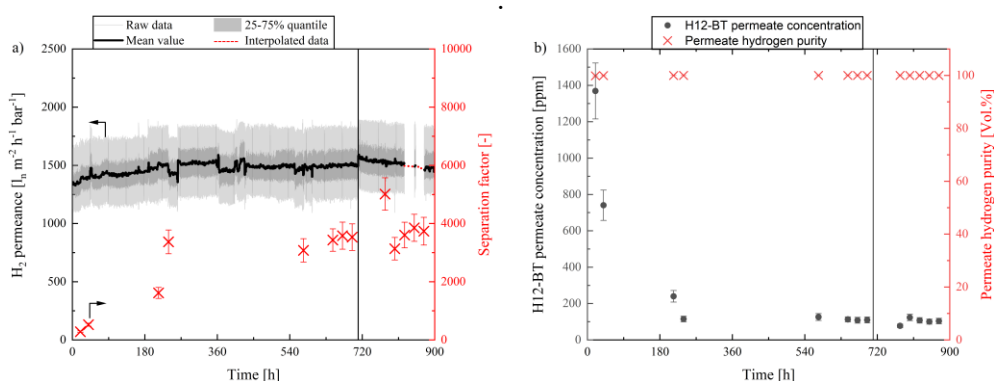
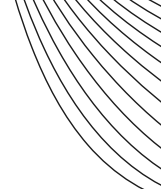


Figure 3: H_2 /H12-BT separation test at condensing conditions (273 °C) for 710 and 190 hours (a) H_2 permeance and H12-BT/ H_2 separation factor; (b) H_2 purity [Vol.%] and H12-BT concentration [ppm] in the permeate stream.

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PROSPECTS FOR DUAL-ACTIVITY MEMBRANES: FLUE GAS SEPARATION AND PHOTOTHERMAL CONVERSION OF CO₂

H. G. Baldoví¹, J. García-Ruiz², M. Álvaro¹, H. García²

¹Departamento de Química, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

²Instituto de Tecnología Química, Consejo Superior de Investigaciones Científicas, Universitat Politècnica de València, Avenida de los Naranjos s/n, 46022 Valencia, Spain (hergarba@upv.es, www.upv.es)

Abstract: The concept of fabricating membranes with dual activity, both for selective gas separation and catalytic purposes, represents a significant advancement in the field of carbon capture and utilisation (CCU)¹. Here, we present a series of low-cost polymeric membranes developed under the European project DAM4CO2 that can perform both tasks simultaneously. Two types of membranes have been evaluated: classical polymeric membranes such as P84, Matrimid, or ULTEM, and novel fluorinated membranes as BTFMA². Also, several catalysts capable of selectively performing the reverse water-gas shift reaction and the Fischer-Tropsch process have been employed to produce C₂₊ alkanes. Since temperatures between 200 and 300 °C are required to activate CO₂ efficiently, we will explain the stress experienced by the membranes regarding their separation capacity and the effect on their photothermal catalytic activity. Additionally, we will focus on the changes in activity and selectivity that catalysts undergo due to the chemical environment created by being embedded within the membranes.

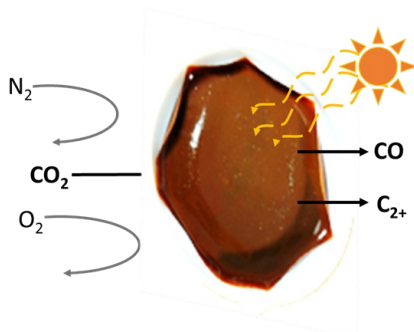


Figure 1. Scheme of the dual-activity membrane for sustainable CO₂ utilization.

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2D CFD SIMULATION OF BORON/WATER SPLITTING AND PH-DEPENDENT BORON REACTIVE TRANSPORT IN BIPOLAR MEMBRANE ELECTRODIALYSIS FOR BORIC ACID PRODUCTION

H. Bazargan Harandi^{1,2*}, J. López^{1,2}, R. Torres³, A. Asadi, J.L. Cortina Pallás^{1,2,4}

¹Chemical Engineering Department, Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politècnica de Catalunya (UPC)-BarcelonaTECH, Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain (hesam.bazargan@upc.edu)

²Barcelona Research Center for Multiscale Science and Engineering (CCEM), Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain

³Department of Fluid Mechanics, Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politècnica de Catalunya (UPC)-BarcelonaTECH, Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain

⁴CETaqua, Carretera d'Esplugues, 75, 08940 Cornellà de Llobregat, Spain

Abstract: Bipolar membrane electrodialysis (BMED) stands out as a highly sustainable alternative for boric acid production. However, optimizing boron recovery efficiency is structurally hindered by complex reactive transport mechanisms governed by pH-dependent speciation transitions and boron/water splitting on the interface of bipolar membranes. Based on this reactive transport, mobile borate anions ($\text{B}(\text{OH})_4^-$) transition into neutral boric acid ($\text{B}(\text{OH})_{3(\text{aq})}$) when entering acidic or neutral fluid channels. This neutral species undergoes uncontrolled passive diffusion from acid channel toward cation exchange layer (CEL) of bipolar membranes (BPM) and experiences weak-electrolyte dissociation at the BPM junction, compromising global current efficiency and escalating product losses. To overcome the limitations of purely experimental trial-and-error evaluations and capture localized channel chemistry, a comprehensive numerical model is required to resolve these coupled multiphysics dynamics and reactions to identify the role of each mechanism and phenomenon like diffusion or splitting in this transport.

In this work, a 2D CFD model of a multi-compartment BMED stack, as shown in Figure 1, featuring three triplets (totaling nine parallel flow channels including electrode rinsing, acid, base, and dilute compartments) was developed in COMSOL Multiphysics version 6.3. Specialized Reaction domains were strategically implemented at the BPM junction to explicitly define the field-enhanced dissociation kinetics (the Second Wien effect) responsible for both water and boron splitting behavior under intense localized electric fields. Concurrently, customized equilibrium chemical reactions were integrated within the channel domains to compute multi-species pH-dependent reactive boron transport.

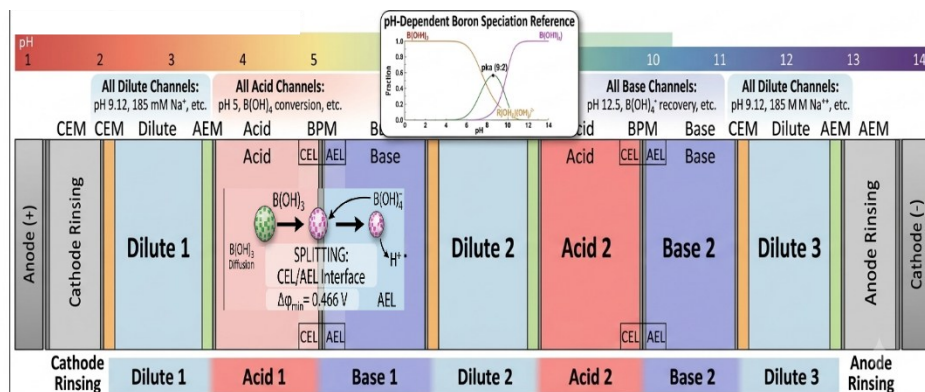
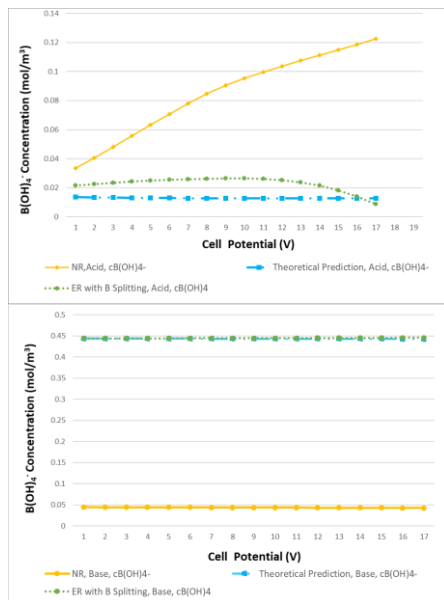
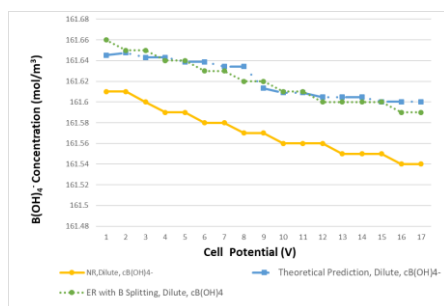


Figure 1. Schematic configuration of the multi-compartment BMED stack featuring three triplets, integrated with local channel pH and a thermodynamic boron speciation diagram in Dilute.

This model simulates BMED behaviour across an operating cell potential range spanning from 1V to 17V, demonstrating that incorporating reactive transport significantly modifies the predicted pH and concentration profiles compared to non-reactive baselines. In the base compartment (pH $\sim$ 12.5), neutral boric acid ($\text{B(OH)}_{3(\text{aq})}$) crossing the Cation Exchange Membrane (CEM) from the dilute compartment via diffusion was immediately deprotonated into borate anions (B(OH)_4^-), yielding the distinct concentration profile in Figure 2a. Conversely, inside the acid channel (pH $\sim$ 5), the shifting equilibrium drives recombination into $\text{B(OH)}_{3(\text{aq})}$, precisely capturing the consumption of B(OH)_4^- passing Anion Exchnage Membrane (AEM) from dilute channel and H^+ ions generated by water splitting on the BPM. In the dilute channel, where the local pH ($\sim$ 9.12) was near the pKa (9.2), the fractions of both species are nearly equal. Across all acid, base, and dilute channels, the theoretical B(OH)_4^- concentrations showed exceptional agreement with theoretical values (Figures 2b and 2c), when equilibrium reactions and water/boron splitting were taken into account.



(b)



(c)

Figure 2. Validation of $B(OH)_4^-$ concentrations across cell potentials (1-17V) comparing theoretical values, reactive, and non-reactive CFD models in the (a) base, (b) acid, and (c) dilute channels.

Furthermore, the model effectively resolved the high-gradient boundaries where boron/water dissociation took place under intense electric fields. Figure 3 illustrates the resulting line graph (Figure 3a) and 2D potential distribution overlaid with current density streamlines (Figure 3b). As the acid channel has a low pH, all available boron species are rapidly converted into neutral boric acid, $B(OH)_3(aq)$. Consequently, the concentration of ions in this channel is very low, resulting in high resistance and therefore large variations in the electrolyte potential.

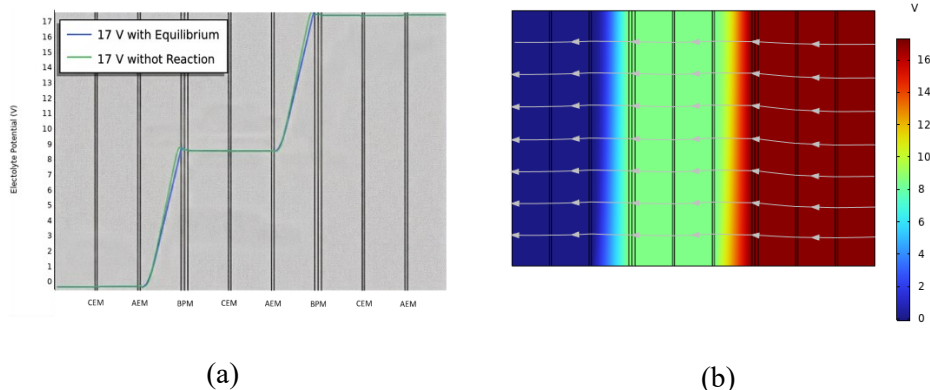


Figure 3. a: Line graph; and b: 2D potential distribution across the entire cell configuration, overlaid with current density streamlines for 17V

To explicitly deconstruct the underlying mass transport mechanisms driving boron recovery, the spatial distribution of the x-component fluxes for boric acid ($\text{B(OH)}_{3(\text{aq})}$) across the BPM junction and its adjacent diffusion layer was evaluated (Figure 4). Inside the CEL of the BPM, mass transport is entirely dominated by the diffusion flux (blue line), confirming that the neutral boric acid species undergoes passive, uncontrolled molecular diffusion through the polymeric matrix in the absence of an electrical migration driving force (red line). Driven by interfacial water/boron splitting dynamics at the BPM junction, this reaction converts neutral boric acid ($\text{B(OH)}_{3(\text{aq})}$) to borate (B(OH)_4^-), facilitating their selective transport through the adjacent anion exchange layer (AEL). Moving leftward into the hydrodynamic boundary layer immediately adjacent to the CEL surface, a clear transition region emerges. Within this localized diffusion layer, boric acid transport is governed by a coupled combination of diffusion and developing convection mechanisms. Finally, as the spatial coordinate extends further into the bulk core of the fluid channel, the diffusion flux decays toward negligible values, and the transport shifts completely to convection (green line), where the bulk laminar flow velocity field becomes the primary driver of species displacement.

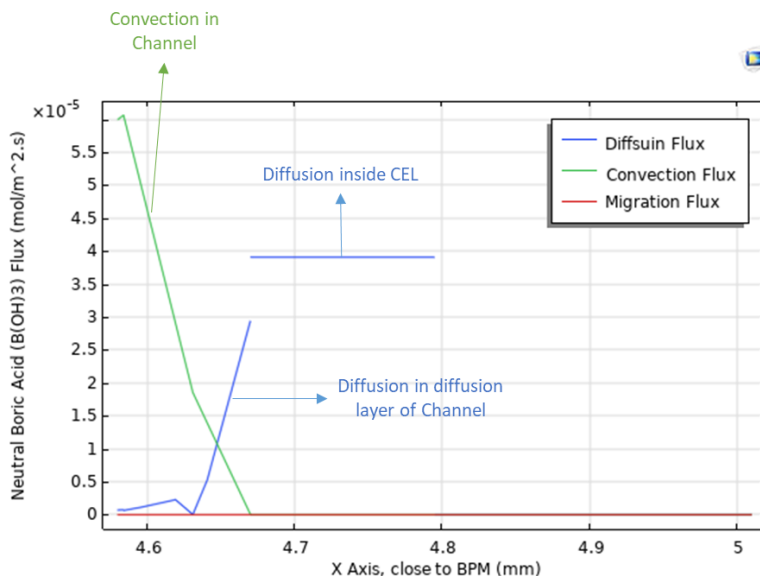


Figure 4. Localized x-component mass transport fluxes of boric acid at the fluid-BPM interface of the BMED stack for 17V

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MIXED MATRIX MEMBRANES FOR CO₂ SEPARATION BASED ON ORGANIC CAGES

R. Ben Abed¹, M. Longo¹, P. Hajivand¹, S. La Cognata², M. Monteleone¹, A. Fuoco¹, E. Esposito¹, V. Amendola², J. C. Jansen¹

¹National Research Council-Institute on Membrane Technology “Enrico Drioli” (CNR-ITM), Via P. Bucci, 17/C, 87036 Rende, CS, Italy.

²Department of Chemistry, University of Pavia, Viale Torquato Taramelli 12, 27100 Pavia, Italy.

Abstract: Advancements in gas separation technologies are essential for reducing industrial emissions and mitigating global warming, making polymeric membranes attractive thanks to their scalability, energy efficiency, and chemical tunability. Nevertheless, enhancing their separation performance remains a key challenge, which can be addressed by incorporating intrinsically porous materials (IPMs) into the polymer matrix to synergistically combine polymer processability with the superior gas separation properties of the filler.

Organic cages represent a type of IPMs formed by single molecules with three-dimensional cavities and a well-defined pore structure in the solid state. One of their main advantages is that they are soluble in organic solvents and therefore more easily processed via solution-casting to yield mixed matrix membranes (MMMs) [1].

In this work we describe a series of different organic cages and their corresponding MMMs in the solvent-processable poly(ether-ether-ketone) PEEK-WC and in ULTEM 1000. Pure gas permeability measurements (H₂, He, O₂, N₂, CH₄, CO₂, C₃H₈, C₃H₆) of the neat polymer and the MMMs are carried out to investigate the effect of the fillers on the gas transport parameters. The results showed that the cages can tailor the gas transport properties of the pure polymer membrane, increasing either the permeability or the selectivity, with the greatest improvement observed in propylene/propane (olefin/paraffin) separation performance. In most cases, the increase in permeability is mainly due to the increase in diffusivity, while the enhanced perm-selectivity is mostly a result of an increase in the size-selectivity of the membrane, *i.e.* the cages favor the transport of the smaller gas molecules over that of the larger molecules.

Further studies will focus on novel imide/imine-based organic cages, comparing pure gas permeability measurements and mixed gas permeation tests, in order to validate the potential of the most promising membranes for the separation of industrially relevant gas mixtures, such as CO₂/CH₄ and CO₂/N₂.

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TAILORING CERAMIC-BASED POLYELECTROLYTE MULTILAYER MEMBRANES FOR NOM REMOVAL IN DRINKING WATER TREATMENT

J. Bennert¹, B. Wendler¹, M. Ernst^{1,2}

¹DVGW Research Center TUHH, Am Schwarzenberg-Campus 3, 21073 Hamburg/Germany, (julia.bennert@tuhh.de, www.tuhh.de/www)

²Institute for Water Resources and Water Supply TUHH, Am Schwarzenberg-Campus 3, 21073 Hamburg/Germany

Abstract: The novel approach of this study aims at tailoring tubular ceramic (Al_2O_3) ultrafiltration (UF) membranes by successive coating of polyelectrolyte multilayers (PEM). This modification shall enhance removal of dissolved water constituents (salts, natural organic matter, NOM) as well as maintaining fouling control to ensure process stability in drinking water treatment. A backwashable tubular UF membrane (Nanostone Water GmbH) shall be turned into a (backwashable) ceramic nanofiltration (NF) membrane. NF as treatment method offers compact high-quality treatment of surface and other raw waters. Ceramic membranes in particular offer mechanical robustness, chemical and thermal stability, low fouling propensity, and long lifetime, and can be effectively chemically and mechanically cleaned.

The PEMs investigated in this study, are screened for their removal efficiencies of mono- and divalent salts, various model NOM compounds in synthetic water, and real surface water. Screening the impact of coatings on retention of single salt solutions provides insights into separation mechanisms and PEM charge characteristics^{1,2,3}, thereby aiding the understanding of different retention behaviors observed with NOM solutions. The PEMs manufactured in this study consist of 8 double layers (DL) of polycation/polyanion combinations being either PDADMAC (poly(diallyldimethylammonium chloride))/PSS (poly(sodium-4-styrenesulfonate)) or PAH (poly(allylamine hydrochloride))/PSS. The coatings were conducted either at the same ionic strength for polyanion and polycation or at combined ionic strength with a lower ionic strength of the cationic solution.

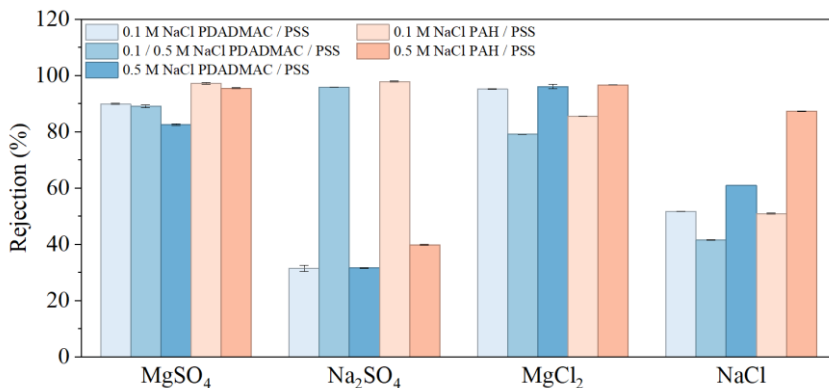


Figure 1 MgSO₄, Na₂SO₄, MgCl₂ and NaCl single salt rejection rates for the PEM tubular membranes each coated with 8 DL of the polyelectrolyte systems PDADMAC/PSS (blue) and PAH/PSS (orange) at varying ionic strengths (0.1/0.5 M NaCl). Filtration parameters: $c_{\text{salt}} = 5$ mmol/l, transmembrane pressure (TMP) = 4 bar, cross-flow velocity (CFV) = 0.7 m/s.

The rejection sequences observed for single salt solutions (Figure 1) for membranes coated with PDADMAC/PSS at 0.1 M and 0.5 M NaCl, as well as for PAH/PSS at 0.5 M NaCl, are consistent with rejection sequences of positively charged membranes^{1,2}. This apparent positive charge occurs despite the anionic termination with PSS of all coatings attributable to charge overcompensation and interdiffusion of the cationic PDADMAC and PAH as reported in prior studies^{3,4}. Conversely, membranes coated with PDADMAC/PSS at combined ionic strength and PAH/PSS at 0.1 M NaCl exhibit rejection patterns characteristic of negatively charged membranes³. These latter membranes are therefore expected to demonstrate enhanced performance in NOM removal and fouling mitigation. To validate this, various NOM solutions, such as Sigma Aldrich Humic Acid, Suwannee River NOM (SRNOM) and real surface water, are screened to assess membrane performance.

Preliminary results for SRNOM removal by two different coatings are shown in Figure 2 as Liquid Chromatography-Organic Carbon Detection (LC-OCD) chromatograms, demonstrating promising rejection rates for all NOM fractions contained in SRNOM.

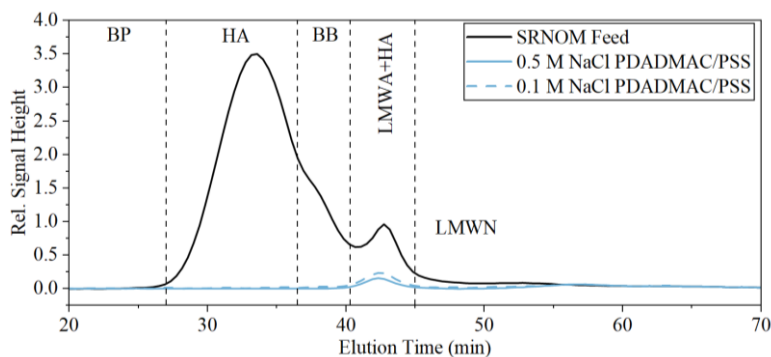


Figure 2 LC-OCD analysis for SRNOM feed solution (5 mg TOC/l, pH = 8) and permeates of ceramic membranes coated with 8 DL of PDADMAC/PSS at 0.1 or 0.5 M NaCl ionic strength of the coating solutions. Filtration parameters: TMP = 2 bar, CFV = 0.7 m/s. NOM

fractions in LC-OCD analysis: Biopolymers (BP), humic acids (HA), low molecular-weight acids and humic acids (LMWA+HA), low-molecular weight neutrals (LMWN).

The results of this study demonstrate that the charge properties of ceramic-based PEM membranes can be precisely controlled through the choice of polyelectrolytes and ionic strength during the LbL coating process. In particular, the identified apparent negatively charged PEM systems show great potential for NOM removal while enabling stable operation. Overall, the findings highlight the application potential of tubular ceramic-based PEM membranes as a robust, adaptable technology for future climate-resilient drinking water supply systems.

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PREDICTION OF PENETRANT-INDUCED SWELLING IN HIGH FREE-VOLUME POLYBENZOXAZOLES MEMBRANES BY NON-EQUILIBRIUM PC-SAFT

C. Brondi¹, A. Baldanza², W. J. Box³, G. Mensitieri⁴, G. Scherillo⁴, M. Galizia³

¹Department of Engineering and Science, Universitas Mercatorum, 00186 Rome, Italy

²Scuola Superiore Meridionale, 80138 Naples, Italy

³School of Sustainable Chemical, Biological and Materials Engineering, University of Oklahoma, 100 E. Boyd Street, Norman, 73019, OK, USA

⁴Department of Chemical, Materials and Industrial Production Engineering, University of Naples Federico II, 80125 Naples, Italy

Abstract: Predicting penetrant-induced swelling in glassy polymer membranes remains a key challenge, mainly due to the intrinsically non-equilibrium nature of glassy materials. Conventional approaches often rely on empirical swelling laws and additional fitting parameters, therefore limiting their predictive capability.

In this contribution, Dry Glass Reference Perturbation Theory (DGRPT) coupled with the PC-SAFT equation of state was applied to model sorption as well as swelling thermodynamics in high free-volume triptycene-based polybenzoxazoles (TPBOs) with varying triptycene content.

Pure polymer and binary interaction parameters were obtained through simultaneous correlation of multicomponent sorption data for CH₄, CO₂, and N₂ across multiple temperatures, together with mixed-gas swelling measurements for N₂/C₂H₆ at 35 °C. The resulting set of parameters accurately reproduces sorption and swelling behavior across all investigated systems. The DGRPT-PC-SAFT framework successfully predicts CO₂-induced swelling in pristine TPBO membranes, with no additional adjustable parameter.

The model was further used to investigate the discrepancy between pure- and mixed-gas ethane swelling. Predictive calculations show that competitive sorption alone cannot explain the experimentally observed higher swelling in pure ethane. By treating the dry polymer density as the sole adjustable parameter, representing conditioning of the glassy polymer matrix, the model quantitatively reproduces pure-ethane swelling data.

Overall, these results demonstrate that the DGRPT-PC-SAFT framework provides a physically grounded, parameter-efficient description of penetrant-induced swelling in high free-volume glassy polymers. Moreover, it offers a quantitative route to identify subtle conditioning effects in advanced membrane materials, supporting the development of robust predictive tools for gas separation processes.

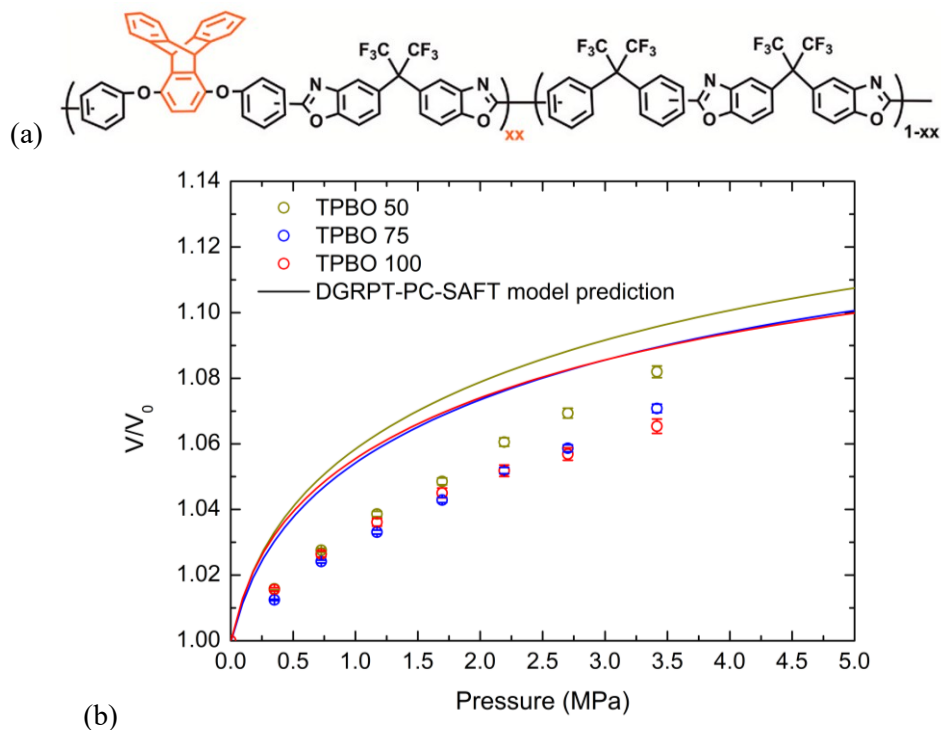


Figure 1. (a) TPBO-xx repeating unit. xx represents the triptycene molar content; (b) swelling of TPBOs induced by pure CO₂ at 35°C. Continuous lines represent DGRPT-PC-SAFT model predictions.

ANTI-SCALING PIEZOELECTRIC THIN FILM COMPOSITE (TFC) REVERSE OSMOSIS (RO) MEMBRANE FABRICATION *VIA* NOVEL ULTRASOUND APPROACH

S. Byun¹, T. H. Chong^{1,2}

¹Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, Clean Tech One, 637141, Singapore

²School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, 639798, Singapore (THChong@ntu.edu.sg)

Abstract: Piezoelectric membranes play a key role in reducing concentration polarization and fouling, leading to long-term operation [1,2]. This study developed a piezoelectric thin-film composite (TFC) reverse osmosis (RO) membrane *via* novel ultrasonic processing, enabling self-arrangement of the β -phase crystalline structure. To investigate anti-scaling performance, a test was conducted with model foulant of 20 mM calcium sulfate-containing brackish water (NaCl 2,000 ppm). Consequently, the TFC RO membrane *via* ultrasound (named TFC-ultra) improved the $F(\beta)$ value ($79.76 \pm 2.24\%$) with high piezoelectric effect, unlike the TFC membrane ($44.23 \pm 0.42\%$) in **Figure 1(a)**. Based on enhanced piezoelectric properties, the TFC-ultra membrane under applied alternative current (AC) demonstrated remarkable anti-scaling performance ($15.79 \pm 9.3\%$ flux decline) for 12 h, whereas the TFC membrane with AC showed a low anti-scaling performance ($29.06 \pm 3.14\%$ flux decline) in **Figure 1b** and **c**. In addition, the TFC-ultra membrane exhibited higher permeance recovery ($\sim 85\%$) and less scalant on the membrane surface (**Figure 1d**). Therefore, the novel ultrasonic approach can be applied to improve the self-arrangement of dipole moments and the piezoelectric β -phase crystalline structure, leading to outstanding anti-scaling performance during long-term operation. Consequently, the piezoelectric TFC-ultra membrane is expected to operate the RO process with stable flux, high-quality permeate water, and a longer lifespan in practical applications.

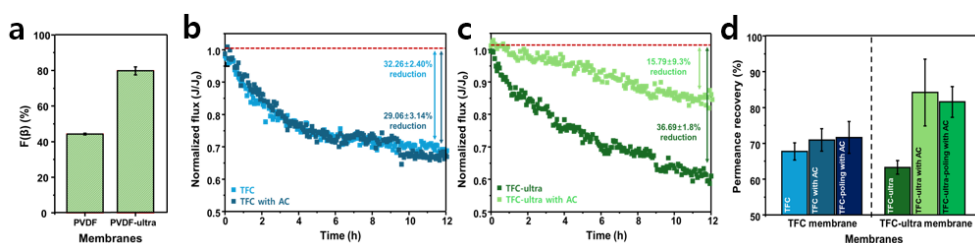


Figure 1 (a) $F(\beta)$ values, (b) normalized flux with TFC membrane, (c) normalized flux with TFC membrane via ultrasound (named TFC-ultra membrane), and (d) permeance recovery

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Acknowledgement

This research is supported by the Ministry of Education, Singapore under its Academic Research Fund Tier 2 (Award no: T2EP50224-0012). This research is supported by the National Research Foundation, Singapore, and PUB, Singapore's National Water Agency under its RIE2025 Urban Solutions and Sustainability (USS) (Water) Centre of Excellence (CoE) Programme which provides funding to the Nanyang Environment & Water Research Institute (NEWRI) of the Nanyang Technological University, Singapore (NTU). Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not reflect the views of the Ministry of Education, Singapore, National Research Foundation, Singapore and PUB, Singapore's National Water Agency.

SOLID-STATE NMR AS A TOOL TO STUDY CO₂ ADSORPTION MECHANISMS IN MEMBRANES

L. Calucci^{1,2}, A. Scarperi¹, S. Bertolozzi¹, F. Nardelli^{1,2,3}, E. Carignani^{1,2}

¹Institute of Chemistry of Organometallic Compounds, Italian National Research Council, via G. Moruzzi 1, 56124 Pisa, Italy (lucia.calucci@cnr.it)

²Center for Instrument Sharing, University of Pisa, Lungarno Pacinotti 43/44, 56126 Pisa, Italy

³Department of Chemistry and Industrial Chemistry, University of Pisa, via G. Moruzzi 13, 56124 Pisa, Italy

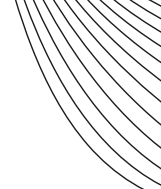
Abstract: Solid-state NMR (SSNMR) spectroscopy has emerged as one of the most powerful techniques for identifying and quantifying both physisorbed and chemisorbed CO₂ species in crystalline and amorphous solid sorbents, providing fundamental insights into CO₂ adsorption mechanisms at the molecular level. In particular, SSNMR has been successfully applied to investigate the structure of species formed upon CO₂ adsorption at porous surfaces via chemical reactions, as well as to characterize the molecular dynamics of physisorbed CO₂ in membranes, including polymers of intrinsic microporosity (PIMs) and mixed-matrix membranes (MMMs). Distinct chemical environments can be discriminated based on the chemical shift of signals in high-resolution spectra acquired under magic-angle spinning (MAS) conditions, as well as on the analysis of static line shapes. Moreover, static ¹³C SSNMR spectroscopy provides valuable information on the dynamics of physisorbed CO₂.

In this contribution, representative examples of MAS and static ¹³C SSNMR applications are presented to elucidate CO₂ adsorption mechanisms in membranes relevant for separation and capture processes. In particular, ¹³C SSNMR spectroscopy, combined with computational methods, is shown to unravel both chemi- and physisorption mechanisms in Amine-PIM-1, shedding light on the origin of enhanced CO₂ selectivity under mixed-gas conditions.¹ Furthermore, additional case studies on MMMs demonstrate how ¹³C SSNMR can be employed to investigate the preservation of physisorption mechanisms in metal–organic frameworks (MOFs) embedded as fillers within polymeric matrices.²⁻³

This project has received funding from the European Union's Horizon Europe research and innovation programme, European Innovation Council and SMEs Executive Agency (EISMEA), under grant agreement No 101115488, project "DAM4CO₂".

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THERMALLY SYMBIOTIC INTEGRATION OF OSMOTIC MEMBRANE DISTILLATION AND ELECTROLYSIS FOR DIRECT SEAWATER HYDROGEN PRODUCTION

G. S. Cassol¹, C. Shang^{1,2}, P. Westerhoff³, Y. Song^{1,4,5}

¹Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong SAR, China

²Hong Kong Branch of Chinese National Engineering Research Center for Control & Treatment of Heavy Metal Pollution, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong SAR, China

³School of Sustainable Engineering and The Built Environment, Arizona State University, Tempe, AZ, 85287, United States of America

⁴Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

⁵Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

Abstract: Power-to-hydrogen systems offer a critical pathway for storing intermittent renewable energy as green hydrogen (H₂)^{1,2}. However, large-scale implementation exacerbates freshwater scarcity, requiring 20–50 L of pure water per kilogram of H₂ produced^{3,4,5}. While oceans provide an inexhaustible water source, conventional direct seawater electrolysis faces catastrophic catalyst degradation from parasitic chlorine evolution and mineral scaling^{6,7}. To bypass these limitations, in situ membrane-integrated electrolysis has emerged as a promising strategy to purify seawater and generate H₂ simultaneously. Existing liquid-phase configurations, such as forward osmosis coupled with water splitting (FOWS), suffer from salt crossover that might poison the catalysts and limit the allowable operating concentration of the electrolyte⁸. Conversely, vapour-phase transport architectures like self-dampening electrolyte-assisted direct seawater electrolysis (SDE-DSE) successfully eliminate salt passage using hydrophobic membranes, but suffer from insufficient water output due to an isothermal operating regime that also restricts optimum electrolysis temperature operation⁹. This work addresses the water-energy nexus by introducing a thermally symbiotic architecture that integrates osmotic membrane distillation (OMD) directly with an alkaline water electrolysis (AWE) stack, as represented in Figure 1. The system establishes a thermodynamic synergy where the waste heat generated by the exothermic electrolysis reaction, an operational burden requiring costly cooling infrastructure, is harvested to satisfy the thermal demand of the OMD unit. Governed by a predictive system-level water balance model, the integrated system achieved a H₂ production flux of 60.2 kg day⁻¹ per m⁻² of membrane, a fourfold increase over liquid-phase FOWS and a 25-fold increase over isothermal baseline systems. Long-term validation using raw seawater demonstrated exceptional operational stability over 500 hours. Ultimately, thermodynamic and techno-economic modelling demonstrates that this self-sustaining loop eliminates external

heating penalties, achieving a specific energy consumption of $51.05 \text{ kWh kg(H}_2\text{)}^{-1}$ and a production cost of $\$5.73 \text{ kg(H}_2\text{)}^{-1}$, establishing a scalable, robust, and autonomous paradigm for offshore green H_2 generation.

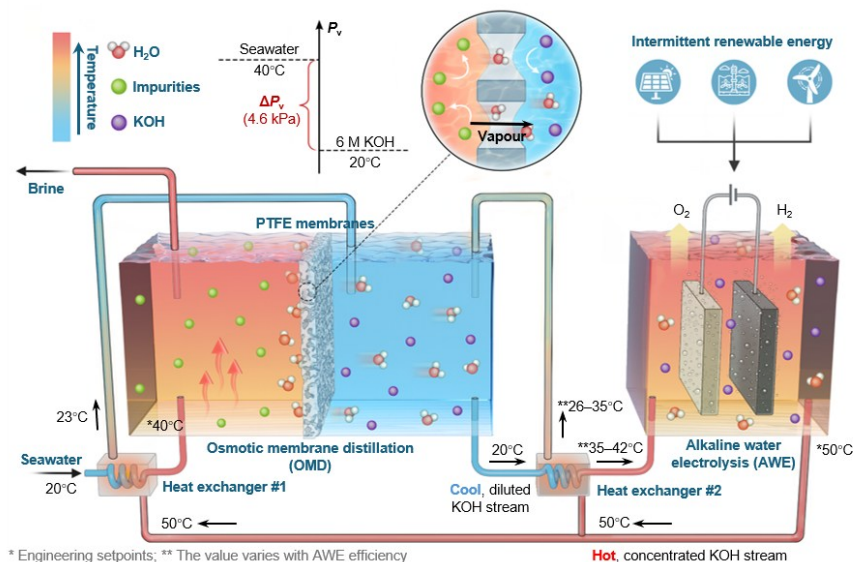


Figure 1. Green H_2 production from seawater using a thermally symbiotic osmotic distillation-alkaline water electrolysis (OMD-AWE) system.

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RATIONAL DESIGN AND SYNTHESIS OF CORE-SHELL STRUCTURED FILLERS FOR ENHANCED CO₂ SEPARATION IN MIXED-MATRIX MEMBRANES

H. L. Choi, Y. Jeong, T.-H. Bae

Department of Chemical and Biomolecular Engineering, Korea Advanced Institute of Science and Technology, Daejeon 34141, Republic of Korea (chleen@kaist.ac.kr)

Abstract: The development of efficient CO₂ separation technologies is vital for climate sustainability. We report two novel core-shell strategies to overcome the limitations of individual porous materials in mixed-matrix membranes (MMMs). First, a CaA@ZIF-8 structure was synthesized via ion-exchange-induced crystallization and post-synthetic conversion.¹ This method ensures exclusive ZIF-8 shell growth on the CaA surface, minimizing secondary nucleation and enhancing filler-polymer compatibility. The CaA core provides selective CO₂ pathways, while the ZIF-8 shell improves dispersion and suppresses nonselective interfacial voids.

Second, hierarchical Meso@Micro-CaA zeolites were developed through impregnation-assisted dry-gel conversion.² The mesoporous LTA core facilitates gas diffusion, while the microporous shell prevents polymer infiltration, maintaining high selectivity. Compared to hydrothermal methods, this approach offers faster synthesis, reduced water usage, and thinner shell formation.

The integration of CaA@ZIF-8 core-shell fillers into a polyimide matrix yielded MMMs with enhanced separation properties, achieving a CO₂ permeability of 1142 Barrer and a CO₂/CH₄ selectivity of 43.3. Similarly, Meso@Micro-CaA/Pebax 1074 membranes achieved a CO₂ permeability of 209 Barrer and a CO₂/N₂ selectivity of 121.3, surpassing the 2019 upper bounds. These results demonstrate that tailored core-shell architectures can significantly advance gas separation membrane performance across various zeolite topologies and MOF types.

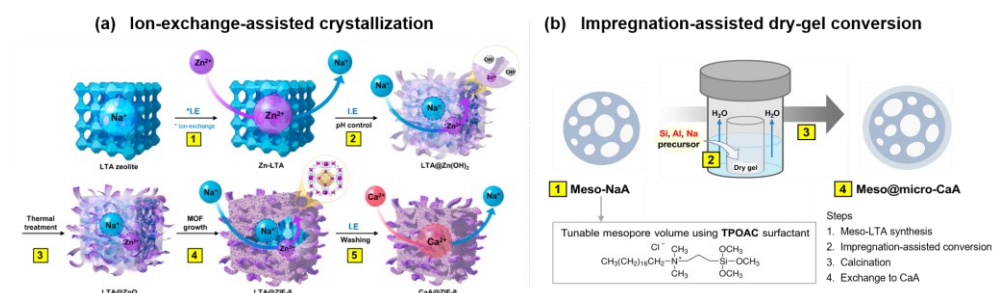


Figure 1. Schematic illustration of the synthetic process for core-shell structured fillers. (a) Ion-exchange-assisted crystallization; (b) impregnation-assisted dry-gel conversion.

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SMARTCE FILTER: FUNCTIONALIZED POROUS MEMBRANES FOR PALLADIUM RECOVERY

M. Cifuentes-Cabezas, N. Khatir, E. Anticó, C. Fontàs

Chemistry Department, University of Girona, C/Maria Aurelia Capmany, 69, 17003 Girona, Spain

(magdalena.cifuentes@udg.edu)

Abstract: The growing demand for Technology-Critical Elements (TCEs) and precious metals has increased the need for sustainable technologies capable of recovering valuable resources from dilute aqueous streams. In this context, the SmarTCE Filter technology has been developed as a membrane-based platform that integrates selective extraction and filtration within a single process.

The developed membranes consist of a biodegradable polycaprolactone (PCL) matrix functionalized with selective extractants. Their porous architecture enables the treatment of dilute aqueous solutions under low-pressure conditions, reducing energy requirements and reagent consumption while allowing membrane reuse.

Among the systems evaluated, membranes composed of 70 wt.% PCL and 30 wt.% trioctylmethylammonium thiosalicylate (TOMATS) showed particularly promising performance for palladium recovery. Scanning electron microscopy revealed well-defined porous structures, while porosity analyses confirmed the development of a nanostructured architecture. Thermogravimetric analyses further demonstrated the successful incorporation and stability of the extractant within the polymer matrix.

Filtration experiments performed with model aqueous solutions achieved palladium recovery efficiencies above 85%. Furthermore, the membranes maintained stable performance over ten consecutive extraction–recovery cycles, demonstrating excellent operational stability and reusability (Figure 1).

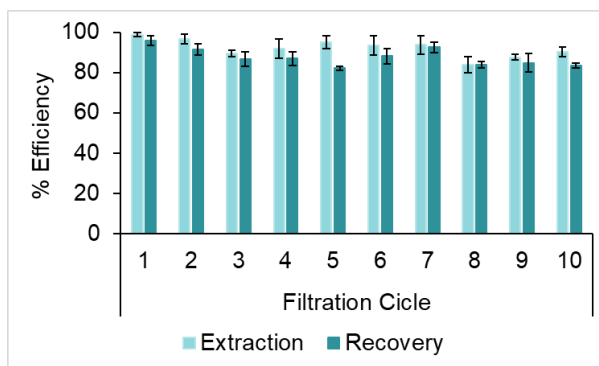


Figure 1. Palladium extraction and recovery over ten cycles

These results demonstrate the feasibility of combining selective extraction and low-pressure membrane filtration for palladium recovery. SmarTCE Filter offers a sustainable approach for future critical raw materials recovery applications.

Acknowledgement: This work was supported by MICIU (PID2022-140312NB-C22) and AGAUR (2025 LLAV 00042). N.K. acknowledges the IFUdG 2022 fellowship and M.C.-C. the Juan de la Cierva fellowship (JDC2023-052641-I).

CHIRAL MIXED MATRIX ION EXCHANGE MEMBRANES AS A MODULAR MEMBRANE PLATFORM FOR SEPARATION OF ENANTIOMERS

J. Cizek^{1,2}, M. Labikova³, M. Drobek⁴, C. Faur⁴, J. P. Mericq⁴, M. Kostejn¹, Z. Hrdlicka⁵, P. Stanovsky¹, J. Florekova⁶, F. Yalcinkaya⁷, Z. Rudolfova^{1,8}, J. P. Jisa^{1,2}, M. Kohout³, P. Izak^{1,6}

¹ICPF CAS, Rozvojova 135, 16500, Prague, Czechia (cizek@icpf.cas.cz, www.icpf.cas.cz)

²Department of Chemical Engineering, UCT Prague, Technicka 5, 166 28 Prague, Czechia

³Department of Organic Chemistry, UCT Prague, Technicka 5, 166 28 Prague, Czechia

⁴IEM (UMR 5635), Univ. Montpellier, CNRS, ENSCM, Place Eugene Bataillon, 34095, Montpellier, France

⁵Department of Polymers, UCT Prague, Technicka 5, 166 28, Prague, Czechia

⁶Department of Physical Chemistry, UCT Prague, Technicka 5, 166 28 Prague 6, Czechia

⁷CXI TUL, TU Liberec, Studentska 1402/2, 461 17, Liberec, Czechia

⁸Faculty of Chemical Technology, Univ. of Pardubice, Studentska 95, 532 10 Pardubice

Abstract: Separation of racemic mixtures is essential yet challenging because enantiomers possess identical physicochemical properties in achiral environments.

We present an innovative enantioselective ion-exchange mixed-matrix membrane for the separation of racemic acids. The membrane incorporates (tert-butylcarbamoyl)-quinidine modified 5 μm silica particles dispersed within poly(ethylene-co-vinyl alcohol) (EVOH) or poly(vinylidene fluoride) (PVDF) polymer matrices¹. Separation proceeds via a sorption-driven mechanism described by the retarded transport model. PVDF-based membranes were prepared by non-solvent-induced phase separation (NIPS) with a high particle-to-polymer packing ratio of 1.2:1, and EVOH-based membranes were prepared by a combination of vapour-induced phase separation (VIPS) and solvent evaporation at 50% relative humidity with a 1:1 ratio.

Successful separation of N-(3,5-dinitrobenzoyl)-leucine enantiomers was achieved using a solvent system composed of methanol and small amounts of acetic acid, and ammonium acetate. Both the EVOH- and PVDF-based membranes reached $\geq 98\%$ enantiomeric excess after five separation stages in concentration-driven process. Average fluxes were $(1513 \pm 255) \text{ mg m}^{-2} \text{ h}^{-1}$ for PVDF membranes and $(1190 \pm 139) \text{ mg m}^{-2} \text{ h}^{-1}$ for EVOH membranes at 1 mg mL^{-1} feed concentration with $\sim 5\%$ stage-to-stage recovery. Pressure-driven enantioseparation using PVDF membranes required approximately 20 stages to achieve $>90\%$ ee but provided significantly higher recoveries of $\sim 49\%$ per stage. The developed membranes are very resilient and enable scalable semi-continuous separation of acidic racemates.

Financial support obtained from the Czech Science Foundation, project 25-15195S, is gratefully acknowledged.

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POTENTIAL OF AN ARSENAZO III-BASED POLYMER INCLUSION MEMBRANES FOR THE SPECTROPHOTOMETRIC DETERMINATION OF LANTHANUM(III)

C. F. Croft¹, M. I. G. S. Almeida¹, S. D. Kolev^{1,2,3}

¹School of Chemistry, The University of Melbourne, Victoria 3010, Australia
(s.kolev@unimelb.edu.au)

²Department of Chemical Engineering, The University of Melbourne, Victoria 3010, Australia

³Faculty of Chemistry and Pharmacy, Sofia University “St. Kl. Ohridski”, 1 J. Bourchier Blvd., 1164 Sofia, Bulgaria

Abstract: The fast development of modern technologies using rare earth elements (REEs) has resulted in increased concentrations of anthropogenic REEs such as La³⁺ in the environment. It is therefore becoming increasingly important to develop methods allowing their quick and cheap detection. Arsenazo III (Az III) is a commonly applied colour reagent for the determination of REEs.¹ However, it is relatively expensive and highly toxic to aquatic life thus making its infield application potentially harmful.² To reduce the costs of analysis and minimize its harmful effect, Az III was encapsulation in a polymer inclusion membrane (PIM)^{3,4} whose composition was optimised. The membrane incorporated 44.5 wt% poly(vinyl chloride) as its base polymer and 45 wt% di(2-ethylhexyl)phosphoric acid as its extractant/carrier. Az III (0.5 wt%) was retained in the PIM by incorporating 10 wt% Aliquat 336 in the PIM composition. By incorporating the PIM in a flow through measuring cell and pumping a series of 20 mL La³⁺ solutions of different concentrations through it using a syringe pump, a working range of $0.5 - 5.0 \times 10^{-5}$ mol L⁻¹ for the determination of La³⁺ was obtained.

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POLY(ETHER ETHER KETONE) HOLLOW FIBERS FOR HARSH INDUSTRIAL ENVIRONMENTS

E. Di Nicolò¹, D. Aurilia¹, X. Revest²

¹Syensqo Specialty Polymers, R&D center, Viale Lombardia 20, Bollate (MI), 20021, Italy

²Syensqo Specialty Polymers, Rue de la Haie Coq 52, Aubervilliers 93308 (France)

emanuele.dinicolo@syensqo.com

Abstract: There is a continuous need in the industry for more robust and chemical resistant membranes in order to accomplish separations tasks which are currently not possible with membranes made with incumbent polymeric materials¹. There exist several opportunities in the chemical and petrochemical sectors in addition to pharmaceutical where membranes could enable a significant process intensification. Examples of issues that significantly reduce polymeric membrane lifetime and hence prevent their use in such environments are lack of performance stability due to plasticization in CO₂ rich environments, solvent-induced swelling and thermomechanical degradation.

PEEK is a semicrystalline polymer which possesses high strength and wear resistance, outstanding temperature and chemical resistance (being virtually insoluble in all organic solvents) with a rated end use of 250°C and for this reason it is widely used in the most demanding environments, such as aerospace, oil & gas, additive manufacturing, automotive, healthcare, semicon and chemical plants². In this study, we present the development of melt-extruded porous poly(ether ether ketone) (PEEK) hollow fibers produced at pilot scale³. We examine their structural and transport properties, comparing them with conventional polymeric membranes such as polysulfones, polyimides, and PVDF. The manufacturing process allows for precise control over the geometry and porosity of the hollow fibers, without relying on traditional solvent-induced phase inversion methods, which are not suitable for PEEK. This technique is highly flexible, enabling the production of various outer/inner diameter (OD/ID) ratios by adjusting the processing conditions (see image below).

In the first part of this work, we will show the influence of processing parameters on surface morphology, pore structure, and mechanical properties. Gas permeance and liquid permeability are characterized, and specific emphasis is placed on durability-related metrics, including resistance to CO₂-induced plasticization, morphological stability after immersion in aggressive organic solvents, and mechanical integrity under stress and high temperature conditions. Preliminary comparative results

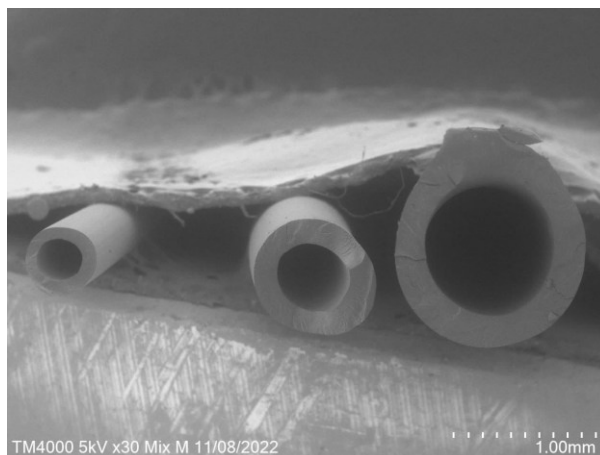
1) Journal of Membrane Science 598 (2020) 117761

2) <https://www.syensqo.com/en/brands/ketaspire-peek>. HANDBOOK OF POLYMERS 3rd Edition, Copyrights 2022; ChemTec Publishing. Pag 385

3) EP 3763435, WO 21018868

indicate that the intrinsic thermal and chemical stability of PEEK can translate into improved resistance to performance drift under harsh exposure relative to selected incumbent materials. In particular in the second part of this work we will show some applicative cases where we envision that those fibers could find applications and where other polymeric materials struggle to be used. More specifically we will show experimental findings related to:

- a) Pervaporation: for this case we will illustrate the separation efficiency of a model system (PEEK Fiber + hydrophilic coating) used in dehydrating a polar aprotic solvent across an extended range of composition and temperature and comparing these data with references in the literature
- b) Organic solvent filtration. In this section we will show the swelling of PEEK hollow fibers to the most used organic solvents and compare those data with other polymeric fibers in the literature. These data confirm the suitability of those fibers in OSN applications
- c) Gas separation: we will show data related to CO₂ separation from other gas mixtures. Here we will show the gas permeance and selectivity evolution over time in aggressive conditions and we will compare them to other incumbent membrane solutions
- d) Membrane distillation experiments where we exploit the hydrophobic nature of PEEK fibers and their high liquid entry pressure



Example of porous PEEK fibers produced in this work. Size and porosity can be fine-tuned depending on the specific application. Here we show an OD range from 0,48mm (left) to 1,37 mm (right)

DEVELOPMENT OF LOW-COST CLAYEY CERAMIC MICROFILTRATION MEMBRANES USING OLIVE POMACE AND SUNFLOWER SEED SHELLS AS BIOADDITIVES FOR WATER TREATMENT

Z. El Bouhali¹, A. Atter¹, O. Thayfi¹, R. Benhida^{1,2}, Khaless^{1*}

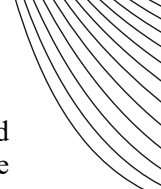
¹Mohamed VI Polytechnic University, Chemical and Biochemical Science, Green Process Engineering (CBS), Benguerir, Morocco.

²Nice institute of chemistry, University Côte d'Azur, Nice, France.

Abstract: The valorization of agro-industrial residues in ceramic membrane manufacturing offers a promising route toward low-cost and sustainable water treatment technologies. In this study, clay-based ceramic microfiltration membranes were developed using olive pomace and sunflower seed husks as bio-porogenic additives. The bioadditive content was varied from 10 to 40 wt.% in order to evaluate its effect on the structural, physical, mechanical, and hydraulic properties of the membranes. The prepared mixtures were shaped by uniaxial pressing and sintered at 900 °C for 2 h using a controlled thermal cycle.

Increasing the bioadditive content significantly modified the membrane structure. For olive pomace-based membranes, mass loss increased from 23.0 to 48.9%, while apparent density decreased from 2.13 to 1.80 g·cm⁻³. Similarly, sunflower seed husk-based membranes showed an increase in mass loss from 22.6 to 46.5% and a decrease in apparent density from 2.01 to 1.73 g·cm⁻³. This confirms the effective burnout of organic matter during sintering and the formation of a porous ceramic network. The porosity increased from approximately 15.8 to 50.0% for olive pomace and from 17.5 to 54.8% for sunflower seed husks. However, this increase in porosity was accompanied by a decrease in flexural strength, from 22.1 to 8.7 MPa for olive pomace-based membranes and from 18.8 to 6.3 MPa for sunflower seed husk-based membranes.

Filtration tests using real tannery wastewater collected from the Medina of Fez, Morocco, first confirmed the practical applicability of the developed membranes under real effluent conditions. During tannery wastewater filtration, the membrane showed stable hydraulic behavior, with water flux decreasing progressively due to the deposition of suspended solids, colloids, and organic matter on the membrane surface, before reaching a quasi-stable regime. The sunflower seed husk-based membrane exhibited the highest water flux, decreasing from about 136 to 71 L·h⁻¹·m⁻², while the olive pomace-based membrane showed a flux decrease from approximately 124 to 65 L·h⁻¹·m⁻². Despite this flux decline, both membranes demonstrated good hydraulic stabilization and excellent clarification performance, with turbidity retention close to 99%.



Pure water permeability tests further confirmed the suitability of the developed membranes for microfiltration applications. Under different transmembrane pressures, the average flux increased from 61.6 to 184.7 L·h⁻¹·m⁻² when the pressure increased from 0.1 to 0.4 bar, with a hydraulic permeability of 416.4 L·h⁻¹·m⁻²·bar⁻¹ and an excellent linearity coefficient of $R^2 = 0.9977$.

Both membranes exhibited excellent clarification performance, with turbidity retention close to 99% throughout the filtration tests. Overall, sunflower seed husks promoted higher porosity and water flux, while olive pomace provided better mechanical resistance. These results demonstrate that both residues can be successfully used as sustainable bioadditives for tailoring low-cost ceramic microfiltration membranes, contributing to biomass waste valorization and circular-economy-based water treatment solutions.

IMPROVING THE PERFORMANCE OF MEMBRANE DISTILLATION UNIT USING MOF SUPPORTED HYDROPHOBIC COMPOSITE MEMBRANE

A.H. El-Shazly, R.I. Saman, A.A. Shahin

Chemical and Petrochemicals Engineering Department, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt.

Abstract: This work investigates the possibility of improving the performance of a direct contact membrane distillation (DCMD) unit by using a fin modified feed region in addition to the application of a superhydrophobic composite of Polyvinylidene Fluoride (PVDF), polystyrene (PS) and Zirconium chloride-Metal organic framework (UiO-66). Many techniques were used for the characterization of the polymer composite such as, SEM, TEM, XRD, FT-IR. In addition, the porosity, contact angle and water entry pressure of the membrane were measured. The fins geometry and arrangement were also investigated. Many operational parameters such as feed water temperature and flow rate, cooling water temperature and flow rate and polymer composite composition were investigated. The phase inversion technique was used for fabrication of the composite membrane and the results showed that a composite membrane of 75% PVDF , 25% PS and 1-1.5 % MOF of the composite has the highest hydrophobicity with contact angle up to 100- 115 and porosity up to 69%. The in-line arrangement of fins showed improved water flux. The flux of the unit for the modified membrane and fined DCMD cell was found to be 28 liter/m².h. Backwash experiments showed a good stability of the membrane and durability.

Keywords: Composite materials- membrane fabrication- membrane distillation- metal organic framework (MOF).

QUATERNIZED HIGHLY CROSSLINKED POROUS POLYMERS AS FILLERS FOR GAS SEPARATION MEMBRANES

E. Esposito¹, G. Bezzu², M. Vaccaro¹, M. Carta³, J.C. Jansen¹, A. Fuoco¹

¹Institute on Membrane Technology (ITM-CNR), Via P. Bucci 17/C, 87036 Rende (CS), Italy

²Department of Chemistry, Faculty of Science and Engineering, Swansea University, Grove Building, Singleton Park, Swansea, SA2 8PP, UK

³Instituto de Síntesis Química y Catálisis Homogénea, CSIC-Universidad de Zaragoza, C/Pedro Cerbuna 12, Facultad de Ciencias, Zaragoza 50009, Spain

Abstract: Mixed matrix membranes (MMMs) were prepared by incorporating quaternized, highly crosslinked porous organic polymers (POPs) based on TAT-TB networks into intrinsically microporous polymer matrices. The resulting hybrid membranes exhibited enhanced molecular sieving properties owing to the combination of polymer microporosity and the permanent porosity of the fillers¹.

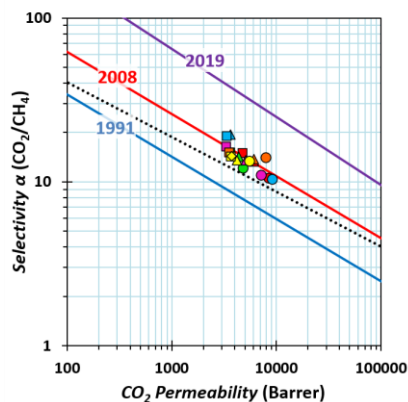


Figure 4 CO₂/CH₄ Robeson upper bound graph

Single-gas permeation measurements were carried out using N₂, O₂, CO₂, CH₄, H₂ and He. Attention was devoted to CO₂/CH₄ and CO₂/N₂ separations because of their relevance to natural gas upgrading and post-combustion carbon capture. The incorporation of quaternized porous fillers led to a significant enhancement in gas transport performance, with CO₂ permeabilities reaching values above 9,000 Barrer and ideal CO₂/CH₄ and CO₂/N₂ selectivities up to approximately 19 and 20, respectively. These findings offer key insights for designing high-performance membranes tailored for sustainable gas separations.

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SHEAR-INDUCED CHANGES IN CASEIN PROPERTIES AND FUNCTIONALITY DURING MEMBRANE CONCENTRATION

J. Faour¹, F. Mardal², B. Razi Parjikolaei², C. A. Quist-Jensen³, L. Ahrné¹

¹University of Copenhagen, Department of Food Science, Copenhagen, Denmark

²Arla Foods Ingredients P/S, Sønderupvej 26, 6920 Videbæk, Denmark

³Aalborg University, Department of Chemistry and Bioscience, Aalborg, Denmark

The authors did not consent to the publication of this abstract.

EXPLORING CHEMICALLY DRIVEN FUNCTIONALIZED MEMBRANES FOR BORON RECOVERY FROM DESALINATION STREAMS

C. Fontàs¹, I. Alcaraz^{1,2}, G. Blandin²

¹Chemistry Department, Universitat de Girona, Girona 17003, Spain
(claudia.fontas@udg.edu)

²LEQUIA, Institut de medi ambient, Universitat de Girona, Campus Montilivi, Girona 17003, Spain (itzel.alcaraz@udg.edu; gaetan.blandin@udg.edu)

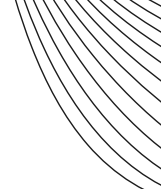
Abstract: Boron is recognized as a critical raw material due to its economic relevance in sectors such as glass manufacturing, agriculture, and electronics. However, elevated boron concentrations in water can pose risks to both human health and agricultural systems, making its control essential. Boron is naturally present in seawater and becomes concentrated in desalination brines. Moreover, conventional reverse osmosis membranes are not highly effective at boron removal without additional treatment steps, allowing a significant fraction to pass into the permeate. This limitation highlights the need for improved boron removal and recovery strategies.

Membrane-based technologies have emerged as promising and sustainable solutions for water treatment and resource recovery. In desalination processes, they offer the dual benefit of water purification and valorization of streams such as permeate and brines.

In this work, polymer inclusion membranes (PIMs) are investigated as functionalized polymeric membranes for boron recovery from desalination streams. The membranes are based on cellulose triacetate (CTA) as the polymer matrix and Aliquat 336 as the carrier, which enables chemically driven boron transport. The study evaluates key parameters influencing boron transport, including membrane composition, the nature of the stripping phase, and the effect of feed solution pH. The results obtained highlight the importance of these parameters in the system's performance, evidencing that membrane composition determines the extraction efficiency, while the selection of the stripping phase directly conditions boron recovery. Furthermore, the feed pH plays a crucial role in transport, as the extraction mechanism relies on ion exchange; consequently, the boron species must be charged, which is achieved at basic pH levels (above 8.5) where the anionic form prevails.

This research contributes to the development of efficient and sustainable membrane-based strategies for boron recovery from high-salinity waters, supporting improved resource management in desalination systems.

Acknowledgement: This work was supported by MICIU (PID2022-140312NB-C22).



ELECTRODIALYSIS FOR THE RECOVERY OF CRITICAL METALS FROM BATTERIES: A PATH TOWARD THE CIRCULAR ECONOMY

E.L. Fouquet, K. Roiz, E. Bringas, Ma.-F. San-Román, R. Ibáñez*

Dpto. de Ingenierías Química y Biomolecular, ETSIIyT, Universidad de Cantabria, Avda. de los Castros, 46, Santander 39005, Cantabria, Spain.

Presenting author: emilia.fouquet@unican.es; *Corresponding author: ibanezr@unican.es

Abstract: The rapid growth of lithium-ion batteries, driven by decarbonization goals, has increased the demand for critical metals such as Li, Ni, Mn, and Co¹. Battery recycling offers a sustainable pathway for resource recovery; however, the selective separation of metal cations from leachates remains a major challenge. Electrodialysis (ED) has emerged as a promising technique for the selective separation of Li⁺ from Ni²⁺, Mn²⁺, and Co²⁺, offering higher selectivity and lower chemical consumption than conventional methods while aligning with EU sustainability objectives³⁻⁵.

Previous studies have demonstrated that electrodialysis (ED) with monovalent-selective membranes enables efficient Li⁺ separation from divalent cations in NMC111 leachates, due to lithium's lower charge and smaller ionic radius, allowing up to five times higher Li recovery compared to Mn³. However, recent results from our research group show a significant reduction in selectivity when treating NMC811, being the main difference cathode composition (Table1). Using NMC811 inorganic acid leachates, high Ni²⁺ concentration limits membrane performance and hinders lithium separation, resulting in a relative Li recovery of ~15% compared to ~7% for divalent cations, but leading to final concentrations of 1585 ppm Li versus 5425 ppm Ni, thus limiting lithium purity.

Table 1. Composition of the cathode of an NMC811 battery

Metals	Li	Ni	Mn	Co
Composition of NMC811 cathode ⁶	10%	75%	5%	10%
Composition of NMC111 cathode ³	7%	20%	19%	20%

To address this limitation, this work proposes the combined use of monovalent-selective membranes and chelating agents to enhance Li⁺ separation. Chelants promote the complexation of divalent cations, reducing their fraction in free ionic form and consequently decreasing their transport through the membrane, thereby improving the effectiveness of monovalent-selective membranes in selectively separating lithium⁷.

To this end, black mass derived from NMC811 cathodes, obtained following the dismantling procedure previously reported⁶, was leached using organic acids, namely citric, DL-malic, oxalic, and gluconic acids. Their performance as leaching and complexing agents was systematically evaluated following a design

of experiments (DOE) methodology. Among them, citric acid ($\text{C}_6\text{H}_8\text{O}_7$) exhibited the best performance under the following conditions: 1.5 M acid concentration, liquid-to-solid ratio of 10, temperature of 65°C , and 0.75% H_2O_2 . Under these conditions, the resulting leachate contained 6030 ppm Li, 45650 ppm Ni, 2575 ppm Mn, and 6120 ppm Co, with an equilibrium pH of 2.9.

Metal speciation in citrate media was investigated to evaluate whether the equilibrium pH (2.9) achieved after leaching enables the reduction of free divalent cations while preserving lithium predominantly in its Li^+ form, as demonstrated in Figure 1.

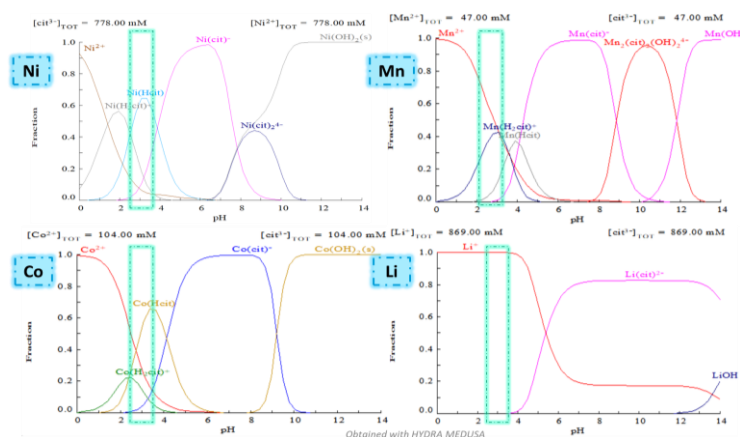


Figure 1. Speciation diagrams of Ni, Mn, Co, Li with citric acid

Electrodialysis experiments are currently conducted using a commercial PCCell system equipped with Neosepta[®] anion- and cation-exchange membranes, the latter being selective for monovalent cations (AMX-fg and CXP-S). Process performance is systematically evaluated by investigating the influence of key operational parameters, including anion nature, cation concentration, electrolyte composition, feed pH, applied current density ($67.5\text{--}250\text{ A}\cdot\text{m}^{-2}$), and membrane stack configuration (1–5 membrane units).

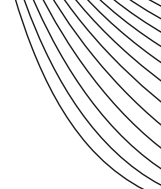
Preliminary results working with model solutions indicate that lithium recovery purity increases with the number of membrane units, which is attributed to the presence of a chelating agent enhancing selectivity. The complete study will enable the identification of optimal operating conditions that maximize lithium recovery and concentration while improving selectivity over competing divalent cations, thereby allowing efficient stage-wise metal separation.

Acknowledgements

Grants PID2023-147888OB-I00 funded by MICIU/AEI/10.13039/501100011033 and by FEDER/EU. Emilia Laura Fouquet is grateful for the predoctoral contract PREP2023-002231. Grant PREP2023-002231 funded by MICIU/AEI/10.13039/501100011033 and by “ESF+”

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DEEP EUTECTIC SOLVENT (DES) FLOW ELECTRODES FOR HIGH-VOLTAGE DESALINATION

E. Gabirondo^{1,2}, H. Saif¹, V. Alves³, J. Crespo¹, L. Tome^{1,4}, S. Pawlowski¹

¹LAQV REQUIMTE, Department of Chemistry, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Portugal (s.pawlowski@fct.unl.pt)

²POLYMAT and Department of Polymers and Advanced Materials: Physics, Chemistry and Technology, Faculty of Chemistry, University of the Basque Country UPV/EHU, Spain

³LEAF—Linking Landscape, Environment, Agriculture and Food Research Center, Instituto Superior de Agronomia, Universidade de Lisboa, Portugal

⁴Department of Chemical Engineering, University of Coimbra, Portugal

Abstract: Flow electrode capacitive deionisation (FCDI) is an emerging electro-membrane desalination technology where flow electrodes (usually activated carbon dispersed in NaCl aqueous solution) replace the fixed electrodes used in other capacitive desalination methods, enabling continuous desalination without a separate electrode regeneration step. However, FCDI is restricted to operating at 1.23 V or, in practice, even lower, to prevent water splitting in the flow electrodes. We pioneered the use of deep eutectic solvents as electrolytes in flow electrodes for FCDI, providing a new, better alternative to water-based flow electrodes. The deep eutectic solvent, choline chloride-urea (ChCl-U), was chosen for its wide electrochemical stability window. The main disadvantage of DESs compared to water is their higher viscosity; therefore, the impact of water addition on the viscosity and performance of DES flow electrodes was also examined. Cyclic voltammetry measurements confirmed electrochemical stability, while rheological measurements and electrochemical impedance spectroscopy demonstrated that adding water reduced viscosity and enhanced the conductivity of ChCl-U, making it suitable for use as flow electrodes in FCDI systems. Desalination experiments were successfully conducted without pH change within a potential range of up to 2.2 V¹. Furthermore, 1H NMR analysis demonstrated the absence of deep eutectic solvent traces in the dilute stream. The results emphasise the potential of DES flow electrodes to enhance desalination processes by enabling higher operational voltages and improved performance, thereby paving the way for more efficient FCDI desalination systems.

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COMPARATIVE TRANSPORT CHARACTERISATION OF NANOFILTRATION MEMBRANES IN TEST CELLS WITH TANGENTIAL FLOW AND UNIFORMLY ACCESSIBLE SURFACE

F. Gaioto¹, A. Yaroshchuk^{2,3}, M. Dezotti¹, Z. Maletskyi⁴

¹Federal University of Rio de Janeiro, COPPE/UFRJ, Programa de Engenharia Química
PO.BOX, 21941-901, Rio de Janeiro, Brazil

²ICREA, pg.L.Company 23, 08010 Barcelona, Spain

³Universitat Politècnica de Catalunya – Barcelona Tech, ETSEIB, av. Diagonal 647, 08028 Barcelona, Spain

⁴Norwegian University of Life Sciences (NMBU), Postboks 5003 NMBU1432 Ås, Norway

Abstract: Design and control of nanofiltration (NF) processes require intrinsic membrane transport parameters. In tangential-flow cells, measured flux and solute rejections are affected by concentration polarisation (CP) that is typically non-uniform over the membrane surface. However, procedures for correction for CP usually disregard this phenomenon. Moreover, the non-uniformity is test-cell specific. Consequently, cross-flow characterisation often provides apparent rather than intrinsic properties that are difficult to transfer quantitatively to practical configurations such as spiral-wound membrane modules, for example.

A uniformly accessible membrane surface offers a way to quantitatively decouple CP from transmembrane transport. This situation occurs, in particular, in test cells with a Rotating Disk-like Membrane (RDM). In this configuration, CP layer thickness is the same over the whole membrane surface, and the dependence of this thickness on the rotation rate (and other system parameters such as fluid viscosity and solute diffusivity) can be described by the celebrated Levich equation. On the other hand, preliminary evidence suggests that Sterlitech CF042 cell may be unsuitable for NF-membrane characterisation at pressures above approximately 5 bar because CP is very pronounced under such conditions but accounting for its inhomogeneity is very difficult.

This study compares transport characterisation of NF membranes in a CF042 tangential-flow cell and in an RDM cell with a uniformly accessible membrane surface. We test the hypothesis that controlled rotation reduces CP inhomogeneity to such an extent that observed rejection and flux data can be quantitatively corrected and intrinsic membrane behaviour revealed.

Commercial flat-sheet NF membranes have been tested in a Sterlitech benchtop system. Fresh coupons were pre-wetted, compacted and characterised using 0.01 M single-salt electrolyte solutions at approximately 20 °C and 0.8 L/min cross-flow rate. RDM experiments varied pressure (5, 10 and 15 bar) and rotation speed (200-1000 rpm), while CF042 experiments used comparable pressures. Additional tests at 10 bar

and 700 rpm compared rejection selectivity for $\text{Mg}(\text{NO}_3)_2$, NaNO_3 , MgSO_4 and Na_2SO_4 in both cells. Permeate samples were collected after steady state was reached and were analysed by mass, conductivity and element composition (ICP-MS). Observed rejections were converted to intrinsic rejections using cross-flow mass-transfer correlations for CF042 and Levich CP correction for the RDM cell.

The comparative study confirms that the RDM cell satisfies the equal-accessibility condition, so that the extent of CP can be treated as uniform over the whole membrane surface. The RDM configuration therefore provides a practical platform for systematic transport characterisation of NF/RO membranes, yielding intrinsic parameters that can be used as inputs for modelling the performance of practical membrane modules.

TECHNO-ECONOMIC ASSESSMENT OF A DUAL-ACTIVE MEMBRANE REACTOR FOR INTEGRATED CO₂ CAPTURE AND CONVERSION TO LIGHT HYDROCARBONS

K. Ghasemzadeh¹, A. Fuoco², M. C. Ferrari¹

¹Institute for Materials and Processes, School of Engineering, University of Edinburgh, Edinburgh, UK

²Institute on Membrane Technology (CNR-ITM), via P. Bucci 17/C, Rende, Italy

Abstract: Combining CO₂ capture and conversion in one compact unit could make carbon capture and utilisation far more practical than today's multi-step processes, cutting down on footprint, cost, and energy use^{1,2}. In this work, as part of the DAM4CO₂ project³, we developed a one-dimensional, non-isothermal model of a hollow fiber dual-active membrane (DAM) reactor that captures CO₂ from flue gas and converts it directly into light hydrocarbons, all within a single module operating below 300°C. The model brings together mass balance, pressure drop, and energy balance equations, and draws on detailed kinetics from the literature^{4,5}. The application to an industrial-scale flue gas rate of 9,850 kmol/h was explored including sensitivity analysis on temperature constraints, membrane permeance and perm-selectivity.

The investigation revealed the importance of the thermal boundary conditions. Because CO₂ hydrogenation releases heat, keeping the reactor temperature under control becomes critical for membrane stability. For instance, thermal distribution for constant wall temperature condition (at 250 °C) is reported in Figure 1. The use of a lower temperature inlet flue gas is a practical way to manage this heat distribution. area, holding the wall temperature at 250°C while outlet temperatures stayed below 255°C.

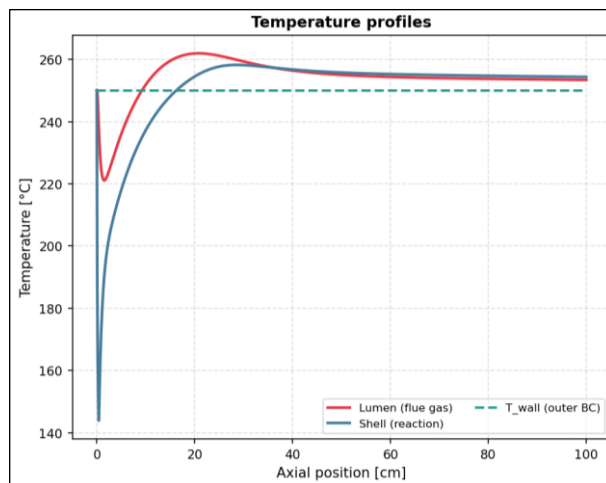


Figure1: Temperature distribution in the retentate stream (lumen side) and permeate stream (shell side) at an inlet temperatures and wall temperature of 250 °C.

Interestingly, membrane perm-selectivity influences the results less than expected and even a fairly low CO₂/N₂ selectivity of 5 was able to sustain competitive performance of the system. The membrane permeance instead has a dramatic impact on the system performance: increasing the permeance tenfold, from 6 to 60 GPU for CO₂ alongside other components, pushed conversion up to 63% and C₁₊ selectivity to 16%, with no thermal penalty (Table 1).

Table1: DAM permeance effect on reactor performance

Case 1: baseline	Case 2: Pei=3×Pei(at baseline)	Case 3: Pei=10×Pei(at baseline)
CO ₂ -conversion%=24.87%	CO ₂ -conversion%=44.64%	CO ₂ -conversion%=63.01%
C ₁₊ Selectivity=13.98%	C ₁₊ Selectivity=14.80%	C ₁₊ Selectivity=15.73%
dP=0.021 bar (lumen)	dP=0.018 bar (lumen)	dP=0.017 bar (lumen)
Outlet temperature= 253 C	Outlet temperature= 255 C	Outlet temperature= 251 C
Outlet-U_lumen (m/s)=0.290	Outlet-U_lumen (m/s)=0.261	Outlet-U_lumen (m/s)=0.211
Outlet-U_Shell (m/s)=0.005	Outlet-U_Shell (m/s)=0.007	Outlet-U_Shell (m/s)=0.012

Given these promising technical results, an economic assessment was carried out for the higher-permeance case. The results are encouraging: an NPV of 1,912 MEuro, an IRR of 11.60%, and a payback period of 8 years, suggesting that with the right membrane, this approach could be a genuinely profitable route to sustainable CO₂ capture and utilisation (Table 2).

Table2. Economic assessment results for case 3 reporting in Table 1

Economic indicators	Values
Total capital investment (MEuro)	3227
Revenue (MEuro/year)	840
Production Cost (MEuro/Year)	438
Net Profit (MEuro/Year)	402
Payback Period (Year)	8
ROI, %	12.51
IRR (%)	11.60
NPV (Meuro)	1912

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CONTINUOUS BRINE CONCENTRATION IN A THREE-STAGE LOW-SALT-REJECTION REVERSE OSMOSIS (LSRRO) CASCADE WITH FLEXIBLE RO (FLERO) STAGES: FROM NaCl BRINES TO MONOVALENT-SELECTIVE ELECTRODIALYSIS CONCENTRATES

G. Gidey-Berhe¹, A. Belkin^{1,2}, J. Gilron¹

¹Zuckerberg Inst. for Water Research, Ben-Gurion University of the Negev, Sylvan Adams Campus, Midreshet Sde Boker, 84990 Israel, berhe@post.bgu.ac.il, www.bgu.ac.il/en/u/sde-boker/bidr/institutes/ziwr/

²Chemical Engineering Department, Ben-Gurion University of the Negev, POB 653, Beer-Sheva, Israel 8410501

Abstract: Minimizing brine volumes is a central challenge in inland brackish water desalination and industrial water treatment, where disposal options are limited and minimal or zero liquid discharge (MLD/ZLD) is increasingly required. In conventional reverse osmosis (RO), the high salt rejection of the membranes causes the osmotic pressure of the concentrate to rise rapidly, so that standard spiral-wound modules, limited to about 70 bar, cannot concentrate brines much beyond 80 g/L NaCl. Low-salt-rejection reverse osmosis (LSRRO) overcomes this barrier by using membranes with intentionally reduced salt rejection in a staged cascade with permeate recycling, allowing brines to be concentrated to osmotic pressures exceeding the applied hydraulic pressure at energy demands far below thermal brine concentrators¹. However, most LSRRO studies to date have been limited to process modeling, and small-scale implementation is hindered by hydraulic constraints: as recovery increases, flows along membrane elements fall below manufacturer minimums, causing operational instability.

Here we report the design and operation of a three-stage LSRRO pilot where each stage was constructed according to the FLERO approach²: internal concentrate recycling within each stage decouples flow from recovery constraints, while pressure intensifiers recover energy from the recycle stream and stage pressures adjust automatically to the local salinity and flux. Each stage was equipped with a single 2540 spiral-wound element with progressively decreasing salt rejection along the cascade, combining a seawater RO (SWRO) element in stage 1 with commercial nanofiltration elements or LSRRO elements prepared in-house by controlled chemical oxidation (NaOCl) of standard RO modules. The flowsheet of the system is displayed in Figure 1.³

The pilot (feed capacity 45 L/h) was operated first on synthetic NaCl brines (26.9–33.3 g/L), and subsequently on a real monovalent-selective electrodialysis (MSED) concentrate (25 g/L TDS) derived from brackish groundwater, in which hardness and silica are largely retained in the ED diluate, providing an NaCl-dominant, low-scaling-risk feed to the LSRRO.

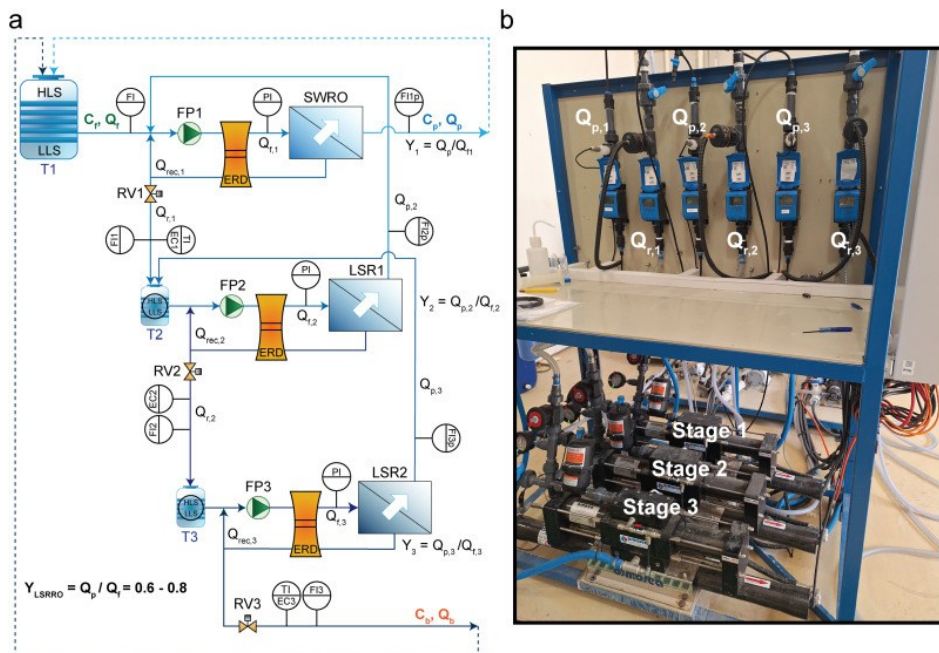


Figure 5: Schematic and photo of pilot LSRRO system (from ³)

On NaCl brines, the pilot consistently achieved water recoveries of 65% and higher, with concentration factors above three and final brine concentrations exceeding 114 g/L NaCl (>1.95 M), at stage inlet pressures well below 70 bar³. Only three membrane elements were required, Specific energy consumption (SEC) was 10–13 kWh/m³ of feed, dominated by the low efficiency (49%) of the small feed pumps; with conventional pump efficiencies (≥80%) the SEC would fall by over 30%, and under ideal pump and energy-recovery efficiencies the process-intrinsic SEC is 3.2–3.8 kWh/m³.

On the MSED concentrate, the cascade ran stably with no pressure increase at steady state or flux decline at recoveries of 67–80%. Final brine volume were reduced to less than 1% of the original brackish RO feed. Ion concentration factors spanned 2.3–5.7, with divalent and scaling-prone species (Ca²⁺, HCO₃⁻, SO₄²⁻) concentrating the most and Br⁻ and SiO₂ the least. SEC on this feed was 9.7–11.3 kWh/m³ (6.3–7.3 kWh/m³ projected with ≥80% efficient pumps), below the 18.5 kWh/m³ typical of thermal brine concentrators.

These results demonstrate that the FLERO-LSRRO configuration makes staged LSRRO trains practical at small scale using commercially available components, tolerating variations in feed salinity and flow while operating far below module pressure limits. Ongoing work focuses on tailoring stage rejections to push recoveries beyond 80%, and developing a validated transport-parameter model of the cascade for both NaCl and MSED concentrate feeds.

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BIOCATALYTIC MEMBRANE REACTORS FOR HIGHLY SELECTIVE AND SUSTAINABLE PRODUCTION SYSTEMS

L. Giorno

National Research Council, Institute on Membrane Technology “Enrico Drioli”, Via P. Bucci 17C, 87036, Rende (CS), Italy (l.giorno@itm.cnr.it)

Abstract: The use of catalysts of biological origin, such as enzymes, allows for highly selective reactions, with no or limited side products, and therefore simplifies downstream bioprocessing. Since enzymes are labile macromolecules, their heterogenization is necessary to enhance their stability. The use of porous/mesoporous membranes as support for the enzyme heterogenization not only enhances enzyme catalytic stability and reusability but also allows for continuous production systems where the simultaneous catalytic reaction and separation of products from the reaction site can be achieved. Physicochemical, structural, and morphological properties of the membrane, as well as transport phenomena, influence enzyme loading (amount, density, distribution), catalytic activity, residence time, reaction rate, conversion degree, and separation efficiency. A series of case studies will be presented to demonstrate their influence. Membranes specifically designed for biocatalytic reactors are not yet commercially available, so membranes intended for other purposes are usually adapted. Attempts to fabricate ad hoc membranes from sustainable materials will be discussed, demonstrating significant benefits in productivity and stability.

Despite the significant potential of biocatalytic membrane reactors, their application in real-world settings remains limited and is mainly confined to the pharmaceutical sector. However, the growing demand for clean production systems that operate with low energy input and minimal carbon and water footprints is expected to drive the development of biocatalytic membrane reactors not only for high-value products but also for commodity chemicals. Breakthroughs are expected from advances in materials and enzyme engineering.

MEMBRANE DISTILLATION APPLIED TO ORGANIC-RICH SURFACE WATER AND BIOLOGICALLY TREATED WASTEWATER: REVEALING FOULING BEHAVIOR

N. F. Himma¹, H. Horn^{1,2}, F. Saravia²

¹Karlsruhe Institute of Technology (KIT), Engler-Bunte-Institut (EBI), Water Chemistry and Water Technology, Engler-Bunte-Ring 9, 76131 Karlsruhe, Germany
(nurul.himma@partner.kit.edu; harald.horn@kit.edu)

²DVGW-Research Center at the Engler-Bunte-Institut (EBI), Water Chemistry and Water Technology, Karlsruhe Institute of Technology (KIT), Engler-Bunte-Ring 9, 76131 Karlsruhe, Germany (saravia@dvwg-ebi.de)

Abstract: Membrane distillation (MD) has emerged as a promising technology for producing high-purity water, relying on water vapor transport through a microporous hydrophobic membrane driven by a temperature gradient across the membrane. However, membrane fouling remains unavoidable during this process, adversely affecting its separation performance. It has been considered a complex phenomenon, governed by complex interactions among various constituents in the feed water and the membrane. Therefore, studies employing model foulants may not accurately represent real fouling behavior in practical MD applications.

In this study, fouling behavior in air gap membrane distillation (AGMD) was investigated using two different water sources: (i) Lake Hohloh (Black Forest, Germany), which is rich in natural organic matter, and (ii) biological treatment effluent from the wastewater treatment plant (Karlsruhe, Germany). The water characteristics are summarized in **Table 1**. For experiments with Lake Hohloh water, NaCl or CaCl₂ was added to obtain an electrical conductivity of ~1000 µS/cm, mimicking the electrical conductivity of the treated wastewater. AGMD experiments were carried out using a commercial hydrophobic microporous polypropylene membrane placed in a custom test cell equipped with optical windows allowing for in-situ scanning by optical coherence tomography (OCT) (**Figure 1 (a)**). The same process parameters as those used in the previous study were applied¹. Digital image processing was performed using Fiji (ImageJ) on the 3D OCT scans, adapting the previously developed in-house approaches^{2,3}.

Table 1. Characteristics of raw water used as feed in membrane distillation experiments

Parameter		Lake Hohloh	Biologically treated wastewater
Dissolved organic carbon	mg/L	30 ± 1	7 ± 1
Electrical conductivity	µS/cm	~40	955 ± 203
pH	-	3.9	7.8 ± 0.1

Results showed that severe organic fouling in the MD of Lake Hohloh water was promoted by the addition of CaCl_2 and occurred at neutral pH. This behavior can be attributed to the interactions between calcium ions and natural organic matter, enhancing its affinity toward the membrane surface. However, both permeate flux and rejections remained stable over the 10-day operation. This could be due to the negligible additional resistance to vapor transport, as the foulants accumulated on the membrane surface without blocking the membrane pores. Meanwhile, a considerable decline of 30% and 40% in flux was observed in the MD of biologically treated wastewater after 10 days and 40 days, respectively (**Figure 1 (b)**). As shown in **Figure 1 (c)**, biofouling was formed on the membrane surface, which was more clustered and less compact compared to the organic fouling formed in the MD with Lake Hohloh water (other B-scans are not shown here). Interestingly, membrane wetting was absent in both cases, highlighting the potential of MD for these applications.

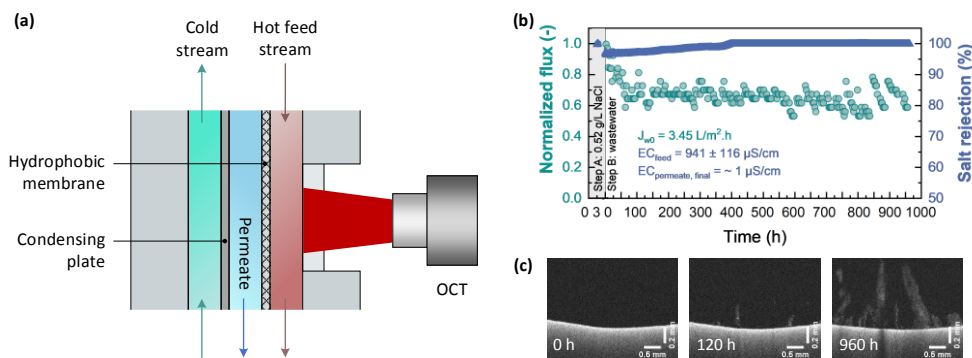


Figure 1. (a) Schematic illustration of air gap membrane distillation (MD) with in situ monitoring by optical coherence tomography (OCT). (b) Normalized flux and salt rejection during MD biologically treated wastewater, and (c) B-scans showing the corresponding progress of membrane fouling.

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MIXED MATRIX MEMBRANES BASED ON 6FDA-BISP POLYIMIDE FOR CO₂/CH₄ SEPARATION

K. Iablochkin, J. Heřmánek, M. Bernauer, V. Fíla

University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czechia

Abstract: Membrane technology has emerged as an energy-efficient alternative to conventional gas separation processes, particularly for biogas upgrading and natural gas sweetening. Mixed matrix membranes (MMMs), which combine polymeric matrices with inorganic fillers, offer a promising route to overcome the permeability–selectivity trade-off that limits conventional polymer membranes.

This study focuses on the preparation and characterization of MMMs based on the novel polyimide 6FDA-BisP and fillers belonging to the ZIF, UiO, and MXene families. Polyimides derived from 4,4'-(hexafluoroisopropylidene)diphthalic anhydride (6FDA) exhibit excellent gas separation properties due to their high free volume and rigid molecular structure. The selected fillers provide high surface areas and favorable interactions with CO₂, making them attractive candidates for enhancing CO₂/CH₄ separation performance.

The synthesized fillers and prepared membranes were characterized using XRD, FTIR, TGA, DSC, SEM, and EDS. The influence of filler type and loading on membrane morphology, thermal stability, and gas transport properties was systematically investigated. Gas permeation experiments were performed using CO₂/CH₄ mixtures at feed pressures ranging from 2 to 8 bar. Membrane permeability and selectivity were evaluated and correlated with membrane structure and filler characteristics.

The results provide valuable insights into the structure–property relationships of 6FDA-BisP-based MMMs and demonstrate their potential for efficient carbon dioxide removal and sustainable biogas upgrading applications.

Among the investigated membranes, the 6FDA-BisP MMM containing 15 wt.% ZIF-8 exhibited the best performance, with the CO₂ permeability increasing by 335%, from 31 to 135 Barrer, compared to the neat membrane while maintaining its original CO₂/CH₄ selectivity.

The research was supported by Czech Science Foundation Grant No. 26-23755S

PHOTOCATALYTIC NANOFILTRATION MEMBRANES FOR SIMULTANEOUS REMOVAL AND DEGRADATION OF CONTAMINANTS OF EMERGING CONCERN

P. Iaconis¹, A. Bosio³, A. Santilli², D. Fabbri², J. Ni¹, C. Morgante¹, M. L. Marín³, P. Calza², V. Boffa¹

¹Department of Chemistry and Bioscience, Fredrik Bajers Vej 7H, 3 305, 9220 Aalborg Øst

²Department of Chemistry, University of Turin Via Giuria 5, 10125 Torino, Italy

³Instituto de Tecnología Química, Universitat Politècnica de València-Consejo Superior de Investigaciones Científicas, Avda. de los Naranjos s/n, Valencia E-46022, Spain

P.Iaconis, paoloi@bio.aau.dk

Introduction

The presence of contaminants of emerging concern (CECs), such as pharmaceuticals and personal care products, poses a significant challenge for conventional water treatment systems due to their persistence and incomplete removal during wastewater treatment¹. Nanofiltration effectively retains these contaminants but generates a concentrated retentate stream requiring further treatment. Photocatalytic nanofiltration membranes offer a promising solution by combining pollutant separation and degradation within a single process². However, current systems often exhibit slow degradation kinetics and are frequently tested only on model dye pollutants³. In this work, a novel photocatalytic nanofiltration membrane based on gallium- and potassium-doped carbon nitride was developed for the removal of CECs. The membrane promotes in situ H₂O₂ generation, which is subsequently activated by Fe²⁺ through a photo-Fenton mechanism to enhance degradation efficiency. Membrane performance was evaluated using caffeine and carbamazepine as representative recalcitrant contaminants.

Materials and methods

Graphene oxide (GO) and gallium/potassium-doped carbon nitride (CN) were combined in different ratios and coated onto a commercial NF90 nanofiltration membrane using the Meyer rod technique. Membrane performance was evaluated using carbamazepine and caffeine (10 mg/L) as model contaminants. Photocatalytic degradation experiments were carried out in the presence of Fe²⁺ (10 mg/L) to activate a photo-Fenton process through the in situ generation of H₂O₂. The best performing membrane was subsequently tested under real solar irradiation.

Results

As shown in Fig. 1a, the membranes were first evaluated for H₂O₂ production under irradiation in a crossflow filtration system equipped with a quartz window. Among the tested compositions, only the GO/CN 20/80 membrane exhibited significant H₂O₂

generation, showing the best H_2O_2 production under real sunlight. The photocatalytic degradation of carbamazepine was then investigated (Fig. 1b-c). In the absence of Fe^{2+} , all membranes showed negligible degradation, indicating the limited effectiveness of photocatalysis alone. Upon Fe^{2+} addition, degradation increased to approximately 50% after 3 h due to photo-Fenton reactions. The GO/CN 20/80 membrane further enhanced degradation to about 70%, owing to the in situ production of H_2O_2 , which promoted additional hydroxyl radical generation and accelerated the photo-Fenton process.

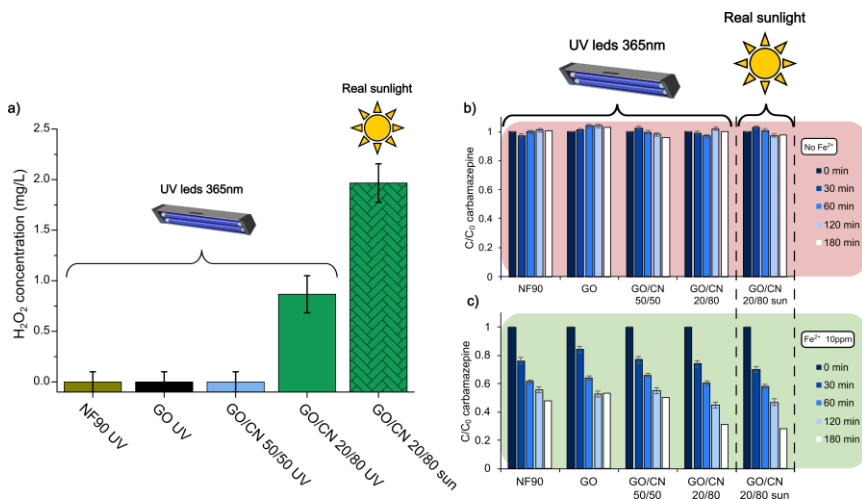


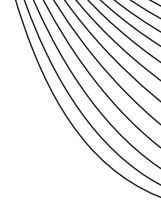
Figure 1: (a) H_2O_2 photoproduction by membranes with different coating compositions during crossflow filtration under UV irradiation (20 W/m^2) after 2 h of operation; the last membrane was tested under natural sunlight. (b-c) Degradation of carbamazepine during crossflow filtration under UV irradiation (20 W/m^2); the last membrane was tested under natural sunlight.

Conclusions

The developed graphene oxide/carbon nitride (GO/CN) membranes showed promising performance for advanced wastewater treatment. Among them, the GO/CN 20/80 membrane exhibited the highest photocatalytic activity due to its ability to generate H_2O_2 under both UV and solar irradiation. In the presence of Fe^{2+} , the resulting photo-Fenton process enhanced pollutant degradation, achieving up to 70% carbamazepine removal within 3 h. These findings highlight the potential of coupling nanofiltration with in situ advanced oxidation processes for the treatment of persistent contaminants.

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SURFACE-FLOATING PVDF BEAD PHOTOCATALYSTS WITH V₂O₅/G-C₃N₄ FOR ENHANCED CIPROFLOXACIN DEGRADATION FROM WATER

J. Jaafar¹, K. S. Ahmad Sohaimi², M. H. D. Othman¹, M. A. Rahman¹, M. H. Putih¹

¹Advanced Membrane Technology Research Centre, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia (juhana@petroleum.utm.my)

²Faculty of Chemical Engineering Technology, Universiti Malaysia Perlis, Padang Besar, Perlis, Malaysia

Abstract: Vanadium pentoxide / graphitic carbon nitride (V₂O₅ / g-C₃N₄) photocatalyst has emerged as a promising approach for treating organic pollutants in wastewater via an advanced oxidation process. However, the powdered form of these photocatalysts suffers from poor recovery and material loss, which limit their practical application multiple times. Herein, we propose an alternative solution by immobilizing V₂O₅ / g-C₃N₄ (VC) onto polyvinylidene fluoride (PVDF) beads using a phase-inversion technique, forming V₂O₅ / g-C₃N₄ photocatalytic beads (VCBs). Unlike conventional powdered catalysts, these PVDF-based floating beads offer easy separation, strong light absorption, and enhanced stability over multiple cycles. This innovative design not only minimizes photocatalyst powder loss but also promotes the antibiotic ciprofloxacin (CIP) degradation efficiency under light irradiation (100 W LED lamp). The unique inner structure of these beads allows them to float on the wastewater surface, optimizing light harvesting and improving photocatalytic performance. The beads achieved 85-90 % of CIP photodegradation under optimized conditions (pH 7, bead dosage 1.0 g/L, initial concentration 10 ppm). Particularly, the VCB structure ensures easy recovery and could maintain high catalytic activity over six cycles (see **Figure 1**), with a reduction only less than 25% in CIP photodegradation performance. This approach addresses the inherent challenges of powdered photocatalyst and demonstrates potential for practical, large-scale application in wastewater treatment. By providing a durable, efficient, and reusable photocatalyst system, this work represents a significant advancement in antibiotics photodegradation technologies.

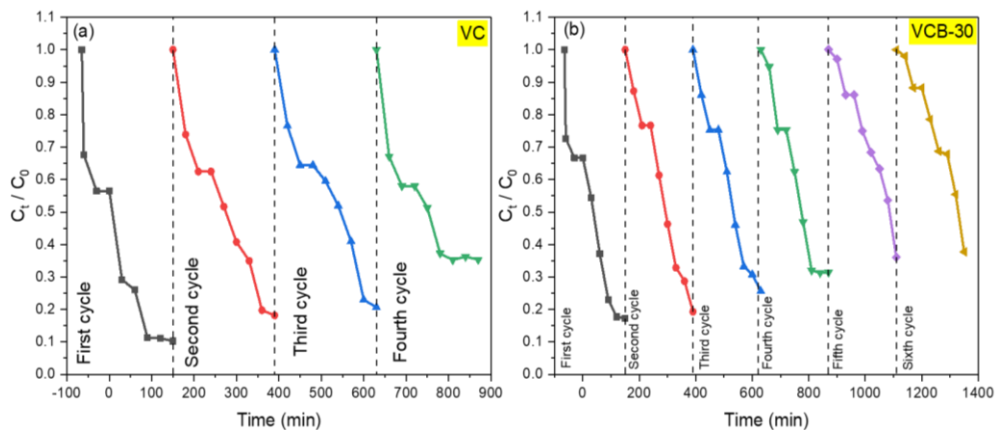


Figure 1: Regeneration of (a) VC photocatalyst powder (b) VCB-30 photocatalytic beads.

DYNAMIC ELECTROPHORETIC ASSEMBLY COUPLED WITH WATER-SPLITTING ENABLES ULTRA-PRECISION ION SIEVING MEMBRANES

M. H. Jandaghian, X. Yang

Department of Chemical Engineering, KU Leuven, Celestijnenlaan 200F, Heverlee, Belgium

Abstract: Effective monovalent-monovalent cation (such as Li^+ , Na^+ and K^+) separation has remained one of the most unresolved challenges in separation science and engineering as a defining bottleneck for next-generation ion-selective membranes^{1,2}. These ions share identical charge and differ in size only subtly by few Å, rendering separation; based solely on charge or size exclusion; intrinsically difficult³. The challenge is further exacerbated in realistic feed streams; such as salt lakes, seawater, and battery-recycling effluents; where target ions are typically present at trace levels⁴.

Here we present a green, catalyst-free route to fabricate defect-free covalent organic framework (COF)-based thin-film composite (TFC) membranes for ultrahigh-precision monovalent-ion sieving. This approach features a unique combined mechanism; i) a locally enriched micrometer-thick layer of COF-forming monomers at the boundary of ion-exchange substrate surface and ii) a transient and spatiotemporally directed delivery of hydronium ion induced by water-splitting to facilitate localized formation of COF primary particles.

The core concept involves the electrophoretic migration of COF-forming monomers under an applied electric field, which promotes the formation of monomer-enriched regions near the surface of cation-exchange membranes (CEMs) used as supports. Then, the water permeability of the ion-exchange membrane (IEM) plays a crucial role, so that the water molecules; supplied at a controlled amount; reach the electrodes and undergo electrolysis, generating hydroxide and hydronium ions. Because CEMs are selectively permeable to hydronium ions, these ions can migrate through the support layer and penetrate the monomer-enriched region, where they act as the catalyst for the condensation reaction between the monomers, leading to the formation of primary COF particles adjacent to the membrane surface. These particles subsequently adhere to the support, forming a continuous COF layer.

The effect of electric field in the proposed scenario even goes further, so that the initial accumulation of charged COF-forming monomers at the surface of the sulfonated CEMs can generate localized interfacial electric fields substantially higher than the externally applied macroscopic field. Consequently, the COF formation process is governed not only by the electrophoretic migration of charged monomers but also by the field-induced modulation of reaction energetics within the monomer-enriched interfacial zone. Such strong local fields are known to alter the stability of reaction intermediates and transition states, thereby affecting the overall kinetics of

interfacial condensation reactions⁵. DFT simulations for a representative imine condensation indicate that the presence of an electric field stabilizes both key transition states along the reaction pathway.

More importantly, the application of an electric field promotes the formation of defect-free COF layers through a self-healing and self-regulating feedback mechanism. As the reaction proceeds, the partial coverage of the CEM surface leads to two distinct regions with markedly different local reaction rates of COF nuclei, i.e., the newly formed patches act as a resistive barrier to both the electric field and hydronium ion transport, thus slowing down further condensation reaction. Conversely, at grain boundaries, microcracks, and uncovered sites, the local field intensity and hydronium ion concentration remain elevated, driving faster reaction rates in these regions. This dynamic contrast establishes a self-regulating feedback loop in which COF growth is selectively promoted at defective sites until a uniform and continuous film is achieved. Subsequently, the system naturally evolves toward homogeneous, defect-free coverage of the CEM surface without the need for external correction or post-treatment.

The proposed membrane formation strategy and the resulting defect-free TFC membrane effectively suppresses non-selective transport pathways and enables rapid formation of highly selective ion-transport channels, resulting in a membrane with near complete fractionation of Li^+ from other monovalent ions (e.g., K^+ and Na^+), while preserving fast ion permeation, exceeding previously reported membranes. The governing ion separation mechanism is elucidated as hydration-shell restructuring under electrostatic confinement.

All in all, the present work establishes a scalable and energy-efficient platform for precise monovalent ion separation and opens new opportunities for membrane-based resource recovery and molecular purification.

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FROM PROCESS UNDERSTANDING TO IMMERSIVE TRAINING: A VIRTUAL REALITY FRAMEWORK FOR ELECTRODIALYSIS SYSTEM

H. Jaroszek¹, A. A. Beşen², A. Karliova², C. Muratlı², E. Vanneste³, M. Laubertova⁴, K. Rajczykowski¹, K. Klejnowska¹, B. Van der Bruggen³

¹Lukasiewicz Research Network - Institute of Non-Ferrous Metals, 5 Sowińskiego Street, 44-100 Gliwice, Poland (hanna.jaroszek@imn.lukasiewicz.gov.pl, edventurevr.com)

²VolareVers Technologies, Barbaros Mahallesi, Nida Kule, Begonya St. 1, Ataşehir West No:1/2 , 34746 Istanbul, Türkiye

³KU Leuven, Celestijnenlaan 200F, B-3001, Leuven, Belgium

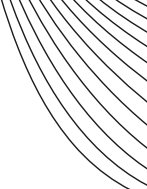
⁴Technical University of Košice, Park Komenského 19, 042 00 Kosice-Sever, Slovakia

Abstract: Electrodialysis (ED) is increasingly applied in desalination, resource recovery and industrial water treatment. However, its key phenomena governing process performance remain invisible to operators and students, making process understanding and practical training challenging. Virtual reality (VR) offers an opportunity to transform these abstract concepts into immersive learning experiences.

This work presents the development of a VR-based training environment for electrodialysis systems combining a physically consistent process model with interactive operator-oriented scenarios. The framework incorporates a simplified representation of a single-stage pilot-scale recirculating ED system, while maintaining a modular architecture that facilitates adaptation to different ED configurations and training objectives. Key relationships between current, flow rate, concentration, pressure and temperature are reproduced, while user actions such as current adjustment, flow control and system start-up directly influence process behavior through deterministic cause–effect relationships.

The environment enables visualization of process dynamics, system-level plant behavior, and operational limits under varying conditions. Users can explore process responses, perform start-up procedures, troubleshoot disturbances and non-ideal operating conditions, and evaluate operational decisions in a safe virtual setting. Two representative use scenarios are considered. In desalination mode, the focus is on decreasing diluate concentration, highlighting resistance growth and approach to transport limitation. In concentration mode, the objective is salt accumulation, emphasizing water transport, volume changes and thermal effects. Additional modules support membrane module assembly and plant installation.

The framework is being implemented as an interactive PC-based VR demonstrator for higher education, industrial training and knowledge transfer. By combining process physics, system behavior and immersive interaction within a visually realistic



environment, the proposed approach offers a novel tool for understanding electrodialysis operation and its underlying transport mechanisms.

Acknowledgements: project EDVenture is funded under the EIT Raw Materials no. 25053.

ENHANCED ALKALINE WATER ELECTROLYSIS PERFORMANCE OF KOH-DOPED POLYBENZIMIDAZOLE MEMBRANES THROUGH SULFONATION AND PHOSPHORIC ACID PRETREATMENT

L. C. Jheng, Y. Z. Chang, H. F. Tan

Department of Chemical and Materials Engineering, National Kaohsiung University of Science and Technology, Jiangong Rd., Kaohsiung 80778, Taiwan
(lcjheng@nkust.edu.tw)

Abstract: Hydrogen energy plays a crucial role in achieving a low-carbon society, and the development of efficient and cost-effective water electrolysis technologies is essential for sustainable hydrogen production. Alkali-doped polybenzimidazole (PBI) membranes represent a novel class of electrolyte materials in which the PBI polymer chemically absorbs potassium hydroxide (KOH) through acid–base interactions. These membranes, commonly referred to as ion-solvating membranes, have attracted considerable interest for alkaline water electrolysis (AWE). Unlike conventional porous diaphragms that retain KOH through physical absorption, ion solvating PBI membranes possess a dense electrolyte structure that effectively suppresses hydrogen crossover, thereby improving the efficiency, safety, and operational reliability of alkaline water electrolyzers.

In this study, a dense KOH-doped hexafluoro-containing polybenzimidazole (6FPBI) membrane was developed as an ion-solvating membrane for AWE applications. To enhance KOH uptake, hydrophilicity, and ionic conductivity, dual modification strategies involving sulfonation and phosphoric acid (PA) pretreatment were employed. The resulting dual-modified membrane (S-6FPBI-PA) exhibited high hydroxide-ion conductivity and excellent mechanical stability in 6 M KOH at 80 °C. As a result, the membrane achieved a current density of 1644.8 mA cm⁻² at 2.2 V and demonstrated stable long-term operation at 200 mA cm⁻². FTIR and conductivity analyses further confirmed its chemical and structural stability under alkaline conditions. These results indicate that the dual-modified 6FPBI ion-solvating membrane combines high conductivity and durability, making it a promising electrolyte material for AWE.

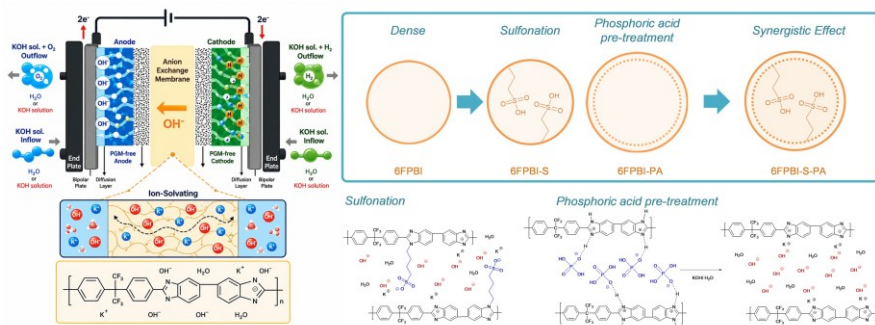


Figure 1. Schematic illustration of alkaline water electrolysis employing KOH-doped 6FPBI membranes modified by sulfonation and phosphoric acid pretreatment.

LINKING STRUCTURE, STABILITY AND PERFORMANCE OF COMMERCIAL ANION EXCHANGE MEMBRANES FOR WATER ELECTROLYSIS

A. M. Kansara¹, P. Perroni², A. Asghar³, L. Landwehrkamp⁴, D. Xing⁵, M. Ulbricht¹

¹Lehrstuhl für Technische Chemie II, Universität Duisburg-Essen, 45141 Essen, Germany.

²Technische Chemie III, Universität Duisburg-Essen, 47057 Duisburg, Germany

³Instrumentelle Analytische Chemie, Universität Duisburg-Essen, 45141 Essen, Germany.

⁴Lehrstuhl für Mechanische Verfahrenstechnik /Wassertechnik (MVT / WT), 47057 Duisburg, Germany.

⁵Lehrstuhl Energietechnik, Universität Duisburg-Essen, Duisburg, 47057 Germany.
(ankitkumar.kansara@uni-due.de, www.uni-due.de/tech2chem)

Abstract: Anion exchange membrane water electrolysis (AEMWE) is a promising technology for cost-effective green hydrogen production due to its compatibility with non-precious metal catalysts¹. However, membrane degradation under alkaline conditions remains a key challenge limiting long-term durability². This study investigates the degradation behavior and electrochemical performance of three commercial anion exchange membranes: quaternary ammonium-functionalized poly(phenylene oxide) (QA-PPO), imidazolium-functionalized poly(styrene-butadiene) (IM-STB), and imidazolium-functionalized polyaromatic hydrocarbon (IM-PARH).

Accelerated ex-situ degradation tests were conducted in KOH solution for defined exposure periods. Membrane stability was evaluated through ion-exchange capacity (IEC), hydroxide ion conductivity, water uptake, swelling ratio, tensile strength, FTIR, TGA, and water electrolysis performance. Degradation pathways were further investigated using GC/MS and NMR spectroscopy. In addition, real-time degradation during electrolysis operation was monitored using ATD-GC/MS.

The results revealed significant differences in degradation resistance among the membranes (Figure 1). IM-PARH exhibited the highest alkaline stability and the lowest susceptibility to chemical degradation. IM-STB demonstrated superior water electrolysis performance while maintaining moderate alkaline stability. In contrast, QA-PPO showed the greatest degradation and the least electrolysis performance. Among the properties investigated, changes in water uptake, swelling ratio, and hydroxide ion conductivity were found to be the most sensitive indicators of membrane degradation. These findings provide valuable insights into structure–property relationships and degradation mechanisms, supporting the development of durable membranes for next-generation AEM water electrolyzers.

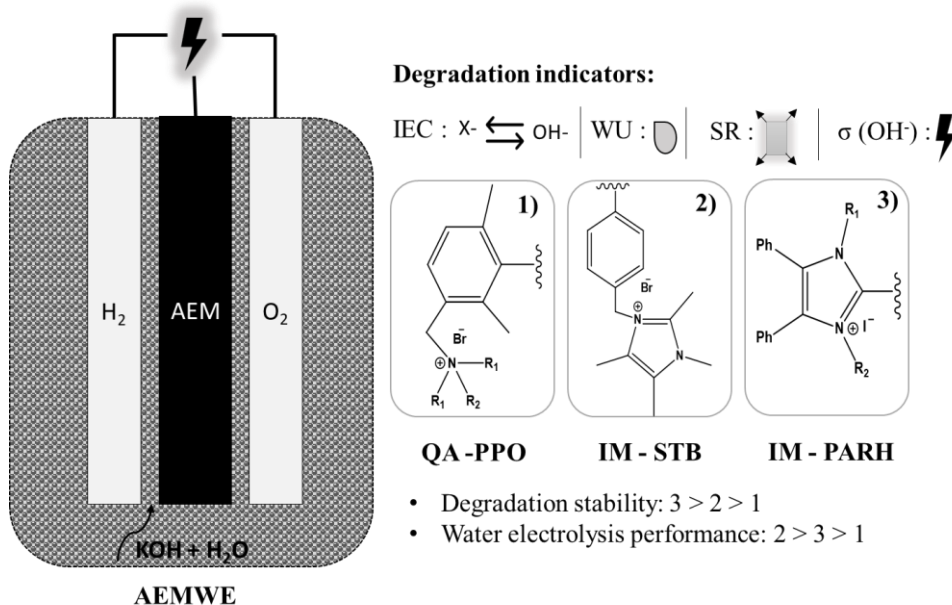


Figure 1. Commercial AEMs with different functional groups and polymer backbones exhibit distinct degradation behaviour under alkaline conditions.

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GRAPHENE OXIDE-MODIFIED BORON NITRIDE MEMBRANES FOR ENHANCED ACETONE TRANSPORT: A DENSITY FUNCTIONAL THEORY STUDY

M. Khajavian¹, H. Jee², S.-U. Lee^{1,3}, J.-M. Lee^{1,3}, E. Yang^{2,**}, K.-J. Chae^{1,3,*}

¹Department of Environmental Engineering, College of Ocean Science and Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

²Department of Marine Environmental Engineering, Gyeongsang Nantional University, Gyeongsangnam-do, 53064, Republic of Korea

³Interdisciplinary Major of Ocean Renewable Energy Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

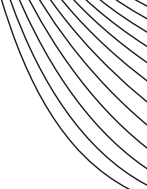
*Corresponding author. Department of Environmental Engineering, College of Ocean Science and Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan, 49112, Republic of Korea. (ckjdream@kmou.ac.kr (K. J. Chae))

**Co-Corresponding author. Department of Marine Environmental Engineering, Gyeongsang Nantional University, Gyeongsangnam-do, 53064, Republic of Korea (yet83@gnu.ac.kr (Euntae Yang))

Abstract: Density functional theory (DFT) calculations were performed to elucidate the molecular-level role of graphene oxide (GO) in GO-modified boron nitride (BN/GO) membranes for acetone transport. The optimized BN and BN/GO structures were used to investigate the electronic, thermodynamic, dielectric, and optical properties governing acetone–membrane interactions. Partial density of states (PDOS) analysis revealed that GO incorporation broadens the electronic energy distribution and introduces additional electronic states at the BN interface. Compared with pristine BN, the BN/GO system exhibited a higher density of states and reduced orbital overlap, indicating significant modification of the local electronic environment. Consistently, electron localization function (ELF) analysis showed reduced electron localization in BN/GO, suggesting enhanced charge redistribution and a more heterogeneous electron distribution throughout the interfacial region.

This behavior originates from the oxygen-containing functional groups and delocalized π -electron network of GO, which perturb the electronic uniformity of the BN framework and generate regions with distinct local electronic environments and interaction strengths. Consequently, the BN/GO interface provides a heterogeneous interfacial landscape capable of interacting with acetone through multiple weak and reversible interaction sites. Thermodynamic calculations further supported this interpretation.

Dielectric and optical analyses provided additional insight into the transport mechanism. The dielectric response and significantly enhanced optical absorption



of BN/GO reflected increased charge delocalization, additional electronic states, and enhanced interfacial polarizability. As acetone is a polar molecule containing a carbonyl group, this polarizable interface can promote favorable dipole-related interactions that assist solvent accommodation and migration while remaining sufficiently reversible to avoid strong adsorption. Structural analysis further revealed that the incorporation of BN nanosheets shortens the effective transport pathway for acetone diffusion compared with conventional GO membranes. Collectively, the combination of a heterogeneous and polarizable interfacial environment, enhanced molecular mobility, and reduced transport-path length provides a molecular-level explanation for the experimentally observed enhancement in acetone permeance through BN/GO membranes.

Acknowledgement

This work was supported by National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2023-00209009, RS-2023-00265777, RS-2025-16064148); Korea Basic Science Institute (National Research Facilities and Equipment Center) grant funded by Ministry of Education (grant No. 2022R1A6C101B738).

SEPARATION OF XYLAN FROM THE LYOCELL SPIN BATH SOLUTION USING ULTRAFILTRATION MEMBRANES: MEMBRANE SCREENING, STABILITY, AND XYLAN PRECIPITATION

U. Khan, M.K. Zafeer, M.N. Khan, J. Nieminen, M. Mänttär

Department of Separation Science, LUT University, 53850 Lappeenranta, Finland

Usman.khan@lut.fi

Abstract: The lyocell process has gained considerable attention as an environmentally favorable route for fiber production due to its efficient cellulose dissolution and closed-loop recovery of N-methylmorpholine N-oxide. However, the presence of sugars (monomeric and polymeric e.g. xylan) originating from cellulose pulp itself can complicate NMMO recovery, requiring additional purification steps such as air flotation and ion exchange. This study aimed to purify NMMO from real lyocell spin bath by separating xylan using different ultrafiltration (UF) membranes including GR-95-PP, UP005-P, GE, GH, GK, and GM membranes and recovering it as a solid by-product through ethanol precipitation. The results showed that the maximum NMMO permeation values were 100%, 99%, 97%, 99%, 99.5%, and 100% for GR-95-PP, UP005-P, GE, GH, GK, and GM, respectively. Similarly, the maximum total sugar (hemicellulose and monomeric sugars) rejection values were 86%, 89%, 93%, 92%, 85%, and 84% for GR-95-PP, UP005-P, GE, GH, GK, and GM, respectively. Considering the overall balance between permeate flux, NMMO permeation, and sugar rejection, UP005-P was selected for xylan enrichment under constant-flux operation, which was carried out through successive volume reduction steps of the feed solution. The results showed that UP005-P maintained stable sugar rejection and high NMMO permeation. Moreover, static and dynamic stability tests were also conducted by exposing the membrane to real industrial lyocell spin bath for extended periods. The results confirmed that UP005P maintained its separation performance, with negligible changes in its performance. In the final stage, xylan-enriched retentate was subjected to ethanol precipitation at different ethanol-to-retentate ratios, with a ratio of 3:1 identified as optimal for xylan precipitation. Overall, this study demonstrates that UF pretreatment effectively enables xylan removal, improving NMMO recovery and lyocell process sustainability.

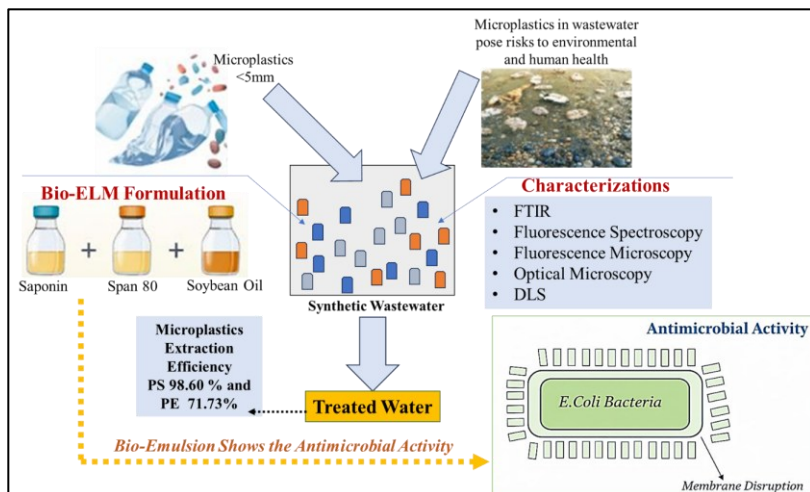
Keywords: NMMO recovery; Sugar rejection; Solvent recycling; Ethanol-induced recovery; Closed-loop cellulose processing; fiber production; sustainable biorefinery operation.

FUNCTIONAL LIQUID MEMBRANE FOR MICROPLASTIC CAPTURE AND MICROBIAL INHIBITION

S. Khuntia, M. Wakle

School of Engineering and Applied Science, Ahmedabad University, Navrangpura,
Ahmedabad, Gujarat, India-380009

Abstract: Microplastics, one of the persistent environmental threats, are the polymer particles, typically 5-6 mm in size, that originate from the degradation of larger plastics. Recent studies show that they can enter the human body via ingestion and inhalation and accumulate within the body. They can contaminate all water sources and remain in the environment for long periods. This work represents a proof of concept for the removal of microplastics using a sustainable bio-emulsion liquid membrane (Bio-ELM). A multifunctional bio-emulsifier was used as a co-emulsifier with Span80 to enhance emulsion stability and develop the Bio-ELM for the extraction of microplastics from the aqueous phase. Parameter optimization during Bio-ELM synthesis identified the best combination as saponin (1% v/v), Span 80 (1.5% v/v), NaOH (0.2 M), MP:IP ratio (1:0.5), stirring speed 800 rpm, and emulsification time 5 min. Creaming index and microscopic images confirm the emulsion stability. Polyethylene (PE), and polystyrene (PS), were used as the model microplastics, and the formulated Bio-ELM shows extraction efficiencies of 98.60% for PE and 71.73% for PS. Fluorescence spectroscopy, fluorescence microscopy, and Fourier-transform infrared spectroscopy (FTIR) were used for the analysis and characterisation of microplastics. Furthermore, a novel antimicrobial study was conducted for Bio-ELM and its components, specifically saponin, Span 80, and soybean oil, owing to their antimicrobial properties. Bio-ELM exhibited microbial growth-inhibition capacity, as indicated by the zone of inhibition (ZOI). The Bio-ELM components show both disruption and inhibition of the bacterial membrane. This makes the Bio-ELM a multifunctional solution for microplastic and anti-microbial activity, which can be further examined for a good fit in the sustainable environmental application.



Graphical abstract of the dual function Bio-ELM for microplastic removal

AMMONIA PERCOLATION LIMIT IN PEMs: EXPERIMENTAL AND MD SIMULATIONS

V. S. Klitgaard¹, C. Arntsen², P. Fortin², E. Drazevic^{1,*}, J. Catalano^{1,*}

¹Department of Biological & Chemical Engineering, Aarhus University, Aabogade 40, 8200 Aarhus N, Denmark

²Department of Sustainable Energy Technology, SINTEF Industry, Strindvegen 4, 7034 Trondheim, Norway

Abstract: The percolation threshold is an important parameter when investigating transport properties in proton exchange membranes (PEM), as it enables transport of polar molecules through the established interconnected ionic network (see Figure 1) [1]. This facilitated transport results in solvent permeabilities much higher than those predicted by diffusion, particularly at or above the percolation threshold[2]. And this can enhance the membrane selectivity towards the solvent compared to inert gases.

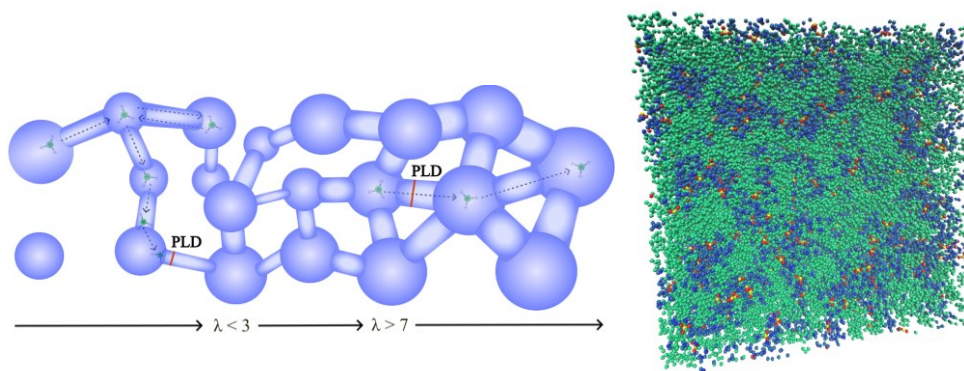


Figure 6 – Schematic representation of the ion channel network form with the pore limiting diameter (PLD) shown on the left. Schematic of simulated Nafion/ammonia system on the right where polymer = green, sulfonate = yellow/red and ammonia = blue.

Knowing the percolation threshold is therefore crucial when designing membrane separation processes.

In this work we consider ammonia as a solvent with Nafion 117 and Aquivion as representative PEMs. We demonstrate how the percolation threshold, defined as the minimum ratio of the moles of ammonia per moles of sulfonic group (λ), can be estimated via ion conductivity data and molecular dynamic (MD) simulations.

To this end, we develop a novel electrochemical pressure-decay system to assess the through-plane conductivity. This system is used to measure the ability of the membrane to transport cations (e.g. protons or ammonium) which changes drastically around the percolation limit. A mathematical expression is derived to describe the ionic resistivity in the vicinity or above the percolation limit. The deviation between the theoretical and experimental values then yields an estimate of the upper bound

for the percolation threshold. This analysis places the percolation limit at $\lambda \sim 4.5$ (see Figure 2).

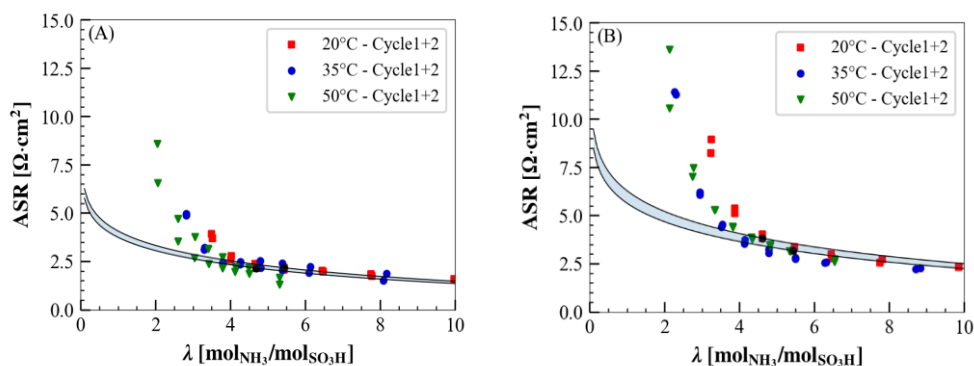


Figure 7 – Area specific resistance (ASR) plotted against λ at three different temperatures for Aquivion (A) and Nafion (B). The shaded areas show the calculated ASR above the percolation threshold.

The experimental results are compared with MD simulations performed on an ammonia/Nafion system. Here the ammonia network is assessed by the analysis of ammonia clustering at different relevant λ (2-10). Two ammonia/ammonium molecules are considered part of the same cluster if they are within a certain cut-off

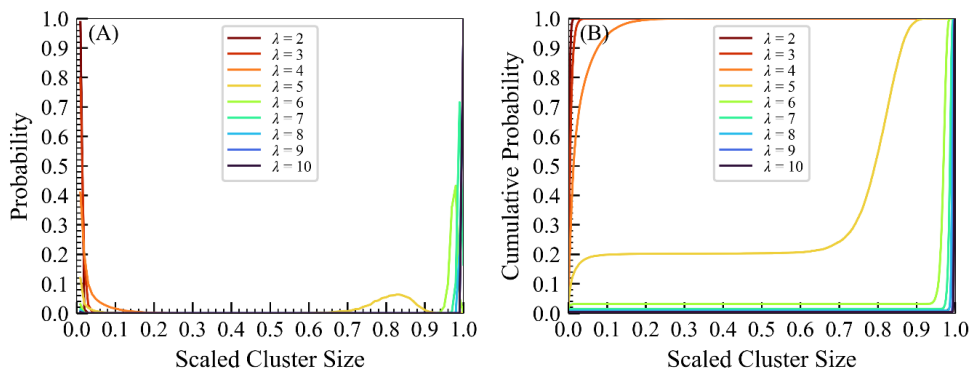


Figure 8 – Scaled cluster size of the ammonia clusters shown as: (A) probability and (B) cumulative probability.

distance.

For the results shown in Figure 3 the chosen cut-off distance was $5\text{\AA}$. Using this criterion a clear transition is seen between λ 4 and 6, in good agreement with the experimentally determined upper-bound.

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WATER MATTERS: THE HIDDEN THIRD COMPONENT IN ORGANIC-ORGANIC PERVAPORATION

K. Knozowska, P. Szczepański, W. Kujawski

Membranes and Membrane Techniques Research Group, Faculty of Chemistry, Nicolaus Copernicus University in Toruń, 7 Gagarina Street, 87-100 Toruń, Poland
(katarzyna.knozowska@umk.pl, www.chem.umk.pl)

Abstract: Binary organic solvent mixtures inherently contain trace amounts of water, which can be considered a third or “hidden” component. The water content in organic solvents can range from a few ppm to 0.5 wt%. The presence of water can directly influence pervaporation efficiency, contribute to equipment corrosion, and induce phase separation. During the pervaporation process, membrane swelling occurs, leading to an increase in free volume and facilitating the transport of permeating species. Water is characterised by a smaller kinetic diameter compared to organic solvents, which facilitates its transport through both hydrophilic and hydrophobic membranes [1].

The aim of this work is to investigate the effect of water on the organo-organic pervaporation of ETBE/ethanol mixtures using native hydrophilic and hydrophobic polymer membranes. Particular attention was devoted to understanding how membrane chemistry, including the presence of different functional groups within polymer chains, and the intrinsic free volume of polymers govern water sorption, transport mechanisms, and ultimately the separation performance. Furthermore, the study evaluates how increasing water content modifies these relationships and influences the efficiency of the pervaporation process.

To evaluate the influence of water on membrane performance, the water rejection factor (R) was introduced, enabling quantitative assessment of the membrane ability to suppress water transport during the process. Hydrophobic membranes, particularly PDMS and Pebax 2533, exhibited the highest resistance to water transport over the investigated range of feed compositions. In contrast, hydrophilic membranes, including cellulose triacetate, polysulfone (PSf), and poly(vinyl alcohol) (PVA), showed significantly lower rejection factors, indicating enhanced water permeation. In addition, chemometric analysis was employed to evaluate the contribution of individual polymer characteristics to water transport through the membranes.

The obtained results demonstrate that water should be regarded as an integral component of organic-organic pervaporation rather than an impurity, as its presence substantially affects membrane efficiency. Neglecting water during proves, particularly for hydrophilic polymers, may result in an overestimation of separation performance.

Acknowledgment

Katarzyna Knozowska gratefully acknowledges the Membranes Travel Award awarded by Membranes (MDPI).

THE EFFECT OF THE ALKYL SUBSTITUENTS' LENGTH OF IMIDAZOLE-BASED LINKERS ON THE TRANSPORT PROPERTIES OF ZIF-67 BASED MEMBRANES

S. Kočí, J. Schneider, O. Vopička, K. Friess

Department of Physical Chemistry, University of Chemistry and Technology in Prague, Technická 5, Praha 6 – Dejvice, 16628, Czechia

Abstract: Zeolitic imidazolate frameworks (ZIFs) are an important class of metal–organic frameworks due to their high surface area, chemical stability, and tuneable pore architecture¹. Among them, ZIF-67, constructed from Co²⁺ ions and 2-methylimidazole, has attracted considerable attention for environmental membrane applications, such as ultrafiltration of dyes² or CO₂ separation.^{1,3-5} However, the influence of ligand steric effects, such as doping with 2-ethylimidazole⁶ on the formation, structure, and thus sorption/separation properties of cobalt-based ZIFs remains relatively underexplored.

In this work, cobalt based ZIFs were synthesized using imidazole ligands with progressively increasing alkyl substituent length, namely 2-methylimidazole, 2-ethylimidazole, 2-propylimidazole, and 2-butylimidazole. The systematic modification of the organic linker influences the framework structure, such as pore size, hydrophobicity. The length of the alkyl groups allows us to synthesize in-reacted ZIFs with polymers using UV-initiated (radical) polymerization with crosslinking monomers as well as mixed-matrix membranes with differing structural and transport properties.

Acknowledgement

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SELECTIVE BROMIDE MITIGATION AND MEMBRANE-BASED BRINE UPGRADING FOR DOWNSTREAM ELECTROCHEMICAL UTILISATION IN SWRO SYSTEMS

P. L. Koo^{1,2}, W. Y. Chia¹, W. L. Tan¹, L. N. Sim¹, T. H. Chong^{1,2*}

¹Singapore Membrane Technology Centre, Nanyang Environmental and Water Research Institute, Nanyang Technological University, Singapore

²School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

Abstract: Seawater reverse osmosis (SWRO) desalination generates large volumes of hypersaline brine enriched with bromide, sulfate, and hardness ions, limiting opportunities for downstream resource recovery and complicating oxidant production due to bromate and brominated disinfection byproduct formation^{1,2}. This study presents an integrated membrane-based brine upgrading framework for selective bromide mitigation and downstream electrochemical utilisation of SWRO brine. The proposed process integrates peroxymonosulfate (PMS)-based bromide oxidation, multi-stage nanofiltration (NF) with recycle operation, ion exchange (IX), and high-recovery concentration processes to selectively condition SWRO brine while preserving monovalent salts for downstream reuse. PMS pretreatment enabled partial bromide removal/recovery and mitigation of brominated precursor formation, while NF selectively rejected sulfate and divalent ions with high monovalent ion retention. Experimental results demonstrated residual bromide concentrations of approximately 10 mg L⁻¹ and sulfate levels below 10 mg L⁻¹ in the NF permeate stream. Subsequent IX polishing further reduced calcium and magnesium ions to below scaling-relevant thresholds, enabling stable operation of downstream high-recovery concentration processes. The pretreated brine was subsequently subjected to an energy-efficient reverse osmosis (EERO) concentration step to achieve target NaCl levels required for downstream electrochemical utilisation. To evaluate downstream electrochemical utilisation under elevated salinity conditions, a membrane-separated chloro-alkali system equipped with a DF2808 perfluorinated ion-exchange membrane was investigated using synthetic concentrated NaCl and NaOH streams representative of the targeted concentrated brine composition. Electrochemical assessment demonstrated successful sodium hypochlorite generation up to ~10.9 wt% under galvanostatic operation. Product formation was strongly influenced by hydrodynamic and electrochemical operating conditions, indicating transport–reaction coupling, concentration polarization, and membrane-mediated ion transport effects within the electrochemical system. The proposed framework demonstrates a modular strategy for selective ion management, membrane-enabled brine upgrading, and downstream oxidant production from saline waste streams. This study provides practical and mechanistic insight into integrating membrane separation and electrochemical conversion for sustainable desalination brine management and future resource recovery applications.

Acknowledgement

This research is supported by the National Research Foundation, Singapore, and PUB, Singapore's National Water Agency under its RIE2025 Urban Solutions and Sustainability (USS) (Water) Centre of Excellence (CoE) Programme which provides funding to the Nanyang Environment & Water Research Institute (NEWRI) of the Nanyang Technological University, Singapore (NTU). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not reflect the views of National Research Foundation, Singapore and PUB, Singapore's National Water Agency.

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NOVEL CELLULOSE IONOGEL MEMBRANES FOR BIOELECTROCHEMICAL APPLICATIONS: SYNTHESIS, CHARACTERIZATION AND PERFORMANCE

L. Koók, Sz. Szakács, É. Hülber-Beyer

Research Group on Bioengineering, Membrane Technology and Energetics, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

Abstract: Bioelectrochemical systems (BES) are often equipped with ion exchange membranes (IEM) to maintain selective transport of certain (usually ionic) species between the electrolytes¹. Besides the significant contribution to the net reactor material cost, frequently used membrane types (such as Nafion) do not fit well to the complex environment of the BES electrolytes in terms of mass transport properties. In this work, novel cellulose ionogel membranes² (CIg) were synthesized, characterized and tested in microbial fuel cells (MFC) to evaluate their performance compared to a Nafion reference material. Firstly, the synthesis process was optimized based on key ionogel properties (mechanical stability, conductivity, etc.). Thereafter, intrinsic properties (and their change after use) were assessed, which showed promising stability of the self-standing cellulose ionogels over a month-long batch operation. CIg-MFC showed current densities (in the $j = 6\text{--}8\text{ A/m}^2$ range) and current generation kinetics similar to Nafion-MFC. Polarization tests indicated more beneficial operation of CIg-MFC under mass transport limitation regime, in addition to comparable internal resistances (Nafion-MFC: 136 Ω , CIg-MFC: 147 Ω), indicating beneficial ion transfer properties. Furthermore, microbial consortia analysis showed that membrane biofouling developed on both membrane types, while CIg was selective to host cellulose degrading species. The post-MFC characterization of the CIg indicates partial deterioration. Accordingly, future studies should focus on long-term stability and CIg regenerability.

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REMOVAL OF ORGANOPHOSPHORUS HERBICIDES FROM WATER BY COMBINING MAGNETIC ION EXCHANGE RESIN (MIEX) WITH NANOFILTRATION

M. Krajewska, P. B. Trinh, A. I. Schäfer*

¹Institute for Advanced Membrane Technology (IAMT), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

(*corresponding author. Email: andrea.iris.schaefer@kit.edu)

Abstract: Glyphosate (GLY), a widely used organophosphorus herbicide, is a small and highly polar compound frequently detected together with its main metabolite, aminomethylphosphonic acid (AMPA), in surface water and groundwater. Conventional water treatment processes may provide insufficient removal of GLY and AMPA at trace concentrations. Although several advanced removal technologies exist, they are often limited by high cost, interference from the real water matrix, or challenges in large-scale implementation. Hybrid processes combining complementary removal mechanisms therefore represent a promising approach for GLY and AMPA removal. In this work, magnetic ion exchange resin (MIEX®) was combined with nanofiltration (NF) on the feed side to evaluate the performance of the hybrid process for GLY and AMPA removal [1]. MIEX provides readily accessible ion-exchange sites for anionic micropollutants, whereas NF provides an additional separation barrier and retains the resin beads. Two membranes with different retention characteristics, NF270 and HY50, were investigated. The contribution of MIEX strongly depended on membrane selectivity. For the denser NF270 membrane, which already provided high GLY and AMPA removal, MIEX addition resulted in little additional improvement. In contrast, suspended MIEX substantially enhanced removal by the looser HY50 membrane, with the improvement exceeding that expected from standalone adsorption and membrane filtration. Experiments conducted at varying MIEX doses and initial GLY/AMPA concentrations further showed that adsorption-assisted retention can partially compensate for insufficient membrane selectivity.

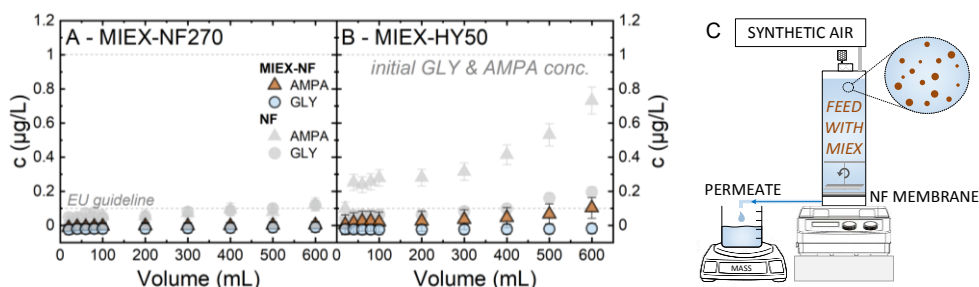


Figure 1. GLY and AMPA conc. for A. MIEX-NF270 and B. MIEX-HY50 (5 mL/L MIEX DOC, flux 50 L/m².h, 1 µg/L GLY/AMPA, 1 mM NaHCO₃, 10 mM NaCl, 20 ± 0.5°C, pH 8.2 ± 0.1). Results for NF were obtained from Trinh et al. [2]. C. Stirred cell with MIEX

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IN-SITU GROWTH OF PVP-MODIFIED HYDROGEL-STABILIZED ZIF-L ON MICELLAR-ENHANCED PAN ULTRAFILTRATION MEMBRANES FOR IONIC CONTAMINANT REMOVAL

A. Kumar, R. Kasher

Department of Desalination and Water Treatment, Zuckerberg Institute for Water Research,
The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev,
Midreshet Ben-Gurion 8499000, Israel

Abstract: The contamination of water resources by ionic pollutants such as nitrate and perchlorate has become a serious global environmental concern, driven by rapid industrialization, intensive agriculture, and expanding urbanization that continue to degrade surface and groundwater resources (Chen et al., 2022; Ma et al., 2025; Wan et al., 2023). These contaminants are frequently detected in drinking water, soil, and food and are associated with adverse health and environmental impacts (Chen et al., 2024; Modi and Kasher, 2024). Nitrate pollution is mainly attributed to excessive fertilizer application, livestock waste, and sewage discharge, contributing to eutrophication and health risks such as methemoglobinemia (Bahmani et al., 2019; Wan et al., 2023). In contrast, perchlorate contamination is primarily associated with industrial activities, including the production and use of rocket propellants, explosives, and fireworks (Hu et al., 2024). Therefore, the development of efficient technologies for removing these pollutants from contaminated water is essential for sustainable water management. Due to their high toxicity, WHO has established guideline limits of 50 mg/L for nitrate and 70 µg/L for perchlorate in drinking water, while the United States Environmental Protection Agency (USEPA) has proposed a health-based maximum contaminant level (MCL) of 56 µg/L for perchlorate (Hu et al., 2024; Modi and Kasher, 2024). Although conventional ultrafiltration operates at relatively low transmembrane pressures, its effectiveness in removing low-molecular-weight ionic contaminants is limited. Micellar-enhanced ultrafiltration (MEUF) overcomes this limitation by associating target ions with surfactant micelles, thereby increasing their effective size and facilitating membrane separation (Acero et al., 2017). MEUF has demonstrated promising performance for removing various ionic contaminants, including nitrate, fluoride, arsenate, and perchlorate, while offering advantages such as high permeate flux and improved fouling resistance (Grzegorzec and Majewska-Nowak, 2018; Modi and Kasher, 2024; Raval et al., 2024). However, membrane modification is required to further improve separation efficiency and mitigate fouling.

Recent studies have explored the incorporation of metal-organic frameworks (MOFs), particularly zeolitic imidazolate frameworks (ZIFs), into polyacrylonitrile (PAN) membranes to enhance surface properties and contaminant removal (Modi et al., 2022; Modi and Kasher, 2024; Yu et al., 2021). Our previous work developed a ZIF-L($\text{Co}^{2+}/\text{Zn}^{2+}$)-coated PAN membrane stabilized with a zwitterionic methacrylate hydrogel. However, non-uniform MOF distribution and irregular particle

morphology resulted in heterogeneous membrane porosity and limited ionic rejection. In the present study, polyvinylpyrrolidone (PVP) was introduced as a shape-controlling agent to regulate ZIF-L growth and achieve a more uniform MOF morphology and distribution, thereby improving the membrane structure and separation performance (Li et al., 2025; Luo et al., 2025; Mphuthi et al., 2021; Yin et al., 2023).

The primary objective of this study is to develop a hydrogel-stabilized MOF composite membrane for enhanced MEUF of nitrate and perchlorate. PVP-modified ZIF-L($\text{Co}^{2+}/\text{Zn}^{2+}$) was grown in situ on PAN ultrafiltration membranes and subsequently stabilized with hydrogel. The effect of PVP concentration on MOF crystallinity, morphology, surface charge, hydrophilicity, stability, and membrane separation performance were investigated. The modified membranes were characterized using XRD, FTIR, FE-SEM, AFM, XPS, water contact angle, and zeta potential analyses. Their performance was evaluated through pure water permeance, MWCO, and ionic rejection tests in the presence and absence of cetylpyridinium chloride (CPC). The effects of feed concentration, ionic strength, and competing ions were also examined. Membrane stability and antifouling performance were assessed through repeated filtration cycles and flux recovery measurements, while a two-stage MEUF system was evaluated for enhanced contaminant removal.

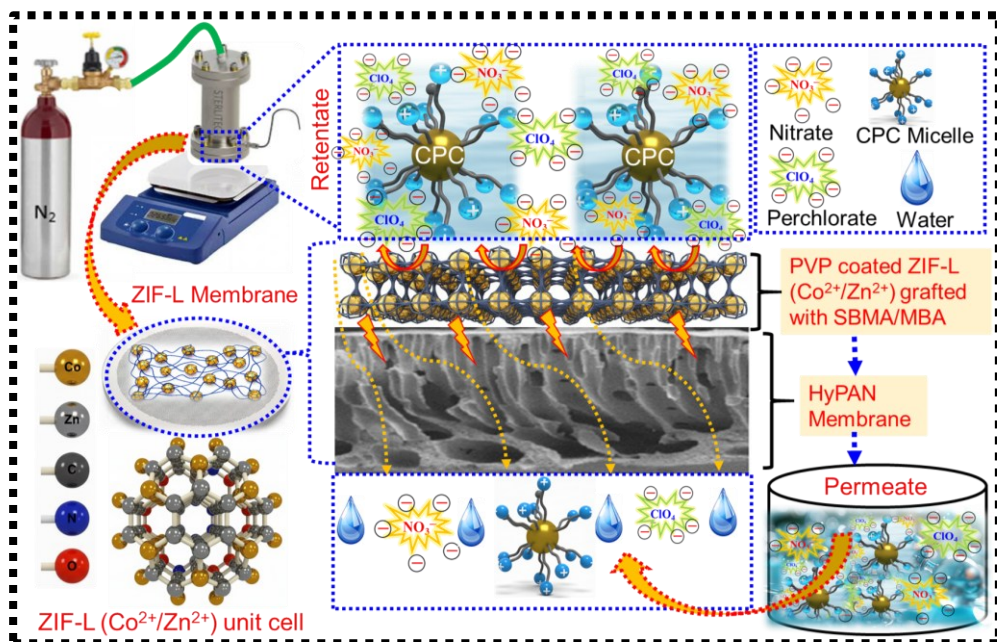


Fig. 1. Schematic representation of nitrate and perchlorate ion removal via micellar-enhanced ultrafiltration (MEUF).

In this study, a PAN ultrafiltration membrane was modified via in situ polyvinylpyrrolidone (PVP)-assisted growth of a hydrogel-stabilized ZIF-L($\text{Co}^{2+}/\text{Zn}^{2+}$) film to enhance micellar-enhanced ultrafiltration (MEUF) performance for nitrate and perchlorate anions rejection. Controlled variation of PVP content enabled precise tuning of MOF stability, surface charge, and hydrophilicity. The optimized HyZif-LG(0.5PVP) membrane achieved high rejection efficiencies of

89.14% for nitrate and 92.04% for perchlorate at 2 bar pressure using a feed concentration of 100 ppm for each anion and 5 mM CPC, while maintaining high permeate flux 7.71 and 8.76 Lm⁻²h⁻¹, respectively. The membrane demonstrated excellent operational stability over five consecutive cycles, with only minor rejection losses (≤14%) for nitrate and (≤7%) perchlorate anions. Superior antifouling behavior was observed, with high flux recovery ratios (>88%) over four cycles, indicating predominantly reversible fouling associated with CPC adsorption and micelle-induced pore blocking. Importantly, no detectable Zn²⁺ or Co²⁺ leaching was observed, confirming strong chemical and structural stability of the ZIF-L(Co²⁺/Zn²⁺)/PVP film. Overall, the HyZif-LG(0.5PVP) membrane provides a robust and efficient platform for simultaneous nitrate and perchlorate removal via MEUF, offering strong potential for advanced water treatment applications.

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EVALUATION AND PROCESS SIMULATION FOR DESALINATION BRINE CONCENTRATION USING LSRRO MEMBRANES PREPARED BY CHEMICAL MODIFICATION

D.Y. Lee¹, J. H. Kim², S.Y. Lee¹, S. Lee¹, Y.J. Choi¹, S.H. Lee¹

¹School of Civil and Environmental Engineering, Kookmin University, Jeongneung-Dong, Seongbuk-Gu, Seoul, Republic of Korea

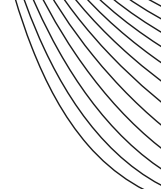
²Samsung E&A Co., Ltd., Seoul, Republic of Korea

*Corresponding author: sanghlee@kookmin.ac.kr

Abstract: Seawater desalination brine disposal poses severe environmental challenges, prompting a critical paradigm shift toward brine reduction and resource mining. These circular economy approaches rely heavily on maximizing brine concentration to minimize the massive capital and energy costs associated with downstream thermal evaporation and crystallization. However, conventional seawater reverse osmosis (SWRO) membranes are strictly restricted by hydraulic pressure ceilings due to extreme osmotic pressure buildup at high salinities, while nanofiltration (NF) membranes provide insufficient total salt rejection. To address this trade-off, low-salt-rejection reverse osmosis (LSRRO) was investigated as a controlled-salt-passage strategy to lower the net driving pressure. Synthetic SWRO desalination brine was prepared using sea salt, yielding a feed total dissolved solids (TDS) concentration of 58,500 mg/L. LSRRO membranes were fabricated via the controlled chemical oxidation of commercial SWRO membranes using sodium hypochlorite (NaOCl) under varied conditions. Water permeability coefficients (B) and salt permeability coefficients (B) were calculated using the measured flux and rejection values in a lab-scale crossflow membrane system. A numerical model based on modified solution-diffusion theory was developed and applied to simulate the performance of a full-scale process for brine management.

Results showed that the LSRRO membranes significantly mitigated osmotic pressure-induced flux decline compared to SWRO, while maintaining superior solute containment over loose NF. The calculated A and B values ranged from 3.5 to 4.5 LMH/bar and from 12 to 15 LMH, respectively. These coefficients were subsequently integrated into the numerical model for process simulation, estimating key performance indices such as average flux, water recovery, and final brine concentration. Based on the simulation results, the optimum ranges of A and B were proposed for practical implementation. In summary, this study established a quantitative, system-level framework for energy-efficient LSRRO-based concentration in seawater desalination plants.

Keywords: Desalination, Seawater Desalination Brine, Low-Salt-Rejection Reverse Osmosis (LSRRO), Process Simulation, Carbon Reduction, Alternative Water Resources



MACHINE LEARNING VS. RESPONSE SURFACE METHODOLOGY FOR MODELING MULTI-ION TRANSPORT COEFFICIENTS IN HIGH-PRESSURE NANOFILTRATION

S.Y. Lee, Y.S. Jeong, S. Lee, J.Y. Lee, Y. Choi¹, S. Lee^{*}

School of Civil and Environmental Engineering, Kookmin University, Jeongneung-Dong, Seongbuk-Gu, 02707, Seoul, Republic of Korea

^{*}Corresponding author: sanghlee@kookmin.ac.kr

Abstract: High-pressure nanofiltration (HPNF) is increasingly applied in seawater desalination, brine concentration, and resource recovery due to its unique ability to separate multivalent ions at high osmotic pressures. However, accurate prediction of water and ion transport coefficients under these conditions remains highly challenging because high-salinity operations trigger severe non-linearities, intense concentration polarization, and coupled electrostatic-hydrodynamic interactions.

This study compared response surface methodology (RSM) with machine learning (ML) algorithms—specifically random forest, gradient boosting, and support vector regression—to map these complex parameters. Using a lab-scale crossflow filtration cell system, experiments were conducted on three commercial membranes (Toray NE90, NE40, and ARM) across a TDS range of 1–10% and pressures of 5–30 bar. Measured permeate fluxes and individual ion rejections (Na^+ , Mg^{2+} , Cl^- , SO_4^{2-}) were transformed into target responses using several distinct transport frameworks, including the solution-diffusion (SD), solution-diffusion-convection (SDC), and Spiegler-Kedem (SK) models.

Results showed that while RSM successfully elucidated explicit factor interactions and provided clear interpretation of non-linear behaviors, its predictive accuracy was constrained by polynomial limitations. On the contrary, the ML models captured the highly non-linear transport behavior at elevated salinities, achieving superior precision across all transport frameworks. Accordingly, it was recommended that RSM be used for initial factor screening and ML for robust forecasting, as this offers an optimized hybrid modelling workflow for HPNF process design and optimization.

USE OF BIOMIMETIC MEMBRANES IN REVERSE OSMOSIS AND FORWARD OSMOSIS AS CONCENTRATION TECHNOLOGIES FOR LIGNIN RECOVERY

L. Lema, X. Yang, L.P. Mazur, C. Martínez

Centro Tecnológico de Investigación Multisectorial (CETIM), Parque empresarial de Alvedro, calle H, 20, 15180, Culleredo, A Coruña, Spain

Abstract: The transition to a circular economy requires a profound reconfiguration of traditional processes within the pulp and paper industry through the biorefinery concept, transforming industrial waste effluents into high-value chemical products. Currently, these residual streams are heavily concentrated in multiple-effect evaporators and subsequently incinerated in the chemical recovery boiler. Although this conventional layout effectively generates bioenergy for mill self-sufficiency and recovers inorganic cooking chemicals, it wastes highly valuable macromolecular organic compounds¹. A promising pathway to enhance the circularity of these industrial processes consists of assessing the technical feasibility of selectively recovering lignin from a real alkaline bleaching effluent from pulp and paper industry, which is characterized by high pH and elevated organic load. This separation pathway typically relies on conventional membrane filtration followed by acid precipitation. However, due to the complexity of the organic matrix, commercial polymeric membranes face severe operational limitations, mainly because of irreversible organic fouling, which leads to a progressive decline in permeate flux. This work investigates the application of aquaporin-based biomimetic membranes operating in forward osmosis (FO) and reverse osmosis (RO) configurations as alternative concentration technologies². The FO trials were carried out utilizing 2 M magnesium chloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) as a draw solution. This configuration induces a continuous water transport driven exclusively by the trans-membrane osmotic pressure gradient. These experiments were initially performed with synthetic lignin solution to evaluate the performance of the membranes without the complexity of the real industrial matrix. In both synthetic and industrial matrix trials, results demonstrated that FO offers a notably superior performance in lignin concentration compared to RO. Specifically, in synthetic trials, FO achieved a concentration factor of 4.43 ± 0.05 compared to 2.96 ± 0.04 . This superior performance was maintained with the real matrix, achieving a concentration factor of 6.2 ± 0.3 compared to 3.9 ± 0.1 for RO and a specific energy consumption of 0.16 ± 0.01 kWh/L compared to 2.4 ± 0.5 kWh/L for RO, as well as a lower tendency for irreversible fouling and minimized reverse salt flux values. Subsequently, the resulting concentrated streams were chemically precipitated via the controlled addition of 1 M HCl to reduce the pH below 2. The precipitated lignin was then successfully isolated via centrifugation at 6500 rpm for 15 minutes and then oven-dried at 50 °C. FO concentrates achieved a final precipitation yield of 47%, contrasting with the 17.5% obtained from RO concentrates. This result suggests that the higher concentration factor achieved by FO facilitates lignin precipitation,

resulting in substantially higher recovery yields than those obtained after RO concentration. The recovered solid fractions were thoroughly characterized using Fourier-transform infrared spectroscopy (FTIR)³ and pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS). The analytical results confirmed that the isolated solid lignin successfully maintained its stable macromolecular structure and exhibited a prominent presence of syringyl monomeric units, matching the structural profile of commercial reference lignin. Specifically, the FO process displayed an outstanding selectivity, maintaining an analytical profile highly proportional to the lignin directly precipitated from the industrial effluent. This achieved a lower concentration of structural impurities compared to RO, a fact attributed to a gentler and more constant concentration mechanism compared to conventional pressure-driven membrane filtration. In conclusion, this work demonstrates the potential of biomimetic membrane technologies, particularly FO, as a robust, cost-effective, and energy-efficient concentration step to optimize the recovery of high-purity lignin from complex effluents in the pulp and paper industry.

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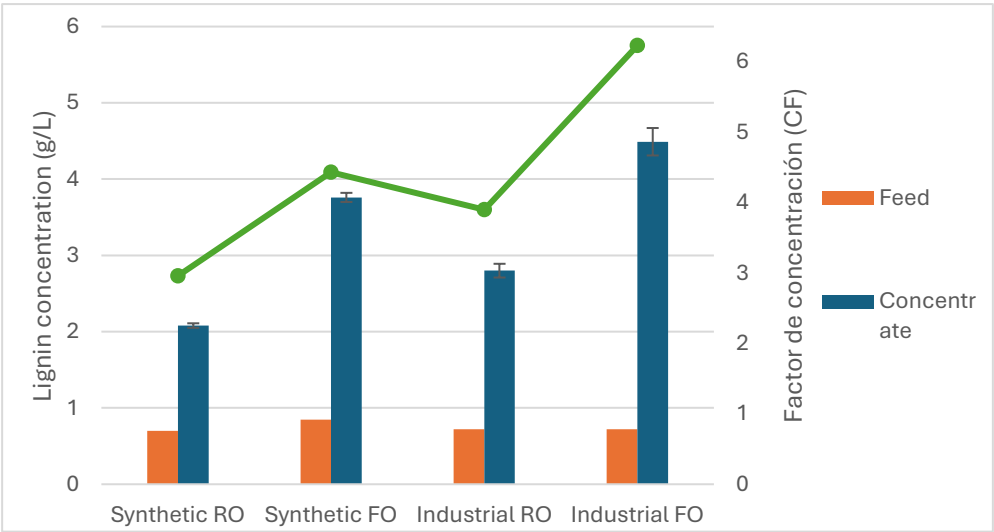


Figure 9. Lignin concentration and concentration factor of synthetic and industrial effluent using RO and FO processes.

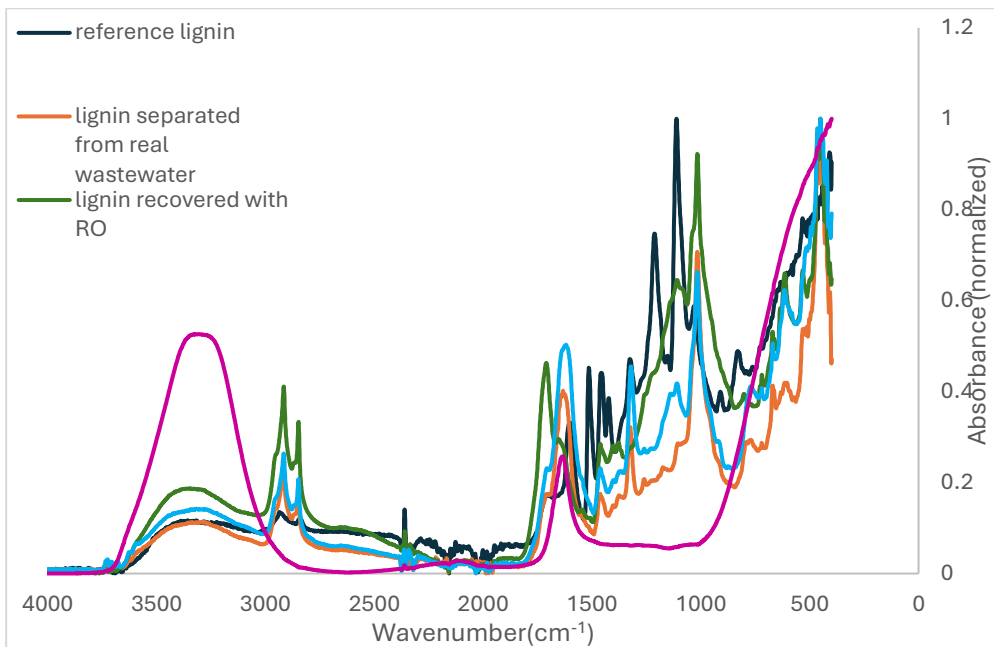


Figure 10. FTIR spectra of the reference lignin, the lignin precipitated from the industrial effluent and from the FO and RO concentrates, and water.

MEMBRANE-BASED CONCENTRATION OF RECOVERED NaOH FOR RESOURCE RECYCLING IN SECONDARY BATTERY WASTEWATER

J. Lim, Y. Choi*

Department of Environmental Research, Korea Institute of Civil Engineering and Building Technology (KICT), 283, Goyang-Daero, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do, Republic of Korea

Abstract: The rapid expansion of secondary battery manufacturing and recycling industries has resulted in the generation of large volumes of alkaline wastewater containing sodium sulfate (Na_2SO_4). Conventional wastewater treatment processes primarily focus on neutralization and disposal. This leads to increased operating costs and the loss of valuable chemical resources. Recently, bipolar electrodialysis (BPED) has attracted considerable attention as a promising technology for recovering sulfuric acid and sodium hydroxide from sodium sulfate-rich wastewater. However, the concentration of recovered sodium hydroxide (NaOH) is generally insufficient for direct reuse in industrial processes, necessitating an additional concentration step.

In this study, a membrane-based concentrator (MBC) was proposed as a post-treatment process to concentrate low-concentration NaOH streams recovered from BPED. The MBC utilizes a membrane distillation (MD) process to concentrate NaOH in the upper part of the reactor. The concentration gradient generated during the operation of the system induces internal circulation, thereby alleviating the concentration increase in the upper MD zone and enabling continuous NaOH concentration (Figure 1.). The target NaOH concentration was set at 25 wt%, which is suitable for reuse in secondary battery precursor manufacturing processes. The proposed MBC process is expected to provide an energy-efficient alternative for NaOH recycling and contribute to sustainable resource recovery from secondary battery wastewater.

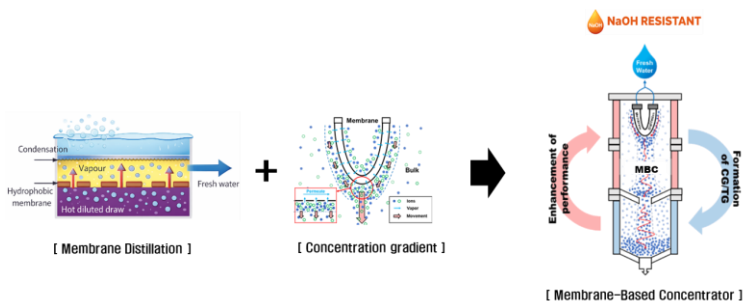


Figure. 1. Schematic illustration of the membrane-based concentrator (MBC) for NaOH concentration.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) and the Commercialization Promotion Agency for R&D Outcomes(COMPA) grant funded by the Korea government(Ministry of Science and ICT)(RS-2026-25530691)

FABRICATION AND EVALUATION OF THIN-FILM COMPOSITE POLYAMIDE MEMBRANES FOR PHARMACEUTICAL CONTAMINANT REMOVAL FROM TREATED WASTEWATER

Y. Manawi, V. Kochkodan

Qatar Environment and Energy Research Institute (QEERI), Hamad Bin Khalifa University (HBKU), Qatar Foundation, Doha, 34110, Qatar

Abstract: Pharmaceutical residues in water have become a significant environmental challenge because of their potential risks to human health and aquatic life. Among these contaminants, cyclophosphamide (CP), a widely used anticancer drug, is commonly found in hospital wastewater and is considered one of the most prevalent antineoplastic pollutants. In this work, innovative thin-film composite (TFC) polyamide (PA) membranes were developed through interfacial polymerization with the incorporation of acacia gum (AG), a naturally occurring amphiphilic biopolymer, into the selective layer to improve the removal of CP and other pharmaceutical compounds from water. Comprehensive membrane characterization was performed using scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), zeta potential measurements, and water contact angle analysis. The addition of AG enhanced membrane porosity, surface hydrophilicity, and negative surface charge owing to its unique structure comprising hydrophilic polysaccharide chains and hydrophobic protein components. Filtration studies conducted with both synthetic wastewater and real treated sewage effluent (TSE) containing CP, acetaminophen, and atenolol revealed that AG-modified membranes achieved CP rejection as high as 98.7%, significantly exceeding the 90.4% rejection obtained with unmodified PA membranes, while simultaneously providing greater water permeability. The developed membranes also demonstrated superior performance compared with commercial NF90 and NF270 membranes. Moreover, AG incorporation improved antifouling properties, decreasing bacterial attachment by over 55%, highlighting the promise of these membranes for efficient and sustainable treatment of pharmaceutical-contaminated wastewater.

TUNING MEMBRANES PROPERTIES FOR ELECTRO-OSMOTIC FEED DEWATERING

S. Mehta, J. Poniatowska, T. Wang, Z. Borneman, D.C Nijmeijer

Department of Chemical Engineering and Chemistry, Eindhoven University of Technology,
5600 MB Eindhoven, The Netherlands (s.mehta@tue.nl)

Abstract: Pressure-driven biomass dewatering is fouling-limited. Electric-field-driven dewatering overcomes this limitation through electro-osmotic (EO) flow, where electromigration of the electric double layer (EDL) at the interface leads to EO flow over charged solid surfaces. EO flow occurs in both the feed and membrane. Since feed EO is material-dependent, optimizing membrane EO (**Figure 1**) provides a practical route to enhance overall dewatering ^[1]. This work presents pathways to optimize membranes for interfacial EO transport by tuning membrane morphology, and charged interface.

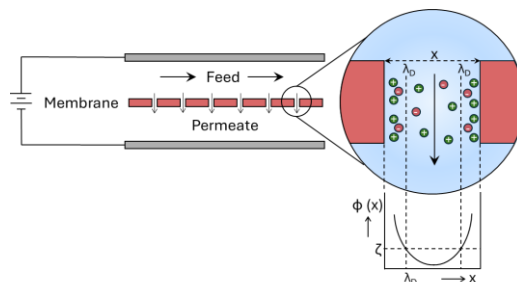


Figure 1 – EO flow in membrane pores upon application of an external electric field.

The effect of morphology on membrane EO transport was systematically studied using phase-inversion membranes with varied dope composition and casting thickness. EO transport was maximized for dope solutions with low polymer (14% PSf), high pore former (12% PEG), and thick casting (500 μm). Optimized membrane had sponge-like morphology and higher thickness, offering high interfacial area for EO transport. These features were balanced by moderate pore size (~ 270 nm), mitigating EDL overlap ($r_p/\lambda_D \approx 8$)^[1]. The EO permeability for optimized membrane was 68 L/m²h at pH 10 and 200 V. For 0.1 wt% cellulosic feed, net EO dewatering increased to 660 L/m²h, through additional EO flow in the feed. Preliminary experiments with fixed-charge blends, using negatively charged sPES or positively charged FAA-3[®] suggest that membrane charge can control EDL polarity and EO flow direction. This is useful when feed and membrane charges align, producing additive unidirectional flow. Overall, EO feed dewatering can be enhanced by tuning membrane properties, offering higher efficiency than pressure-driven processes.

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SUSTAINABLE PES - PVDF MEMBRANE PREPARATION USING KJCBPA-100 A NOVEL SUSTAINABLE SOLVENT VIA VAPOR ASSISTED NON-SOLVENT INDUCED PHASE SEPARATION: THERMODYNAMIC STUDY-DYE REMOVAL APPLICATION

M. Mekki¹, F. Russo¹, M. Bonora², D. Venturi², K. Teramoto³, A. Figoli¹

¹Institute on Membrane Technology, National Research Council of Italy (CNR-ITM), Via P. Bucci 17/C, 87036 Rende, CS, Italy

²GVS SpA, via Roma 50, 40069 Zola Predosa (BO), Italy

³KJ Chemicals Corporation, 3-6 Nihonbashi Honcho 3-Chome, Chuo-ku, Tokyo 103-0023, Japan

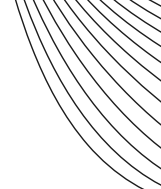
Abstract: The development of sustainable manufacturing processes is a key challenge in membrane technology. To address this challenge, novel flat-sheet polyethersulfone (PES) and polyvinylidene fluoride (PVDF) membranes were prepared by using 3-Butoxy-N, N-dimethylpropanamide (KJCBPA-100) as a novel sustainable solvent. KJCBPA-100 is an environmentally friendly solvent characterized by an amphiphilic structure that integrates a hydrophobic butoxy chain and a hydrophilic amide group¹. This property makes it an alternative green solvent for membrane preparation². Preliminary thermodynamic study such as Hansen and Hildebrand solubility parameters and kinetic study confirmed that this solvent exhibits the physicochemical properties to be exploited in membrane development. The vapor assisted non-solvent induced phase separation technique was used to produce the flat sheet membrane by varying the exposure time to relative humidity of 0, 2.5 and 5 minutes. The developed membranes were fully characterized in terms of morphology, surface wettability, pore size, porosity and mechanical resistance. The results showed that the PES and PVDF membranes exhibited different structures and a tunable pore size in the range of ultrafiltration (UF) making them highly suitable for water treatment applications. The membranes also exhibited high removal efficiency for methylene blue (MB).

Acknowledgment

This research was supported by GVS S.p.A. within the GREEN-FLOW project (Prog. n. F/350179/00/X60 – CUP: B39J23002570005, financed by the Italian Ministry for Economic Development, MIMIT). The authors gratefully acknowledge the financial support and resources provided for the development of this work

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RECYCLED NANOFILTRATION MEMBRANES AS AN ACCESSIBLE STRATEGY FOR PFAS REMOVAL AND WATER SAFETY

M. M. Miranda^{1,2}, F. Zouaoui², L. Paugam², A. Szymczyk², P. Loulergue², E.C. de Paula¹, M. C. S. Amaral¹, V. R. Moreira^{1*}

¹Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, 6627 Antonio Carlos Avenue, Campus Pampulha, MG, Brazil. *Corresponding author e-mail: victor@desa.ufmg.br

²Univ Rennes, Ecole Nationale Supérieure de Chimie de Rennes, CNRS, ISCR – UMR6226, F-35000 Rennes, France

Abstract: Access to safe drinking water remains a major challenge in remote and isolated regions, where conventional treatment infrastructure is often limited. This challenge becomes even more critical in the presence of emerging contaminants such as per- and polyfluoroalkyl substances (PFAS), which are highly persistent and mobile. Pressure-driven membrane processes, particularly nanofiltration, are promising alternatives for improving water quality due to their compact configuration, high separation efficiency, and potential for decentralized applications. However, the cost of commercial membranes can still limit their implementation in economically constrained contexts. In this perspective, recycled nanofiltration membranes produced from end-of-life reverse osmosis modules may represent a low-cost and circular alternative, extending membrane lifespan while reducing material disposal. Despite this potential, their performance must be validated under environmentally relevant conditions, especially for PFAS-contaminated surface waters. Recycled nanofiltration membranes were produced by chemical modification of end-of-life reverse osmosis membranes through oxidative treatment with sodium hypochlorite (NaClO 938 mg/L – 2h), aiming to partially degrade the polyamide selective layer and obtain membranes with NF-like separation properties. They were compared with commercial NF90 membranes in experiments carried out in a stainless-steel flat-sheet membrane module with an effective filtration area of 0.004 m², tangential filtration mode (144 L/h). Feed (PFOA and PFOS: 0.2 mg/L; TOC: 12 mg/L), permeate, and concentrate streams were characterized for total organic carbon (TOC-V CPH, Shimadzu) and PFAS concentration by HPLC-MS (Waters Acquity UPLC). Both commercial and recycled NF membranes showed high efficiency for PFAS removal, with rejection values above 99%. For NF90, pressure did not impact the PFAS concentration in the permeate. The recycled membrane achieved average rejections of approximately 99.5% for both PFOA and PFOS after 30 h (Figure 1), while the membrane maintained low permeate flux decay, J_f/J_0 of 0.85, suggesting low fouling potential. These results indicate that recycled NF membranes can provide high PFAS rejection with limited fouling, supporting their potential as a lower-cost alternative for surface water treatment.

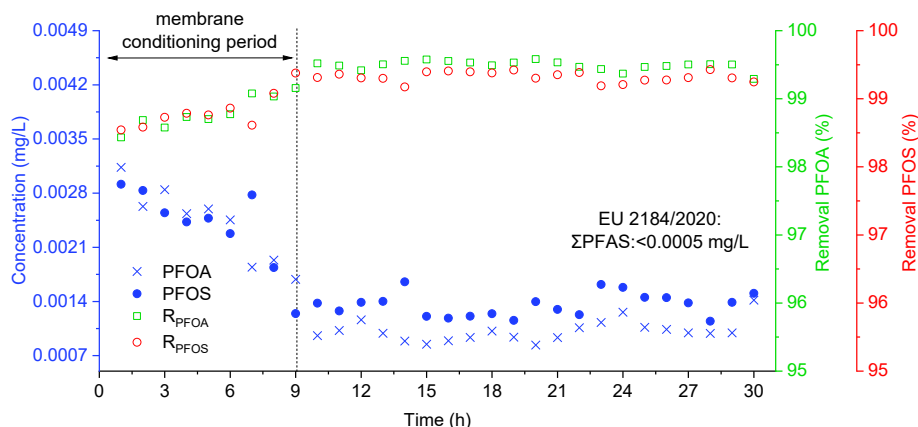


Figure 1. Concentration of PFOA and PFOS in the permeate of the recycled membrane during recycled NF operation. Operating pressure: 10 bar.

The high rejection values can be attributed to the combined contribution of steric hindrance, electrostatic/Donnan exclusion, hydrophobic interactions, and adsorption/partitioning within the active layer. PFOA and PFOS are long-chain PFAS and are predominantly anionic under typical surface water pH, favoring their rejection by negatively charged NF membranes through electrostatic repulsion. In addition, natural organic matter may contribute to the formation of a thin interfacial conditioning layer or modifying membrane surface charge, enhancing PFAS exclusion (Zhi *et al.*, 2025). It is important to note that the feed solution contained elevated PFAS concentrations, which imposed a particularly challenging condition for membrane treatment. Although removals above 99% were achieved, the permeate concentrations shown in Figure 1 did not meet the parametric values established by Directive (EU) 2020/2184 for drinking water, ($0.50 \mu\text{g L}^{-1}$ for total PFAS). Therefore, while the results demonstrate high PFAS removal efficiency, future confirmation of compliance with EU drinking-water parametric values would benefit from ultra-trace analytical methods specifically targeted to the regulatory concentration range. Overall, this study demonstrates that recycled NF membranes obtained from end-of-life RO modules can provide high PFAS rejection from surface water. These findings are particularly relevant for remote or resource-limited regions, where the cost and availability of conventional high-performance membranes may restrict the implementation of advanced treatment technologies. Therefore, recycled NF membranes represent a promising circular and accessible strategy for decentralized PFAS treatment, although further ultra-trace analytical validation is required to confirm compliance with drinking-water regulatory thresholds.

Acknowledgements

CAPES – Coordination of Superior Level Staff Improvement; COFECUB – French Committee for the Evaluation of University Cooperation with Brazil. The authors would like to thank the intern Sohan Titouan Floris Herpin for his support.

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IN SITU GROWN COVALENT ORGANIC FRAMEWORK MEMBRANES STABILIZED BY METHACRYLATE HYDROGELS FOR EFFICIENT DYE–SALT SEPARATION

S. Mishra, R. Kasher

Department of Desalination and Water Treatment, Zuckerberg Institute for Water Research,
Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev,
Midreshet Ben-Gurion, 8499000, Israel

smriti@post.bgu.ac.il; kasher@bgu.ac.il

Abstract: The discharge of textile wastewater, characterized by stable organic dyes and high salt concentrations, poses a significant environmental challenge. Effective dye–salt separation remains a major hurdle in wastewater treatment. Covalent organic frameworks (COFs) have emerged as highly attractive nanomaterials for membrane applications due to their high porosity, large internal volume, controllable structure, and excellent chemical and thermal stability. However, the adhesion and integrity of a COF film on polymeric membranes might be disrupted because membranes swell and deform under aqueous conditions. Therefore, achieving robust and continuous COF films on membranes requires strong interfacial interactions, high COF–substrate contact, and geometric compatibility, that may be achieved by in situ COF fabrication.

This study demonstrates the development of a high-performance membrane via in situ synthesis of imine-linked COF-LZU1 utilizing 1,3,5-triformylbenzene (TFB) and p-phenylenediamine (PDA) monomers on commercially available ultrafiltration (UF) membranes. The COF-modified membranes were grafted with methacrylate hydrogels, stabilizing the COF film under flow conditions, while providing a hydrophilic and permeable interface, following an approach recently demonstrated by our group for metal-organic frameworks (MOF) membranes.¹ Various monomer compositions were screened, specifically crosslinking the negatively charged 3- sulfopropyl methacrylate (SPM) with the positively charged [2- (Methacryloyloxy)ethyl]trimethylammonium chloride (MOETMA) in different ratios.

Scanning electron microscopy (SEM) analysis confirmed the successful formation of COF-LZU1 nanoparticles, which retained their characteristic crystal morphology² (Figure 1). The pristine PAN and hydrolyzed PAN (Hy) supports exhibited water permeance values of 268 ± 4.3 and 431.3 ± 4 $\text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \cdot \text{bar}^{-1}$ respectively. Upon COF- hydrogel modification, a decrease in water permeance was observed across all modified membranes, with the 1:1, 1:9, and 9:1 SPM:MOETMA ratio membranes exhibiting values of 87.7 ± 2.4 , 56 ± 2.4 , and 54.5 ± 1.1 $\text{L} \cdot \text{m}^{-2} \cdot \text{h}^{-1} \cdot \text{bar}^{-1}$, respectively. The rejection of organic dyes, including Reactive Red, Reactive Black, Reactive Blue, and Methyl Orange increased significantly for all modified membranes

as compared to the pristine PAN membrane (Figure 2). The membrane optimized with 1:9 SPM:MOETMA ratio demonstrated exceptional separation efficacy, achieving remarkable rejections of $96.8 \pm 1.2\%$ for Reactive Black, $98.0 \pm 1.3\%$ for Reactive Blue, $98.8 \pm 1\%$ for Reactive Red, and $56.4 \pm 1.7\%$ for Methyl Orange. In comparison, the pristine PAN membrane exhibited substantially lower rejections of $29.4 \pm 3.2\%$ for Reactive Black, $49.7 \pm 3.7\%$ for Reactive Blue, $79.9 \pm 1.1\%$ for Reactive Red, and $8.9 \pm 1.9\%$ for Methyl Orange. In situ growth of COF nanoparticles together with a charge-tunable grafted hydrogel effectively stabilizes the COFs on the porous support, providing a robust strategy to fabricate performance membranes optimized for dye-salt separation for textile wastewater treatment.

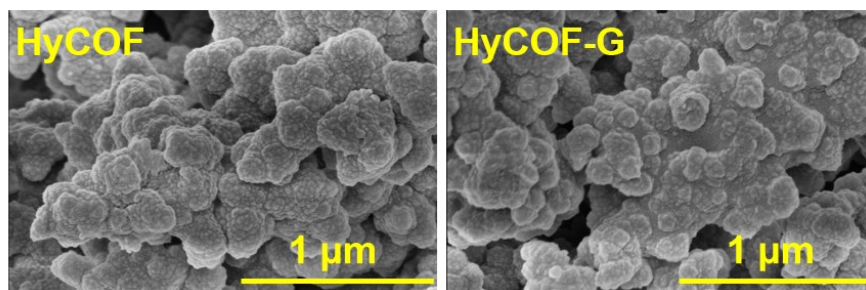


Figure 1. SEM image of hydrolyzed PAN membranes modified with COF-LZU1 nanoparticles (HyCOF; left) and with COF-hydrogel grafting (HyCOF-G; right).

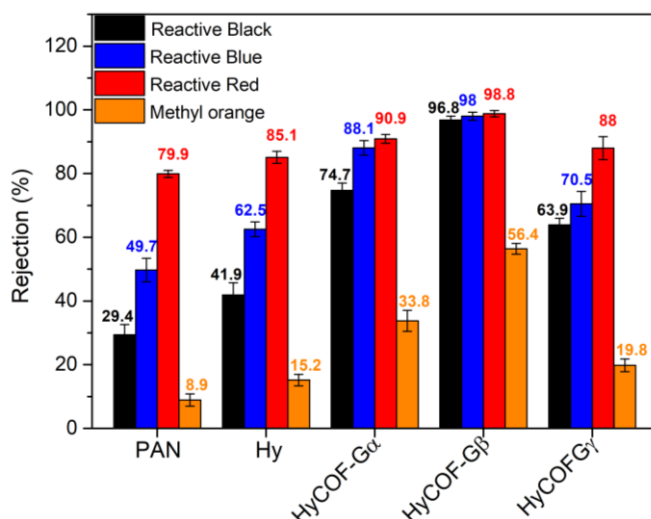


Figure 2. Rejection of Reactive Black, Reactive Blue, Reactive Red, and Methyl Orange dyes by pristine PAN, Hy and HyCOF-G membranes (HyCOF-G α , HyCOF-G β , and HyCOF-G γ denote HyCOF-G membranes prepared with SPM:MOETMA ratios of 1:1, 1:9, and 9:1, respectively).

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PREDICTION OF ION SELECTIVITY IN ELECTRODIALYSIS SYSTEM IN MULTIVALENT, MULTI-COMPONENT ION SYSTEMS

S. Morinaga^{1,2}, Y. Kakihana^{3,4}, M. Higa^{3,4}

¹Faculty of Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube, 755-8611, Japan

²School of Environment and Society, Institute of Science Tokyo, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8550, Japan

³Graduate School of Sciences and Technology for Innovation, 2-16-1 Tokiwadai, Ube, 755-8611, Japan

⁴Blue Energy center for SGE Technology (BEST), Yamaguchi University, 2-16-1 Tokiwadai, Ube, 755-8611, Japan (mhiga@yamaguchi-u.ac.jp)

Introduction: Ion-exchange membranes are used in processes such as electrodialysis (ED) and reverse electrodialysis (RED), where seawater is often utilized. Seawater mainly contains Na^+ and Cl^- ions, along with divalent ions such as Mg^{2+} , SO_4^{2-} , and Ca^{2+} . The presence of divalent ions decreases power generation efficiency in RED, and in ED desalination processes, it causes membrane degradation due to scale formation. In this study, to predict ion transport behavior in ED, the ion concentrations within a cation-exchange membranes (CEM) in mixed monovalent–divalent ion solutions are estimated using the fixed charge density of CEM and membrane affinity. Using the ion concentrations and the ion mobility in CEM, ion transport in ED was simulated. To verify the validity of the simulation method, the calculated results were compared with the experiments obtained from ED test.

Experiments: To measure the ion concentration in commercial CEM, Neosepta® CSE (Astom Corp., Japan) was immersed in mixed solutions of KCl and NaCl with varying concentrations, as well as in mixed solutions of NaCl and MgCl_2 .

In this study, the ion concentrations in the CEM were predicted in terms of the Donnan equilibrium theory using C_x and Q_i , which represents the affinity and activity coefficient between the membrane and the ions.

We also conducted the ED experiment to measure the ion selectivity of CSE. In this experiment, a constant current of 180 mA was applied, and the time-dependent changes in concentration within both the concentrate and dilute chambers were measured at an initial concentration of 0.1 M. The experimental results were then compared with the simulated values using the correction factor α , which accounts for the effect of the pore size distribution—specifically, the restriction where ions cannot pass through pores smaller than their own size.

Results and Discussion: Figure 1 (a) shows the relationship between the ionic concentration in a CEM, C_i^m , and that in the external salt solution, C_i^s for mixed solution of KCl and NaCl. In this system, when C_i^s was below 0.3 M,

the concentrations of K^+ and Na^+ within the membrane remained nearly constant. When C_i^s exceeded 0.3 M, all the ion concentrations increased sharply. The Q_i values that gave good agreement between the experiments and simulations were $Q_{Na} = 1.8$, $Q_K = 3$, and $Q_{Cl} = 1$, with a fixed charge density $C_x = 7.0$ M. Figure 1(b) shows the relationship between C_i^s and C_i^m for mixed solution of NaCl and $MgCl_2$. In this system, at low C_i^s , most of the counterions within the membrane were Mg^{2+} . As C_i^s increased, C_{Na}^m rose significantly, while C_{Mg}^m gradually decreased. When C_i^s increased further, all the ion concentrations increased sharply. the C_x and Q_i values that provided good agreement between the experiments and simulations in the KCl and NaCl mixed solution system were also used in the simulation for the NaCl and $MgCl_2$ system to predict the ion concentrations C_i^m in the NaCl and $MgCl_2$ mixed solution system. The Q_i values determined from the partition experiments and simulations were applied to predict CEM selectivity in the ED experiments.

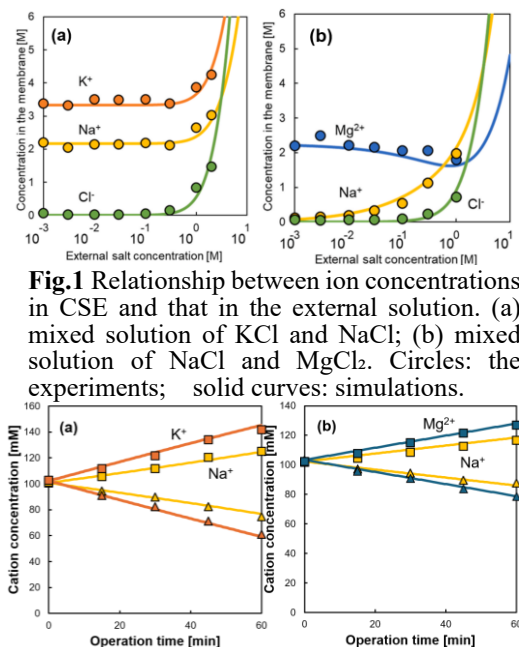


Fig.1 Relationship between ion concentrations in CSE and that in the external solution. (a) mixed solution of KCl and NaCl; (b) mixed solution of NaCl and $MgCl_2$. Circles: the experiments; solid curves: simulations.

Figure 2(a) shows the relationship between concentration and time in ED tests for the KCl and NaCl system. In this system, the CSE exhibits a K^+ selectivity that is 1.6 times higher than that for Na^+ . The α values that gave good agreement between the experiments and simulations were $\alpha_K=0.50$ $\alpha_{Na}=0.58$. Figure 2(b) shows the relationship between concentration and time in ED test for the NaCl and $MgCl_2$ mixed solution system. In this system, the selectivity for Mg^{2+} relative to Na^+ was found to be 1.72. To predict this ion selectivity in the NaCl and $MgCl_2$ mixed solution system, the α values that provided a good agreement between the experiments and simulations in the KCl and NaCl mixed solution system were applied ($\alpha_{Mg}=0.32$ $\alpha_{Na}=0.58$). The simulated values quantitatively matched the experimental ones, even when using the α values obtained from the other mixed solution system.

Fig.2 Relationship between ion concentrations in concentrate chamber (■) and dilute chamber (▲) and time. (a) mixed solution of KCl and NaCl; (b) mixed solution of NaCl and $MgCl_2$. Squares, Triangles: experiments; solid curves: simulations.

The quantitative agreements between the experiments and simulations indicate that this approach is useful for predicting ion transport in CEM in multicomponent ionic systems. Ion concentration and ion mobility inside membrane are highly effective for quantitatively predicting the ion selectivity of CEM in the systems. Therefore, this simulation method will be useful for designing ED systems with high ion selectivity and low energy consumption.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP26H02586.

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ADVANCING SUSTAINABLE POME TREATMENT THROUGH MULTIFUNCTIONAL DUAL-LAYER HOLLOW FIBER MEMBRANES

M. S. Muhammad, R. Kamaludin, S. M. Jasman, M. H. Puteh, J. Jaafar, M. A. Rahman, A. F. Ismail, M. H. D. Othman*

Advanced Membrane Technology Research Centre, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.
(dzarfan@utm.my)

Abstract: The treatment of Palm Oil Mill Effluent (POME) using direct contact membrane distillation (DCMD) is severely constrained by membrane wetting, fouling, and thermal inefficiency. This study addresses these limitations by developing an energy-efficient, omniphobic, photothermal dual-layer hollow fiber membrane that decouples mechanical support from active selective functions. The research was executed in three phases. First, multifunctional, antibacterial nanoparticles optimized for stable photothermal response were synthesized. Second, dual-layer polyvinylidene fluoride (PVDF) hollow fiber membranes were fabricated, incorporating varying nanoparticle loadings into the outer layer to optimize morphology and liquid entry pressure. Third, the membranes underwent surface modification via chemical etching and fluorination to lower surface energy and create a stable, textured architecture capable of repelling low-surface-tension liquids. The optimized membranes demonstrated a superior balance of structural and functional properties. Incorporating 1.0 wt.% of the functional nanoparticles yielded the highest improvements in surface area and porosity. Following surface modification, the membranes transitioned to an omniphobic state, exhibiting water contact angles exceeding 134° and significantly enhanced oil resistance. Under solar-assisted DCMD trials with synthetic effluent, the photothermal response achieved an energy-efficiency gain of 43.1% and a solar utilization efficiency of 77.9%. When tested against real final discharge POME during prolonged operation, the modified membranes proved highly robust, maintaining 95–98% flux retention with minimal foulant accumulation. This study demonstrates that synergizing antibacterial and photothermal functionalities with induced omniphobicity effectively mitigates thermal loss and pore wetting. The scalable dual-layer hollow fiber configuration offers a sustainable, energy-efficient pathway for industrial water reclamation from high-strength agro-industrial effluents.

STABILIZATION OF NANOFIBROUS MULTILAYER HETEROGENOUS ION EXCHANGE MEMBRANES

S. Nevyhoštěný¹, F. Umlauf²

¹MemBrain s.r.o , Pod Vinicí 87, Stráž pod Ralskem, Czech Republic

²Technical University of Liberec, Department of nonwovens, Studentská 1402, Liberec, Czech Republic

Abstract: Heterogenous ion exchange membranes (IEMs) hold a specific position in the industry, because they strike an interesting balance between price and performance. Their properties, however, prevent them from being utilized in several areas, namely those where high hydraulic permeability is required. Enantiomer separation is one of those areas and both heterogenous and homogenous IEMs have been used as a substrate for further functionalization with a chiral selector. However, the heterogenous IEM has not been tested for enantiomer separation capability due to very low hydraulic permeability (about a thousand times lower than homogenous membrane), which would result in extremely slow sorption and desorption rates¹.

In this work, we designed and prepared a multilayered nanofibrous heterogenous anion exchange membranes via electrospinning and hot-pressing. This procedure was reported on previously with success by other research groups². We have found the upper limit for ion exchange resin (IER) loading to be about 50 % w/w with selected polymer systems. At this concentration, the nanofibers could be produced continuously without clogging of the carriage of the Elmarco Nanospider machine. The materials were then layered and compressed together with the pressing temperature being just below the glass transition temperature for the carrier polymers. This resulted in a compact, consolidated foil, which showed no delamination of the layers, but still maintains the porous, fibrous structure and therefore high resin availability.

We have evaluated physical and electrochemical properties of the prepared samples and compared them with the referenced research where possible. The samples prepared have achieved almost identical ion exchange capacity as the reference IEMs and therefore a similar number of functional groups can be utilized for further modification. The measured electrical resistances and permselectivities were much lower than in the case of the membranes, pointing towards free space in the fibrous structure, which should again be beneficial for the interaction with the processed solution. All the electrochemical parameters prove the IER particles are not fully encapsulated by the carrier polymer and are free to interact with processed solution. Of great interest was the hydraulic permeability of the samples, where we observed increase of the flux with increased IER loading. To improve the material durability, we have also tested lamination of the multilayer between two sheets of nonwoven textiles. With this modification, the permeability stayed almost the same, but significant reduction in pressure needed was observed. Krypton sorption and BET analysis has shown doubling of the surface area in samples loaded with IER particles.

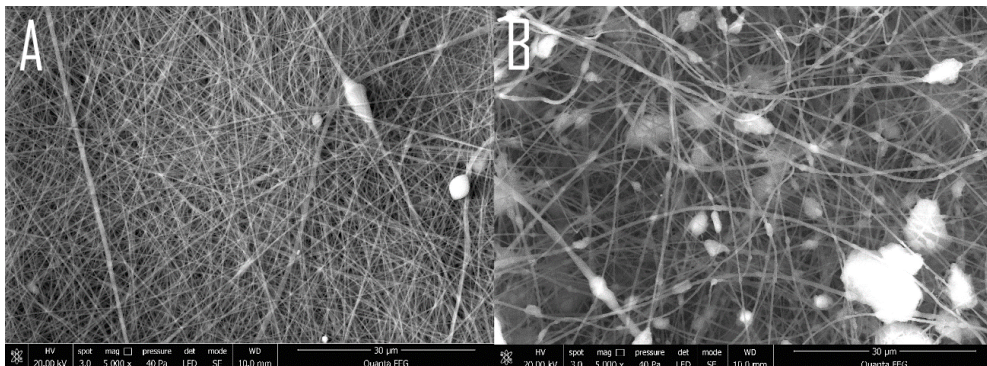


Figure: SEM images of pristine fibers (A) and fibers with 50 w/w% IER loading (B)

Acknowledgment: The work was carried out within the framework of the project “A long-term concept for the development of the research organization” supported by the Ministry of Industry and Trade of the Czech Republic, using the Membrane Innovation Centre infrastructure.

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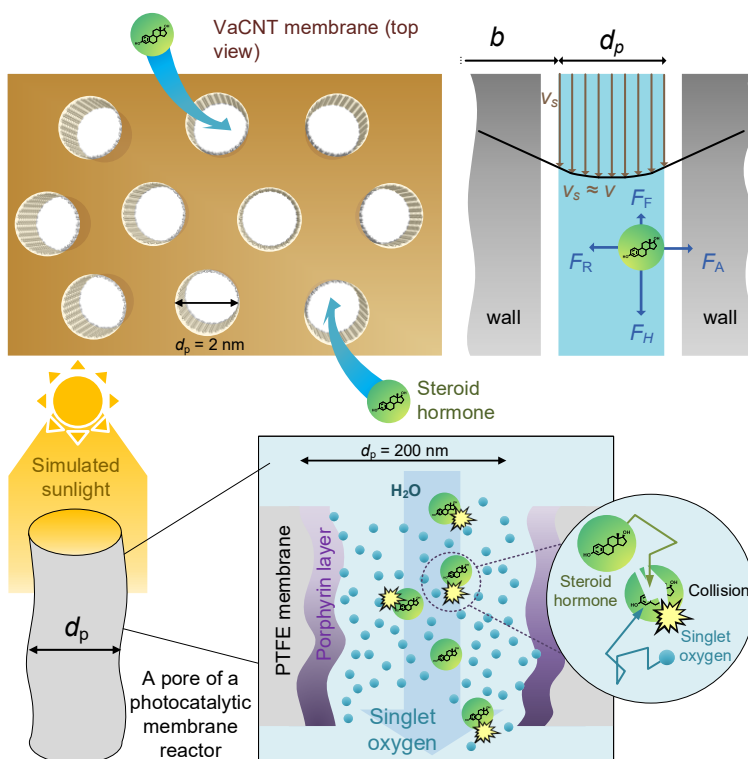
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NANOFLUIDIC TRANSPORT GOVERNING ADSORPTION AND REACTION IN MEMBRANE NANOPORES

M. N. Nguyen, A. I. Schäfer

Institute for Advanced Membrane Technology (IAMT), Karlsruhe Institute of Technology,
Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
(minh.nguyen@kit.edu)

Abstract: The transport of micropollutants (MPs) through membrane nanopores plays a critical role in determining their removal *via* adsorption to pore surfaces and photocatalytic reactions with reactive oxygen species. This presentation explores how the principles of force interplay and collision theory influence MP behavior and can be used to predict removal efficiency.



In small nanopores (diameters $< 10 \text{ nm}$), MPs tend to interact strongly with the pore walls. This adhesion competes with several other forces: hydrodynamic drag acting along the flow direction, friction against the flow, and electronic repulsion between the MP and the wall. The balance among these forces dictates whether an MP adheres to the membrane surface or passes through the pore. Investigating this interplay requires precise experimentation using vertically aligned carbon nanotube

membranes, of which cylindrical and atomically smooth pores (1.7–3.6 nm) minimize variations in surface roughness, tortuosity, and chemical heterogeneity [1].

Conversely, in larger pores (100–400 nm in diameter), MPs are more likely to diffuse freely throughout the pore volume. In photocatalytic membrane nanoreactors with such pores, the overall reaction rate is limited by the diffusion of and collision between the reactive oxygen species generated at the pore surface and the MPs. The classical collision theory was adapted to predict the reaction rates and process limitations in photocatalytic membrane reactors [2].

Together, these two frameworks provide complementary perspectives for pollutant transport and reaction at two distinct nanopore scales, and can be leveraged to enhance removal and selectivity.

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METHOD FOR RELIABLE ION-EXCHANGE MEMBRANE RESISTANCE MEASUREMENT IN INDUSTRIALLY RELEVANT CONDITIONS

H. Oakuche¹, L. Dammak², W. Garcia-Vasquez¹

¹Greennovation, 139 rue Philippe de Girard 84120 Pertuis, France
(wendy@greennovation.fr, www.greennovation.fr)

²Institut de Chimie et des Matériaux Paris-Est, 2 rue Henri Dunant 94130 Thiais, France

Abstract: Ion-exchange membrane resistance is a key parameter for the design, scale-up and troubleshooting of electrodialysis and related processes, as it directly contributes to ohmic losses and energy consumption. However, membrane resistance and ionic conductivity values reported in the literature often show significant discrepancies, even for widely used commercial membranes.

These discrepancies arise because, depending on the method used, the measured resistance may include contributions from the membrane itself, the electrolyte solution, diffusion boundary layers, electrode polarization, reference-electrode geometry and membrane/electrode interfacial effects. While direct-contact methods have recently been improved^{1,2} to access intrinsic membrane conductivity, the difference method remains particularly relevant for electrodialysis because the membrane is measured in its equilibrating electrolyte and the current passes through the membrane in the through-plane direction.

In this work, we propose a strengthened and easy-to-apply difference-method protocol for ion-exchange membrane resistance measurement under industrially relevant electrodialysis conditions. The method is based on two and four-electrode electrochemical impedance spectroscopy (EIS), building on the conductivity clip approach described by Nouri et al.³ and on more recent developments using reference electrodes for differential impedance measurements. Membrane resistance is obtained from a differential blank–membrane–blank sequence, in which the impedance of the electrolyte is measured immediately before and after the membrane measurement.

The proposed protocol was validated using commercial cation- and anion-exchange membranes equilibrated in NaCl solutions representative of electrodialysis operating conditions. Measurements were performed over a concentration range relevant to membrane benchmarking and process diagnosis, with a particular focus on 0.5 M NaCl, a condition commonly used for membrane area resistance comparison.

The resulting area resistance values were compared with corrected direct-contact measurements and literature data in order to define the reliable operating range of the method.

Finally, the method was applied to the measurement of ion-exchange membrane resistance during the autopsy of membranes used in a drinking-water desalination plant. The outcome is a robust, reproducible and industrially applicable protocol for membrane resistance measurement that remains non-destructive, rapid, reliable and precise.

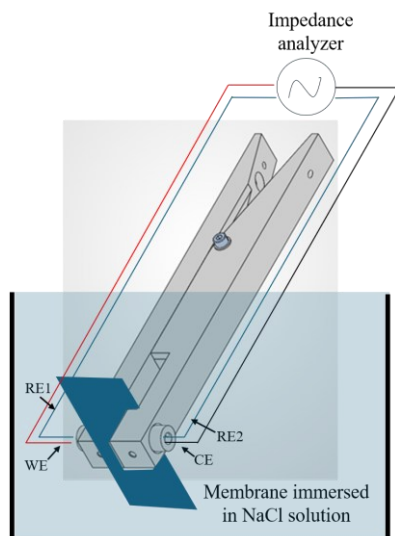


Figure 1. Four-electrode conductivity clip used for ion-exchange membrane resistance measurement by EIS. The membrane is immersed in NaCl solution and connected to a potentiostat/impedance analyzer through working, counter and two reference electrodes. Membrane resistance is obtained by differential impedance measurement.

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DIRECT CONTACT MEMBRANE DISTILLATION FOR WASTEWATER REUSE IN ELECTROLYSER WATER SUPPLY USING LOW-GRADE WASTE HEAT

J. Paetzold¹, R. Rosink², D. van den Heuvel³, C. Hoefer¹

¹Water & Process Technologies Research Group, AEE – Institute for Sustainable Technologies, Feldgasse 19, 8200 Gleisdorf, Austria (j.paetzold@aee.at)

²Waterschap Vechtstromen, Postbus 5006, 7600 GA Almelo, The Netherlands

³H₂ Hub Twente, Kolthofsingel 8, 7602EM Almelo, The Netherlands

1) Introduction: The investigated use case is located at H₂Hub Twente in Almelo, The Netherlands, where high-purity water is required for electrolysis while treated wastewater from a nearby wastewater treatment facility and low-grade waste heat from the electrolyser system are locally available. This combination provides a suitable basis for integrating water reuse and heat recovery within a circular hydrogen hub concept. Membrane distillation (MD) is a thermally driven separation process in which water vapour passes through a hydrophobic microporous membrane due to a vapour pressure difference induced by a temperature gradient. Non-volatile contaminants are retained in the feed, while purified water is recovered on the permeate side. Since MD can operate at moderate temperatures and low hydraulic pressure, it is particularly suitable for using low-grade waste heat. In this context, Direct Contact Membrane Distillation (DCMD) can contribute to resource efficiency and industrial symbiosis by linking wastewater treatment, waste heat recovery and hydrogen production across different industrial branches and resource flows.

2) Materials & Methods: In a laboratory-scale DCMD test facility at AEE INTEC, several experiments were conducted in batch mode using 24 L of feed solution and approximately 3 L of deionized water in the permeate circuit. The setup consisted of a heated feed tank, feed circulation pump, membrane test cell and a permeate loop with cooling. Treated wastewater from the H₂Hub Twente was used as feed after preliminary setup validation with tap water. The feed was heated to 50 °C or 60 °C, resulting in mean temperature differences (ΔT) between feed and permeate of approximately 20–26 K. Two commercially available flat-sheet PTFE membranes on polypropylene support were tested, with nominal pore sizes of 0.20 μm (Membrane A) and 0.45 μm (Membrane B). Performance was evaluated by measurement of feed and permeate electrical conductivity, and calculation of transmembrane flux (J), dilution factor, concentration factor, as well as conductivity-based ion rejection rate.

3) Results & Discussion: In total, 21 DCMD laboratory experiments were conducted, with 6 baseline experiments with tap water and 15 experiments with treated wastewater, respectively. Overall, the system showed stable hydraulic operation and reliable separation performance. Permeate fluxes ranged between 11 -

18 kg H₂O m⁻² h⁻¹, with higher fluxes at 60 °C feed temperature due to the larger vapour pressure gradient. Across the experimental campaign, 17 experiments met the target specifications for electrolyser-relevant water quality. One individual deviation was attributed to plant contamination rather than to membrane performance. The best-performing experiments achieved low permeate conductivities and rejection rates up to approximately 99.7%, despite feed conductivities in the range relevant for treated wastewater. These results demonstrate that DCMD can produce permeate suitable for the selected electrolyser specifications (Table 1).

Longer experiments over three consecutive days confirmed potential suitability for continuous operation. Membrane A maintained stable performance over approximately 18 h of cumulative operation with fluxes above 17 kg m⁻² h⁻¹ and mean permeate conductivity below 10 µS cm⁻¹. Membrane B showed increasing permeate conductivity and declining rejection during long-run operation, indicating the onset of membrane wetting. This underlines that membrane selection for high long-term ion rejection ensurance is a key requirement for practical implementation.

Table 1: Comparison of Feed, Permeate and the electrolyzers target specifications including analytic results for critical components.

Parameter	Fe	Cl ⁻	Suspended Solids	Dry Residue	Electrical Conductivity
Unit	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	mg L ⁻¹	µS cm ⁻¹
Treated wastewater (feed)	0.05	130	10.4	250-800	660
Target specification for electrolysis	1	2	1	7	10
Measured value in MD permeate	<0.03	<0.3*	<1*	<10*	Average: 6.2; Max: 13.2

*Values correspond to detection limits

4) Theoretical Upscaling: For scale-up, the batch system was conceptually transferred to a semi-continuous make-up and bleed configuration. In this approach, fresh wastewater feed is continuously added, permeate is withdrawn, and concentrated feed is removed as bleed to maintain a stable feed concentration. A sensitivity analysis was performed for the expected feed conductivity range of 300–1200 µS cm⁻¹ to assess the influence of feed variability on operation, bleed flow and energy demand. It indicated that the available excess heat of approximately 23 kW is sufficient for a target permeate production of 15 L h⁻¹ under controlled operating conditions. However, system feasibility is governed less by heat availability than by the achievable and stable rejection rate. At lower rejection rates, increasing feed conductivity results in transmembrane flux quality which does not meet the permeate quality criteria and strongly increases bleed and make-up flow requirements. Rejection rates of approximately 99.5% or higher would enable robust operation across the full expected feed conductivity range.

5) Conclusion: Results demonstrate that DCMD can meet electrolyser-relevant target specifications even when treating wastewater with comparatively high feed conductivity. This confirms the strong potential of MD for coupling wastewater

reuse, low-grade waste heat utilisation and hydrogen production in circular industrial hub environments. Further work should focus on robust membrane performance, rejection stability, heat recovery integration and semi-continuous process control to advance the concept beyond TRL 3–4.

REUSABLE GRAPHENE-BASED MEMBRANES FOR FAST REMOVAL OF PESTICIDES FROM REAL WATER MATRIXES

E. Pagalday¹, H. Salazar¹, C. R. Tubio¹, B. Alonso², T. Kuhnt², A. Elmaraki³, L. Ruiz-Rubio^{1,4}, S. Lancers-Mendez^{1,5}

¹BCMaterials, Basque Center for Materials, Applications and Nanostructures, UPV/EHU Science Park, 48940, Leioa, Spain

²Graphenea SA, Mikeletegi 83, 20009, San Sebastián, Spain

³Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK

⁴Macromolecular Chemistry Group (LQM), Physical Chemistry Department, Faculty of Science and Technology, University of the Basque Country, 48940, Leioa, Spain

⁵IKERBASQUE, Basque Foundation for Science, 48013, Bilbao, Spain

Abstract: There is significant concern regarding the widespread water contamination and a high demand for advanced methods to remediate it. The global crisis of pesticide-laden water is a growing concern, as these chemicals threaten both human health and ecosystem biodiversity. This study develops graphene oxide-based composite membranes using different strategies for the adsorption of thiacloprid (THI) from wastewater. The membranes were prepared via thermal-induced phase separation (TIPS) and salt leaching (SL), using poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) and graphene oxide (GO). GO proved to be an effective and fast adsorbent, reaching an adsorption capacity of 35.7 mg/g after only 3 min. Composite membranes prepared using SL exhibited superior porosity, hydrophilicity, and availability of active sites, achieving the highest THI adsorption capacity (84.6 mg/g after 45 min). The composite membranes also demonstrated high efficiency under real-world scenarios, being effective on removing THI from both surface and groundwater effluents, as well as consistent performance over multiple cycles. Furthermore, the adsorption mechanism was elucidated by confirming hydrogen bonding as the driving force contributing to the adsorption process. These findings highlight the suitability of GO-based membranes for water purification, offering robust performance under real-world environmentally relevant conditions, making them suitable for advanced water treatment technologies.

STEROPE PROJECT: MEMBRANE CONTACTORS FOR CO₂ CAPTURE USING AQUEOUS PIPERAZINE SOLUTIONS

M. Pagliero^{1,2}, T. Rubattu^{1,2}, M. Traverso¹, A. Iebole^{1,2}, I. Rizzardi^{1,2}, A. Comite^{1,2}

¹Department of Chemistry and Industrial Chemistry, University of Genoa, Via Dodecaneso 31, 16146, Genoa, Italy

²National Interuniversity Consortium of Materials Science and Technology (INSTM), Research Unit of Genoa, Via Dodecaneso 31, 16146, Genoa, Italy

Abstract: The steady increase in global emissions of CO₂ and greenhouse gases in general has become a topic of discussion within the international community in recent years due to the long-term negative effects that will arise if action is not taken as soon as possible. The study and development of CO₂ capture technologies is playing an increasingly central role in the containment of emissions primarily from energy and industrial plants, where carbon dioxide is generated in large quantities ¹. In this context, the EU-funded Horizon Europe project STEROPE (Grant Agreement No. 101235659) aims to address decarbonisation challenges by demonstrating integrated and sustainable value chains for advanced renewable fuels based on innovative carbon capture and utilisation (CCU) technologies ².

This work is focused on studying CO₂ absorption performance using a membrane contactor and aqueous piperazine solutions.

First, the absorption performance in a batch stirred reactor was assessed, varying the operating conditions such as the absorbent solution concentration and the number of fibers in the module.

Secondly, the system was up-scaled to simulate the actual operating conditions of a continuous pilot plant, evaluating the effects of the gas and liquid flow rates, of the solution concentration and temperature and of the gas pressure.

An increase in system removal efficiency was observed as the piperazine concentration increased, reaching, in some cases, values approaching 100%.

For the same concentration, using a module with more fibers resulted in an increase in the exchange surface area and gas contact time within the fibers, allowing for higher separation efficiencies.

In the second part of the study, the system was scaled up, moving from a batch reactor to a system with a recirculating flow contactor. In this case, gas-side overpressure improved system performance, due to the increase of CO₂ partial pressure. Moreover, higher liquid flow rates allowed for faster renewal of the solution surrounding the film at the interface, resulting in higher absorption efficiencies.

At higher gas flow the performance of the setup decreased from initial values of 99% to less than 50%, due to the shorter gas contact time within the fibers (Figure 1). However, using integral calculus to find theoretical moles removed, it was observed that the moles of CO₂ absorbed was virtually the same in all tests.

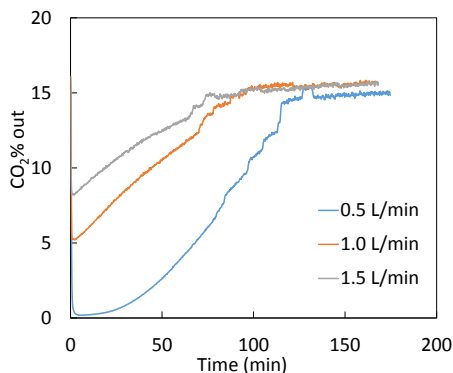


Figure 1: CO₂ concentration profiles in the outlet gas at different gas flow rates.

Using larger volume of absorbent solution and higher piperazine concentration improved the system absorption capacity, due to the increased availability of amine with which the CO₂ can react and, calculating the theoretical moles removed, it was observed that the number of moles of CO₂ absorbed increased linearly with the solution volume.

The analysis of the effect of the solution temperature on the absorption process provided very important results. Specifically, above a critical temperature, membrane flooding occurred, causing a sudden absorption efficiency loss (Figure 2).

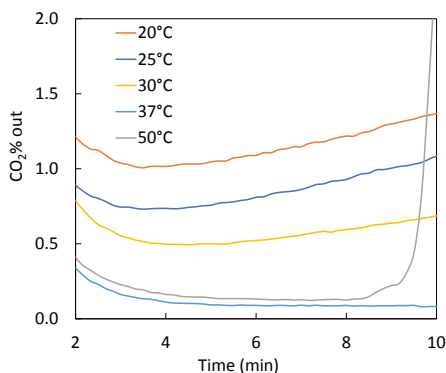


Figure 2: CO₂ concentration profiles in the outlet gas at different absorption solution temperatures.

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A DEEP INVESTION ON POLYMERIZABLE IONIC LIQUID AS BUILDING BLOCK OF ION-CONDUCTIVE MEMBRANES

S. Palermo¹, D. Talarico¹, F. Galiano¹, G. Di Profio¹, R. Mancuso², L. Guazzelli³, C. S. Pomelli³, B. Gabriele², A. Figoli¹, E. Fontananova¹

¹Institute of Membrane Technology “Enrico Drioli”- National Research Council (ITM-CNR), Rende (CS), Italy

²Laboratory of Industrial and Synthetic organic Chemistry (LISOC), Department of Chemistry and Chemical Technologies, University of Calabria, Rende (CS), Italy

³Department of Pharmacy, University of Pisa, Pisa, Italy

Abstract: Polymerizable ionic liquids (PILs) are a special category of ionic liquid containing at least one polymerizable functional group. PILs emerging as promising materials for the preparation of ion-exchange membranes due to their tunable chemical structure and ability to combine the unique physicochemical properties of ionic liquids with the mechanical stability of polymer networks.^{1,2}

In this work, ion-exchange membranes were fabricated through UV-induced photopolymerization of a PIL in combination with an acrylic monomer and a crosslinking agent.

The proposed approach provides a simple and versatile route for the preparation of functional membranes with tunable ionic transport properties. A series of membranes containing different amounts of polymerizable ionic liquid with respect the co-acrylic monomer, was prepared to investigate the influence of casting solution composition on electrochemical properties (e.g., conductivity and permselectivity). Particular attention was devoted to understanding the relationship between ionic liquid content, membrane wateruptake and ion transport properties.

Preliminary results revealed a marked dependence of membrane swelling on ionic liquid loading, indicating that the concentration and chemistry of ionic moieties strongly influences membrane hydration and network organization. The observed trend suggests that optimization of the polymerizable ionic liquid content may represent an effective strategy for balancing electrochemical performance and durability.

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This work has received funding from the Italian Ministry of Environment and Energetic Security (MASE) in the framework of the project System Research - Frontier materials for energy uses (PTR_25_27_CNR_1_4)..

CATALYTIC MIXED-MATRIX MEMBRANES EMBEDDING FEZNCUK OXIDES FOR MILD CO₂-TO- HYDROCARBONS CONVERSION

F. Panagini^{1,2}, M. Cavallo¹, A. Porta³, B. Rolandi³, C. Larghi³, M. Vaccaro⁴, C. Rizzuto⁴, A. Fuoco⁴, H.G. Baldovi⁵, S. Bordiga¹, V. Crocellà¹, M. Signorelli¹

¹University of Turin, Department of Chemistry, NIS and INSTM Via Gioacchino Quarello 15, Turin, Italy (matteo.signorile@unito.it)

²University of Perugia, Department of Chemistry, Biology and Biotechnology, Via dell'Elce di Sotto, Perugia, Italy

³Politecnico di Milano, Department of Energy, via La Masa 34, Milano, Italy

⁴Institute on Membrane Technology (CNR-ITM), via P. Bucci 17/C, Rende, Italy

⁵Universitat Politècnica de València, Departamento de Química, Camino de Vera s/n, Valencia, Spain

Abstract: The increase in the concentration of greenhouse gases, mainly CO₂, observed over the last 60 years has become a major concern, as it has contributed significantly to the global warming phenomenon. A possible strategy to mitigate this issue is the capture and sequestration of atmospheric CO₂ through a Carbon Capture and Utilization (CCU) approach, which converts CO₂ into value-added products such as chemicals and renewable fuels.¹ However, the low concentration of CO₂ in diluted streams (e.g., flue gas or biomethane) remains a significant limitation to the direct implementation of conversion processes at emission sources, as isolating CO₂ from other gas-phase components, which may negatively affect the reaction, requires a dedicated capture/separation stage upstream of the conversion unit. Integrating CO₂ separation and subsequent conversion within a single device would therefore be highly desirable to improve process efficiency and reduce energy demand. This is the key concept underlying the DAM4CO2 project,² which aims at developing a dual-active membrane (DAM) that performs both CO₂ separation and its conversion on the permeate side by a dedicated catalytic process. This contribution will focus on the development of the conversion function of the DAM, highlighting the major difficulties found in promoting catalytic CO₂ upgrade to hydrocarbons in conditions suitable for overall functioning of the whole technology.

Focusing on the conversion function, in order to sustain a sufficiently selective and energy-efficient CO₂ separation, the catalytic conversion process is forced to take place at significantly milder conditions (in terms of temperature and pressure) than typically used in standard operation. To circumvent such limitation, DAM4CO2 exploits a combined thermal- and photo-induced CO₂ reduction, taking advantage of convenient photochemical paths, potentially enabling lower working temperatures. Among possible candidates fulfilling the strict project requirements, a very promising catalyst is a mixed FeZnCuK oxide, whose performances in purely

thermal Reverse Water-Gas shift (RWGS) and Fischer-Tropsch synthesis (FTS) cascade reactions for CO₂ upgrade has been demonstrated previously (Figure 1).^{3,4} Since temperatures of at least 200-250 °C are required to achieve significant levels of conversion, the choice of the polymeric matrices was driven by thermal stability performances. Upon several trials, we selected BTFMA-DPE, a newly developed polymer of intrinsic microporosity,⁵ as the optimal matrix. Interestingly, the activity of the catalyst largely depends on its preactivation, affecting both overall activity and products selectivity. Preliminary tests under sunlike irradiation also shows an incremental effect on products yield, in particular boosting the RWGS step. Still, once embedded in the matrix, the catalyst exhibits lower productivity with respect to the bare powder form, in particular concerning the FTS stage. The reasons for this lower productivity and strategies implemented to circumvent it will be discussed.

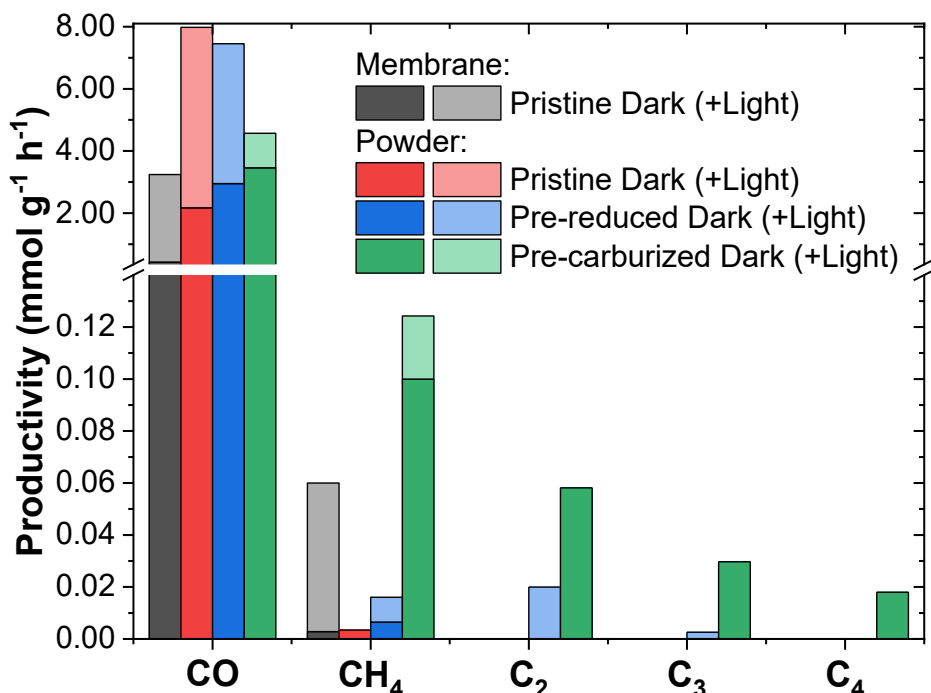


Figure 1. Productivity for main products of cascade RWGS and FTS on FeZnCuK, in powder form (including different pretreatments) and embedded in a membrane.

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CAN FLUX INTENSIFICATION REDUCE ENERGY CONSUMPTION? INSIGHTS FROM OSCILLATORY MEMBRANE DISTILLATION FOR INDUSTRIAL WATER REUSE

M. F. Pane¹, H. E. Qaissoumi¹, L. Sullmann¹, C. Jeges¹, C. Hoefer¹, R. Pfeiffer¹, M. Harasek², B. Muster-Slawitsch¹

¹Water & Process Technologies Research Group, AEE – Institute for Sustainable Technologies, Feldgasse 19, 8200 Gleisdorf, Austria (m.pane@aee.at)

²Circular Bioeconomy and Biorefineries Research Group, Institute of Chemical, Environmental and Bioscience Engineering, TU Wien, 1060 Vienna, Austria

1. Background

Membrane distillation (MD) is a thermally driven separation process with strong potential for industrial water reuse and resource recovery due to its ability to utilize low-grade heat and achieve near-complete rejection of non-volatile compounds. However, its industrial implementation is limited by temperature polarization, membrane fouling, and relatively high specific energy consumption (SEC), primarily governed by thermal energy input [1]. Oscillatory-enhanced MD (OMD) addresses these limitations by superimposing controlled oscillatory flow on the feed stream, enhancing near-membrane mixing, reducing boundary-layer resistance, and improving heat and mass transfer without increasing net recirculation rates.

2. Methodology

Experiments were performed in a laboratory-scale OMD system equipped with a baffled module containing hydrophobic polypropylene hollow-fiber membranes (3M®). The system operated with temperature-controlled loops at 60 °C (feed) and 20 °C (permeate), while oscillatory flow was generated via a piston-driven mechanism superimposed on the feed circulation.

Three feed streams were tested: deionized water (DI-water), pulp and paper (P&P) effluent, and steel industry effluent. Performance was assessed via gravimetric transmembrane flux measurements, alongside continuous monitoring of pressure, temperature, pH, and conductivity. Hydrodynamic conditions were characterized using the oscillatory Reynolds number.

The study evaluates the coupling between oscillatory hydrodynamics, membrane performance, and energy demand, targeting operating conditions that maximize flux enhancement while minimizing SEC.

3. Results

Within the Horizon Europe project *CORNERSTONE*, OMD was applied to industrial streams from the P&P and steel sectors, achieving up to 52% higher transmembrane flux compared to conventional (non-oscillatory) MD operation for wastewaters.

The highest performance was obtained at 12.5 mm amplitude and 2 Hz frequency, corresponding to elevated oscillatory Reynolds numbers, reaching $\sim 3.9 \text{ kg} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ under identical operating conditions (Figure 1).

For DI-water, flux increased consistently with oscillatory Reynolds number, whereas industrial effluents showed a more complex response, highlighting a strong influence of feed composition on process performance. In particular, P&P effluent exhibited similar fluxes at low ($Re_{os,n} = 4386$) and high ($Re_{os,n} = 9138$) oscillatory conditions, indicating that comparable performance can be achieved without increasing oscillation intensity, with potential benefits for reducing SEC.

Despite significant flux enhancement, the impact of oscillatory operation on energy efficiency remains insufficiently quantified. While mixing improvements enhance mass transfer, they come at the cost of additional energy input for oscillation generation, making the net effect on SEC unclear.

Ongoing work addresses this trade-off by coupling hydrodynamic optimization with power consumption analysis [2], aiming to identify operating windows that maximize flux while minimizing SEC through optimized oscillatory parameters and reduced net circulation requirements.

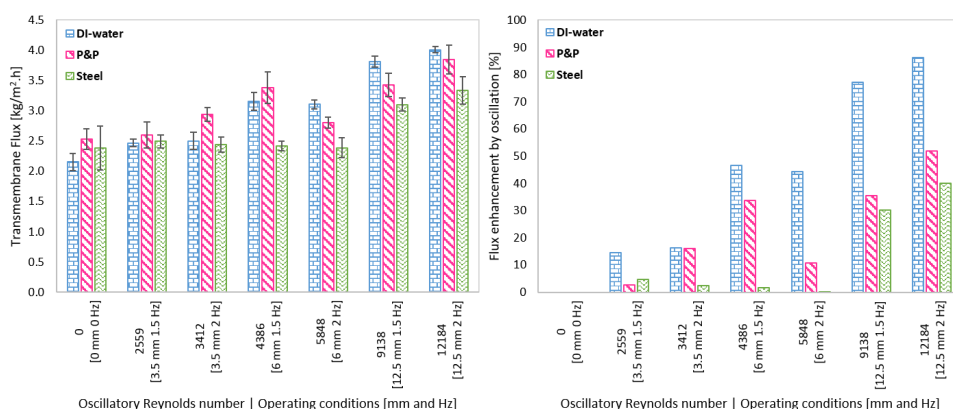


Figure 1. Transmembrane flux (left) and flux enhancement induced by oscillation (right) as a function of the oscillatory Reynolds number, primarily varied through changes in oscillation amplitude and frequency during OMD treatment of industrial process waters. Experimental conditions: feed flow rate = 3.02 L min^{-1} , permeate flow rate = 0.15 L min^{-1} . Source: AEE INTEC (2025, unpublished).

4. Expected Impact

This study aims to determine whether hydrodynamic intensification through oscillatory flow can simultaneously enhance membrane performance and enable

operation at reduced temperature differences, thereby contributing to lower SEC. By linking flux enhancement with energy efficiency, the work seeks to provide a stronger basis for industrial implementation of membrane distillation in water reuse and resource recovery applications. The latest results from the ongoing optimization campaign and SEC assessment will be presented at the conference.

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MODULATING PORE SIZE OF POLYSULFONE ULTRAFILTRATION MEMBRANES THROUGH SURFACTANT-ASSISTED NONSOLVENT-INDUCED PHASE SEPARATION

F. Passaro¹, M. Pagliero^{1,2}, K. Plakas³, S. Patsios³, G. Penloglou^{3,4}, A. Comite^{1,2}

¹Department of Chemistry and Industrial Chemistry, University of Genoa, Genoa, Italy
(francesca.passaro@edu.unige.it)

²INSTM - National Interuniversity Consortium of Materials Science and Technology, RU of Genoa, Florence, Italy

³Centre for Research and Technology Hellas (CERTH), Chemical Process and Energy Resources Institute (CPERI), Thessaloniki, Greece

⁴Department of Environmental Engineering, School of Engineering, International Hellenic University (IHU), Sindos, Thessaloniki, Greece

Abstract: Polysulfone (PSU) membranes are widely used in ultrafiltration and gas separation because of their chemical and thermal stability and good mechanical properties. However, their permeability and pure water flux can be low, which limits their application. The standard technique used to create through-pores is a nonsolvent-induced phase separation (NIPS) of a polymer solution, in which the polymer-rich phase forms the membrane matrix, and the polymer-poor phase forms the pores. To increase pore size and membrane permeability, a modified NIPS method (surfactant-assisted NIPS, SA-NIPS) can be applied by adding a surfactant to an aqueous nonsolvent bath¹ to enhance the pore-forming effect of additives such as polyethylene glycol (PEG). Surfactants are already well known for their ability to increase membrane porosity; however they are commonly used as an additive for polymer solution rather than for the coagulation bath².

In this work, novel hydrophilic PSU membranes were prepared by phase inversion of a solution of PSU in dimethylacetamide (DMAc), using PEG ($M_w=1000$ Da) as an additive. Precipitation was carried out in an aqueous medium, containing different concentrations of sodium dodecyl sulphate (SDS). The resulting membranes were characterized by liquid-liquid displacement porometry (LLDP), their surfaces and cross-sections were examined with a field-emission scanning electron microscope (FESEM), and their surface compositions were analysed by Fourier transform infrared spectroscopy (FTIR). Membrane performance was evaluated in a dead-end ultrafiltration setup, in terms of pure water permeability (PWP) and rejection of a globular protein, bovine serum albumin (BSA).

The addition of SDS increased the mean pore size of the membranes – up to 130 nm when a 2 wt% SDS solution was used as the coagulation bath, compared with samples prepared using pure water, which had a mean pore size of 15 nm (Figure 1). This

increase in pore size could enable a broader range of applications for PSU membranes, from tight microfiltration to ultrafiltration.

Even the permeability (Figure 2), expressed as the slope of permeate flux versus transmembrane pressure, increased as the SDS concentration in the coagulation bath was raised. In fact, the permeability of the membranes prepared in water was too low to be shown in the Figure, and this type of membrane was prone to compaction, producing almost no flux at pressures higher than 1.5 bar.

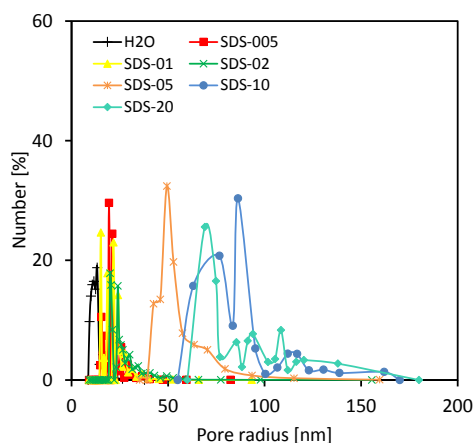


Figure 11: Pore size distributions for membranes prepared by the SA-NIPS procedure.

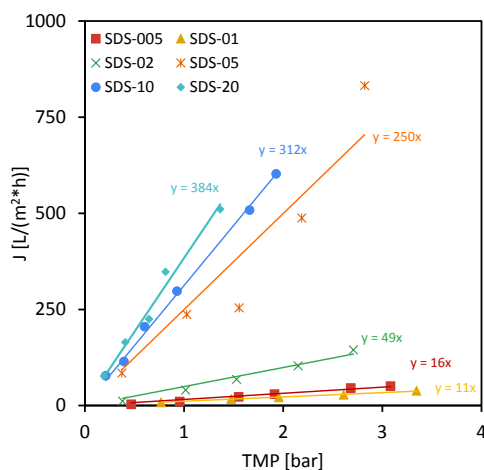
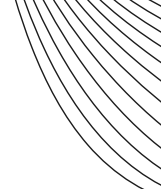


Figure 12: Permeability of membranes prepared with different SDS concentrations in the coagulation bath, in terms of permeate flux and relative transmembrane pressure.

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GMT'S COMPOSITE MEMBRANES FOR SUSTAINABLE INDUSTRIAL SEPARATION

K.-V. Peinemann, H. Taghavian

GMT Membrantechnik GmbH, 79618 Rheinfelden (Baden), Germany

Abstract: GMT Membrantechnik, founded in 1995 in Rheinfelden, Germany, and now part of the Borsig Group, is a leading developer and manufacturer of membranes and membrane modules for gas and organic vapor separation. GMT membrane modules operate worldwide in hundreds of industrial-scale plants, enabling the recovery of harmful or valuable components from industrial process streams and off-gases. Emerging applications such as carbon capture and organic solvent nanofiltration further expand the scope of these technologies, and selected examples will be presented. In this context we will discuss the major hurdles for the transfer of academic membrane research to large scale industrial membrane production. In addition, insights into GMT membrane design and transport mechanisms will be given. Nearly all GMT membranes possess a composite structure with to up to 5 layers. While composite membranes are widely used in industry, their transport behavior can exhibit strikingly counterintuitive features. Contrary to conventional intuition, the introduction of an additional resistance layer into a two-layer membrane can, under specific conditions, *increase* rather than decrease the overall permeation flux of the resulting three-layer system. This phenomenon is essential for the superior performance of many GMT membranes.

RUBIDIUM CHLORIDE RECOVERY BY VACUUM MEMBRANE CRYSTALLIZATION: MOLECULAR-LEVEL INSIGHTS INTO A DUAL-CONFIGURATION SYSTEM

P. Perri^{1,2,*}, G. Prenesti³, E. Tocci², F. Macedonio², A. Caravella¹

¹Department of Computer Engineering, Modelling, Electronics and Systems Engineering (DIMES), University of Calabria, Via P. Bucci, Cubo 42/A, 87036 Rende (CS), Italy

²Institute on Membrane Technology “Enrico Drioli”, National Research Council of Italy (CNR-ITM), c/o University of Calabria, Via P. Bucci 17/C, 87036 Rende, CS, Italy

³Institute of Advanced Membrane Technology, Karlsruhe Institute of Technology, KIT Campus North, Building 352, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Abstract: Rubidium is an increasingly strategic alkali metal owing to its relevance in high-value technological applications, including atomic clocks, quantum technologies, biomedical imaging, and specialty glasses. Its technological importance, however, contrasts with its scarcity and supply sensitivity, as rubidium rarely occurs in economically viable concentrations and is not currently extracted from dedicated primary mines.¹ Since its production largely relies on by-product recovery from lithium-related processes, often within geographically concentrated supply chains, rubidium remains vulnerable to price instability and potential supply disruptions. In this context, recovering rubidium from secondary liquid streams represents a sustainable strategy to ensure the availability of this valuable metal while improving water and resource management and reducing the environmental and economic burdens associated with increasingly complex primary extraction routes.²

Vacuum membrane crystallization (V-MCr) is particularly attractive for this purpose, as it combines selective solvent removal with controlled supersaturation generation under mild operating conditions.³ However, the extent to which supersaturation level and membrane–solution interactions affect RbCl nucleation kinetics and crystal-growth pathways remains insufficiently understood. Clarifying this relationship is essential to develop membrane crystallization not only as a recovery operation, but also as a tuneable platform for controlling crystal formation.

This work investigates the recovery of rubidium chloride (RbCl) from aqueous solutions through an integrated experimental and molecular-simulation approach. Lab-scale V-MCr experiments were carried out using two different plant configurations, namely single-pass and double-pass operation, designed to distinguish membrane-assisted solvent removal from cooling-induced supersaturation effects. These configurations enabled the comparison of different crystallization environments, including membrane-assisted and bulk-like crystallization conditions. The differences observed between the two configurations in terms of permeate flux, crystallization onset, crystal population, morphology,

and crystal-size distribution raised the question of whether RbCl nucleation and crystal-growth kinetics are governed solely by supersaturation or may also be influenced by the presence of the membrane interface.⁴

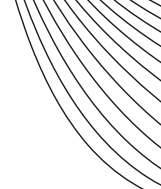
From an atomistic perspective, molecular dynamics (MD) simulations were performed on both bulk and membrane-containing RbCl aqueous systems, reproducing the crystallization conditions investigated at the lab scale. This allowed us to assess whether the polymeric interface and different supersaturation regimes modify local ion organization, nucleation kinetics, and crystal-growth pathways. The crystallization process was further investigated using a combination of collective variables (CVs), Markov State Models (MSM), and DBSCAN clustering to characterize the underlying nucleation and growth mechanisms. By projecting the molecular trajectories from the time domain into a collective-variable space specifically designed to describe ion aggregation and crystalline ordering, it was possible to identify solid-like clusters, estimate characteristic transition times, reconstruct preferential crystallization pathways, and describe the associated free-energy landscape.

Experimentally, the double-pass configuration enhanced water removal, increasing the average permeate flux from 1.05 to 1.92 L m⁻² h⁻¹ while maintaining salt rejection close to 99.98%. It also promoted earlier crystallization, with crystals appearing after 0.5–1 h instead of 2–6 h in the single-pass configuration. However, faster supersaturation generation produced smaller and more heterogeneous crystals, as reflected by the lower PD₅₀ of the double-pass system, 51.59 ± 19.50 μm versus 81.80 ± 4.48 μm, and by its higher coefficient of variation, 67.76 ± 9.03% versus 47.88 ± 3.93%. At the molecular scale, DBSCAN and MSM analysis of bulk RbCl simulations revealed progressive ion-aggregate growth and dominant transitions between metastable states, indicating a predominantly one-step crystallization mechanism with no clear evidence of long-lived pre-nucleation clusters within the explored supersaturation range. These results provide a reference framework to assess whether the polymeric membrane interface can further affect local ion organization, nucleation kinetics, and crystal-growth pathways.

This multiscale perspective highlights membrane crystallization not only as a recovery process, but as a tuneable platform to control rubidium nucleation, growth, and selective extraction from secondary liquid streams.

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POLYMER MEMBRANES FOR DIAPER SOILING DETECTORS

Z. Pientka¹, L. Brožová¹, M. Otmar¹, L. Kubáč², J. Pařízek², J. Pfleger¹

¹Institute of Macromolecular Chemistry, Academy of Sciences of the Czech Republic, Heyrovský Sq. 2, Prague, Czech Republic (www.imc.cas.cz)

²Centre for Organic Chemistry, Rybitvi, Czech Republic

Abstract: Driven by global population aging, the demand for effective home and aftercare solutions for dependent individuals is rising rapidly. Telemedicine, particularly through wireless monitoring devices, offers a promising framework to support these healthcare services. This study introduces newly developed sensors designed to simultaneously detect urine saturation and fecal soiling in adult diapers. The operational principle relies on a functional polymer membrane engineered to selectively sorb specific fecal components. Unlike urine, feces contain target analytes such as short-chain and long-chain fatty acids, their corresponding salts, and related lipid derivatives.

The wireless detector utilizes an RLC resonant circuit comprising a planar coil integrated into the membrane and/or a resistive elongation sensor (Fig. 1). Analytes sorption induces membrane swelling, which alters the parameters of the resonant circuit. These electromechanical changes can be monitored remotely using a radio-frequency tracker, enabling non-invasive, real-time indication of diaper soiling.

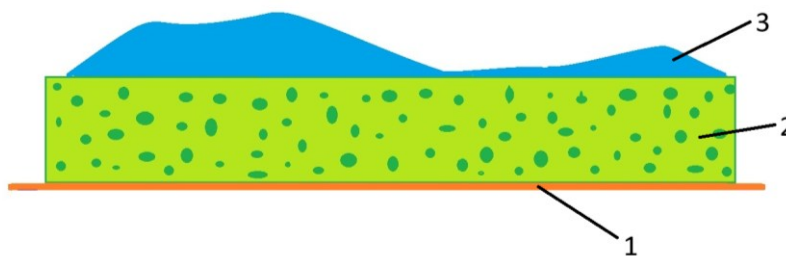


Fig. 1. Schematic of the wireless diaper soiling detector: RLC circuit (1) integrated with the polymer membrane (2) for analyte (3) sensing.

Suitable membrane materials must exhibit sufficient sorption affinity and capacity for the targeted analyte components. Presented high-performance membranes utilize a poly(styrene-*block*-ethylene-*ran*-butylene-*block*-styrene) (PSEBS) copolymer backbone. For these purposes, PSEBS functionalized with tertiary amine group bearing carbohydrate moiety (meglumine) proves highly effective (Fig. 2). This framework enables a dual interaction mechanism: fatty acids bind specifically to amine-functionalized styrene domains via electrostatic attraction, while simultaneously engaging with the ethylene-butylene segments through hydrophobic interactions. Consequently, the membrane swells significantly more in the presence

of feces than in urine. A comparison of the sensing performance among the various investigated membrane materials is illustrated in Fig. 3.

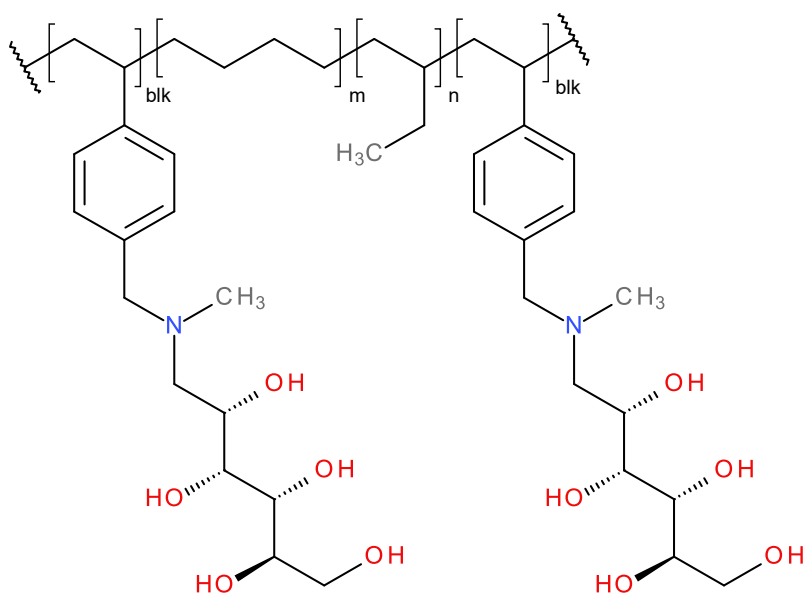


Fig.2. Structure of meglumine functionalized PSEBS.

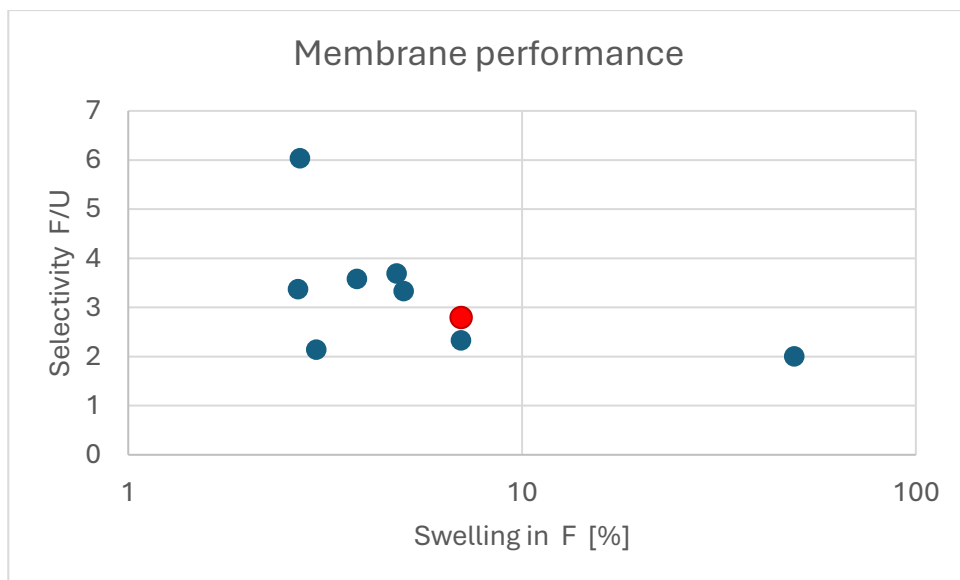


Fig. 3. Sensing performance of various investigated membrane materials: Each data point represents an individual material formulation. The red point is for meglumine functionalized PSEBS. (F: feces, U: urine).

This research was carried out with the financial support of the Czech Republic's Center of Competence Program, project FEIM TN02000067, DP15.

MOLECULAR INSIGHTS INTO LiCl ADSORPTION AT POLYMER INTERFACES: A COMPARATIVE STUDY OF PVDF AND PP MEMBRANES

G. Prenesti^{1,2,*}, M. Paloni³, A. Cassano², A. Caravella¹, M. Salvalaglio³, E. Tocci²

¹Department of Computer Engineering, Modelling, Electronics and System Engineering (DIMES), University of Calabria, Via P. Bucci 42C, 87036 Rende (CS), Italy

²Institute on Membrane Technology–National Research Council of Italy (CNR-ITM), Via P. Bucci 17C, 87036 Rende (CS), Italy

³Thomas Young Centre and Department of Chemical Engineering, University College London, London WC1E 7JE, United Kingdom

*Current address: Institute of Advanced Membrane Technology, Karlsruhe Institute of Technology, KIT Campus North, Building 352, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany (giuseppe.prenesti@kit.edu)

Abstract: Brine valorisation and the recovery of valuable resources are key challenges for achieving sustainable desalination processes, while simultaneously offering significant opportunities for the development of circular economy strategies [1]. Among the emerging technologies, membrane distillation–crystallization (MD-MCr) has emerged as a promising approach for the integrated recovery of freshwater and high-value salts from saline streams and industrial effluents [2]. Membranes enable selective separation and controlled environment through molecular-level interactions, making the choice of material crucial for both efficiency and product quality. Polymer–solute interactions, however, can play a dual role: they can either promote crystallization or negatively affect the process by inducing membrane wetting and structural degradation. This behavior is particularly well illustrated by PVDF membranes, whose chemical interactions with LiCl have been reported to promote wetting and structural deterioration, as demonstrated by FTIR and Raman analyses [3], in contrast to PP membranes, which show a higher resistance to wetting and preserve their structural integrity, thereby supporting LiCl membrane-assisted crystallization.

To resolve the molecular origin of these contrasting behaviours, we employ constant chemical potential molecular dynamics simulations (C μ MD) to probe the early-stage interfacial phenomena occurring between LiCl solutions and PVDF or PP membranes. Unlike conventional MD, where the bulk progressively depletes as ions adsorb at the interface, C μ MD keeps the bulk concentration, and hence the chemical potential, constant throughout the run, so that adsorption is studied under a stable, well-defined thermodynamic driving force [4,5].

This concentration control is achieved by applying forces to the ions within a defined region of the simulation box, called control region (CR), which acts as a reservoir, effectively driving them in or out to maintain the desired target concentration. The

simulations were performed using GROMACS 2024.3 coupled with PLUMED 2.9.4, with ten independent simulations per polymer, each one at a different bulk concentration. The simulation setup is illustrated in Figure 1.

The results clearly highlight the distinct chemical nature of PVDF and PP in contact with LiCl solutions across different concentrations. PVDF exhibits stronger interactions with the electrolyte, whereas PP behaves in a more inert manner. Ion concentration profiles are similar for both species, showing a pronounced peak near the membrane surface and indicating no preferential ion adsorption. For PVDF, the peak intensity increases with bulk concentration, while it remains essentially constant for PP. The adsorption isotherms and the concentration-dependent adsorption energy barrier consistently confirm the higher affinity of PVDF for LiCl. RMSD analysis indicates that PVDF, although intrinsically more flexible, is constrained by the surrounding ionic environment.

Overall, this study provides new insights into the early stages of interfacial phenomena in membrane-assisted crystallization. These findings are essential for the quantitative characterization of polymer–solute interactions and may guide the selection and design of membranes to optimize nucleation and crystal growth.

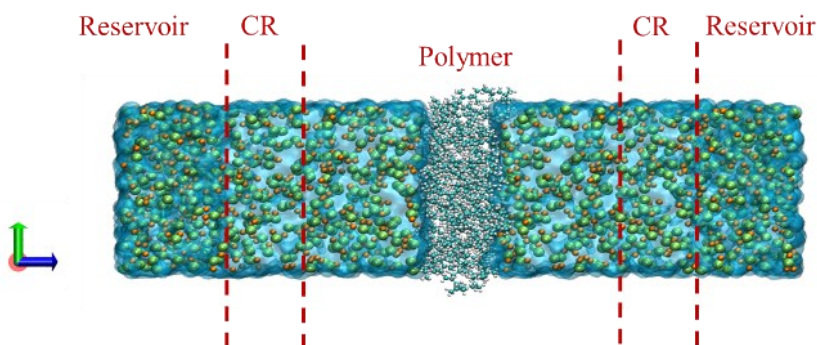


Figure 1: Simulation set-up (Readapted from[6].

Acknowledgements: This work was funded by the Next Generation EU - Italian NRRP, Mission 4, Component 2, Investment 1.5, call for the creation and strengthening of 'Innovation Ecosystems', building 'Territorial R&D Leaders' (Directorial Decree n. 2021/3277) - project Tech4You - Technologies for climate change adaptation and quality of life improvement, n. ECS0000009.

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CONDUCTIVE CARBON-BASED DUAL-LAYER FIBRE FOR ENHANCED ANAEROBIC DIGESTION OF PALM OIL MILL EFFLUENT

M. H. Puteh^{1,2}, A. A. Alkhadi^{1,4}, M. H. D. Othman^{1,3}, M. F. Abdul-Wahab⁴, J. Jaafar^{1,3}, M. A. Rahman^{1,3}, N. Z. Ramly⁵

¹Advanced Membrane Technology Research Centre, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

²Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

³Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

⁴Faculty of Science, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

⁵Faculty of Science and Technology, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia

Abstract: Palm oil mill effluent (POME) is a high-strength wastewater with significant potential for renewable energy recovery through anaerobic digestion (AD). However, conventional AD systems are limited by slow microbial electron transfer and low methane (CH₄) yield. Conductive materials have emerged as a promising solution to enhance direct interspecies electron transfer (DIET), thereby improving methanogenesis. This study introduces a conductive carbon-based dual-layer fibre (CBDLF) as a novel medium to enhance AD performance for POME treatment. CBDLF was fabricated using a phase inversion-based co-extrusion technique, incorporating empty fruit bunch (EFB) biochar and polyaniline (PANI) into a polysulfone matrix to form a dual-layer structure. Fibres were produced at varying outer extrusion rates (OER: 5, 10, and 15 mL/min) to control thickness and morphology. Batch anaerobic digestion experiments were conducted under mesophilic conditions (37°C) using serum bottles over 60 days. Methane production was measured using gas chromatography, while fibre morphology, conductivity, and mechanical strength were analysed using SEM, potentiostat, and tensile testing. The CBDLF exhibited a unique star-like porous structure that enhanced microbial colonisation and electron transfer. The fibre fabricated at 5 mL/min OER showed the highest conductivity (1.41×10^{-3} S/m after AD) and superior mechanical stability. This condition achieved the highest methane yield of 133.84 mL CH₄/g VS, significantly outperforming the control (21.81 mL CH₄/g VS). Higher OER values resulted in denser fibre structures, reducing conductivity and performance. COD removal efficiency was also improved, reaching 60.13% compared to 40.75% in the control. The enhanced performance is attributed to improved DIET, increased surface area for microbial attachment, and better substrate diffusion. This study demonstrates that CBDLF is an effective conductive medium for enhancing anaerobic digestion of POME. The optimised fibre structure significantly improves methane production, COD removal, and system stability. Fibre thickness plays a critical role in balancing conductivity, porosity, and mechanical integrity. The findings highlight the potential

of engineered conductive fibres as a scalable and sustainable strategy for improving biogas recovery and advancing waste-to-energy applications in the palm oil industry.

NANOFILTRATION FOR THE TREATMENT OF BLEACHING EFFLUENTS FROM THE PULP AND PAPER INDUSTRY: A CASE STUDY

A. Ronca^{*}, C. F. Galinha, J. G. Crespo

LAQV-REQUIMTE, DQ, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal

Abstract: The pulp and paper industry is among the most water-demanding industrial sectors, producing large quantities of highly contaminated effluents^{1,2}. In particular, the effluent from the bleaching stage is characterized by extreme pH values and high concentration of compounds containing chlorine, some of which are toxic to humans and the aquatic environment (e.g. chlorophenols, AOX, polychlorinated dibenzodioxins)³. In the context of increasing environmental constraints and the transition towards circular water use, it is essential the development of efficient wastewater treatment and reuse technologies. This study investigates the feasibility of applying nanofiltration (NF) for the treatment of bleaching effluent from a Portuguese pulp and paper industry, aiming to reuse the treated water within the process. Experiments were conducted at laboratory scale using real industrial wastewater and three different commercial NF membranes (NF-DK, NF-90 and NF-270). The performance of each membrane was evaluated in terms of hydraulic behaviour, permeate quality, pollutant rejection, fouling phenomena, and the influence of osmotic pressure under increasing concentration conditions.

The results demonstrated that NF can significantly reduce the organic load and conductivity of the effluent, leading to a permeate that could be considered for internal reuse applications within the industrial process. Nevertheless, membrane performance was strongly influenced by fouling, which led to flux decline over time and affected overall process efficiency. Additionally, complex interactions between solute rejection, concentration polarization, and operating conditions were observed, highlighting the importance of process optimization. To address these limitations, a two-stage hybrid configuration was also considered, combining NF-270 and NF-90. This configuration showed potential improvements in stability and overall performance. Finally, a preliminary economic assessment indicated that NF-based treatment could be a competitive option when integrated into water reuse strategies, although the optimization of cleaning protocols and fouling control remains crucial for long-term industrial application.

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FERRATE(VI)-BASED PRETREATMENT FOR ENHANCED REVERSE OSMOSIS PERFORMANCE IN SEAWATER DESALINATION

E. Saeбноori, D. Riba Lopez, M. de Vries

Ferr-Tech B.V., Hesselterlandweg 6, 7942 HZ Meppel, the Netherlands

Abstract: Seawater reverse osmosis (SWRO) is the leading desalination technology worldwide; however, membrane fouling remains a major operational challenge. This study investigates the application of Ferrate(VI) solution as an innovative pretreatment technology for seawater desalination. Ferrate(VI) acts simultaneously as a strong oxidant, disinfectant and coagulant, enabling the removal of suspended solids, colloidal matter, organic contaminants and biofouling precursors prior to reverse osmosis. Laboratory-scale investigations were conducted using seawater representative of desalination feed streams. The effects of Ferrate(VI) dosage, both individually and in combination with ferric chloride, were assessed through turbidity reduction and clarification performance. Results demonstrated substantial improvements in feed-water quality, with optimized treatment conditions achieving up to 98–99% turbidity reduction. Furthermore, Ferrate(VI)-based treatment reduced the required dosage of conventional coagulants while maintaining excellent clarification efficiency and generating lower sludge volumes. The multifunctional nature of Ferrate(VI) offers a promising route for mitigating membrane fouling, reducing chemical consumption, and improving the sustainability of seawater reverse osmosis systems.

RATIONAL DESIGN OF DEEP EUTECTIC SOLVENT-MEDIATED MOF-BASED MEMBRANES FOR THE RECOVERY OF PB (II) AND CR (III) IONS TOWARD A CIRCULAR ECONOMY

Saif-ur-Rehman¹, U. Ahmad¹, M. Jamal¹, A. Husain¹, B. Van der Bruggen^{1,2,*}, A. H. Al-Marzouqi³

¹Department of Chemical Engineering, ProcESS-Process Engineering for Sustainable System, KU Leuven, Celestijnenlaan 200F, Leuven B-3001, Belgium (saifurrehman.saifurrehman@kuleuven.be)

²Department of Chemical and Biochemical Engineering, Korea University, 145 Anam-Ro, Sungbuk-Gu, Seoul 02841, Republic of Korea

³Chemical and Petroleum Engineering Department, UAE University, Al Ain, United Arab Emirates

Abstract: The sustainable recovery of high-value metals from wastewater has garnered significant attention in light of the circular economy and environmental preservation. Because of its appealing characteristics, membrane separation technology is essential for the sustainable and effective recovery of valuable metals from wastewater, in contrast to conventional methods, which are chemical- or energy-intensive. In this study, a rational design approach was utilized to synthesize a metal–organic framework (MOF) using a deep eutectic solvent (DES) as a mediating medium to control the reaction of framework formation and particle properties. While DESs have been widely used for the physical modification of materials, their role as a chemically modifying medium during MOF synthesis for structural tailoring remains less explored. This synthesized MOF (DM-Zn-PDC@MOF) was further introduced as filler in polysulfone (PSf)-based mixed matrix membranes (MMMs). The performance of DM-Zn-PDC@MOF within the polymer matrix was examined. Several characterization techniques were used to thoroughly analyze the morphological, chemical, and physical characteristics of the MMMs and DM-Zn-PDC@MOF. The addition of the filler material significantly enhanced the membrane characteristics, including pure water flux, hydrophilicity, porosity, surface roughness, pore size, and heavy metal resource recovery in comparison with the pristine membrane. Stable incorporation of the filler within the membrane matrix was indicated by much less filler leaching (<5%) at all concentrations. With DM-Zn-PDC@MOF loading, the pure water flux increased more than nine times from 102.8 L/m²h (M-0) to 971.5 L/m²h (M-4). The functionalized membranes showed better flux retention in high-value heavy metal resource recovery using simulated wastewater: 871.8 L/m²h when filtering a Pb(II) ion solution (compared to M-0 with flux 120.6 L/m²h) and 526.8 L/m²h when filtering a Cr(III) ion solution (compared to M-0 with flux 97.1 L/m²h). These values represented approximately 7-fold and 5-fold improvements, respectively. Overall, Pb⁺² > Cr⁺³, but the rejection of Cr(III) ions was also improved, when compared with M-0. The high flux of the membrane makes it easier to process large volumes and

concentrate metals in the retentate, turning diluted contaminated streams into a concentrated feedstock for subsequent recovery procedures.

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DECENTRALIZED WATER TREATMENT WITH RENEWABLE ENERGY POWERED NANOFILTRATION OR ELECTRODIALYSIS: TECHNOLOGICAL OPPORTUNITIES AND LIMITATIONS

A. I. Schäfer

Institute for Advanced Membrane Technology (IAMT), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
(Andrea.Iris.Schaefer@kit.edu)

Abstract: As a pressure-driven membrane process, nanofiltration (NF) can achieve varying degrees of selectivity between mono- and multivalent ion rejection. The pressure is provided by an electrical pump that can be coupled directly to renewable energy. In remote areas, this electrical power can be provided by photovoltaics, thus enabling autonomous operation. This enables the implementation of advanced and decentralized technologies¹. Direct coupling of photovoltaics and membrane filtration requires DC pumps and avoids the losses and operational risks of batteries and inverters, while fluctuations in irradiance due to clouds, as well as the position of the sun, disrupt the availability of power. This may result in a reduced transmembrane pressure or pump shutdown.

Such a renewable-energy powered NF system has been used extensively in Central Australia (uranium removal from brackish groundwater)²⁻⁴ and Tanzania (fluoride removal from ground and surface waters)⁵⁻⁸. Due to the relative simplicity of NF process operation and low cost of membranes, NF is a natural first choice for decentralized systems. Challenges occur in terms of the retention of some dissolved species, the limitation by osmotic pressure and concentration polarization, colloidal fouling, the requirement for high-pressure pumps, and the excessive removal of ions that would be beneficial for water quality.

Electrodialysis (ED) may be able to solve some of these challenges, while it adds different challenges. For example, ED enables a controlled reversal for fouling control, has a different mechanism of ion removal and hence can target different salts, while larger molecules are not removed. ED cannot remove pathogens and colloids, which will require a separate treatment process. Perhaps most importantly, ED is a much less adapted process; membranes are significantly more expensive, and hence both costs and operational experience are important. Seeing market uptake rapidly alters actual cost, it is important to understand the advantages of ED for decentralised treatment, and this requires a process comparison. Existing comparative data is limited to salinity and does not consider single-pass process design.

This presentation attempts to compare the performance of an NF system with a 4'' module with a single-pass ED system designed and built by Deukum with a comparable production capacity⁹. The application is in the brackish water range. To enable a reasonably fair comparison, a number of operational parameters were

modulated as a function of salinity. The results are embedded in a 25-year research project focused on the removal of dissolved ions. This experience with NF has highlighted some of the general implementation challenges that will be discussed. Further work will examine the decentralised treatment with single-pass ED to examine specific ion removal from real water, fluctuations, and operational opportunities. The prospects of ED as a suitable technology for such applications will be discussed. The vision of this work is 'I have a dream: safe water for all children'.

A vision with an open invitation to collaborate and advance this global challenge.

Keywords: membrane; nanofiltration; electrodialysis; desalination; solar energy; water quality; drinking water supply

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SYNERGISTIC CARBON-BASED SUPPORTS AND IONIC LIQUIDS IN CTA MEMBRANES FOR ENHANCED CO₂/N₂ SEPARATION

J. Schneider, J. Floreková, S. Kočí, A. Barchánková, K. Friess

Department of Physical Chemistry, University of Chemistry and Technology in Prague, Technická 5, Praha 6 – Dejvice, 16628, Czechia

Abstract: Carbon-based materials have emerged as promising components for advanced gas separation membranes owing to their high flux, processability, and excellent thermal and chemical stability.^[1–3] In this work, we investigate the synergistic incorporation of single-walled carbon nanotubes (CNTs) into cellulose triacetate (CTA) membranes containing high loadings of ionic liquids (ILs) for selective CO₂ separation.

Membranes were prepared by vacuum filtration using CNTs as a porous support, onto which solutions of CTA and either 1-ethyl-3-methylimidazolium dicyanamide ([EMIM][DCA]) or trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl)phosphinate ([P66614][TMPP]) were deposited. The resulting mixed-matrix membrane materials were evaluated by single-gas permeability measurements using an integral permeameter with a constant-volume cell, together with gas sorption measurements using a custom gravimetric sorption apparatus.

CNT–CTA membranes containing more than 50 wt% [EMIM][DCA] showed a pronounced enhancement in both CO₂ permeability and ideal CO₂/N₂ selectivity relative to the corresponding neat materials, exceeding the Robeson 2008 upper bound for the CO₂/N₂ gas pair^[4]. More broadly, [EMIM][DCA]-containing membranes exhibited increasing permeability with increasing IL content while maintaining CO₂/CH₄ selectivity and improving CO₂/N₂ separation performance. In contrast, membranes containing [P66614][TMPP] showed only limited performance enhancement.

Thermal, structural, and compositional characterization was carried out using TGA, DSC, FTIR, XRD, CSI, SEM–EDX, ICP–MS, and CHN analysis. These analyses provided insight into IL loading, distribution, and retention within the membrane matrix, as well as the morphological changes associated with IL incorporation. Overall, the results demonstrate that the combination of CNT-based supports, CTA, and high [EMIM][DCA] loadings offers a promising strategy for designing high-performance membranes for CO₂-selective gas separations.

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MEMBRANE-BASED PURIFICATION OF NISIN: ULTRAFILTRATION OPTIMIZATION FROM LABORATORY TO PILOT SCALE

M. Scrive¹, F. Krier¹, C. Jama², L. Firdaous¹

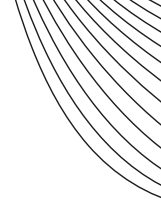
¹UMR Transfrontalière BioEcoAgro N° 1158, Univ. Lille – Institut Charles Viollette, F-59000 Lille, France

²Unité Matériaux et Transformations, École Nationale Supérieure de Chimie de Lille, Avenue Dimitri Mendeleïev – Bât C7a, Villeneuve d'Ascq 59655, France.

Abstract: Nisin is a bacteriocin produced by *Lactococcus lactis*, widely recognized for its thermal stability and broad-spectrum antimicrobial activity against foodborne pathogens. As the only bacteriocin granted GRAS (Generally Recognized As Safe) status by the U.S. FDA and authorized as a food additive (E234), it is extensively used as a natural preservative in the food industry. However, its widespread industrial adoption is hampered by low fermentation yields and costly downstream purification, which conventionally relies on salting-out, solvent extraction, and chromatography. These techniques are characterized by poor recovery rates and limited scalability.

This study investigates membrane-based separation, specifically ultrafiltration (UF), as a cost-effective alternative to improve nisin recovery efficiency. Two objectives were pursued: (1) optimization of UF conditions at laboratory scale using three fermentation media and two polyethersulfone (PES) membranes with distinct molecular weight cut-offs (5 kDa and 10 kDa), and (2) transposition of optimized parameters to pilot scale. Laboratory-scale experiments were conducted using a LabCell system (28 cm²). Three fermentation media were evaluated: MRS (standard reference), a protein-rich medium (CL), and a protein-depleted medium (WP). After fermentation, UF was performed in recirculation mode. Process performance was assessed by measuring nisin content (by HPLC and antimicrobial activity assay), total protein, dry matter content, and membrane fouling. Key parameters such as transmembrane pressure and MWCO were systematically varied to identify optimal conditions, which were then applied in concentration mode, combining ultrafiltration with two sequential diafiltrations. The optimal parameters were 3 bar and 5kDa MWCO. Results demonstrated a significant improvement in nisin purity rising from $0.045 \pm 0.002\%$ to $0.747 \pm 0.132\%$. Membrane fouling was markedly reduced with the whey permeate medium, attributed to its low protein content and reduced formation of nisin–protein aggregates. Flux recovery after cleaning was near-complete. Surface analyses by ATR-FTIR and SEM-EDX confirmed limited adsorption of medium components onto PES membranes, supporting their suitability for this application. Pilot-scale UF experiments are currently underway to assess scalability and further purification performance. Findings will be presented at the conference. This work is part of the NISINNOV project, funded by the French National Research Agency (ANR).

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REDOX-ACTIVE ICOFS ENABLE ULTRA-SELECTIVE COBALT RECOVERY FROM BATTERY WASTE

A. Siekierka¹, P. Ratajczak¹, M. Posadzy¹, D. Minta¹, M. Ulatowska¹, K. Gwóźdź²

¹Department of Process Engineering and Technology of Polymer and Carbon Materials, Faculty of Chemistry, Wrocław University of Science and Technology, Wybrzeże Stanisława Wyspiańskiego 27, 50-370 Wrocław, Poland (anna.siekierka@pwr.edu.pl)

²Department of Experimental Physics, Faculty of Fundamental Problems of Technology, Wrocław University of Science and Technology, Wybrzeże Stanisława Wyspiańskiego 27, 50-370 Wrocław, Poland

Abstract: The rapid expansion of lithium-ion battery technologies has intensified the need for sustainable, energy-efficient recycling strategies that recover critical transition metals from complex waste streams. However, the separation of chemically similar multivalent ions, such as Co^{2+} , Ni^{2+} , and Mn^{2+} , remains a major challenge, limiting the efficiency of current hydrometallurgical recycling routes.

Herein, we present a new electrochemical approach for highly selective cobalt recovery based on redox-active, imide-functionalized ionic covalent organic frameworks (iCOFs) engineered as cathodic materials for Hybrid Capacitive Deionization (HCDI). The proposed iCOFs combine precisely tailored nanochannels with carboxylate ion-exchange networks, enabling controlled electromigration, reversible insertion, and selective release of target cations under low-energy electric fields. Through a customised PDA-IPA solvothermal synthesis, the resulting frameworks exhibit significantly enhanced affinity toward cobalt ions while suppressing the uptake of competing species.

Integration of these materials into HCDI cells resulted in a substantial increase in cobalt recovery efficiency, from approximately 20% for the reference system to 52% for the optimised iCOF electrode. Consequently, the final elemental recovery composition reached an exceptional Co:Ni:Li:Mn ratio of 0.74:0.22:0.02:0.02, corresponding to a 30% increase in cobalt selectivity, a deliberate 15% reduction in nickel co-adsorption, and a 7.5-fold suppression of manganese incorporation. Competitive multi-ion experiments further confirmed the outstanding separation performance, yielding selectivity coefficients of $\beta_{\text{Co/Ni}} = 1.40$, $\beta_{\text{Co/Li}} = 1.15$, and an extraordinary $\beta_{\text{Co/Mn}} > 7.5$. The energy-normalised adsorption capacity reached 1.1 mg/J, while the maximum power density attained 1.52 W/g. Remarkably, the charge efficiency nearly doubled during cycling, increasing from 43.8% in the first cycle to 85.3% after 10 consecutive cycles, with stable pH conditions.

By combining molecular-level framework engineering with high-rate electrochemical separation, this work establishes a scalable platform for low-carbon urban mining and opens a new strategy for electrified recycling technologies to secure critical raw materials for a sustainable energy economy.

Acknowledgements: This research was funded as a whole by the National Science Centre, Poland, Sonata 2022/47/D/ST5/00298.

INFLUENCE OF IONIC STRENGTH ON PICRIC ACID RETENTION BY PSS–PDADMAC POLYELECTROLYTE MEMBRANES

A. Sikach, Kh. Semenyshyn, V. Konovalova

Department of Chemistry, National University of Kyiv-Mohyla Academy, 2 Skovoroda Street, 04070 Kyiv, Ukraine (a.sikatch@ukma.edu.ua)

Abstract: Nitroaromatic compounds belong to the group of hazardous organic contaminants because of their toxicity, persistence, and wide distribution in industrial effluents. Among them, picric acid (2,4,6-trinitrophenol, PA) attracts particular attention as a highly reactive phenolic pollutant that may be present in aqueous environments. Membrane-based methods are considered promising for the removal of phenolic contaminants from water^{1,2}. However, in polyelectrolyte membrane systems, pollutant retention is not determined solely by size exclusion, but may also involve sorption and solute partitioning within the membrane matrix^{3,4}. For PSS–PDADMAC materials, this issue is especially relevant because such systems possess ion-exchange capacity⁵ and are able to incorporate aromatic molecules into the film bulk^{6,7}. Therefore, the contribution of membrane sorption, as well as the effect of water composition and ionic strength remains unclear and poorly quantified.

In this work, PSS–PDADMAC polyelectrolyte membranes prepared via aqueous phase separation were evaluated for picric acid removal from aqueous media. The membrane surface exhibited a homogeneous porous morphology with a network of interconnected open pores and a low root-mean-square roughness ($R_q = 1.94$ nm), indicating a relatively uniform structure. Transport studies performed in a dead-end filtration cell demonstrated efficient picric acid retention, with a rejection coefficient exceeding 90%. Notably, concentration analysis of the bulk solution above the membrane revealed no significant PA accumulation. This anomalous behavior suggests that the retention is governed not only by size exclusion or electrostatic repulsion but is heavily driven by specific membrane–solute interactions. To elucidate the underlying mechanism, complementary sorption experiments were conducted.

The membrane behavior during sorption experiments exhibited a pronounced affinity toward PA accompanied by concentration-dependent yellow coloration (Fig. 1.a). UV–Vis measurements confirmed a gradual decrease in PA concentration during contact with the membrane, indicating uptake of the pollutant by the membrane matrix, with a maximum sorption capacity of $3.2 \pm 0.2 \mu\text{M} \cdot \text{g}^{-1}$. To further investigate the retention mechanism, the influence of ionic strength was studied using NaCl solutions in the concentration range of 100 to 5000 mg/L. Increasing ionic strength resulted in progressively higher residual picric acid concentrations in solution, demonstrating suppression of pollutant uptake by the membrane (Fig. 1.b). The effect became more pronounced at elevated salt concentrations, indicating that membrane–

solute interactions are strongly affected by the ionic composition of the surrounding medium.

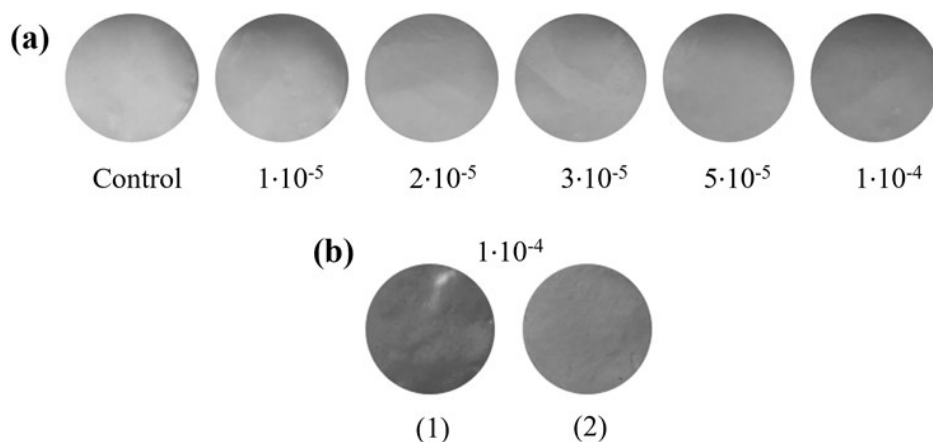


Fig.1. Visual response of PSS–PDADMAC membranes during picric acid (PA) sorption: (a) effect of PA concentration after 15 min of exposure in 5 mL of PA solution; (b) effect of ionic strength on membrane coloration after 24 h of sorption in 20 mL of PA solution: (1) PA solution without NaCl; (2) PA solution containing 5000 mg L⁻¹ NaCl.

The obtained results demonstrate that picric acid retention by PSS–PDADMAC membranes is governed by a sorption-assisted mechanism rather than conventional size exclusion. While the primary electrostatic attraction to the membrane's binding sites is subject to screening by ionic strength, hydrophobic π – π interactions effectively sustain residual PA uptake at high salinity. Understanding these coupled effects provide crucial insights for predicting membrane performance and behavior in realistic, high-salinity water treatment and environmental monitoring scenarios.

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ZIF-11@PEI-PSF MIXED MATRIX MEMBRANES: A NOVEL STRATEGY FOR HIGH-PERFORMANCE CO₂ SEPARATION

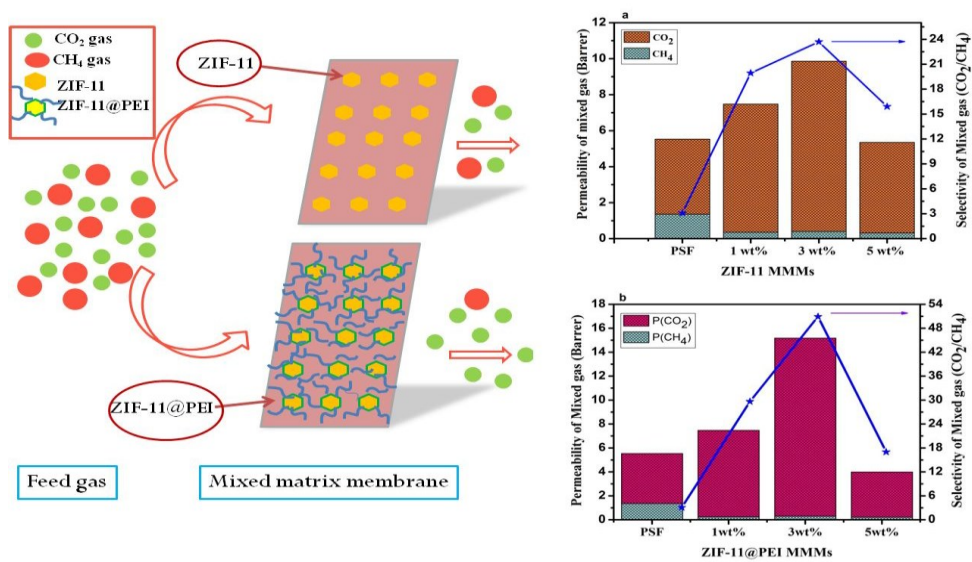
M. K. Sinha¹, A. Gawali¹, S. S. Jampa¹, S. Khuntia²

¹Department of Chemical Engineering, School of Energy Technology, Pandit Deendayal Energy University, Gandhinagar 382426, India

²School of Engineering and Applied Science, Ahmedabad University, Ahmedabad 380009, India (manish.sinha@sot.pdpu.ac.in)

Abstract: In the class of Zeolitic Imidazolate Frameworks (ZIFs), ZIF-11 incorporated polysulfone (PSF) mixed matrix membranes (MMMs) typically exhibit limited CO₂ permeability. To overcome this drawback, we report for the first time a direct blending strategy in which synthesized ZIF-11 was combined with branched polyethyleneimine (PEI) and incorporated into the PSF matrix, without relying on functionalization or post-synthesis modification. The branched PEI established strong chemical interactions both internally with ZIF-11 and externally on the membrane surface. This dual effect generated surface-anchored (-NH₂) groups on ZIF-11@PEI MMMs, which facilitated stronger affinity toward non-polar CO₂ molecules and enhanced their diffusion rate. Gas permeation studies confirmed the improvement: at 3 wt% loading, CO₂ permeability increased by 69% in pure gas tests and by 57% in mixed gas (CO₂/CH₄) separation compared to ZIF-11 MMMs without PEI. This demonstrates the novelty of our approach. The membranes were thoroughly characterized using FTIR, TGA, SEM, EDS, and XRD analyses. These observations establish that metal-organic frameworks (MOFs) can be directly blended with branched PEI into polymer matrices to create effective barriers for gas separation, offering a promising route for high-performance MMMs.

Graphical Abstract:



SOLUTE-INDUCED GRAVITATIONAL CONVECTION FOR SAME-VALENCE ION SEPARATION IN ELECTRODIALYSIS

M. Škrhák, V. Láznička, A. Zubov, Z. Slouka

University of Chemistry and Technology Prague, Faculty of Chemical engineering,
Technická 5, 166 28 Praha 6 - Dejvice

Abstract: Access to potable water remains a pressing issue in many developing countries, where communities rely on various separation technologies, including electrodialysis.¹ One limitation of this technology is that the concentrate (a high-concentration solution) produced as a by-product consists of a complex mixture of ions and is often treated as a waste stream despite its potential value.² In this work, we investigate the influence of solute-induced gravitational convection at ion-exchange membranes as a mechanism for concentrate stratification, enabling the treatment of the concentrate as multiple by-products with potentially different compositions of individual ionic species.

Solutions of Group 1 chlorides (LiCl, NaCl, KCl, RbCl, CsCl, and HCl) were investigated to evaluate their ion-specific buoyancy-driven behaviour. First, a theoretical analysis of the system was performed using COMSOL Multiphysics software. A system of partial differential equations, namely the Navier–Stokes, Nernst–Planck, and Poisson equations, was solved to investigate the hydrodynamics, ion transport, and electrostatic potential within the system. This analysis was further supported by experimental data obtained using specially designed electrochemical cells. Electrochemical characterization techniques were combined with direct microscopic visualization and particle image velocimetry to characterize the system.

The mathematical model, together with the experimental data, demonstrates the dependence of solute-induced gravitational convection on electrolyte composition. Different ions exhibited different solute-induced flow rates near the membrane, suggesting the possibility of separating the concentrate into multiple by-products with different ionic compositions. This phenomenon could be utilized to achieve same-valence ion selectivity in electrodialysis systems through appropriately optimized geometry and flow configurations.

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IONIC TRANSPORT IN SPACER-FREE DILUTE AND CONCENTRATE ELECTRODIALYSIS CHANNELS

Z. Slouka, V. Láznicka, J. Pagáč, J. Strnad

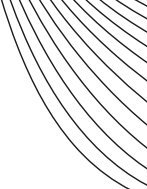
Department of Chemical Engineering, University of Chemistry and Technology in Prague,
Technická 3, Prague, 16628, CZ (sloukaz@vscht.cz)

Abstract: The transport of ionic species from the bulk solution to ion-exchange membranes, enabling selective separation, is a key step in the operation of electrodialysis systems. In this contribution, we examine the role of gravitational convection in ionic transport and discuss its effects in the context of other coupled reaction–transport phenomena, such as electroconvection and water splitting. Although gravitational convection in electrodialysis systems has been recognized for several decades, our experimental and modeling studies reveal new aspects of its potential to enhance ionic transport and improve electrodialysis performance. In particular, spacer-free electrodialysis offers promising opportunities for the practical utilization of gravitational convection, for example through the implementation of so-called side streams.

To investigate these effects, we employ specifically designed experimental cells that allow direct observation of convective streaming developing at the interface between ion-exchange membrane(s) and the surrounding electrolyte at various current densities, thereby inducing membrane polarization. The resulting concentration gradients give rise to density gradients that drive gravitational convection on both sides of the tested membrane. In particular, we observe an upward stream on the dilute side of the membrane and a downward stream on the concentrate side. These flows may be interpreted either as (i) a mechanism enhancing ionic transport to and from the membrane¹, or (ii) a process leading to stratification of the processed solutions², thereby enabling single-channel separation.

Building on these fundamental observations, we examine the effect of gravity in a laboratory-scale, spacer-free, single-channel electrodialysis system that enables both electrochemical characterization and visualization of convective streaming in the dilute channel. Gravity strongly influences overall system performance when polarized solution layers form in the dilute channel during the passage of electric current. By optimizing the channel geometry, the processes occurring in the spacer-free dilute channel can completely desalinate the processed solution while requiring a relatively low operating voltage on the order of hundreds of millivolts³.

We further demonstrate, both theoretically and experimentally, that gravitational convection redistributes salt concentration within the dilute channel. This effect significantly enhances electrodialysis when the pressure-driven feed flow is directed upward, i.e., against gravity. In contrast, when the flow is oriented downward, electrodialysis performance deteriorates due to pronounced and undesirable polarization, particularly at the cation-exchange membrane. Flow analysis



in the diluate channel reveals gravity-driven self-reorganization of the flow field: in the upward orientation, the feed is directed toward the polarized regions near the membranes, whereas in the downward orientation the feed flow is concentrated in the center of the channel. In horizontally oriented cells (with gravity acting perpendicular to the pressure-driven flow), gravity-induced convection produces the aforementioned solution stratification, making the system suitable for the integration of side and withdrawal streams in both the diluate and concentrate compartments. Our experiments show that a virtually desalted solution can be obtained from a side stream withdrawn from the top of the diluate channel of a horizontally oriented cell, even though the overall desalination of the feed reaches only 40–50%. These qualitative and quantitative observations are in good agreement with predictions obtained from mathematical simulations performed in COMSOL Multiphysics.

From a proof-of-concept perspective, these results demonstrate the feasibility of operating electrodialysis systems integrated with side streams.

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COMPARATIVE EVALUATION OF COMMERCIAL NANOFILTRATION MEMBRANES FOR ION SEPARATION FROM SWRO BRINE

H. Son, Y. Woo*

Department of Environmental Engineering and Energy, Myongji University, 116 Myongji-ro, Cheoin-gu, Yongin-si, Gyeonggi-do, 17058, Republic of Korea

Abstract: Seawater reverse osmosis (SWRO) desalination produces a highly concentrated brine stream enriched with major ions such as Na^+ , Cl^- , Mg^{2+} , Ca^{2+} , and SO_4^{2-} . The accumulation of these ions can restrict additional water recovery and raise concerns regarding brine discharge. In this study, nanofiltration (NF) was examined as a post-treatment strategy for the fractionation of SWRO concentrate, with the aim of improving overall system recovery and enabling selective control of ionic species.

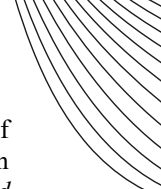
The ion separation performance of fifteen different commercial NF membranes was comparatively evaluated under SWRO concentrate conditions. Both on-site real seawater and synthetic feed solutions were used, and SWRO concentrate was generated using an SWRO unit operated at approximately 50% recovery. Membrane performance was assessed based on permeate flux, individual ion rejection, and average divalent ion removal. Ion concentrations in feed and permeate samples were determined by ion chromatography (IC) and inductively coupled plasma (ICP) analysis. To verify data reliability, overall mass balance was confirmed within the range of 95–105%.

All membranes showed clearly different ion separation behaviors. Several membranes exhibited preferential rejection of divalent ions, especially SO_4^{2-} and Mg^{2+} , with removal efficiencies reaching approximately 70%, while permitting comparatively greater passage of monovalent ions. This divalent-ion selectivity was retained under SWRO concentrate conditions corresponding to about 50% recovery. Based on the comparative evaluation, membranes with both stable flux behavior and improved divalent ion selectivity were identified.

These findings indicate that commercial NF membranes can be effectively applied to high-recovery desalination systems for selective ion fractionation of SWRO concentrate. Further optimization through staged NF operation and integration with advanced reverse osmosis processes may contribute to enhanced water recovery and improved process efficiency.

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ENGINEERING ULTRATHIN ORIENTED $\text{Zn}_2(\text{BIM})_4$ METAL-ORGANIC FRAMEWORK MEMBRANES FOR HIGH-TEMPERATURE H_2/CO_2 SEPARATION

S. Song, K. V. Agrawal

Laboratory of Advanced Separations, Institute of Chemical Sciences and Engineering, École Polytechnique Fédérale de Lausanne (EPFL), Rue de l'Industrie 17, 1951 Sion, Switzerland

(shuqing.song@epfl.ch)

Abstract: Metal-organic framework (MOF) membranes are attractive for energy-efficient gas separations because their crystalline micropores can provide molecular-scale discrimination. However, translating ultrathin MOF films into practical membranes requires simultaneous control over orientation, thickness, continuity and transfer to porous supports. In this contribution, we present a development pathway for $\text{Zn}_2(\text{benzimidazolate})_4$ [$\text{Zn}_2(\text{bim})_4$] membranes, combining the molecular-sieving performance of ultrathin oriented films with large-area membrane engineering for high-temperature H_2/CO_2 separation¹. Ultradilute interfacial crystallization enables continuous $\text{Zn}_2(\text{bim})_4$ films with preferential out-of-plane orientation, where the crystallographic c-axis and its narrow transport aperture are aligned perpendicular to the film surface². When integrated with nanoporous graphene supports, sub-5 nm $\text{Zn}_2(\text{bim})_4$ selective layers deliver high mixed-gas H_2/CO_2 separation performance, including H_2 permeance above 2200 GPU with a separation factor above 140 at 150 °C, and even higher permeance at 180 °C. These results establish the intrinsic molecular-sieving capability of oriented $\text{Zn}_2(\text{bim})_4$ films. To move from microscopic model membranes toward scalable devices, controlled multicycle growth and transfer strategies were further developed to produce continuous, large-area $\text{Zn}_2(\text{bim})_4$ films on porous polybenzimidazole supports. Systematic optimization of substrate pretreatment, film thickness and transfer conditions suppresses nonselective defects and improves membrane reproducibility over centimeter-scale coupons. Grazing-incidence wide-angle X-ray scattering, electron microscopy and atomic force microscopy confirm the retained crystallinity, preferential orientation and continuous coverage of the supported films. The optimized membranes show reproducible H_2/CO_2 selectivity, with ten-cycle membranes reaching average separation factors above 44 and best values around 67 at 150 °C, while maintaining high H_2 permeance and stable operation over extended testing. Together, these studies demonstrate how crystalline orientation and macroscopic processability can be combined in MOF membranes to bridge the gap between nanoscale molecular sieving and practical gas separation. Ongoing efforts focus on further simplifying interfacial growth and integrating $\text{Zn}_2(\text{bim})_4$ selective layers with thermally robust supports, offering a route toward scalable membranes for hydrogen purification and pre-combustion carbon capture.

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LIGNIN-BASED MEMBRANES FOR SUSTAINABLE SEPARATION APPLICATIONS

F. H. B. Sosa¹, N. Dijoux², J. A. P. Coutinho¹, P. Carvalho¹

¹CICECO – Aveiro Institute of Materials, Chemistry Department, University of Aveiro, 3810-193 Aveiro, Portugal

²ENSIACET – Toulouse Graduate School of Chemical, Materials and Industrial Engineering, Materials Department, Toulouse INP, 31030 Toulouse, France

Abstract: The replacement of petroleum-based membranes with bio-derived alternatives is a key objective in sustainable materials research.¹ Lignin, an abundant byproduct of the pulp and paper industry, was selected as the primary building block due to its rich functional chemistry, hydrophilicity, and film-forming ability. In this work, lignin-based formulations were developed by varying crosslinker type, lignin-solvent ratio, and processing conditions.² Due to their intrinsic instability as standalone materials, these formulations were deposited as thin selective layers onto polypropylene supports, forming thin-film composite membranes.³ The membranes were characterized by FTIR, SEM, TGA, and contact angle measurements to evaluate chemical structure, morphology, thermal stability, and surface properties. Separation performance was assessed using water, salt, and polyethylene glycol (PEG) filtration experiments to determine molecular weight cut-off. Dye filtration tests using Tartrazine (Acid Yellow 23) demonstrated the ability of lignin-based membranes to concentrate solutes. Starting from 50 mg/L, four consecutive filtration cycles with a lignin–erythritol layer increased the dye concentration to 68.3 mg/L (36.6% enrichment), while the bare support showed negligible rejection. Extrapolation indicates that higher concentrations (>90 mg/L) could be achieved with additional cycles. Overall, these results demonstrate that lignin-based thin-film composite membranes are a promising sustainable platform for selective separation and solute recovery.

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FLUE GAS SORPTION AND PERMEATION IN PEEK-IONENES AND POLYMERS OF INTRINSIC MICROPOROSITY

P. Stanovský¹, J. Škvára^{1,3}, O. Vopička², P. Izák^{1,2}, K. Friess², J. Bara⁴, S. Ravula⁴

¹Institute of Chemical Process Fundamentals, Rozvojová 135, Prague 6, 165 00, Czech Republic (stanovsky@icpf.cas.cz, www.icpf.cas.cz)

²Department of Physical Chemistry, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic

³Faculty of Science, Jan Evangelista Purkyně University in Ústí nad Labem, Ústí nad Labem, 400 96, Czech Republic

⁴Department of Chemical & Biological Engineering, The University of Alabama, Tuscaloosa, AL 35487-0203, USA

Abstract: This work combines an innovative experimental sorption methodology with conventional grand canonical Monte Carlo (GCMC) and molecular dynamics (MD) simulations to advance understanding of gas sorption and permeation in membrane materials for CO₂ and SO₂ removal from industrial flue gases. Gas sorption was investigated experimentally and computationally for sour gases, namely CO₂ and SO₂, as well as CH₄, N₂, and SO₂/N₂ mixtures, in advanced poly(ether ether ketone) (PEEK)-ionene composite membranes and selected polymers of intrinsic microporosity (PIMs). The PEEK-ionene membranes studied consist of PEEK segments interconnected by imidazolium groups and incorporate varying amounts of ionic liquid (IL).

The effect of imidazolium-moiety structure and IL loading on gas sorption in PEEK-ionene composite membranes was evaluated [1]. SO₂ exhibited the strongest sorption affinity, including in diluted SO₂/N₂ mixtures at approximately 5000 ppm. The overall sorption preference followed the order SO₂ > CO₂ > CH₄ > N₂. Among the investigated PEEK-ionene variants, the material without a methyl substituent on the imidazolium core exhibited higher CO₂/N₂ solubility selectivity than the methyl-substituted analog. However, this difference decreased by approximately a factor of five as pressure increased. This behavior is hypothesized to result from reduced polymer-chain mobility at elevated pressure, which causes the free IL phase within the composite to become increasingly dominant in gas transport. Molecular simulations further showed that the polymer end-to-end distance is largest in composites with 2 equivalents of IL. In contrast, further addition of IL leads to polymer chain contraction, accompanied by a decrease in polymer density.

In addition, SO₂ sorption in gas mixtures with and alone N₂ sorption at different pressures were studied in a series of PIMs, ranging from PIM-1 to the ultrapermeable PIM-TMN-Trip. These materials were used to assess how the conformation units responsible for inefficient chain packing influence gas selectivity and permeability

[2,3]. The computationally efficient sorption simulations of these glassy polymer molecular sieves showed excellent agreement with experimental data. Moreover, the simulations enabled interpretation through advanced sorption models and provided deeper insight into gas selectivity in complex industrial mixtures at elevated pressures.

The support of the Czech Science Foundation under project 24-10288S is gratefully acknowledged.

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NONPOROUS POLYMER MEMBRANES FOR DOWNSTREAM SEPARATION PROCESSES: POTENTIAL AND APPLICATIONS

P. Stanovský¹, K. Friess², P. Izák¹

¹Institute of Chemical Process Fundamentals, Rozvojova 135, Praha 6, 165 00, Czech Republic (izak@icpf.cas.cz)

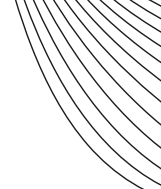
²University of Chemistry and Technology, Technická 5, Prague 6, 160 00, Czech Republic

Abstract: This talk summarizes results and also the potential of separation of fluids through nonporous membranes. Two approaches were selected for this study ionic liquids membranes and thin film composite (TFC) membranes. TFC have molecular-level sieving structures consisting of multiple layers of polymeric materials. The three-layer film configuration has the proper mechanical stability and high selectivity of undesired materials to generate a high filtration rate [1]. The first (top) layer serves as a dense selective barrier with a thickness of around 1 μm , which is made of polyamide that swells in water and make perm-selective membrane [2]. Two other layers are thicker to ensure mechanical rigidity with higher porosity than the top layer. A water-swollen spiral-wound membrane filter was used to separate CH_4 from two types of feed streams: a synthetic binary mixture of CH_4 and CO_2 and raw agrobiogas. At a pressure of 3 kPa of the synthetic biogas, CH_4 content increased from 52 vol% of the feed stream up to 98 vol% of the retentate stream. Two filters aligned in parallel increased the recovery ratio by 8.5% from the single filter operation, which is ascribed to doubling the biogas retention time in the parallel filters by bisecting the feed stream. The water-swollen membrane technology developed in this study proved efficient in producing high-quality biomethane and desulfurizing feed biogas. The retentate streams had a biomethane concentration of 95-98 vol% of pure CH_4 and a low concentration of H_2S of an order of 10 ppmv [3]. Experimental controlling factors may include but are not limited to the feed flow rate, pressure, membrane properties, and module configuration. More extensive experimental research, to be supported by theoretical analysis, is required to further improve biomethane production using water-swollen membrane technology.

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DESIGN OF FUNCTIONALIZED COVALENT ORGANIC FRAMEWORKS (COFs) FOR UREA ADSORPTION AND MECHANISM STUDY

C. Sun, Y. Woo*

Department of Environmental Engineering and Energy, Myongji University, 116 Myongji-ro, Cheoin-gu, Yongin-si, Gyeonggi-do, 17058, Republic of Korea

Abstract: Urea (molecular weight: 60 g/mol) is a low-molecular-weight (LMW) organic compound that exhibits non-ionic characteristics under neutral pH conditions. Due to its small molecular size and lack of charge, urea is difficult to effectively remove by conventional Ultra-Pure Water (UPW) production processes and has been reported to adversely affect UPW quality and semiconductor manufacturing yield. Typical UPW treatment trains include reverse osmosis (RO), ion exchange (IX), and UV oxidation. However, RO primarily relies on size exclusion and electrostatic repulsion mechanisms, resulting in limited rejection of LMW and non-ionic compounds. Similarly, IX processes show little selectivity toward uncharged species.

To address these limitations, we explored the use of a covalent organic framework (COF) for urea removal. COFs are crystalline, porous materials built from organic building blocks, composed of C, H, O, and N, held together by strong covalent bonds. By varying the choice of precursors and linkers, a wide range of framework structures can be achieved, giving researchers the flexibility to design materials tailored to their specific needs. This tunability, combined with the intrinsic selectivity of COFs toward target molecules, makes them attractive adsorbents. Notably, compared to activated carbon, COFs offer ordered nanoporous channels and the ability to engage in polar interactions with urea, which has been shown to result in markedly higher adsorption capacity.

The β -ketoenamine linkage formed between aldehyde and amine precursors yields an irreversible keto-enamine form, which confers the structural and chemical stability needed to preserve crystallinity in aqueous environments. To further reinforce hydrogen bonding, the primary mechanism driving urea adsorption on COFs, we aim to boost adsorption efficiency through two strategies: tailoring the composition of precursors and linkers and introducing additional hydrogen-bonding functional groups post-synthetically.

Conventional COF syntheses reported in the literature have relied on pyrex ampoules as reaction vessels, which present drawbacks including limited scalability and the need for flame-sealing. To address these issues, we plan to employ a hydrothermal reactor that enables repetitive experiments, leveraging its robust pressure and thermal resistance to facilitate rapid crystal growth. Building on this approach, we intend to utilize β -ketoenamine-linked modified COFs to evaluate their adsorption performance and analyze changes in crystallinity following modification.

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CONTROLLING FUNCTIONAL GROUPS IN UiO-66 FRAMEWORKS WITHIN MIXED MATRIX MEMBRANES FOR ADVANCED HYDROXIDE ION CONDUCTION

H. L. Tak, S. Jo, D. Chung*, T.-H. Bae*

Department of Chemical and Biomolecular Engineering, Korea Advanced Institute of Science and Technology, Daejeon, 34141, Republic of Korea (takhye24@kaist.ac.kr)

Abstract: Anion exchange membrane water electrolysis (AEMWE) is a promising technology for green hydrogen production, yet it suffers from a trade-off between hydroxide (OH^-) conductivity and dimensional stability[1]. To address this bottleneck, introducing functionalized porous fillers into an ionomer matrix has emerged as a viable strategy [2]. Herein, we report the pioneer incorporation of functionally modified UiO-66 frameworks into a polyaromatic anion exchange matrix to systematically investigate the role of filler charge density on ion transport. Three metal-organic frameworks—pristine UiO-66 (neutral), UiO-66- NH_2 (amino-functionalized), and cationic UiO-66 (positively charged)—were synthesized and blended with the polymer matrix to fabricate mixed matrix membranes (MMMs). Structural and morphological analyses confirmed successful functionalization and defect-free membrane formation. The MMMs showed a stepwise increase in OH^- conductivity with increasing filler charge density, while excessive swelling was suppressed by the chain confinement effect. Notably, the cationic UiO-66 embedded membrane demonstrated the lowest activation energy (E_a), proving that fixed positive charges facilitate electrostatic hopping pathways that accelerate hydroxide transport for high-performance anion exchange membranes.

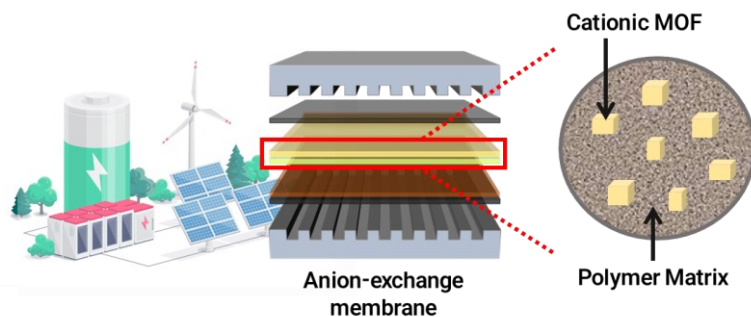


Figure. Schematic representation of Cationic MOF-based PBI mixed-matrix membranes

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TOWARD AFFORDABLE SOLVENT-RESISTANT OSN MEMBRANES: IN SITU CROSSLINKING OF SPSPU

I. Tontul^{1,2}, C. Nikiforidis¹, I. Achterhuis³, W. de Vos³, A. Asadi Tashvigh¹

¹Biobased Chemistry and Technology, Wageningen University, Bornse Weiland 9, Wageningen, 6708WG, Netherlands

²Necmettin Erbakan University, Faculty of Engineering, Department of Food Engineering, Konya, Türkiye

³Membrane Science and Technology, University of Twente, Faculty of Science and Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands

The authors did not consent to the publication of this abstract.

REMOVAL OF HERBICIDE GLYPHOSATE AND AMINOMETHYLPHOSPHONIC ACID (AMPA) BY MEMBRANE TECHNOLOGIES

P. B. Trinh, A. I. Schäfer*

Institute for Advanced Membrane Technology (IAMT), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

(*corresponding author. Email: Andrea.Iris.Schaefer@kit.edu)

Abstract: Glyphosate (GLY) is the most used herbicide worldwide and exists in the environment at high concentrations from 0.2 to 400 µg/L. Conventional water and wastewater treatment technologies have not shown adequate removal of GLY. In this study, a comprehensive comparison between three different water treatment technologies is investigated for the removal GLY and its main metabolite aminomethylphosphonic acid (AMPA) in waters. Three chosen technologies are nanofiltration membrane (NF) [1], ultrafiltration membrane with permeate side polymer based- spherical activated carbon (UF-PBSAC) [2], and TiO₂-coated poly(vinylidene fluoride) membrane (PVDF-TiO₂) [3].

Six different NF membrane with the molecular weight cut off (MWCO) in the range of 80–3000 Da were chosen for the filtration of GLY and AMPA in water. A composite of UF membrane (10 kDa PLHGC, Millipore Corp., USA) with PBSAC (Blücher Co., Germany) placed in the permeate side was prepared in a stirred cell system. PVDF-TiO₂ membrane was supplied by the Institute of Surface Engineering (IOM), Leipzig, Germany. Filtration of feed with GLY and AMPA at concentrations of 1 µg/L was performed through in flow-through mode. Liquid chromatography with tandem mass spectrometry (LC-MS/MS) was used to determine GLY and AMPA concentration with limit of detection of 10 ng/L.

NF membrane can remove 50–80 to 90% GLY and AMPA. The rejection by NF membrane is strongly dependent on membrane MWCO, pH, and flux. With a thin layer of UF-PBSAC, 77 % GLY and 52 % AMPA were removed in filtration experiment. The saturation was not reached due to the tremendous adsorption capacity of PBSAC. At the optimized conditions of hydraulic resident time and PBSAC characteristics, UF-PBSAC can remove 98% GLY and 95% AMPA, reaching EU guidelines for herbicides (0.1 µg/L for each herbicide). The photocatalytic degradation by PVDF-TiO₂ membrane under the solar spectrum can remove 63–65% GLY and 21–25% AMPA at standard conditions, and can remove 95% GLY and 80% AMPA at optimized conditions. In conclusion, NF can remove GLY and AMPA from water but requires high pressure for operation. UF-PBSAC can effectively remove GLY and AMPA, but the HRT is long. PVDF-TiO₂ membrane can be an alternative option, but the incomplete reactions create unwanted by-products.

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NANOFILTRATION-ASSISTED CRYSTALLIZATION

M. Turek

Silesian University of Technology, Faculty of Chemistry, B. Krzywoustego 6, 44-100 Gliwice, Poland

Abstract: The removal of calcium, magnesium and sulphate ions using nanofiltration is increasingly being employed as a method of pre-treatment for saline water in its utilization processes. Brackish water prepared in this way can then be concentrated without the risk of calcium sulphate crystallization; however, at high water recovery rates, the risk of crystallization is transferred to the nanofiltration unit. This paper presents the results of nanofiltration carried out at high water recovery and very high calcium sulphate supersaturation. In accordance with the research program, the calcium sulphate supersaturation of the NF retentate was to be subsequently reduced, and a significant portion of the retentate, depleted of most of the calcium sulphate, was to be recirculated to minimize salt losses.

In the three-stage pilot plant, 2540 nanofiltration modules equipped with spacers of an original design were used. To calculate the relative saturation of the NF retentate with calcium sulphate and to determine whether it was supersaturated with this compound (defined as relative saturation exceeding 100%), the PHREEQC v.3 software, developed by the US Geological Survey, was used, utilizing the built-in pitzer.dat database.

The system's ability to operate with a high permeate yield, even exceeding 90%, was confirmed. Multi-day tests of continuous operation at relative calcium sulphate saturations of 316% and 282% showed no changes in the permeate flow rate that might indicate membrane scaling. The crystallization of calcium sulphate dihydrate was carried out in a continuous stirred tank crystallizer.

It was found that in the presence of a $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ suspension at a concentration of 150 g/dm^3 , the relative saturation decreases from 186–214% to 132–138% after just 5 minutes in the crystallizer, i.e. considerably below the required 160%.

TWO-STAGE ELECTRODIALYSIS FOR DESALINATION AND CONCENTRATION OF PULP MILL WASTEWATER

L. Václavík, R. Formánek

Engineering department, Membrain, Pod Vinicí 87, 47127 Stráž pod Ralskem, Czech
Republic (lukas.vaclavik@membrain.cz, www.membrain.cz)

The authors did not consent to the publication of this abstract.

HYBRID REVERSE OSMOSIS–FREEZE CONCENTRATION FOR INTEGRATED TREATMENT OF RO BRINE FROM BRACKISH GROUNDWATER

B. O. Vasyliv, O. O. Kovalenko, O. B. Vasyliv

Odesa National University of Technology, 112 Kanatna str., Odesa, 65039, Ukraine
(bvasyliv41@gmail.com)

Abstract: The expansion of global desalination capacity is accompanied by large brine volumes whose disposal is a pressing environmental and technological problem [1,2]. Membrane methods dominate current installed capacity, primarily reverse osmosis (RO, about 69 %) [2], and are complemented by thermal (MSF, MED, MVC, MD), electromembrane (ED, BMED), and freeze (FD) technologies [2,3].

The first part of the work compares desalination technologies by key indicators and establishes the place of membrane methods among them. The comparison covers specific energy consumption (SEC), carbon (CF) and water (WF) footprints, technology readiness level (TRL), water recovery rate (WRR), operating salinity range, and ZLD compatibility. RO is the most energy-efficient method for low- and medium-salinity waters, with SEC of about 0.4–1.5 kWh/m³ for brackish water and 2–6 kWh/m³ for seawater, one of the lowest CF and WF values, and the highest maturity (TRL 9). Thermal methods and membrane distillation show substantially higher SEC and CF, whereas freeze desalination remains at the pilot level (TRL 4–5) but retains operability across salinity ranges that are challenging for RO and many conventional desalination configurations [3]. Despite its maturity, RO retains several unresolved problems that limit further development. The principal constraints are membrane fouling and the restricted ability to treat highly concentrated brines: as salinity rises, osmotic pressure and energy demand increase nonlinearly, membrane aging accelerates, and economic feasibility declines. State-of-the-art seawater RO plants can reach a second-law thermodynamic efficiency of about 59–61 %, so further SEC reduction is possible only through incremental improvements. Current RO development trends target these limitations through high- and ultra-high-pressure systems (HPRO, UHPRO), low-pressure high-recovery RO (LPHRRO), multi-stage RO (MSRO), and closed-circuit or semi-batch configurations (CCRO/CLRO) that increase WRR and moderately reduce SEC. However, fundamental thermodynamic constraints make integration of RO with alternative processes essential for deep brine concentration, making brine disposal a critical direction for the field.

Modern brine management is shifting from simple discharge toward concentration, water reuse, and recovery of valuable components within minimum/zero liquid discharge (MLD/ZLD) strategies [1]. MLD typically targets high water recovery, often around 80 % or higher, with co-production of salts, whereas ZLD aims at near-complete water recovery, commonly 95–99 %, and elimination of liquid waste. Both involve pretreatment, concentration, and crystallization/conversion, with the latter two stages accounting for the dominant share of costs. Final stages employ thermal

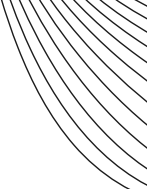
crystallization, freeze crystallization, or membrane distillation coupled with crystallization, yielding recovered water and solid salts such as Na_2SO_4 and NaCl [1,3]. Within this hierarchy, freeze concentration occupies the boundary between concentration and crystallization stages and can be integrated with RO in hybrid schemes. Many mineral-water bottling plants now also produce drinking water by desalinating natural brackish groundwater with RO. This is accompanied by the formation of brines with lower salinity than those produced after seawater desalination. Traditionally, less attention has been paid to the disposal of such brines. Yet for scarce brackish groundwater, the loss of part of the water with the reject stream has not only environmental but also resource significance, and these brines may contain components of potential recovery value. The second part of the work therefore investigates freeze concentration (FC) of real brackish-water RO brine at a mineral-water bottling plant in southern Ukraine as a brine-treatment route within a hybrid RO+FC scheme [4].

The feed was a natural mineral groundwater of the chloride–sodium type, classified as medicinal-table water, with total dissolved solids (TDS) of 3.618 g/L. The brine from the industrial RO unit, operating at 62 % water recovery, reached a TDS of 9.312 g/L. Concentration freezing was performed on a laboratory setup consisting of a vapor-compression refrigeration module and a crystallizer. A 2.0 L brine solution was frozen for 4000 s, and the resulting ice block was subjected to gravitational drainage for 3600 s at 21–23 °C. For all fractions – feed water, RO permeate and brine, ice melt, and freeze concentrate – macro-ion composition (Ca^{2+} , Mg^{2+} , Na^+ + K^+ , HCO_3^- , SO_4^{2-} , Cl^-), TDS, and total hardness were determined. Based on these data, membrane selectivity, salt distribution coefficient, brine concentration coefficient, and total mass balance were calculated [4].

The experimental study confirmed that single-stage freezing without ice post-treatment is ineffective. Gravity drainage of the ice block substantially improved salt separation and yielded a more concentrated brine suitable for further treatment. A differentiated ion-specific removal pattern was observed, with divalent ions rejected more strongly than monovalent ones and anomalously high removal of Ca^{2+} that is consistent with partial precipitation of sparingly soluble calcium phases during freezing. This opens up possibilities for selective concentration and salt recovery. Based on the results, three hybrid schemes approaching MLD/ZLD are proposed: recycling the ice melt to the RO unit to raise overall water recovery, multi-stage freeze concentration, and final crystallization of the concentrate to recover mineral salts. Overall, the results support the use of RO+FC with gravity ice drainage as an integrated brine-treatment route for small-scale brackish-water and mineral-water bottling plants and justify further development toward MLD/ZLD [4].

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EXPLAINABLE AI FOR APPLICABILITY DOMAIN CONSTRAINED OPTIMIZATION OF POLYMER CHEMISTRY FOR GAS SEPARATION

V. Vigna, A. Fuoco, E. Tocci

Institute on Membrane Technology, CNR-ITM, Via P. Bucci 17/C, 87036 Rende, CS, Italy
(v.vigna@itm.cnr.it)

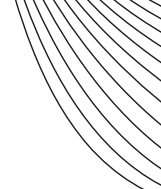
Abstract: Artificial intelligence and machine learning are rapidly transforming the design of functional materials, offering tools to explore chemical spaces that remain largely inaccessible through traditional experimental approaches. In the field of polymeric membranes for gas separation, particularly for CO₂ capture, the central objective remains the simultaneous optimization of permeability and selectivity, a tradeoff historically constrained by the Robeson upper bound. However, two well known limitations are rarely addressed together: fingerprint based descriptors are affected by bit collision¹, and polymers are commonly represented as saturated monomers, an approximation that discards structural information at the edge of the molecule where the repeating unit would normally continue²; in addition, models that fail to generalize are typically used to extrapolate predictions beyond their applicability domain, or AD, without this limitation being explicitly accounted for³. Here we present RAGMODEX (Retrieval Augmented Generation for Molecular Design and Explainable AI), a model agnostic platform originally developed for molecular discovery and here extended to guide the rational optimization of polymer chemistry for gas separation performance. RAGMODEX addresses bit collision through an interface that makes the user explicitly aware of this potential ambiguity in structure property attributions. More importantly, rather than producing optimistic and potentially unreliable predictions that extrapolate beyond the applicability domain, RAGMODEX prioritizes optimization within the AD: instead of identifying substructures predicted to push a polymer beyond the Robeson upper bound, it identifies substructures that shift the polymer toward the upper bound, a more realistic and conservative optimization target. By integrating explainability, applicability domain aware validation, and guided design within a single framework, RAGMODEX lays the groundwork for more reliable computational screening of new polymeric materials for CO₂ capture.

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Acknowledgements This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101115488. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Innovation Council and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.



ELECTRIC-FIELD-ASSISTED PREPARATION OF PHOTOCATALYTIC PVDF FIBROUS MEMBRANES

Z. Vilamová¹, L. Svoboda¹, J. Bednář²

¹CNT, CEET, VSB – Technical University of Ostrava, 17. listopadu 2172/15, Ostrava – Poruba, 708 00, Czech Republic

²CPIT, FMT, VSB – Technical University of Ostrava, 17. listopadu 2172/15, Ostrava – Poruba, 708 00, Czech Republic

zuzana.vilamova@vsb.cz

Abstract: The development of functional fibrous membranes with tailored surface properties is of increasing interest for advanced environmental and catalytic applications. This work presents an electric-field-assisted approach for the immobilization of photocatalytic particles onto electrospun poly(vinylidene fluoride) (PVDF) fibrous membranes in a liquid medium. Unlike conventional coating techniques, the proposed method exploits electric-field-driven particle transport to achieve controlled immobilization, where the deposition process is governed by the combined influence of the electric field, deposition medium, and membrane surface properties.

The influence of key processing parameters, including particle type, solvent composition, electric field conditions, and membrane surface pretreatment, was systematically investigated to optimize particle immobilization and coating uniformity. The resulting membranes were characterized in terms of surface morphology and particle distribution, while photocatalytic degradation of tetracycline under visible-light irradiation was employed to evaluate the functionality of the prepared materials.

The developed deposition strategy provides a versatile platform for the fabrication of hybrid photocatalytic fibrous membranes and offers new opportunities for the preparation of functional membrane materials with controlled surface architecture and enhanced performance for environmental applications.

Acknowledgment

This work was financially supported by the European Union under the REFRESH – Research Excellence For Region Sustainability and High-tech Industries project number (CZ.10.03.01/00/22_003/0000048) via the Operational Programme Just Transition, by the “Advanced Materials for Energy and Environmental Technologies” project, reg. nr. (CZ.02.01.01/00/23_021/0008592) within the Programme Johannes Amos Comenius

PVDF-BASED MEMBRANE FOR ENANTIOSELECTIVE SEPARATION CHIRAL ACIDS: INFLUENCE OF SOLVENT COMPOSITION AND MOBILE PHASE MODIFIERS

Z. Vorbova^{1,2}, J. Cizek^{2,3}, P. Jisa^{2,3}, M. Kohout³, M. Labikova³, P. Izak^{2,3}

¹University of Pardubice, Faculty of Chemical Technology, Pardubice, Czech Republic

²Institute of Chemical Process Fundamentals of the Czech Academy of Sciences, Prague, Czech Republic

³University of Chemistry and Technology, Faculty of Chemical Engineering, Prague, Czech Republic

Abstract: Chiral molecules play a crucial role in numerous fields, particularly in the pharmaceutical, agrochemical, and fine chemical industries, where the two enantiomers of a compound may exhibit significantly different biological, pharmacological, or toxicological properties. Consequently, the efficient production and separation of optically pure enantiomers remain major challenges in modern chemical engineering. Chromatographic techniques are currently the most widely applied methods for industrial-scale enantioseparation. In contrast, membrane-based separation processes represent a promising alternative owing to their low energy requirements, ability of continuous mode of operation, and excellent potential for large-scale implementation.

In this work, enantioselective mixed matrix membranes based on poly(vinylidene fluoride) (PVDF) were employed for the separation of N-(3,5-dinitrobenzoyl)-leucine (DNB-leucine) enantiomers. The membranes contained silica particles functionalized with quinidine-derived chiral selector, combining the mechanical robustness of PVDF with highly selective chiral recognition sites.¹

Enantiomeric transport through the membranes was investigated under concentration-driven conditions. Methanol–water mixtures containing 50–100% methanol and various amounts of formic acid and triethylamine as modifiers were investigated.² Increasing the water content resulted in enhanced retention and improved enantioselective performance compared with purely methanolic systems. Furthermore, the addition of formic acid to the feed solution increased the enantiomeric excess, whereas the addition of triethylamine together with formic acid resulted in a lower enantiomeric excess. The PVDF-based membranes exhibited excellent stability, and regenerability throughout repeated separation experiments.

Significant differences in the transport rates of DNB-leucine enantiomers were observed, confirming the effectiveness of the incorporated chiral selectors. Enantiomeric excess values approaching 90 % were achieved under optimized conditions, which were 25 or 50 mM of formic acid in the mixture and higher content

of water in solution, demonstrating the strong potential of these membranes for enantiomer enrichment with the condition of regenerating this membrane in ammonium acetate methanolic solution. The results highlight the applicability of PVDF-based mixed matrix membranes as a promising platform for scalable chiral separations and further development of continuous enantiomer purification processes.

Acknowledgements We gratefully acknowledge the financial support from the Czech Science Foundation, project No. 25-15195S. This work was also supported by the Internal Grant Agency of the University of Pardubice under project No. SGS_2026_006.

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CLOSING THE LOOP: ACID AND BASE RECOVERY FROM TUNGSTEN MINING WASTEWATER USING A TWO-STAGE ELECTRODIALYSIS PROCESS

L. Weisz, S. Lamparter, J. Krampe, N. Kreuzinger

Institute for Water Quality and Resource Management, TU Wien, Karlsplatz 13/226-1, 1040 Vienna, Austria

Background

The conventional production of tungsten metal and tungsten carbide powders relies on multiple chemical and thermal processing steps that consume substantial quantities of sodium hydroxide (NaOH) and sulfuric acid (H₂SO₄). In current industrial practice, NaOH is applied for alkaline digestion and subsequently neutralized with H₂SO₄, resulting in sodium sulfate (Na₂SO₄) as a by-product. Since the upstream production of both NaOH and H₂SO₄ is energy-intensive and associated with significant greenhouse gas emissions, the development of an *in situ* alternative for reagent regeneration and reuse would be beneficial for improving process sustainability.

Methods

This work investigates the recovery of NaOH and H₂SO₄ from Na₂SO₄-containing tungsten wastewater streams in a two-stage electrodialysis process. In the first stage, bipolar electrodialysis (BPED) was applied to regenerate acid and base¹. A feed-and-bleed operational strategy was implemented, in which acid and base compartments were partially discharged and replenished with deionized water once a predefined electrical conductivity (EC) threshold was reached (90 mS/cm for the base and 80 mS/cm for the acid).

Three lab-scale BPED experiments were conducted over 40 h each and consisted of five consecutive 8 h sub-experiments, during which portions of the generated acid and base streams were replaced with deionized water after each sub-experiment. The volumetric ratio of feed to both base and acid streams in the first stage was 1:3.

In the second stage, the bleed fractions collected from sub-experiments 2 and 3 in the feed-and-bleed configuration were pooled and further concentrated using conventional electrodialysis (ED)² until a diluate EC of 10 mS/cm was reached for both streams. Similar to the first stage, the second stage was operated at a concentrate-to-diluate volumetric ratio of 1:3.

Results

As shown in Figure 1, the EC difference (Δ EC) of the regenerated acid and base streams increased during each sub-experiment. However, the rate of increase declined

with each subsequent sub-experiment due to the decreasing EC of the feed solution. In the second stage (Phase 2), a high concentrate concentration was achieved within a short processing time of 30-40 minutes.

In absolute terms, the base EC increased to 121 ± 12 mS/cm in stage 1 and further to 227 ± 11 mS/cm in stage 2. The acid EC increased to 81 ± 11 mS/cm in stage 1 and to 118 ± 10 mS/cm in stage 2.

Chemical characterization of the regenerated acid and base streams is ongoing.

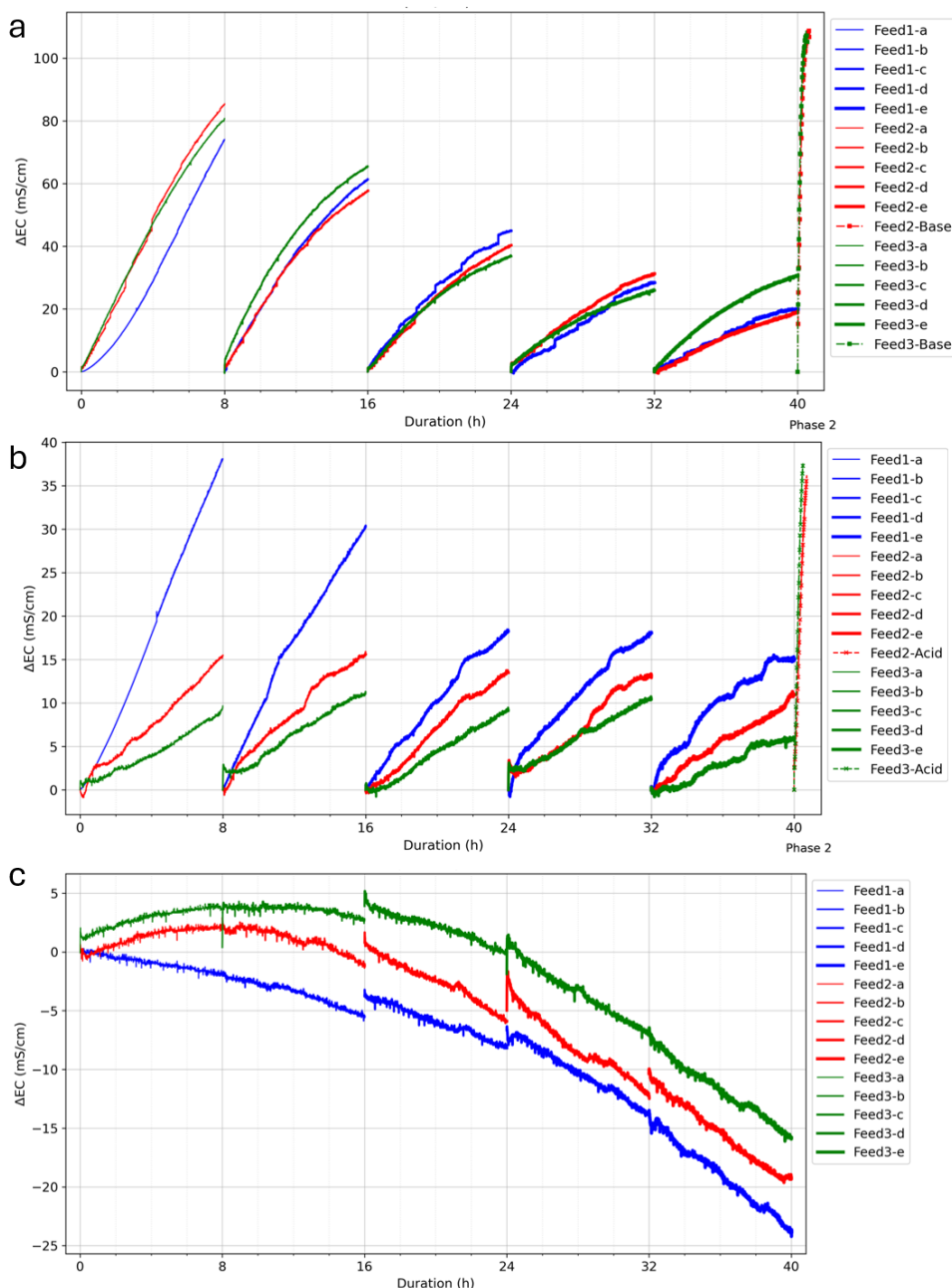


Figure 1. ΔEC of the generated base (a) and acid (b) as a function of experiment duration during phase 1 (0-40 h) and phase 2 (>40 h) experiments, and (c) ΔEC of the Na_2SO_4 -containing tungsten wastewater during the phase 1 experiments.

Conclusions

The proposed integrated two-phase electrodialysis approach demonstrates the potential for closed-loop reagent management in tungsten production, with the aim of reducing virgin chemical consumption, lowering environmental impacts, and improving process economics. However, further work is required to assess the

technical and economic feasibility of the process at larger scale and under continuous operating conditions.

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COMPATIBILIZING INTERLAYERS IN MULTILAYER THIN-FILM COMPOSITE HOLLOW FIBER MEMBRANES FOR HUMID CO₂/N₂ SEPARATION

S. Xu¹, K. Goh¹, D. Y. F. Ng¹, Y.X. Dai¹, S. Q. Wang¹, R. Wang^{1,2}

¹Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore, 637141, Singapore

²School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, 639798, Singapore (rwang@ntu.edu.sg (R. Wang))

Abstract: Thin-film composite (TFC) hollow fiber membranes are promising for post-combustion CO₂ capture, but achieving high permeance, selectivity, and stability under humid CO₂/N₂ mixed-gas conditions remains challenging. Herein, a lumen-side multilayer membrane was constructed by sequentially depositing a crosslinked amino-terminated poly(dimethylsiloxane) (PDMS-NH₂) gutter layer, a poly(ether-block-amide) (Pebax®) 2533/poly(dimethylsiloxane)-poly(ethylene glycol) (PDMS-PEG) interlayer, and a Pebax® 1657 selective layer onto a porous polysulfone hollow fiber substrate. The amphiphilic PDMS-PEG modifier, incorporated into the Pebax® 2533 interlayer, bridges the siloxane-rich gutter layer and the Pebax® 1657 selective layer through combined siloxane-siloxane and Pebax®-Pebax® affinity. With an optimal PDMS-PEG loading of 10 wt%, the membrane achieved a CO₂ permeance of 552 ± 33 GPU and a CO₂/N₂ selectivity of 35.5 ± 1.6 under a 20/80 vol% CO₂/N₂ mixed-gas feed. Increasing the relative humidity (RH) from 0 to 90% caused only a 15.2% decrease in CO₂ permeance, while the selectivity remained nearly unchanged. After 25 days of continuous operation at 60% RH, the membrane retained a CO₂ permeance of 446 GPU and a CO₂/N₂ selectivity of 35.1. These results demonstrate that a PDMS-PEG-modified Pebax® compatibilizing interlayer is effective for constructing multilayer hollow fiber membranes with balanced mixed-gas separation performance and humidity stability.

POLYELECTROLYTE-ASSISTED INTERFACIAL POLYMERIZATION FOR HIGH-PERFORMANCE PH RESISTANT HOLLOW FIBER POLYUREA MEMBRANES

Q. Xue, Y. J. Lim, R. Wang

Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, 637141, Singapore
(qiang.xue@ntu.edu.sg)

Abstract: A scalable fabrication of hollow fiber nanofiltration (NF) membranes is often hindered by interfacial instability and defect formation during interfacial polymerization (IP) on curved inner surfaces. Here, a polyethyleneimine (PEI)/poly(sodium 4-styrenesulfonate) (PSS) polyelectrolyte interlayer was employed to anchor amine monomers at the reaction interface, thereby stabilizing their interfacial distribution and preventing uneven diffusion during IP reaction. This interfacial stabilization ensures a continuous and homogeneous amine supply, promoting uniform film growth and effectively suppressing defect formation. As a result, a uniform and defect-free polyurea selective layer is formed via the reaction between PEI and toluene diisocyanate (TDI). The optimized polyurea membranes achieve a high water permeance of $24.4 \text{ Lm}^{-2}\text{h}^{-1}\text{bar}^{-1}$ and an MgCl_2 rejection of 93.4%, together with excellent rejection of multivalent rare-earth cations. Excellent chemical stability is maintained after prolonged exposure to 10 wt% H_2SO_4 or 5 wt% NaOH for 28 days. Importantly, this strategy can be extended to module-scale fabrication, where the membranes maintain high performance after scale up to larger module size. This work provides a practical route toward scalable and pH-resistant hollow fiber NF membranes.

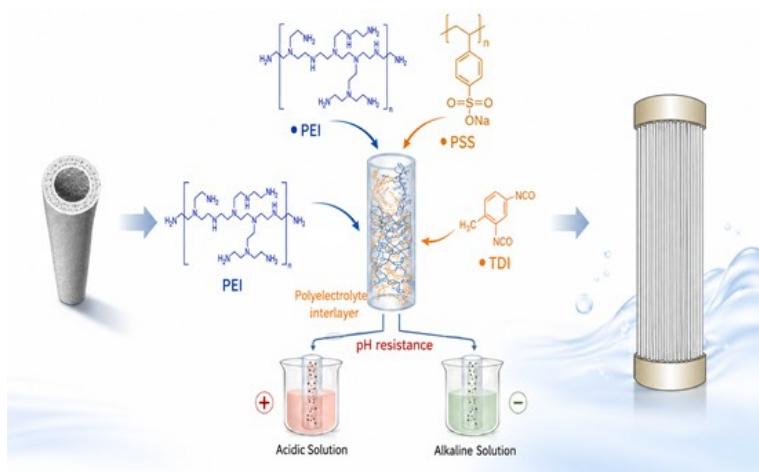


Figure 1. Polyelectrolytes-assist IP in the preparation of scalable, high-performance acid and alkali resistant polyurea membranes.

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NANOPOROUS GRAPHDIYNE MEMBRANES FOR ENERGY-EFFICIENT GAS SEPARATION

A. Yadav^{1,2}, D. J. Babu¹

¹Department of Materials Science and Metallurgical Engineering, Indian Institute of Technology, Hyderabad, Kandi, Sangareddy, Telangana, 502284, India

²Centre for Interdisciplinary Programs, Indian Institute of Technology, Hyderabad, Kandi, Sangareddy, Telangana, 502284, India

Abstract: Separation processes alone account for approximately 10-15% of global energy consumption, motivating the development of more energy-efficient alternatives. Membrane-based separations are particularly attractive because they do not involve a bulk-phase change, resulting in lower energy requirements than conventional separation technologies. The performance of a membrane is determined by its ability to simultaneously achieve high permeance and high selectivity. Atomically thin two-dimensional materials such as graphene have emerged as promising membrane materials due to their extremely low thickness.^[1] However, pristine graphene is impermeable to gases and therefore requires the incorporation of nanopores to enable molecular transport.^[2] In practice, pore-generation strategies typically produce a distribution of pore sizes, which can adversely affect membrane selectivity.

Nanoporous graphene analogues offer an alternative approach. Graphdiyne (GDY), a crystalline carbon allotrope with an intrinsically nanoporous structure, possesses a high density of uniformly distributed pores. These characteristics make GDY and related materials attractive candidates for membrane-based gas separations.^[3] In this work, the gas separation characteristics of graphdiyne analogues, including graphdiyne (GDY) and hydrogen-substituted graphdiyne (HsGDY), are explored. The influence of membrane structure and stacking sequence on gas permeation is discussed. Molecular size sieving gas separation is observed with GDY thin film with selectivity much higher than Knudsen selectivity. Depending on the type of graphdiyne analogue and its stacking arrangement, gas permeation can be tuned, offering opportunities to tailor membrane performance. Although controlling the stacking sequence remains challenging, ongoing studies are directed toward achieving greater control over stacking and the resulting transport properties.

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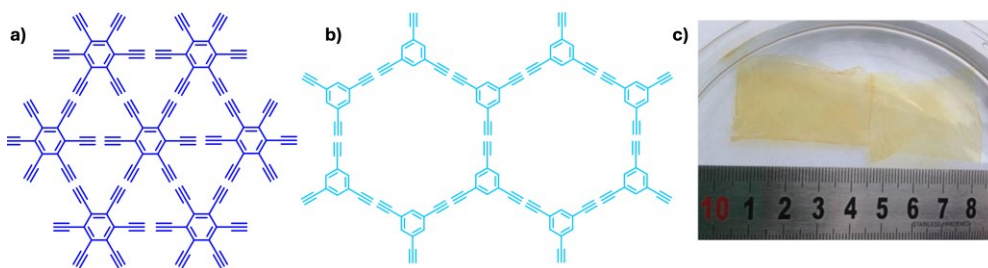


Figure 13: Nanoporous two-dimensional materials for membrane-based gas separation: a) Graphdiyne, b) Hydrogen-substituted Graphdiyne, c) 2D films of GDY.

BIOMIMETIC REVERSE OSMOSIS FOR WATER REUSE AND RESOURCE RECOVERY FROM STEEL INDUSTRY WASTEWATER

X.F. Yang, L. Lema, L.P. Mazur, C. Martínez

CETIM Technological Center, Parque empresarial de Alvedro, Rúa H, 20, 15180 Culleredo, A Coruña.

Abstract: Industrial wastewater reuse is becoming increasingly important to reduce freshwater consumption and support circular economy strategies in water-intensive sectors such as steel manufacturing. In addition to water recovery, the concentration of valuable dissolved compounds can create opportunities for downstream resource recovery and contribute to zero liquid discharge approaches¹. In this study, the performance of an aquaporin-based biomimetic reverse osmosis (BRO) membrane was evaluated for the treatment of real wastewater generated by a steel production facility and compared with a conventional reverse osmosis (CRO) membrane².

Both membranes achieved high-quality permeates suitable for industrial water reuse. Complete removal of suspended solids and turbidity was achieved, while chemical oxygen demand (COD) was reduced from approximately 51 mg L⁻¹ to below 5 mg L⁻¹. Strong rejection of dissolved salts, nutrients and metals was also observed.

The BRO membrane demonstrated significantly higher permeability than the CRO membrane, achieving 26.3 ± 0.4 LMH compared to 14 ± 1 LMH while operating at lower pressure (12 bar versus 15 bar). Water recovery reached 93–94% for both membranes.

To further improve performance, a process optimisation strategy combining closed-loop operation and temperature control at 30 °C was implemented. Under these conditions, permeability increased to 40.1 ± 0.4 LMH. Permeate quality remained unchanged, confirming that increased flux did not compromise membrane selectivity.

Besides water reuse, closed-loop BRO enabled substantial concentration of dissolved compounds in the retentate stream. Magnesium, identified as target resources for downstream recovery, reached concentration factors of approximately 18-fold. Significant enrichment of calcium, sodium, sulphate and trace metals was also observed. Magnesium concentration increased from 46.8 mg L⁻¹ in the feed to 871 mg L⁻¹ in the concentrate, while calcium increased from 113 mg L⁻¹ to 2134 mg L⁻¹. These results demonstrate the potential of BRO not only as a water reclamation technology but also as a pre-concentration step for subsequent resource recovery processes.

Overall, the study demonstrates that BRO can simultaneously achieve high-quality water reuse, reduced energy consumption and concentration of valuable resources from steel industry wastewater. The integration of advanced membrane materials

with process optimisation strategies represents a promising pathway towards circular water management and near-zero liquid discharge in industrial applications³.

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BIOMIMETIC MXENE MEMBRANES VIA CHANNEL-ENTRANCE ENGINEERING FOR HIGH-EFFICIENCY MONO-/DIVALENT CATION SEPARATION

H. Yu^{1,2}, R. Xu^{1,2}, W. Zhang^{1,2}

¹State Key Laboratory of Water Pollution Control and Green Resource Recycling, School of the Environment, Nanjing University, Nanjing 210023, China

²Research Center for Environmental Nanotechnology (ReCENT), Nanjing University, Nanjing 210023, China

Abstract: The efficient separation of monovalent and divalent cations (e.g., $\text{Li}^+/\text{Mg}^{2+}$) is critical for sustainable resource recovery and brine upgrading. While two-dimensional (2D) lamellar membranes, such as MXene ($\text{Ti}_3\text{C}_2\text{T}_x$), exhibit immense potential for ion separation, they persistently suffer from the permeability-selectivity trade-off limit: Conventional sub-nanochannel molecular functionalization enhances selectivity but severely restricts overall ion permeation. Inspired by the structural elegance of biological ion channels, this presentation introduces a novel channel-entrance-directional functionalization strategy that seamlessly integrates selective recognition with rapid ion transport¹. By directionally anchoring α -cyclodextrin (α -CD) molecules exclusively at the entrances of MXene sub-nanochannels, we constructed biomimetic ion channels. This architecture localizes recognition sites at the channel entrance to guide precise ion separation, while maintaining structurally unhindered internal pathways for fast monovalent cation transport. Consequently, the resulting membranes demonstrate exceptional mono-/divalent cation selectivity exceeding 10^3 , while preserving high permeability for monovalent ions, surpassing the trade-off limits of current separation membranes. Furthermore, combined experimental and computational investigations reveal a paradigm-shifting mechanism: rather than relying predominantly on conventional ion-molecule binding energy differences, the highly efficient separation is primarily driven by alterations in ion transport pathways dictated by distinct ion hydration structures within the sub-nanochannels. This work establishes channel-entrance engineering as a highly effective platform for advancing environmental materials, offering new mechanistic insights and scalable solutions for critical ion separation technologies.

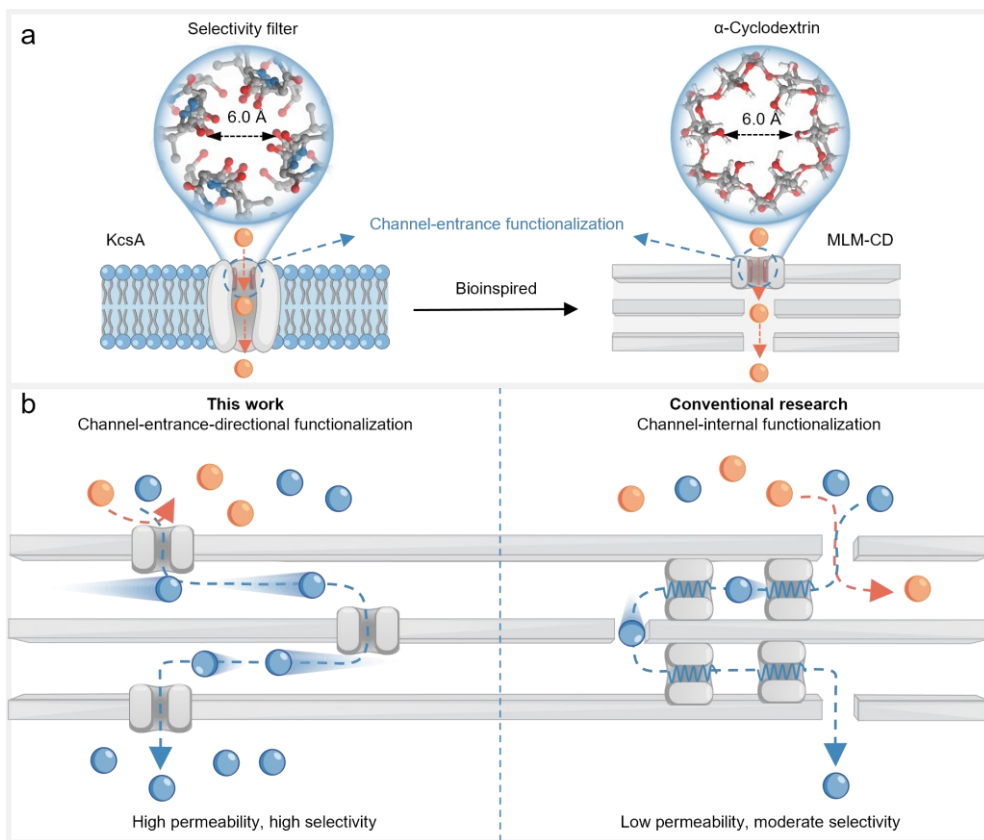


Figure. 1 Design principle and functionalization strategies for ion-separation membranes. **a**, Schematic comparison between the KcsA potassium channel and the designed membrane functionalized with α -cyclodextrin (α -CD). The spacing between hydroxyl oxygen atoms in α -CD (~ 6.0 Å) resembles the ion-coordination environment in biological selectivity filters. **b**, Comparison of functionalization strategies. Left, channel-entrance-directional functionalization allows fast transport of monovalent cations through unmodified interlayer channels while impeding divalent ions. Right, channel-internal functionalization obstructs ion transport pathways and raises energy barriers, compromising permeability. Blue and orange spheres represent monovalent and divalent cations, respectively, the grey capsules denote α -CD, and dashed arrows indicate representative ion transport pathways.

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COMPUTATIONAL SCREENING OF METAL-ORGANIC FRAMEWORKS FOR SURFACE MODIFICATION OF POLYMERIC MEMBRANES

K. Zeru¹, I. Kass², J. Young³, R. Kasher¹

¹Department of Desalination and Water Treatment, Zuckerberg Institute for Water Research, The Jacob Blaustein Institutes for Desert Research, Ben Gurion University of the Negev, Midreshet Ben-Gurion, 8499000, Israel (kisanetz@post.bgu.ac.il)

²Ilse Katz Institute for Nanoscale Science & Technology, Ben Gurion University of the Negev, Beer Sheba, Israel

³Department of Chemical and Materials Engineering, New Jersey Institute of Technology, Newark, New Jersey 07102, United States

Abstract: Metal–organic frameworks (MOFs) have emerged as promising materials for membrane fabrication due to their crystallinity, structural tunability, high internal surface area, and chemical versatility. The abundance of available MOFs presents both an opportunity and a great challenge, as identifying the most suitable MOF for a given polymeric membrane is highly challenging. Here, we show a high-throughput computational screening to identify MOFs with optimal properties for surface modification of polymeric membranes.

A high-throughput computational screening was designed to identify zinc-based zeolitic imidazolate frameworks (ZIFs) MOFs from the computation-Ready, Experimental (CoREMOF) database that could be integrated with PAN ultrafiltration membranes. Out of 4764 MOFs, only 220 met the initial chemistry criteria, accounting for 4.69% of the total entries (Table 1). These MOFs were further examined for lattice compatibility using tolerances defined by Tarzia *et al* [1]. Supercells of both PAN and ZIFs were constructed, and the Zur and McGill algorithms were applied to identify nearly identical lattice vectors and angles, enabling the identification of binding planes. The supercell lattice matching step resulted in 100 MOFs, which are only half of the chemistry-compatible ZIFs. These ZIFs were further analyzed if they have chemical compatibility at the interface, with potential binding pairs identified between nitrogen atoms on PAN and zinc atoms in the MOFs. The interfacial screening identified 54 promising ZIFs, which were reduced to 10 candidates after applying synthesis feasibility criteria and the availability of commercial ligands.

Table 1. Selection through the computational screening process from 4764 MOFs of the CoREMOF database.

Screening steps	No. of MOFs passed	% of MOFs from the database
Chemistry-based screening step	220	4.69
Lattice matching step	110	2.34
Interface matching step	54	1.15

Synthesis-based screening step	10	0.21
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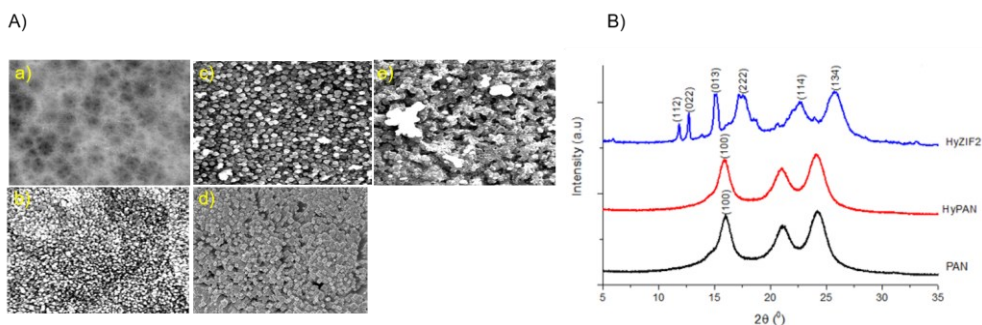


Fig 1. A) SEM images of a) pristine PAN, b) HyZIF2, c) HyZIF8, d) HyZIF2G, e) HyZIF8G membranes. B) XRD patterns of PAN, hydrolyzed PAN, HyZIF2G membranes.

Experimental validation involved in situ growth of ZIFs on the hydrolyzed PAN ultrafiltration membranes, followed by methacrylate hydrogel coating via redox-initiated graft polymerization to enhance the MOF film stability under water flow conditions [2]. Characterization using SEM, ATR-FTIR, and XRD confirmed the formation of uniform MOF layers. In the SEM analysis, the pristine membrane showed a smooth surface, while the MOF-modified membranes are characterized by a uniform distribution of sharp, well-defined crystals (Fig 1A). XRD confirmed crystalline structures with sharp peaks in the modified membrane, while pristine and hydrolyzed PAN showed broad peaks (Fig 1B). In situ growth of ZIF-2 and ZIF-8 films on the hydrolyzed PAN membrane produced robust, stable MOF films, which validated the computational screening approach. The ZIF-2 and ZIF-8 modified membranes grafted by methacrylate hydrogels, namely HyZIF2G and HyZIF8G membranes, respectively, achieved an excellent filtration performance compared to the pristine PAN membrane. HyZIF2G and HyZIF8G showed strong Congo red rejection under both saline and non-saline conditions, as shown in Fig 2A. This improved rejection efficiency of the nanocomposite membranes is attributed to the high-water permeability and adsorption capability of the embedded ZIF-2/ZIF-8 nanoparticles. The molecular-weight cutoff of HyZIF2G and HyZIF8G was lower than that of the pristine PAN membrane, implying that the incorporation of ZIF nanoparticles narrowed pore sizes and enhanced selectivity. The MOF membranes showed enhanced antifouling performance with high flux recovery across three cycles, and maintained consistent Congo red rejection during extended filtration, confirming long-term stability, Fig 2B.

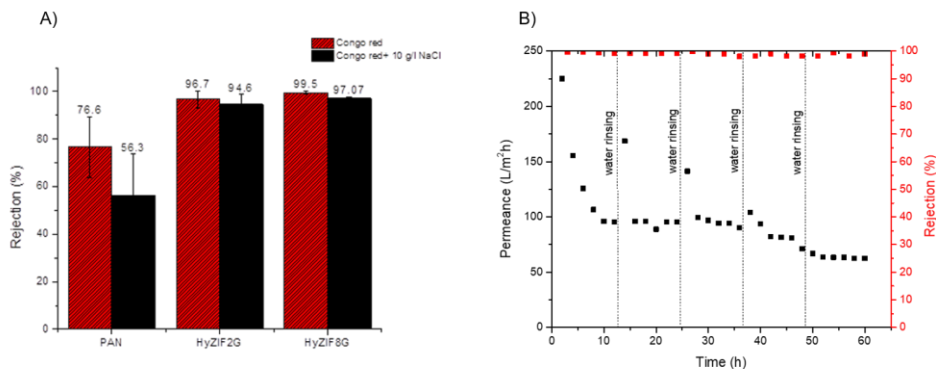


Figure 2. A) Separation of Congo red (100ppm) using the pristine PAN, HyZIF2G, and HyZIF8G membranes with and without 10 g/l NaCl. B) Long-term filtration of Congo red (100 ppm) using HyZIF8G membrane

This integrated computational–experimental approach provides a versatile strategy for rational design of MOF-modified membranes and expands the toolkit for surface engineering of water treatment polymeric membranes. The computational screening prediction, accompanied by experimental validation, may be broadly applicable to other MOF–polymeric membrane systems and offers an advanced membrane modification technology that can be used for water and wastewater treatment.

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TUNING NANOFILTRATION MEMBRANES FOR OPTIMAL OMP REMOVAL AND SALT PASSAGE

N.M. Zwart, D. Sudmalis, N. Sutton, J.H. Bitter, A. Asadi Tashvigh

Wageningen University, Bornse Weiland 9, 6708 WG Wageningen, Netherlands

The authors did not consent to the publication of this abstract.

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CFD INVESTIGATION OF $\text{Mg}(\text{OH})_2$ PRECIPITATION AND WATER-SPLITTING PHENOMENA IN SELECTIVE ELECTRODIALYSIS FOR LI BRINE PROCESSING

A. Asadi, J. López^{1,2}, H. Bazargan Harandi^{1,2}, R. Torres³, J. L. Cortina Pallás^{1,2,4}

¹Chemical Engineering Department, Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politècnica de Catalunya (UPC)-BarcelonaTECH, Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain (hesam.bazargan@upc.edu)

²Barcelona Research Center for Multiscale Science and Engineering (CCEM), Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain

³Department of Fluid Mechanics, Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politècnica de Catalunya (UPC)-BarcelonaTECH, Av. Eduard Maristany 16, Campus Diagonal-Besòs, 08019 Barcelona, Spain

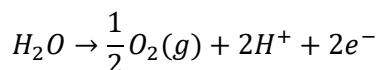
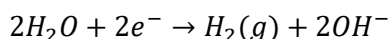
⁴CETAqua, Carretera d'Esplugues, 75, 08940 Cornellà de Llobregat, Spain

Abstract: As demand for Lithium-ion batteries and renewable energy storage continues to grow, lithium has become one of the most strategically important materials for modern energy technologies. Approximately 60% of the world's lithium resources are located in the Lithium Triangle of South America, where lithium is extracted from naturally occurring brines. However, these brines contain high concentrations of magnesium, which complicate lithium recovery and purity as carbonate during crystallization. Therefore, efficient separation of Mg^{2+} from Li^+ is an essential step for producing high-purity lithium compounds.

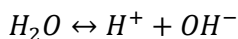
Electrodialysis has emerged as a promising technology for the selective separation and recovery of ions from industrial effluents and saline streams. Among the different electrodialysis configurations, selective electrodialysis (SED), equipped with monoselective ion-exchange membranes (IEMs), can separate double-charge ions from single-charge ones without requiring any chemical consumption. However, the presence of Mg^{2+} ions poses significant challenges to the operation of SED. Under alkaline conditions, Mg^{2+} can precipitate as $\text{Mg}(\text{OH})_2(\text{s})$, leading to scaling on the surfaces of IEMs and electrodes, which can substantially reduce process efficiency and limit the applicability of SED for lithium recovery. In addition, Mg^{2+} ions are known to promote water-splitting reactions at membrane interfaces, resulting in localized pH variations that further increase the risk of $\text{Mg}(\text{OH})_2(\text{s})$ precipitation and scaling¹. The precipitation process itself alters the solution chemistry and pH. Therefore, this study delves into the application of SED to separate Mg^{2+} and Li^+ ions from Lithium Triangle brines by developing a comprehensive numerical model that couples ion transport with electrochemical, water-splitting, and precipitation reactions to capture the localized effects of Mg^{2+} precipitation on SED performance and to assess the potential for membrane scaling.

To investigate these coupled phenomena, a two-dimensional CFD model of a SED system was developed in COMSOL Multiphysics 6.3. The modeled stack consists of 3 cell pairs, which include three dilute channels, three concentrate channels, two electrode-rinsing solution (ERS) channels, four cation-exchange membranes (CEMs), and three anion-exchange membranes (AEMs), as illustrated in Figure 1. To ensure accurate representation of the system behavior, all relevant transport processes and electrochemical reactions were incorporated into the model. The governing reactions considered in the simulations are listed below:

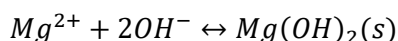
1. Electrochemical reactions:



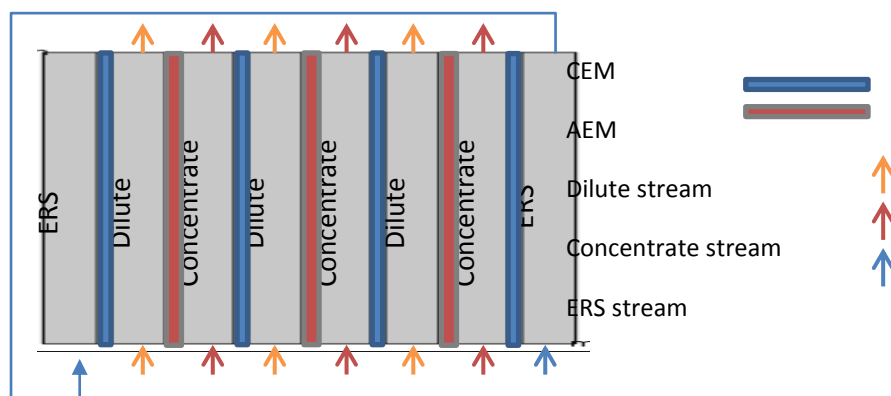
2. Water self-dissociation:



3. Magnesium hydroxide precipitation²:



Electrochemical reactions were imposed at the electrode surfaces, while $Mg(OH)_2(s)$ precipitation reactions were incorporated within the flow channels. Water-splitting reactions were considered in both the membrane and channel domains to account for H^+ and OH^- generation throughout the system. Furthermore, to capture the possible enhancement of water dissociation under strong electric



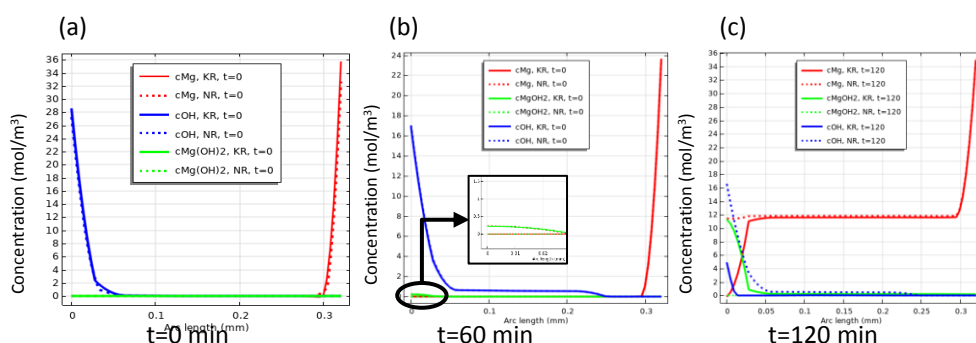
fields, the Wien effect was incorporated into the model.

Figure 1. Schematic configuration of the multi-compartment SED.

Following the development of the comprehensive SED model, the simulation results were analyzed to investigate the formation of $Mg(OH)_2(s)$ scaling and its impact on the local ion distribution. Since $Mg(OH)_2(s)$ precipitation occurs under

alkaline conditions, scaling is expected to primarily occur in the cathode channel, where hydroxide ions are generated through electrochemical reactions.

Figure 2 presents the concentration distributions of Mg^{2+} , OH^- , and $\text{Mg}(\text{OH})_2(\text{s})$ at different operating times ($t = 0, 60$, and 120 min). Across all time steps, OH^- generation due to the cathodic electrochemical reaction is evident at the cathode surface ($x = 0$). At the beginning of the process ($t = 0$), the Mg^{2+} concentration in the cathode channel is negligible. As Mg^{2+} ions migrate from the adjacent dilute channel, they accumulate near the CEM surface ($x = 0.32$ mm) and



do not initially reach the cathode surface, where OH^- ions are concentrated. Consequently, due to mass-transfer limitations and the spatial separation of Mg^{2+} and OH^- ions, $\text{Mg}(\text{OH})_2(\text{s})$ precipitation does not occur at this stage. As operation proceeds, the Mg^{2+} concentration in the cathode channel gradually increases, allowing Mg^{2+} to reach regions with high OH^- concentrations near the cathode surface. As a result, $\text{Mg}(\text{OH})_2(\text{s})$ precipitation is initiated and progressively intensifies with time. As illustrated in Figure 2(c), the formation of $\text{Mg}(\text{OH})_2(\text{s})$ consumes both Mg^{2+} and OH^- ions, altering their local concentration profiles and leading to a pH drop adjacent to the cathode surface.

Figure 2. OH^- , Mg^{2+} , and $\text{Mg}(\text{OH})_2(\text{s})$ concentrations at cathode channel at (a) $t=0$ min, (b) $t=60$ min, and (c) $t=120$ min. $X = 0$ represents the cathode surface, and $x = 0.32$ represents the surface of CEM facing the cathode.

Although $\text{Mg}(\text{OH})_2(\text{s})$ precipitation is generally associated with the alkaline conditions present in the cathode channel, the simulations reveal that precipitation can also occur within the dilute and concentrate channels despite their overall acidic bulk pH. This behavior is attributed to localized pH variations induced by water-splitting reactions at the IEM interfaces. Previous studies have reported that the presence of multivalent ions, such as Mg^{2+} and Ca^{2+} , can significantly enhance water dissociation at membrane surfaces, leading to the generation of H^+ and OH^- ions¹.

As shown in Figure 3 (a), water splitting occurs at both the CEM and AEM surfaces in the dilute channel, creating localized acidic and alkaline regions adjacent to the membrane interfaces. In particular, the accumulation of OH^- ions near the membrane surface results in a local increase in pH (see Figure 3 (b)), even though the bulk solution remains acidic. These localized alkaline regions provide

favorable conditions for $\text{Mg}(\text{OH})_2(\text{s})$ precipitation, as illustrated in Figure 3(b). Consequently, OH^- consumption through precipitation and the associated water-splitting reactions modify the pH distribution throughout the stack, leading to the pH drop in the dilute and concentrate channels.

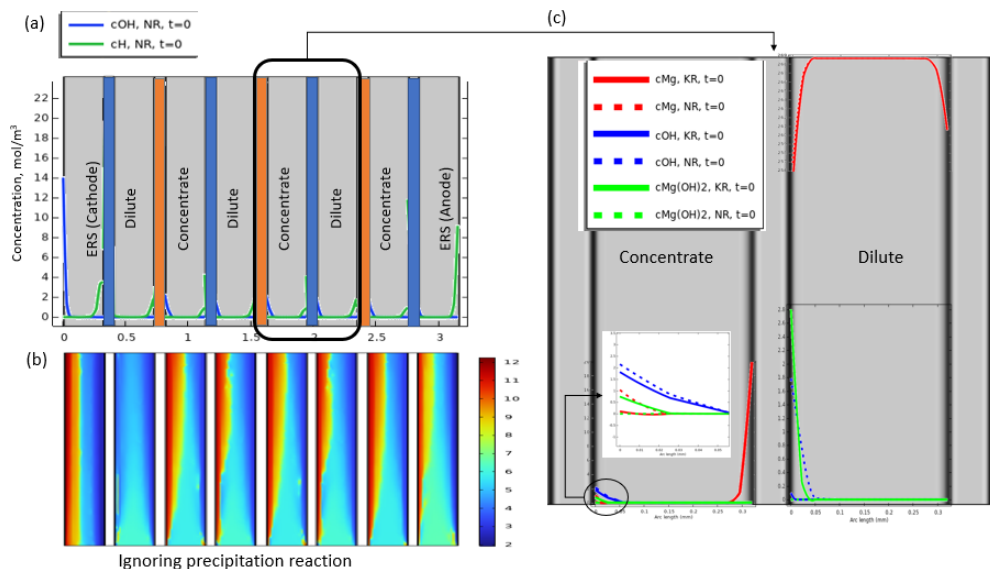


Figure 3. Water splitting and its effect on the $\text{Mg}(\text{OH})_2(\text{s})$ precipitation by investigation (a) H^+ and OH^- concentration through SED, (b) pH variation through SED, and (c) Mg^{2+} , OH^- and $\text{Mg}(\text{OH})_2(\text{s})$ concentrations in a cell.

Figure 4 compares the $\text{Mg}(\text{OH})_2(\text{s})$ concentration distributions at three operating times ($t = 0, 60$, and 120 min), illustrating the evolution of precipitation locations throughout the SED process. At the initial stage of operation ($t = 0$ min), $\text{Mg}(\text{OH})_2(\text{s})$ precipitation occurs primarily near the IEMs interfaces in the dilute channel. This behavior is attributed to water-splitting reactions, which generate localized alkaline regions favorable for $\text{Mg}(\text{OH})_2(\text{s})$ formation despite the acidic bulk conditions. As the SED operation progresses, the Mg^{2+} concentration in the dilute channel gradually decreases, reducing the field-enhanced water-splitting effect at the membrane interfaces. Consequently, the extent of localized $\text{Mg}(\text{OH})_2(\text{s})$ precipitation in the dilute channel becomes negligible after approximately 60 min of operation. In contrast, precipitation increasingly occurs in the cathode channel, where the electrochemical generation of OH^- maintains strongly alkaline conditions ($\text{pH} > 10$). As a result, $\text{Mg}(\text{OH})_2(\text{s})$ formation becomes dominated by cathodic precipitation at longer operating times. This shift in the dominant precipitation location explains the observed increase in magnesium concentration within the concentrate channel, as less magnesium is lost through precipitation in the dilute and concentrate channel and a greater fraction is transported across the membrane system.

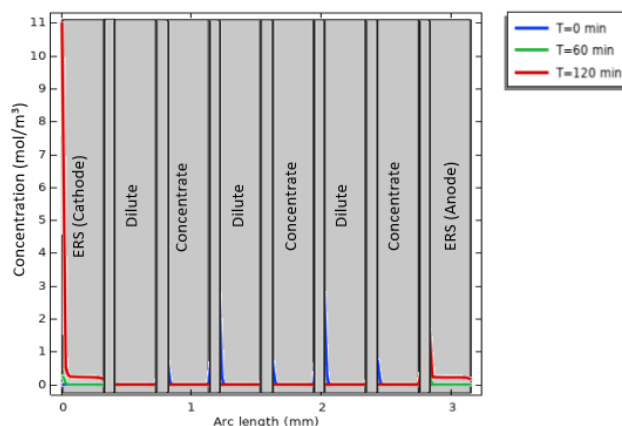


Figure 4. $\text{Mg}(\text{OH})_2$ concentration at $t=0$, 60, and 120 min.

Conclusions

In this study, a comprehensive 2D CFD model of a SED was developed to investigate the coupled effects of ion transport, water splitting, and $\text{Mg}(\text{OH})_2(\text{s})$ precipitation during $\text{Mg}^{2+}/\text{Li}^+$ separation. The results demonstrated that localized water-splitting generate significant pH gradients near membrane surfaces, leading to $\text{Mg}(\text{OH})_2(\text{s})$ precipitation even in channels with acidic bulk pH. As operation progresses, $\text{Mg}(\text{OH})_2(\text{s})$ scaling becomes more pronounced in the cathode channel due to the electrochemical reactions. The dominant precipitation mechanism shifts from membrane-induced precipitation in the dilute channel to cathode-induced precipitation as the operation proceeds.

Acknowledgements

This project has been financed by the Spanish Agency of Research (AEI) through the project “*Development of upcycling approaches in the agri-food and process industries to promote on-site and sustainable chemicals production*” (UPCYCLING, PID2023-147160OB-C21). Support for the research of J.L. Cortina was also received through the “ICREA Academia” recognition for excellence in research funded by the Generalitat de Catalunya. Additionally, the authors acknowledge the project CEX2023-001300-M funded by MCIN/AEI / 10.13039/501100011033. Finally, the Catalan Government (ref. 2021-SGR-596) is also acknowledged.

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HOW SURFACE CHEMISTRY CONTROLS IN-SITU GROWTH OF UiO-66 FOR HIGH-PERFORMANCE MOF MEMBRANES

S. Ataklti, R. Kasher

Department of Desalination and Water Treatment, Zuckerberg Institute for Water Research, The Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Israel (solyanaataklti3@gmail.com)

Abstract: Achieving continuous, well-integrated metal-organic framework (MOF) separation layers on polymeric supports remains a principal challenge, limiting the practical implementation of MOF-based membranes¹. Although synthesis parameters such as precursor concentration and reaction temperature have been widely investigated, the role of substrate surface chemistry in nucleation and film formation remains insufficiently understood. Zirconium-based UiO-66, valued for its chemical stability and well-defined microporosity, provides an attractive model system for probing surface-directed crystal growth². Herein, we systematically investigate how substrate chemical functionality governs the in-situ growth of UiO-66. Gold-coated model substrates functionalized with self-assembled monolayers terminated with carboxyl (-COOH), amino (-NH₂), hydroxyl (-OH), and methyl (-CH₃) groups were used to isolate the effects of surface chemistry on nucleation, crystal orientation, film continuity, and interfacial integration³. These mechanistic insights were translated to polyacrylonitrile (PAN) membranes through controlled alkaline hydrolysis, generating carboxyl-rich surfaces that favor zirconium-precursor adsorption and direct UiO-66 growth on a polymeric support. Materials were characterized by X-ray diffraction and electron microscopy, followed by evaluation of water permeance and dye-salt separation performance. UiO-66 nucleated on all functionalized substrates; however, the -COOH terminated surface produced markedly superior crystallinity and film coverage, evidenced by a pronounced (111) diffraction peak at $2\theta = 7.4^\circ$ and well-intergrown octahedral crystals. Film quality followed the order -COOH > -NH₂ > -OH > -CH₃, confirming substrate chemistry is a decisive parameter under the investigated conditions. Consistent with the model-surface results, hydrolyzed PAN membranes promoted preferential (111)-oriented UiO-66 crystallization and formation of a well-integrated MOF layer. The resulting UiO-66/PAN membrane achieved outstanding 99.9% Congo red rejection with a high pure water permeance of 124 L.m⁻².h⁻¹.bar⁻¹ and over 96% NaCl passage, confirming that interfacial chemistry control translates into high separation performance. This work establishes substrate surface chemistry as a key design parameter for engineering continuous MOF layers, offering a transferable strategy for sustainable water treatment.

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RATIOMETRIC LUMINESCENT OXYGEN-SENSITIVE POLYAMIDE MEMBRANE FOR IN SITU MONITORING OF EARLY BIOFOULING

H. Ayele¹, J. Lima¹, L. Giorno², J. Crespo^{1,3}, C. Portugal¹

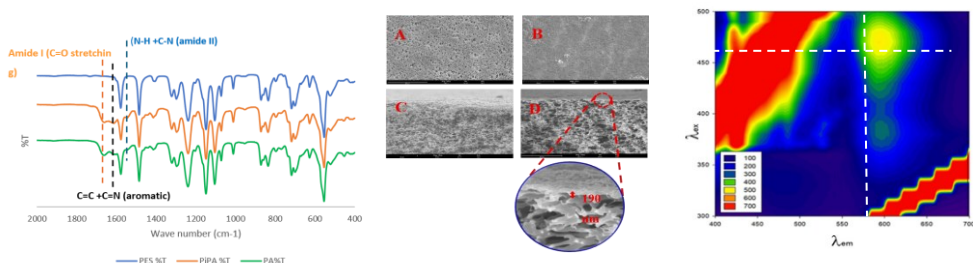
¹LAQV, Departamento de Química, NOVA School of Science and Technology, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

²Institute on Membrane Technology (CNR-ITM), c/o University of Calabria ITM-CNR, Italy

³Instituto de Biologia Experimental e Tecnológica, Universidade Nova de Lisboa, 2829-516 Oeiras, Portugal

Abstract: RO and NF are established pressure-driven membrane technologies with broad application in bioprocessing for water purification, product and concentration recovery because of their selectivity and energy efficiency[1]. However, their long-term operation is constrained by biofouling[2]. The attachment and growth of microorganisms on membrane surfaces compromise product quality, increase energy consumption, and shorten membrane lifespan. It is often difficult to detect early-stage biofouling during operation using conventional performance indicators, such as TMP rise and flux decline. Typically, biofouling becomes apparent only after it is established, allowing microbial colonization to progress unnoticed during its early stage[3]. During early colonization, microorganisms consume dissolved oxygen via aerobic respiration, creating localized oxygen depletion at the membrane-solution interface. This occurs before measurable hydraulic changes and therefore provides a direct and sensitive indicator of biological activity[4]. This work aims to develop a real-time, non-invasive monitoring strategy to track dissolved oxygen dynamics associated with microbial colonization at the membrane-solution interface.

Ratiometric oxygen-sensitive thin film composite (TFC) membranes (PiPA) were developed by incorporating chemically anchored fluorophores into the polyamide (PA) layer during interfacial polymerization (IP) on a porous PES support. An oxygen-sensitive ruthenium(II) polypyridyl complex was co-incorporated with an oxygen-insensitive coumarin-based probe serving as an internal reference. The sensing mechanism is based on oxygen-dependent luminescence quenching of the ruthenium probe, which generates the sensing signal. The reference compensates for fluctuations arising from local environmental factors, such

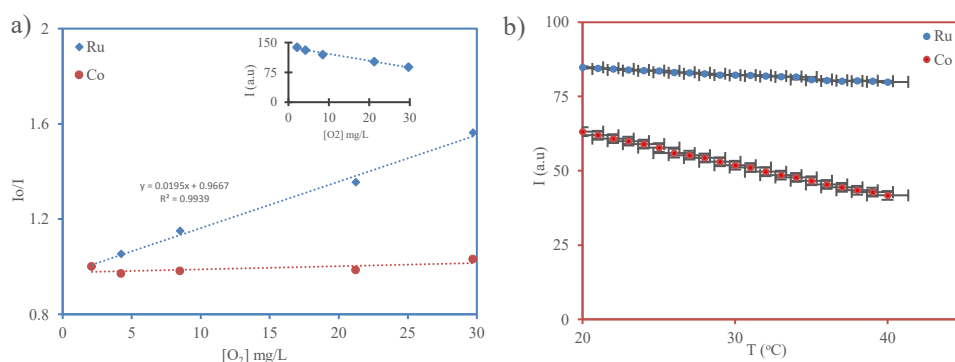


as temperature and probe distribution heterogeneity.

a) b) c)

Fig.1 a) ATR-FTIR spectra b) SEM image of surface and cross section of PES (A,C) and PiPA (B,D) c) Fluorescence EEM of PiPA membrane with probes at 21% O₂

ATR-FTIR spectra confirmed the successful formation of the aromatic PA layer after probe incorporation, with characteristic amide I (1660-1680 cm⁻¹) and amide II (1570-1590 cm⁻¹) bands comparable to those of the unmodified PA membrane. Probe-integrated membranes showed a slight change in amide II band intensity due to overlap with the C=N stretching vibration of the ruthenium complex ligands. SEM observations revealed that incorporating the sensing probes did not introduce visible defects or significant changes in membrane morphology. Fluorescence spectroscopy confirmed strong emission and clear spectral separation.



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Fig.2 (a) Oxygen sensitivity at 20 °C and (b) temperature response at 21% O₂ of the Ru and Coumarin emission signal in the PiPA membrane under filtration conditions.

The Ru emission intensity decreased with increasing dissolved oxygen concentration, following Stern-Volmer behavior ($K_{sv} = 0.195$ L/mg, $R^2 = 0.994$) over a range of 2–30 mg/L at 20 °C, while the coumarin emission remained unaffected, confirming its suitability as a reference signal. Both probes showed changes in emission intensity (5.7% for Ru and 34% for coumarin) over the temperature range of 20–30 °C at a fixed oxygen concentration (21%). Dye leaching remained low, with a cumulative release of < 0.6% over 7 days of immersion (orbital shaker at 150 RPM), indicating stable covalent incorporation. The membranes showed a permeance of 0.5 LMH/bar and a NaCl rejection of 96%, consistent with PA-based RO membranes[1].

These results indicate the feasibility of integrating a ratiometric oxygen sensor into the PA network without compromising membrane performance. By combining separation and sensing functions in a single membrane, the platform enables real-time, in situ monitoring of the membrane interface, providing a valuable tool for early detection of biofouling in pressure-driven membrane processes.

Keywords: Ratiometric oxygen sensing; Luminescence probe; Biofouling monitoring; Polyamide membrane.

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INTEGRATED ELECTRODIALYSIS – PRECIPITATION TECHNOLOGY FOR PHOSPHORUS RECOVERY AND VALORISATION OF SALINE GLYCOL WASTEWATER

R. Barannikov, T. Kotala

MemBrain, s.r.o., Pod Vinicí 87, 471 27 Stráž pod Ralskem, Czech Republic

(ruslan.barannikov@membrain.cz)

Abstract: Industrial wastewater generated during tantalum capacitor production is a complex multicomponent stream containing monoethylene glycol (MEG), phosphates, organic acid salts, mainly formates and acetates, and minor inorganic ions. The initial wastewater contains approximately 37 wt.% MEG, 1.0 wt.% phosphates and 15 g/L total dissolved solids (TDS). This stream is currently treated by primary electrodialysis (ED1), producing a glycol-rich diluate containing approximately 36 wt.% MEG, 0.2 wt.% phosphates and 3 g/L TDS. Although ED1 enables recovery of most of the glycol fraction¹, it also generates a concentrated residual stream containing approximately 2 wt.% MEG, 2.2 wt.% phosphates and 38 g/L TDS. This ED1 concentrate represents a problematic waste stream due to its high phosphate and salt content, but also a potential source of recoverable materials.

This work presents the evaluation and pilot verification of an integrated technology concept developed for the treatment and valorisation of this ED1 concentrate using real industrial wastewater-derived material. The process combines selective phosphate precipitation with secondary electrodialysis (ED2). In the first step, phosphates are precipitated using calcium hydroxide, forming a solid calcium phosphate product with hydroxyapatite as the dominant phase². After precipitation and solid-liquid separation, the treated liquid phase contains approximately 2 wt.% MEG, 0.1 wt.% phosphates and 26 g/L TDS, confirming substantial phosphorus removal from the ED1 concentrate.

The resulting filtrate is then adjusted to the required pH and processed by ED2. This step produces a low-salinity diluate and a concentrate enriched mainly in sodium formate and sodium acetate. The final ED2 diluate contains approximately 2 wt.% MEG, 0.003 wt.% phosphates and 1.5 g/L TDS, demonstrating further reduction of phosphate concentration and dissolved solids. The ED2 concentrate contains <0.1 wt.% MEG, approximately 0.15 wt.% phosphates, 1.5 wt.% acetate and 3.7 wt.% formate, indicating effective concentration of organic acid salts with only minimal undesired glycol transport into concentrate.

Pilot testing confirmed the technical feasibility of the proposed treatment route and provided data for material and energy balances, operational assessment and scale-up evaluation. The process converted the original ED1 concentrate into three defined output streams: a phosphorus-rich calcium phosphate solid, a low-salinity ED2 diluate and an organic salt-rich ED2 concentrate. Product and stream quality were verified using complementary analytical techniques, including ionic

composition and elemental analysis of the precipitated solid. The results confirmed effective redistribution of target components and supported the formation of a phosphorus-rich calcium phosphate product.

The proved technology concept was also assessed from an operational and economic perspective, including membrane area requirements, energy demand, chemical consumption and process integration. Overall, the results demonstrate that the proposed electrodialysis – precipitation process provides a technically feasible circular-economy route for phosphate-rich ED concentrate from glycol-based industrial wastewater, combining phosphorus recovery, reduction of residual wastewater load and generation of potentially valuable by-products^{3,4}.

This result was achieved with institutional support for the long-term conceptual development of a research organization provided by the Ministry of Industry and Trade of the Czech Republic.

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EFFECT OF FUNCTIONALIZED MEMBRANES FOR ENHANCED SEPARATION PERFORMANCE

M. Barooah

School of Engineering, Assam Science and Technology University, Guwahati, India
(mridusmita@astu.ac.in)

Abstract: Functionalized membranes play a crucial role in enhancing separation performance across various industries, from water purification to pharmaceuticals and beyond. Functionalization allows membranes to selectively separate specific molecules or ions based on size, charge, polarity, or other chemical properties. Functionalization can enhance membrane permeability, allowing for increased flux rates. By modifying the membrane surface at a molecular level, functional groups can reduce fouling and enhance the flow of substances through the membrane, thereby improving separation efficiency. Functionalized membranes often exhibit greater chemical stability compared to unmodified membranes. This increased stability can allow for longer operational lifetimes and better performance under harsh conditions, such as high temperatures or extreme pH levels. Functionalization allows for the creation of membranes with enhanced selectivity and efficiency in separating target compounds from complex mixtures. This can lead to higher purity in the separated components and reduced energy consumption in separation processes. Apart from that these membranes can contribute to environmental sustainability by enabling more efficient separation processes, reducing energy consumption, and minimizing the need for chemical additives. This can lead to lower operating costs and reduced environmental impact compared to traditional separation methods. The addition of modifying agents also plays a pivotal role in improving the gas transport performance (CO_2 permeability as well as CO_2/N_2 selectivity). A critical discussion on the fillers used and its consecutive modification has been discussed in detail in this following work. The influence of these material on the overall physicochemical property of the membrane material has been discussed in detail.

- This article provides a comprehensive review with respect to the utility of MMMs (constituting a bulk and a filler scattered phase) towards CO_2 separation. A thorough analysis was carried out with respect to the filler particles in the MMM and their ability to enhance the CO_2/N_2 gas transport properties.
- This study provides alternate advanced fabrication methods to achieve MMMs with high performance in gas separation.
- Modifying agents have been added to improve the physico-chemical properties of the membrane. As indicated, the size, shape and porosity of the filler particles significantly influence the gas separation characteristics of the MMMs. Characterization studies concluded that the functionalization agents improve the membrane performance.

- The high-end separation technology provided opportunity for large-scale gas separation operation and a very viable approach to be replaced with the conventional separation technology in terms of physico-chemical property enhancement and gas separation performance.

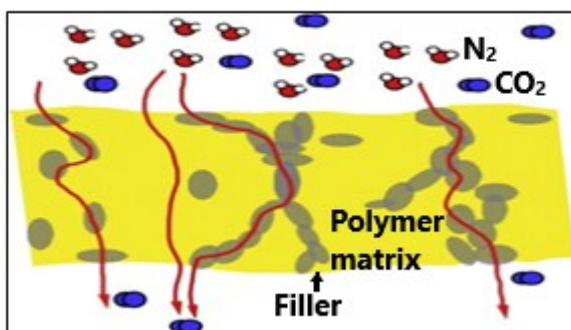


Figure: Schematic diagram of gas transport in a mixed matrix membrane comprising of a polymer matrix and filler (ideal condition)

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OPTIMIZATION OF NON-DISPERSIVE SOLVENT EXTRACTION BY SPIRAL HOLLOW FIBER CONTACTOR

S. Bey¹, N. Zeghouati¹, A. Figoli², A. Criscuoli²

¹Laboratory of Membrane Processes and Techniques of Separation and Recovery, Faculty of Technology, University of Bejaia, 06000, Bejaia, Algeria (saidbey06@yahoo.com; said.bey@univ-bejaia.dz)

²Institute on Membrane Technology (ITM-CNR), Via P. Bucci 17/C, 87036 Rende (CS), Italy

Abstract: In the present study, a spiral hollow fiber membrane contactor was successfully used for chromium (VI) removal from aqueous solution with Aliquat 336 as an extractant. A two-level full factorial design is used to study the effect of four factors such as chromium concentration (50 and 100 ppm), aqueous phase flow rate (0.125 and 0.25 ml/s), temperature (20 and 40) and the concentration of Aliquat 336 (10 and 30%) and their interactions on chromium extraction efficiency. The results showed that the temperature presents the most significant effect in this system, while the concentration of chromium and the concentration of the Aliquat 336 had a negative influence on the chromium extraction efficiency. The predicted response generated by the mathematical model showed a satisfactory and rational agreement with the experimental data with a correlation coefficient of 99.8%. Process optimization was performed for maximum extraction efficiency of 100% under the optimal operating conditions, which are: Feed concentration at 100 ppm, temperature at 40°C, flow rate at 0.25 ml/s and the concentration of the organic phase at 29.41%.

POLYMER INCLUSION MEMBRANES BASED ON POLYLACTIC ACID

P. Bikić, S. Perinović Jozić, I. Šakić, I. Krešić, M. Jakić

University of Split, Faculty of Chemistry and Technology, Ruđera Boškovića 35, Split, Croatia (sanja@ktf-split.hr, <https://www.ktf.unist.hr/>)

Abstract: Polymer inclusion membranes (PIMs) are a type of liquid membranes designed to eliminate inadequate mechanical stability or the risk of carrier leakage with an efficient metal ions removal from wastewaters.¹ Biodegradable polymers presents alternative to commonly used non-biodegradable polymers, but exhibit poor mechanical properties that can be modified.² This provides great opportunity for the further investigations. In this study, polylactic acid (PLA) with different amount of bis(2-ethylhexyl) phosphate (D2EHP) as an ion liquid carrier or extractant (10, 20, 30 and 40 wt%) was used for PIMs preparation. These components were integrated through the solution casting method and obtained materials were evaluated for their potential as PIMs. Optimization of the processing procedure during preparation of the membranes, in first place mixing and drying, has proved as very important issue. The variation of mixing time significantly changes the material integrity. The most stable membrane was the one with 10 wt% of D2EHP. Various analytical methods, including differential scanning calorimetry (DSC), thermogravimetry (TG) and infrared spectroscopy with Fourier transformation (FT-IR) were employed to explore the structure-property relationships of the PIMs. DSC analyses revealed development of semicrystalline membrane structures with dominant amorphous phase. The crystallization process of PLA during heating and cooling is under the influence of the carrier. D2EHP acts as plasticizer within the PLA matrix. Depression of the glass transition and the melting is evident and indicates the miscibility of the components, but the change is the same for every amount of the carrier. Extending the mixing time of solutions in the membrane processing has significant impact on the thermal properties of PLA membranes and has to be further investigated. According to the TG analysis drying of the membranes has to be prolonged to eliminate residual 5% of the solvent. Pure PLA has one degradation stage while with the carrier has two degradation stages. Thermal stability of the carrier is better when it is incorporated in the PLA membrane, especially this is the case in the membranes with 10 and 20 wt% of D2EHP. This effect proofs the existence of the secondary chemical bonds that was also evident from the DSC analysis. Thermal stability of the PLA was improved in the membrane with 10 wt% of the carrier. The membranes with the prolonged mixing time also shows better thermal stability of D2EHP and PLA. The most pronounced effect is noticed in membrane with 10 wt% of the carrier. It is evident that longer mixing time of the components in the solution provides different membrane morphology that has different thermal properties. The FT-IR analysis wasn't unambiguous since the PLA vibration bands important for showing secondary bonds overlap with the vibration bands of the D2EHP. The changes in the wavenumbers are observed, but it cannot be determined with certainty whether

these are interactions present or whether this is just the result of the presence of the D2EHP and the increase of its content.

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Acknowledgements: *This research is funded by European Union – NextGenerationEU project (No. IP-UNIST-29).*

MECHANISTIC ORIGIN OF CHIRAL RECOGNITION: INTRINSIC AND TEMPLATE AFFINITY IN ALD-MODIFIED POLYCARBONATE MEMBRANES

L. Brožová¹, J. Škvára^{2,3}, M. Otmar¹, P. Izák^{2,4}

¹Institute of Macromolecular Chemistry, Academy of Sciences of the Czech Republic, Heyrovský Sq. 2, 162 06 Prague 6, Czech Republic (brozova@imc.cas.cz, www.imc.cas.cz)

²Institute of Chemical Process Fundamentals, of the Czech Academy of Sciences, v.v.i. Rozvojová 135, 165 00 Prague 6 – Suchbát, Czech Republic)

³Faculty of Science, Jan Evangelista Purkyně University in Ústí nad Labem, Pasteurova 1, 400 96 Ústí nad Labem, Czech Republic

⁴Department of Physical Chemistry, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic

Abstract: Chiral separation remains a persistent challenge in chemical and pharmaceutical manufacturing, agrochemicals, and fine chemicals, where racemates are common and the undesired enantiomer may exhibit reduced activity or adverse biological and environmental effects. As the demand for enantiomerically pure products increases, established methods, such as asymmetric synthesis, preferential crystallization and chromatographic resolution, often remain costly and operationally complex, motivating the development of scalable alternatives.

Enantioselective polymer membranes present a promising approach for achieving continuous, low-energy separations without phase changes or the incorporation of chiral additives.

This work investigates the introduction of chiral recognition into polycarbonate membranes hydrophilized with polyvinylpyrrolidone (PVP). Chiral imprints of α -pinene enantiomers were created using Atomic Layer Deposition (ALD) technology. The hydrophilic surface layer of PVP enabled the formation of chiral imprints that generated enantioselective sorption. The pristine polycarbonate showed an intrinsic preference for (–)- α -pinene, creating a baseline selectivity that could either enhance or compete with the imprint response. Experiments supported by molecular simulations show that the overall membrane performance is governed by the interplay between bulk polymer affinity and surface imprinting. Imprinting with (–)- α -pinene resulted in a synergistic regime, as the induced surface selectivity was consistent with the intrinsic enantioselective preference of the polycarbonate matrix. In contrast, imprinting with (+)- α -pinene generated a competitive regime, reflecting opposition between the imprinted surface interactions and the inherent bulk affinity. Nevertheless, membranes lacking inorganic stabilization exhibited a progressive decline in separation performance during repeated sorption cycles. Deposition of Al₂O₃ by ALD prior to imprint formation increased the rigidity of the PVP surface layer and suppressed enantiomer-specific interactions, thereby

inhibiting effective chiral imprinting. Although the resulting membranes demonstrated improved structural stability, their enantioselective response was governed predominantly by the intrinsic affinity of the polycarbonate support toward the (–)- α -pinene enantiomer. The results reveal a fundamental trade-off between functional imprinting and long-term stability, with the timing of ALD determining whether selectivity is preserved or inhibited.

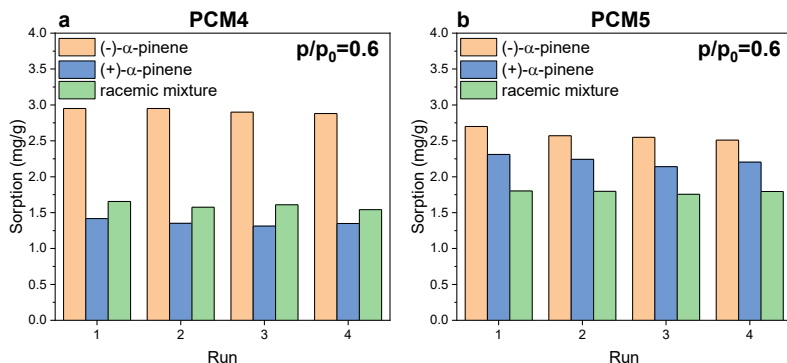


Fig. 1 Comparison of the sorption of (–)- α -pinene, (+)- α -pinene, and their racemic mixture at a relative pressure of $p/p_0 = 0.6$ in PCM4 membranes modified with Al_2O_3 and (–)- α -pinene by ALD (a) and PCM5 membranes modified with Al_2O_3 and (+)- α -pinene by ALD (b).

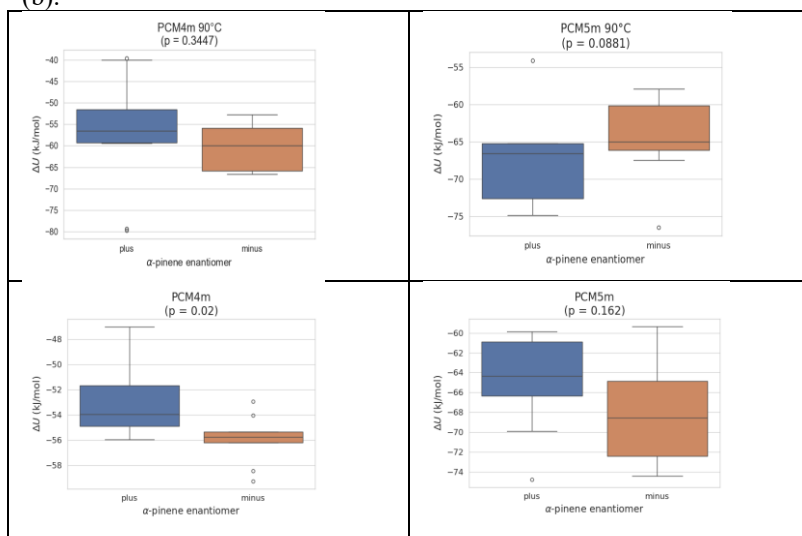


Fig. 2 Comparison of binding energies of α -pinene enantiomers to PCM membranes at 90 °C, where chiral templating occurs (top), and after cooling to 30 °C (bottom). The left column corresponds to membranes treated with (–)- α -pinene (PCM4), while the right column corresponds to membranes treated with (+)- α -pinene (PCM5). Values in parentheses indicate p-values obtained from the Mann-Whitney U test.

Acknowledgements

L. Brožová, J. Škvára, M. Otmar, and P. Izák would like to gratefully acknowledge financial support from the Czech Science Foundation, Project No. 26-21718S. The

computational resources were provided by the e-INFRA CZ project (ID:90254), supported by the Ministry of Education, Youth and Sports of the Czech Republic.

MULTIFUNCTIONAL β -CYCLODEXTRIN–MAGNETITE ELECTROSPUN MEMBRANES FOR PESTICIDE REMOVAL FROM WATER

N. Calderón-Armijo, B. Herrera, N. Yutronic, P. Jara

Chemistry Department, Universidad de Chile, Las Palmeras 3425, Ñuñoa, Santiago, Chile.

Abstract: Pesticide contamination of water is an environmental concern due to the persistence and potential toxicity of these compounds. Adsorption is widely used for their removal due to its simplicity and efficiency. In this work, electrospun polymeric membranes were developed using poly(vinyl alcohol) (PVA), β -cyclodextrin (β -CD), citric acid, and magnetite nanoparticles (Fe_3O_4). β -CD provides host–guest interactions with contaminants, while Fe_3O_4 nanoparticles impart magnetic functionality, facilitating membrane recovery and potential reuse after treatment. Coaxial electrospinning was explored to combine these functionalities, while citric acid was used as a crosslinking agent to improve aqueous stability.

Figure 1 presents the electrospun membrane at the macroscopic scale on the left and a representative SEM image of its fibrous morphology on the right. Further characterization will include SEM, TEM, AFM, XRD, TGA, and contact angle measurements to establish relationships between the membrane's chemical, structural, and surface properties. HPLC will be used to quantify pesticide removal. Preliminary results showed removal efficiencies of approximately 75% for linuron and 65% for pirimethanil.

These results highlight the potential of PVA/ β -CD- Fe_3O_4 electrospun membranes as multifunctional materials for pesticide removal from water.

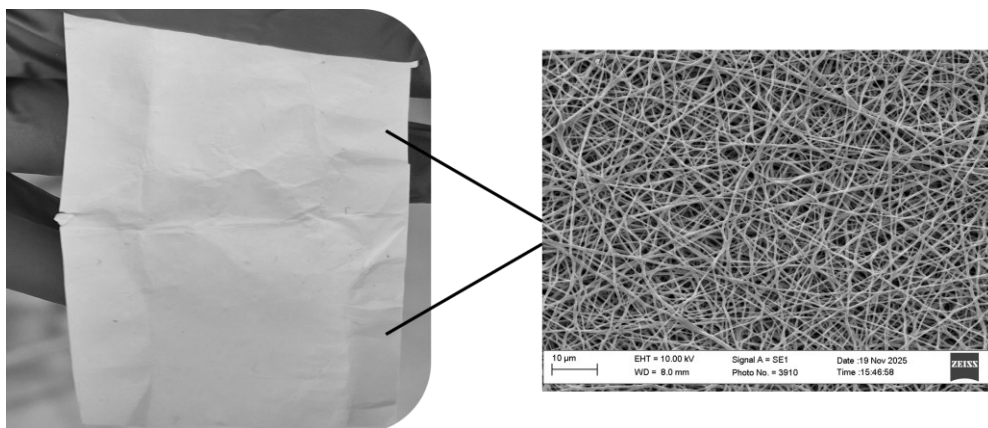


Figure 1. Macroscopic view of the electrospun membrane (left) and representative SEM image of its fibrous morphology (right).

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VALORIZATION OF OLIVE MILL WASTEWATER THROUGH REVERSE OSMOSIS: MEMBRANE PERFORMANCE, FOULING CHARACTERIZATION, AND RETENTATE UPCYCLING INTO SLOW-RELEASE FERTILIZERS

A. L. Q. Candido, P. M. de Oliveira, M. C. S. Amaral, V. R. Moreira

Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, 6627 Antônio Carlos Avenue, Campus Pampulha, 31270-901 Belo Horizonte, MG, Brazil

Abstract: Olive oil production in expanding agricultural frontiers generates severe environmental liabilities, notably high-strength liquid effluents and solid pomace. Conventional management routes often fail due to high phytotoxicity and logistical constraints. This study investigates an integrated membrane-based circular bioeconomy platform (Figure 1), coupling low-pressure reverse osmosis (RO) treatment with the synthesis of value-added slow-release granular organic fertilizers (C-GOF).

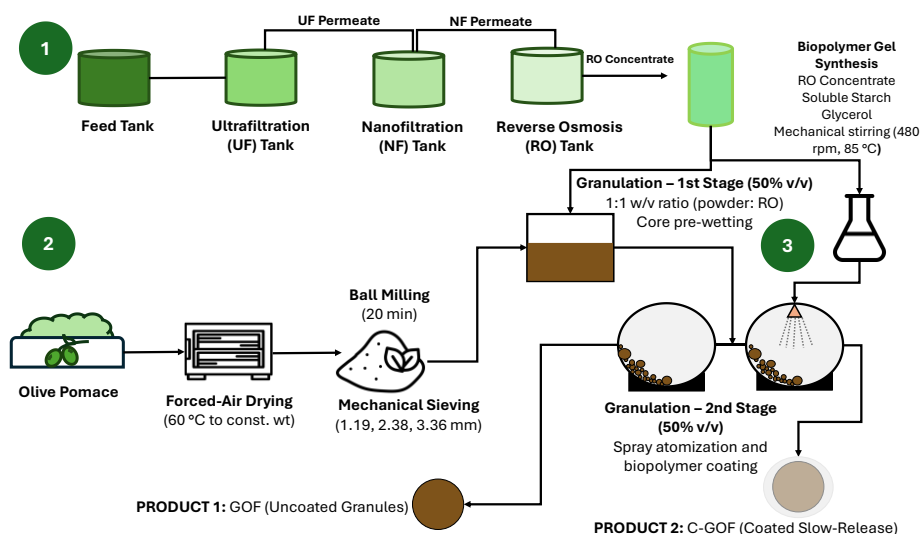


Figure 1. Schematic workflow of the integrated membrane separation and fertilizer synthesis route: wastewater pre-treatment, RO concentration, and pan wet granulation using RO retentate as a liquid binder and coating hydrogel.

The treatment train integrated sequential ultrafiltration (UF) and nanofiltration (NF) stages as an advanced pre-treatment to selectively remove macromolecular foulants and polyphenolic fractions. The resulting NF permeate was subsequently processed in a low-pressure reverse osmosis (RO) system equipped with a spiral-wound thin-film composite polyamide membrane (Canature 2012-100-NPD) operated at 6 bar.

The RO unit exhibited high operational stability, maintaining an average permeate flux of $8.30 \text{ L} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ with a normalized flux decline (J/J_0) of 0.778, comparable to performance profiles reported for industrial high-pressure membranes (such as GE/Suez AK series).¹ Specific energy consumption (SEC) remained low and steady between 0.09 and $0.11 \text{ kWh} \cdot \text{m}^{-3}$, demonstrating that upstream foulant removal by the UF-NF barrier mitigated membrane fouling and preserved system energetics under low operating pressures.²

Attenuated total reflectance FTIR analysis confirmed foulant layer composition, showing characteristic peaks of oleic acid, tyrosol, and polysaccharides ($2925\text{-}2854 \text{ cm}^{-1}$ and $1043\text{-}1034 \text{ cm}^{-1}$). Chemical cleaning effectively removed this organic layer, restoring polyamide active layer signals at 1586 cm^{-1} (Amide II) and 1237 cm^{-1} (Amide III), with no membrane degradation.

As detailed in Table 1, the RO permeate met requirements for internal industrial reuse (olive washing and equipment sanitation), showing 96.9% color removal and 86.6% conductivity reduction. Concurrently, potassium was concentrated five-fold in the retentate ($1,874 \text{ mg/L}$).

Table 1. Physicochemical characterization of feed, retentate, and permeate streams during RO operation. R%: removal percentage.

Parameter	Feed	Retentate	Permeate (R%)
pH	6.30 ± 0.05	6.81 ± 0.04	6.38 ± 0.1
EC ($\mu\text{S/cm}$)	52.4 ± 0.20	69 ± 7.00	7 ± 1.0 (86.6%)
Color (PtCo)	35.3 ± 0.60	188 ± 3.00	1.1 ± 0.8 (96.9%)
Turbidity (NTU)	3.5 ± 0.20	8.3 ± 0.70	1.0 ± 0.1 (71.4%)
K (mg/L)	376 ± 34.00	1874 ± 170.00	1.5 ± 0.6 (99.6%)
Na (mg/L)	19 ± 1.00	30 ± 1.00	0.4 ± 0.1 (97.0%)
Total Phenols (mg/L)	< 2.00	5.1 ± 0.20	< 2.0

This potassium-rich concentrate was utilized as a functional binder in pan wet granulation of ball-milled pomace, increasing matrix K concentration in a granulated ($d_{50}=3.08\text{-}3.28 \text{ mm}$) organic fertilizer. Furthermore, formulating a starch-glycerol biopolymer coating with the RO retentate created a multi-layered diffusional barrier, retarding rapid nutrient leaching while trapping sodium via steric interactions.³ The integrated approach turned an agro-industrial effluent into reusable water and high-value circular inputs, reinforcing the critical role of membrane processes in sustainable biorefineries.

Acknowledgments: CAPES, CNPq, and FAPEMIG.

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THERMORESPONSIVE HYDROGEL-ASSISTED FORWARD OSMOSIS USING THIN-FILM COMPOSITE MEMBRANES

A. Das, S. Seiffert

Department of Chemistry, Johannes Gutenberg University of Mainz, Duesbergweg 10–14, 55128, Mainz, Germany

Abstract: The growing demand for sustainable freshwater resources has intensified the need for energy-efficient desalination technologies. Forward osmosis (FO), which utilizes natural osmotic pressure gradients rather than external hydraulic pressure, offers a promising alternative to conventional desalination processes. However, its practical implementation remains limited by internal concentration polarization (ICP), reverse solute flux, and challenges associated with draw-solution regeneration.¹ In this study, an integrated FO system combining thin-film composite (TFC) membranes and thermoresponsive hydrogel draw agents was developed (**Figure 1**) that is capable of osmotic water uptake and temperature-triggered water release. TFC membranes comprising porous polyethersulfone (PES) or polysulfone (PSf) supports and an ultrathin polyamide (PA) selective layer were fabricated to improve separation performance and mitigate ICP. FO experiments using NaCl feed solutions (3–10 g L⁻¹) produced stable water fluxes of 0.4–1.0 L m⁻² h⁻¹, with flux decreasing as feed salinity increased. The hydrogel crosslinking density had little effect on water flux, indicating that the osmotic driving force was primarily governed by the ionic contribution. Post FO conductivity measurements revealed minimal reverse salt transport, demonstrating high membrane selectivity and the effectiveness of the membrane–hydrogel system for low-energy and regenerable desalination.

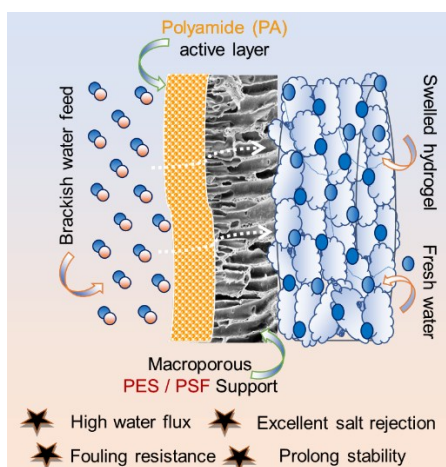


Figure 1. Schematic representation of FO-combining with TFC membranes and thermoresponsive hydrogels for brackish water desalination.

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MULTISCALE MODELLING OF CRYSTAL SIZE DISTRIBUTION IN MEMBRANE PERCRYSTALLIZATION

T. Deb^{1,2}

¹Tremplin A., Lyon, France

²Marie Skłodowska-Curie ESR (last position hold); Erasmus Mundus Fellow (Masters in Membrane Engineering)

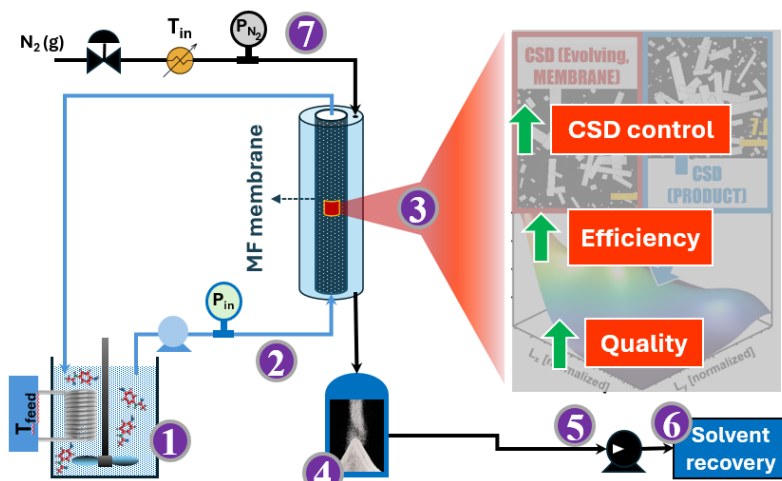
Abstract: The production of high-purity, size-controlled crystals requires processes that minimize chemical additives and unit operations while enabling precise supersaturation control. Pervaporation-based membrane percrystallization (PerX) offers a compelling route by generating localized supersaturation through selective solvent removal, promoting crystallization near the membrane surface without antisolvent addition and enabling control over crystal size and morphology.

This work presents a hybrid, multiscale PerX modelling framework for predicting crystal size distribution (CSD) by coupling falling-film hydrodynamics, solvent-evaporation-induced supersaturation, surface crystallization, and operating-condition-dependent crystal detachment from the membrane vicinity. A continuum model simulates falling-film dynamics on the permeate side of a tubular microfiltration membrane, incorporating hydrodynamics, heat transfer, and evaporative solvent flux to predict axial profiles of film thickness, temperature, and supersaturation. Concurrently, a stochastic kinetic Monte Carlo (kMC)-based 2D population balance module simulates time-dependent surface events—heterogeneous nucleation, subsequent adsorbed-unit growth, agglomeration, and shear-assisted detachment—on a discretised membrane lattice, where detachment rates are mechanistically derived from adhesion energy, gravity, and the local wall shear stress exerted by the falling film. The entire numerical study was conducted using Python and OpenFOAM.

Owing to its fully parametric nature, the framework predicts the spatiotemporal evolution of the CSD in the membrane vicinity and the final detached CSD representing the recovered product across membrane characteristics (pore sizes, membrane dimensions, hydraulic resistance, surface functionalities), molecule-selective crystallization kinetics (nucleation, growth, aggregation), and operating conditions (temperature, pressure, shear-stress distribution). For four molecule of pharmaceutical-cosmetic interest with known kinetics, operating-condition-driven control of the final CSD is demonstrated, with volume-equivalent median crystal diameters (d_{50}) tunable from 1 μm to 15 μm , alongside controllable polydispersity.

The simulated CSD outputs are compared against different experimental data from the literature for closely comparable membrane crystallizers and analogous processes, underscoring the framework's predictive reliability and utility for production-process design and optimization.

Graphical representation



(1) a temperature-controlled reservoir containing a near-saturated drug solution; (2) feed flow to the membrane module; (3) nucleation and crystal growth in the vicinity of the membrane on the permeate side; (4) crystal collection from the membrane module; (5) a sweep-gas stream on the permeate side to collect solvent vapour; (6) a vacuum pump applied to the permeate side drives sweep flow; and (7) condensation and recovery of the solvent from the permeate (evaporated) stream.

Conflict of interest

The authors declare that they have no conflicts of interest and that no other individuals were involved in the preparation, conduct, analysis, or reporting of this work.

PHYSICS-INFORMED GRAPH NEURAL NETWORKS FOR PREDICTING AND DESIGNING MOLECULAR PERMEABILITY OF DRUG CANDIDATES

T. Deb^{1,2}

¹Tremplin A., Lyon, France

²Marie Skodowska-Curie ESR (last position hold); Erasmus Mundus Fellow (Masters in Membrane Engineering)

Abstract: Whether, and to what extent, a drug molecule permeates a biological barrier is a structured negotiation between molecular architecture, functional-group chemistry, and the physicochemical processes regulating membrane permeation. Prescriptive rational drug design and optimization require this negotiation to be decoded into quantitative attributions: a predicted permeability value, decomposed into how much each substructure and functional group adds to or subtracts from permeability.

To this end, a physics-informed graph neural network framework is presented that integrates detailed molecular properties with solvation–diffusion physics to predict membrane permeability and quantify the contributions of individual molecular substructures and functional groups to permeation.

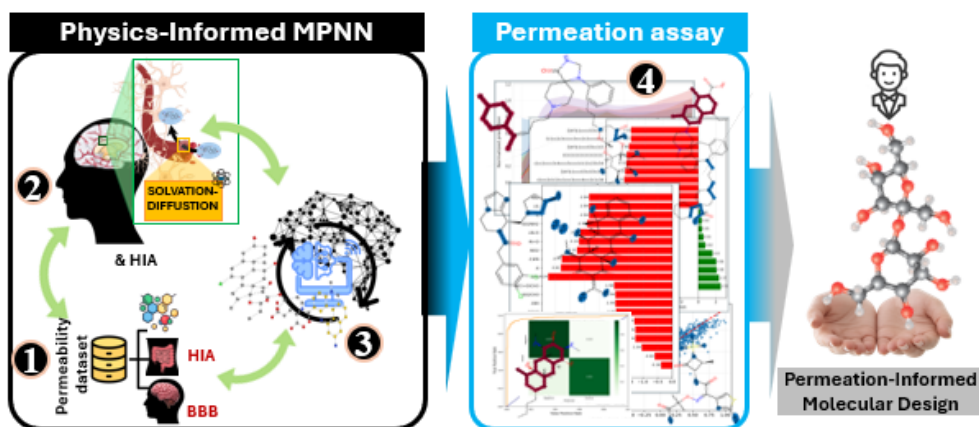
It begins by encoding molecular structures as molecular graphs containing atom- and bond-level features. Next, a gated message-passing neural network (MPNN) captured local atomic interactions through information exchange between neighboring atoms, while a multi-head self-attention transformer readout integrated atomic representations and learned the relative importance of distinct molecular regions. The resulting graph-level embeddings serve as the molecular representative for both permeability prediction and the identification of salient structural features. To infuse mechanistic knowledge, the prediction loss was augmented with a physics-based loss derived from literature-supported solvation–diffusion correlations to guide and regularize the learning of structure–permeability relationships. Finally, molecular interpretation at the atom, functional-group, and scaffold levels identified and ranked structural features associated with membrane permeation.

The optimized model validation against blood–brain barrier (BBB) and human intestinal absorption (HIA) data—covering classification and regression—yields strong performance: 93.5% accuracy and an AUC of 0.99 for BBB classification, alongside a Pearson correlation of 0.87 (MSE = 0.04) for regression. For HIA, classification yielded 98.6% validation accuracy and an AUC of 0.98, while regression achieved a Pearson correlation coefficient of 0.84 and an MSE of 0.12 on the normalized scale. The physics-coupled model incurred a modest < 2.0% reduction in prediction accuracy relative, while incorporating mechanistic constraints and interpretable structure–permeability relationships. Molecular

attribution analysis further identified and quantified structurally and mechanistically consistent features associated with the permeation process.

The framework transforms generic permeability prediction from a passive screening tool into an active screening filter and an interpretable design engine for drug product developers—paving the way for the rational, in silico construction of drug candidates with precisely tunable permeation behavior. Further model enrichment and validation with expanded datasets are already underway.

Graphical abstract



(1) Molecular structures and experimental permeability data, (2) Literature derived solvation–diffusion theory as mechanistic priors, (3) Constrained MPNN model trained to integrate data with physical principles, and (4) Multiscale structural interpretation to identify key permeation drivers and guide molecular design.

Conflict of interest

No competing interests are associated with this work, which was carried out without the involvement of any external parties in any capacity.

MEMBRANE SELECTION AND CATHODE CATALYST ENGINEERING FOR ENHANCED BIOHYDROGEN PRODUCTION IN MICROBIAL ELECTROLYSIS CELLS

T. Eisa^{1,2}, J.-Y. Kwon^{1,2}, A. Bahaa^{1,2}, S.-U. Lee^{1,3}, S.-W. Choi^{1,3}, D. Kim^{1,3}, L. Koók³, P. Bakonyi³, Z. Pientka⁴, W. Kujawski⁵, K.-J. Chae^{1,3,*}

¹Department of Environmental Engineering, College of Ocean Science and Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

²Interdisciplinary Major of Ocean Renewable Energy Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

³Research Group on Bioengineering, Membrane Technology and Energetics, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

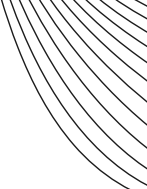
⁴Institute of Macromolecular Chemistry, AS CR, Heyrovsky Sq. 2, 162 06 Prague 6, Czech Republic

⁵Faculty of Chemistry, Department of Physical Chemistry, Nicolaus Copernicus University in Toruń, Gagarin Street 7, 87-100 Toruń, Poland

Abstract: The urgent need to mitigate carbon dioxide emissions has accelerated the transition toward carbon-neutral energy systems, with hydrogen emerging as a clean and sustainable energy carrier. Conventional hydrogen production relies on energy and water systems such as water electrolyzers and gas reformers. On the other hand, microbial electrolysis cells (MECs) offer a promising route for biohydrogen production from organic waste at reduced theoretical energy input compared to conventional electrolysis cells.

However, the energy demand increases in MECs due to pH imbalance caused by membrane ion transport limitations. As the anode and cathode reactions proceed, the pH of their respective electrolytes diverges due to the membrane's inefficient ion transport, which imposes additional thermodynamic demand on the hydrogen evolution reaction and exacerbates any existing losses at the cathode, therefore, inhibiting its performance.

Systematic evaluation of membranes in MEC, via experimental and statistical analysis, revealed that the membrane material, reinforcement, and type play an important role in their utility in MECs. Reinforced cation exchange polysulfone membranes showed higher product purity, while reinforced anion exchange polyphenylene oxide membranes showed higher charge conduction and hydrogen production at lower pH imbalance. Furthermore, although ion exchange capacity enhanced MEC hydrogen production, it also correlated with the instability of the membrane. The membrane analysis highlights the key considerations for membrane future engineering.



To improve cathode performance, we synthesized the novel catalyst CuCo-MOF/g-C₃N₄. Incorporating g-C₃N₄ into CuCo-MOF addresses MOF ohmic and reaction losses. DFT calculations revealed that g-C₃N₄ altered the CuCo-MOF electronic structure by increasing the band gap (0.036 vs. 0.002 eV) and the density of states near the Fermi level, suggesting improved charge-transfer behavior and proton reduction energetics. Electrochemical measurements confirmed the enhanced catalytic activity, with the CuCo-MOF/g-C₃N₄ catalyst exhibiting a lower overpotential at 10 mA/cm² (0.639 V) than bare CuCo-MOF (0.828 V), approaching Pt/C performance (0.458 V) in 0.1 M phosphate buffer, approaching Pt/C performance. In MEC operation, the composite achieved a maximum hydrogen production rate of 166.24 mL/L·d and a hydrogen yield of 653.01 mL/gCOD removed, with high hydrogen cathodic recovery (87.81%) and Coulombic efficiency (~70%). These findings demonstrate the importance of material selection for the membrane and cathode to improve cost effective MEC operation and hydrogen production.

Acknowledgement

This work was supported by National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2023-00209009, RS-2023-00265777, RS-2025-16064148); Korea Basic Science Institute (National Research Facilities and Equipment Center) grant funded by Ministry of Education (grant No. 2022R1A6C101B738).

MOLECULAR-WEIGHT-DIRECTED PORE ENGINEERING OF Li_2TiO_3 GRANULES USING PEG/PVP CO-POROGENS FOR LITHIUM RECOVERY FROM BRINE

T. Erfando^{1,2}, M. Hosny¹, A. Sharifi Haddad¹, R. Rafati¹

¹School of Engineering, King's College, University of Aberdeen, AB24 3UE, United Kingdom (t.erfando.22@abdn.ac.uk)

²Faculty of Engineering, Universitas Islam Riau, Pekanbaru, 28282, Indonesia

Abstract: The increasing demand for lithium has intensified interest in sustainable extraction from aqueous resources, including subsurface brines. Lithium-ion sieve (LIS) adsorbents have emerged as promising alternatives to conventional solar evaporation due to their rapid lithium uptake and potentially lower environmental impact. However, the practical application of LIS materials remains challenging because powder-form adsorbents are difficult to handle and recover, highlighting the need for mechanically stable and highly porous structured adsorbents.

In the present study, co-blending polyvinylpyrrolidone (PVP) and polyethylene glycol (PEG) as porogens was proposed to engineer the pore size distribution at the surface and within the interior of composite materials, thereby tailoring their pore structure. The effects of PEG molecular weight (2,000-10,000 g/mol) and the PEG mass ratio on adsorption performance were systematically investigated. Varying the PEG molecular weight enabled control over pore size while introducing hydrophilic characteristics to the composite surface, thereby reducing mass-transfer resistance and accelerating adsorption kinetics. These effects facilitated lithium transport within the granules and enhanced lithium adsorption. Furthermore, the lithium selectivity of the optimized granules was evaluated using brines containing competing Mg^{2+} , Ca^{2+} , Na^+ , and K^+ ions. The combined use of PEG and PVP provides an effective approach for engineering the pore structure of LIS granules while maintaining their structural integrity, thereby improving their potential suitability for practical lithium recovery from complex brine resources.

PEBAX®/IONIC LIQUID COMPOSITE MEMBRANES FOR GREENHOUSE GASES SEPARATION

B. F. Esteves, R. Nunes, B. R. M. Ferreira, P. J. Carvalho

CICECO – Aveiro Institute of Materials, University of Aveiro, Aveiro, Portugal

Abstract: Greenhouse gas (GHG) emissions have risen sharply in recent decades, increasing their atmospheric concentrations and intensifying the natural greenhouse effect. Annual global emissions are now around 50 billion tons of CO₂ equivalents, mainly CO₂, CH₄, N₂O and fluorinated gases. A range of mitigation technologies has been investigated, including absorption, adsorption and electrochemical reduction, but these often face significant drawbacks such as high energy requirements, limited efficiency and solvent toxicity. These limitations highlight the need for more efficient and sustainable GHG mitigation strategies.

Non-volatile solvents, particularly ionic liquids (ILs), have emerged as attractive alternatives to conventional solvents, owing to their negligible vapor pressure, high thermal stability and tuneable physicochemical properties. However, their direct use in traditional separation units is constrained by the large equipment size and high energy consumption associated with solvent regeneration. To overcome these challenges, we propose a membrane contactor based on hollow-fiber polyetherimide membranes coated with a thin Pebax® layer functionalized with ILs, thereby combining the high sorption capacity and selectivity of ILs with the modularity and scalability of membrane technology.

Acknowledgements: The present study was developed in the scope of the Project “Agenda ILLIANCE” [C644919832-0000035 | Project n.º46], financed by PRR-Plano de Recuperação e Resiliência under the Next Generation EU from the European Union and the project CICECO-Aveiro Institute of Materials, UID/50011 & LA/P/0006/2020 (DOI 10.54499/LA/P/0006/2020), financed by national funds through the FCT/MCTES (PIDDAC). The authors acknowledge Arkema for kindly supplying Pebax®1657. B.F.E. acknowledges FCT for her Ph.D. Grant 2024.02809.BDANA.

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COSMO-RS SCREENING OF 19 MILLION IONIC LIQUIDS FOR SEPARATION-ENHANCED CO₂ HYDROGENATION TO METHANOL

J. Fabian, M. Alcântara, F. H. B. Sosa, J. A. P. Coutinho

CICECO, University of Aveiro, Universidade de Aveiro, 3810-193 Aveiro, Portugal

Abstract: Carbon capture and utilization have emerged as a key strategy to reduce greenhouse-gas emissions while enabling the production of value-added chemicals. Among the available routes, the hydrogenation of CO₂ to methanol is particularly attractive because it combines carbon mitigation with the synthesis of an important platform molecule and energy carrier. However, this process is limited by thermodynamic equilibrium at the high temperatures required for industrial operation, while the simultaneous formation of water further restricts conversion.¹ In this context, separation-assisted process concepts based on selective liquid media have attracted growing attention, as the in situ removal of reaction products can contribute simultaneously to CO₂ utilization and equilibrium shifting. Ionic liquids (ILs) are promising candidates for this role because of their negligible volatility, structural tunability, and potential affinity toward methanol, water, and CO₂.² However, the vast combinatorial space arising from the large number of possible cation–anion combinations make the identification of optimal ILs a nontrivial task. To address this, a high-throughput computational screening of approximately 19 million ILs was performed to identify candidates suitable for intensified CO₂-to-methanol processing at 513 K. The workflow combined machine learning and molecular thermodynamics. Melting temperature, viscosity, and thermal decomposition temperature were predicted using ILBERT, a BERT-based model developed for ionic-liquid property prediction.³ In parallel, the affinity of each IL toward methanol and water was evaluated through COSMO-RS calculations, allowing the identification of solvents with favorable product-uptake behavior under reaction conditions. Candidate ranking was then established by combining thermodynamic selectivity with physical-feasibility constraints required for high-temperature operation. The workflow yielded a ranked set of ILs for separation-enhanced CO₂-to-methanol conversion, subsequently validated for chemical and thermal stability. This approach reduces a vast chemical space to viable candidates and demonstrates how machine learning combined with predictive thermodynamics can accelerate IL discovery.

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PRODUCTION OF ORGANIC ACIDS FROM THEIR SALTS USING ELECTRODIALYSIS WITH BIPOLAR MEMBRANES

H. Fárová¹, V. Kúdelová¹, L. Šeda¹, A. S. Oualah²

¹Membrain s.r.o., Pod Vinicí 87, 471 27 Stráž pod Ralskem, Czech Republic
(hana.farova@membrain.cz, www.membrain.cz)

²Research Center on Chemical Product and Process Technology, Pro2TecS, Higher Technical School of Engineering, University of Huelva, Avda. de las Fuerzas Armadas, s/n. 21007 Huelva, Spain

Abstract: Formic, acetic and lactic acids are common organic acids widely used in different industrial applications. Some methods of their production (fermentation, special chemical synthesis, etc.) result in formation of salts which must be later converted to acids. Electrodialysis with bipolar membranes (EDBM) presents an environmentally friendly alternative to conventional methods of conversion salts to acids (acidification, ion exchange, solvent extraction etc.) since it does not require additional chemicals and generates high-purity hydroxide which can be reused in the production process.

A laboratory-scale module ED-H3/2x10 equipped with ten membrane pairs of cation-exchange membranes Fumatech® FKL-PK and bipolar membranes Gouchukeji® GBM was used for production of organic acids from sodium formate, acetate and lactate. The effects of initial salt concentration, target acid purity, and NaOH operating mode (with or without conductivity control by dilution) on NaOH purity, current efficiency and energy consumption were studied.

Organic acids with purity ranging from 95 % to more than 99 % were prepared from their salts of initial concentration either 50 g/kg, or 180-200 g/kg. NaOH conductivity was either maintained at about 250 mS/cm by addition of demineralized water, or it was not controlled. In the first case, the NaOH concentration of about 4.5 to 5.5 % was achieved, whereas up to 9.9 % NaOH was obtained in the second case. Increasing the initial salt concentration, target acid purity, and final NaOH concentration generally led to lower NaOH purity, reduced current efficiency, and higher energy consumption.

RHODIASOLV® POLARCLEAN AS A SAFER ALTERNATIVE TO DMF FOR POLYSULFONE RO MEMBRANE CASTING

L. Germano¹, L. Luciani¹, M. Giagnorio¹, F. Russo², A. Figoli²

¹MANN+HUMMEL Water & Fluids Solutions S.p.A., Via Pian di Morro 1, Cerreto d'Esi (AN), Italy

²CNR – Istituto per la Tecnologia delle Membrane, Rende (CS), Italy

The authors did not consent to the publication of this abstract.

AREA RESISTANCE CHARACTERIZATION OF HOMOGENEOUS AND HETEROGENEOUS ION-EXCHANGE MEMBRANES USING DIFFERENTIAL ALTERNATING CURRENT MEASUREMENTS

A. Grabowski

Ertel IonStream GmbH, Bahnhofstr. 82, 70806 Kornwestheim, Germany
(andrej.grabowski@ertel-ionstream.com, www.ertel-ionstream.com)

Abstract: Reliable characterization of the electrical resistance of ion-exchange membranes is essential for the evaluation and comparison of membranes used in electrodialysis, electrodeionization and related electrochemical processes. Building on previous investigations of differential AC resistance measurements with membrane conductivity test cell (MCTC), the present study examines the applicability of this approach to homogeneous and heterogeneous ion-exchange membranes equilibrated with electrolyte solutions of different concentrations.

The reproducibility and transferability of the differential measurement approach were investigated by performing measurements using two different cell designs. The resulting membrane resistance values are compared and the influence of cell geometry and measurement configuration on the obtained results is shown.

The results provide further insight into the concentration-dependent electrical behavior of different ion-exchange membrane types.

The work provides guidance for selecting suitable test-cell geometries and experimental conditions for reliable membrane resistance characterization.

COMPARISON OF DEPOSITION METHODS ON COMPOSITE MEMBRANE SUBSTRATES

K. Havelková¹, J. Schneider², D. Gardenö², G. Broncová¹, T. V. Shishkanova¹, K. Friess²

¹Department of Analytical Chemistry, Faculty of Chemical Engineering, University of Chemistry and Technology, Technická 5, 166 28 Prague 6, Czech Republic (havelkos@vscht.cz)

²Department of Physical Chemistry, Faculty of Chemical Engineering, University of Chemistry and Technology, Technická 5, 166 28 Prague 6, Czech Republic

Abstract: The development of new membrane materials with enhanced separation efficiency remains one of the major challenges in contemporary membrane science. A promising approach involves modifying membrane surfaces with conductive polymers to enhance their functional properties.¹ Therefore, the deposition of polyaniline (PANI) on graphene oxide (GO), single-walled carbon nanotube (SWCNT) composite membranes, and selected synthetic membranes (PA 6, PESO, and PI) (**Fig. 1**) was investigated to test the influence of substrate surface properties, polymerization conditions on the quality of the deposited PANI layer. The membranes were modified by the oxidative polymerization of aniline in an acidic medium at 0 °C. The membrane surfaces were characterized using contact angle measurements, SEM, and profilometry (**Fig. 2**). The results demonstrated that the chemical composition of the substrate significantly influences its wettability, the polymerization time required for deposition of compact and stable of the PANI coating. In contrast to the hydrophobic surfaces of GO and SWCNT based membranes, the more hydrophilic substrates derived from PA 6, PESO, and PI promoted faster formation of homogeneous PANI coatings. However, surface hydrophilicity alone was not sufficient to ensure the formation of the homogeneous and mechanically stable PANI layers. It was found that the polymerization time also played a crucial role, and its optimization significantly improved the quality of the deposited PANI coatings on the substrates differing chemical composition and lipophilicity. These findings provide new insights into the relationship between membrane substrate properties and the deposition of conductive polymer coatings.

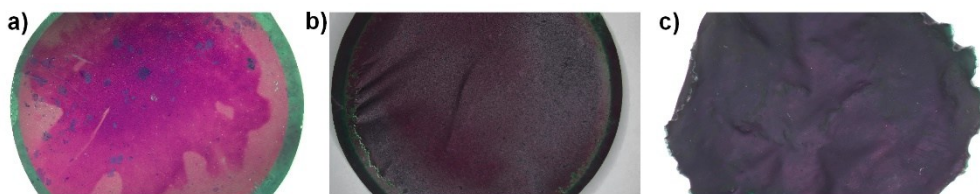


Figure 1 Quality of the PANI coating deposited by chemical polymerization on the surface of (a) GO based membrane after 16 h, (b) SWCNT based membrane after 16 h, and (c) PA 6 membrane after 10 min.

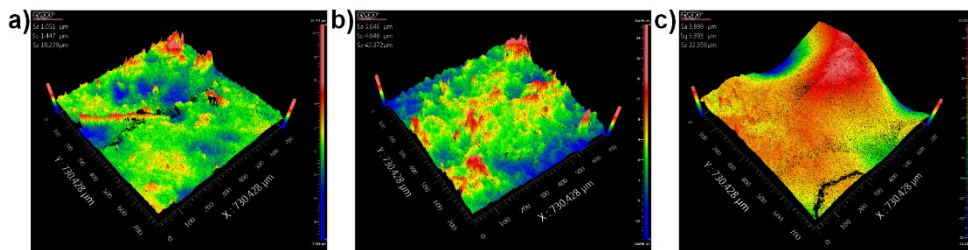


Figure 2 Optical profilometry images showing the surface topography of deposited PANI coatings on (a) GO based membrane, (b) SWCNT based membrane, and (c) PA 6 membrane present in Figure 1. The corresponding areal surface roughness (S_a) values are 1.051, 3.646, and 3.899 μm , respectively.

Acknowledgement: The authors are grateful for the support from the projects of the Czech Science Foundation (GAČR 24-11041S). This work was supported from the Ministry of Education, Youth, and Sports of the Czech Republic by the grant of Specific university research – grant No A1_FCHI_2026_002.

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MIXED MATRIX MEMBRANES BASED ON POLYIMIDES AND THICALIXARENES

J. Heřmánek¹, K. Iablochkin¹, M. Tlustý², P. Lhoták², V. Fíla¹

¹Department of Inorganic Technology, University of Chemistry and Technology Prague, Technická 5, Prague, 166 28, Czech Republic

²Department of Organic Chemistry, University of Chemistry and Technology Prague, Technická 5, Prague, 166 28, Czech Republic

Abstract: Mixed-matrix membranes (MMMs) frequently incorporate fillers like MOFs, COFs, or zeolites. Recently, macrocyclic molecular fillers with defined cavities—such as cucurbiturils and calixarenes—have emerged as promising alternatives, though systematic studies on their fundamental behavior remain scarce¹. This work systematically investigates the influence of thiacalix[4]arene (H-TC) and *p*-*tert*-butylthiacalix[4]arene (tBu-TC) on the morphology, mechanical strength, and gas separation performance of solution-cast 6FDA-DAM and Matrimid polyimide membranes. Membranes loaded with 0–20 wt% filler were evaluated under 2–8 bar overpressures using CO₂/CH₄ and H₂/CH₄ mixtures at 1:3, 1:1, and 3:1 feed ratios. While low filler loadings yielded homogeneous, defect-free structures, exceeding a matrix-specific threshold triggered filler crystallization. Notably, tBu-TC in Matrimid demonstrated the highest crystallization resistance, remaining stable up to 20 wt%. Mechanical testing revealed divergent matrix dependencies: thiacalixarene addition enhanced the tensile strength of 6FDA-DAM by up to 103%, but slightly compromised Matrimid's mechanical integrity. Crucially, certain Matrimid-based MMMs achieved a simultaneous increase in permeability and in selectivity for H₂/CH₄ separation, up to 127% and 117%, respectively.

The research was supported by Czech Science Foundation Grant No. 26-23755S

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FROM CONVENTIONAL TO GREEN SOLVENTS: TAILORING CELLULOSE ACETATE MEMBRANES THROUGH SOLVENT SELECTION

B. Hermanová^{1,3,4}, Z. Vilamová², B. van der Bruggen^{4,2}, K. Kočí^{1,5}, D. Plachá^{6,7}

¹Institute of Environmental Technology, CEET, VŠB-Technical University of Ostrava
(barbora.hermanova@vsb.cz)

²Nanotechnology centre, CEET, VŠB-Technical University of Ostrava

³Faculty of Materials Science and Technology, VŠB-Technical University of Ostrava

⁴Faculty of Engineering Science, KU Leuven

⁵Faculty of Technology, Tomas Bata's University

⁶Czech Advanced Technology and Research Institute, Olomouc

⁷Faculty of Medicine, University of Ostrava

Abstract: The choice of solvent plays a key role in determining the physicochemical properties of polymer solutions and the resulting morphology of cast films.^{1,2} In this study, the influence of conventional and green solvents on the dissolution behavior, solution properties, and film formation of cellulose acetate (CA) was systematically studied. Solvent–polymer interactions were investigated using solubility parameters alongside key solvent characteristics such as volatility and polarity. Both conventional and green solvents enabled rapid dissolution of CA, allowing comparable processing routes. However, differences in volatility and polarity significantly influenced solution behavior and membrane structure. Low-volatility solvents resulted in slower evaporation and denser structures. Medium-volatility solvents produced more porous membranes with larger pore sizes. Highly volatile solvents also yielded porous structures, though with distinct pore characteristics. The other trend following the polarity of these solvents showed that higher polarity solvents promoted stronger interactions and enhanced pore formation. Acetone produced structures suitable for water treatment applications due to higher porosity; however, its high volatility is a limitation, and its sustainability depends on its production source. FTIR spectra confirm consistent chemical structure across all samples. SEM reveals significant differences in porosity, while XRD indicates predominantly amorphous structures with minor crystallinity across all samples. These findings demonstrate that membrane morphology can be precisely tailored through solvent selection, highlighting the potential of green solvents as sustainable alternatives for cellulose acetate membrane fabrication

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QUANTIFICATION OF WETTING PROGRESSION IN MEMBRANE DISTILLATION BASED ON OPTICAL COHERENCE TOMOGRAPHY

N. F. Himma¹, H. Horn^{1,2}, F. Saravia², M. Wagner^{1,3}

¹Karlsruhe Institute of Technology (KIT), Engler-Bunte-Institut (EBI), Water Chemistry and Water Technology, Engler-Bunte-Ring 9, 76131 Karlsruhe, Germany
(nurul.himma@partner.kit.edu; harald.horn@kit.edu)

²DVGW-Research Center at the Engler-Bunte-Institut (EBI), Water Chemistry and Water Technology, Karlsruhe Institute of Technology (KIT), Engler-Bunte-Ring 9, 76131 Karlsruhe, Germany (saravia@dvgw-ebi.de)

³Karlsruhe Institute of Technology (KIT), Institute of Biological Interfaces (IBG-1), 76344 Engenstein-Leopoldshafen, Germany, michael.wagner@kit.edu

Abstract: Combining membrane and evaporative processes makes membrane distillation (MD) a highly attractive process, particularly because of its ability to achieve a complete rejection of non-volatile matter. For this, a microporous hydrophobic membrane is employed, selectively allowing water vapor to pass through while effectively preventing the transport of liquid water and non-volatile solutes. However, membrane wetting may occur depending on the feed characteristics, membrane properties, and operating conditions. When the liquid entry pressure is exceeded, the feed solution can penetrate the membrane pores and leak to the permeate side, declining the separation performance. Real-time monitoring and quantitative assessment of membrane wetting are necessary to gain a deeper understanding of its progression and the underlying mechanisms. Our recent study [1] has successfully visualized localized wetting progression in MD using optical coherence tomography (OCT).

In this work, novel approaches were developed for the quantitative assessment of membrane wetting, enabling enhanced characterization of wetting behavior and its progression. The wetting progression was evaluated based on (i) changes in signal intensity distribution within OCT datasets (three-dimensional, C-scans) and (ii) displacement of the wetting front (vapor–liquid interface), detected locally. Several wetting parameters were quantified, including local and average wetting depth, spatial variability of wetting depth, wetting ratio, and fully-wetted fraction. Digital image processing was carried out using macros developed in Fiji (based on ImageJ 1.54p) [2], complemented by a Python script. Detailed descriptions of the developed image-processing methods can be found elsewhere [3].

As shown in **Figure 1 (a-c)**, the wetting front was successfully detected by applying derivative values of intensities along each A-scan, and the wetting distribution depicted in heat maps is shown in **Figure 1 (d-f)**. Wetting in some parts of the membrane progressed more rapidly compared to other parts, and fully-wetted parts, indicated by the dark blue spots, were observed. Wetting was more pronounced near the inlet compared to the middle of the MD module. After 20 minutes of MD

operation with 50 mg/L CTAB and 3g/L NaCl, ~70% of the membrane area monitored near the inlet of the MD module was fully wetted, with 83% of the membrane volume wetted, while it was only ~20% for the fully-wetted fraction with a slightly lower wetting ratio of 71% for the membrane monitored in the middle of the MD module. This indicates that an increase in the volume of wetted membrane (expressed as the wetting ratio) does not necessarily correspond to an increase in the membrane area that is fully wetted (expressed as the fully-wetted fraction). This highlights the importance of early detection of the wetting front in wetting-prone areas, which would allow for more effective process control.

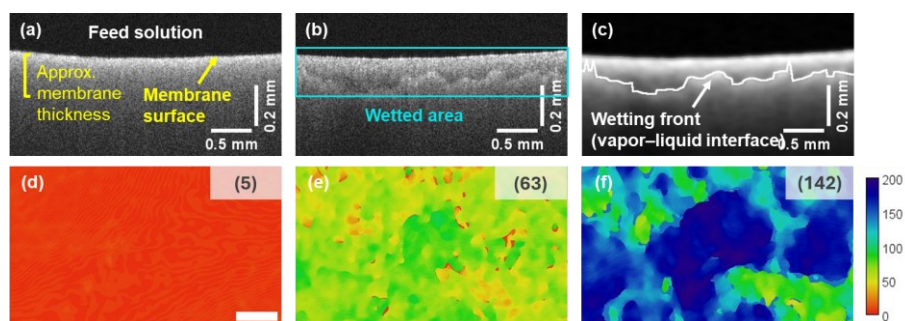


Figure 1. B-scans showing (a) unwetted membrane, (b) wetted membrane, and (c) traced wetting front. Maps of wetting distribution, comparing the (d) unwetted membrane and (e and f) wetted membrane at the beginning and after 20 minutes of operation with CTAB, respectively. The calibration bar shows the wetting depth in μm ; complete wetting is shown in dark blue color. Scale bar (white horizontal line) equals 0.5 mm. The calculated average wet depth for each map is shown in brackets.

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OPERATING BOUNDARIES IN SUBMERGED HOLLOW FIBER MEMBRANE DISTILLATION CRYSTALLIZATION OF REAL SWRO BRINE

M. Hossein Panah^{1,2}, S. Lee³, M. S. Camilleri Rumbau¹, G. Razi Parchikolaei¹, F. Lipnizki², X. Martínez-Lladó¹, S. Casas-Garriga¹

¹Eurecat, Water, Air and Soil Unit (WAS), Spain (presenter: maria.camilleri@eurecat.org)

²Department of Process and Life Science Engineering, Division of Chemical Engineering, Lund University, Lund 22100, Sweden

³School of Civil and Environmental Engineering, Kookmin University, Seongbuk-gu, Seoul, 02707, Republic of Korea

The authors did not consent to the publication of this abstract.

PREPARATION OF AN NH_4^+ -SELECTIVE SEPARATION MEMBRANE AND EVALUATION OF ITS NH_4^+ CONCENTRATION PERFORMANCE

M. Hozaki¹, Y. Kakihana^{1,2}, M. Higa^{1,2}, P. Durga³, T. Kawamoto³

¹Graduate School of Sciences and Technology for Innovation, Yamaguchi University (YU);
2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

²Blue Energy center for SGE Technology (BEST), YU

³National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba,
Ibaraki 305-0046, Japan

1. Introduction

Since nitrogen compounds in the environment can cause air pollution and eutrophication, they need to be removed. Consequently, the Ministry of Economy, Trade and Industry has proposed a new nitrogen cycle system that converts and concentrates nitrogen compounds in exhaust gases and wastewater into ammonia, which can then be used as fuel and industrial-grade ammonia¹. The conversion and concentration of ammonia not only suppresses the release of nitrogen compounds but also enables a sustainable nitrogen cycle. However, current ammonia conversion and concentration methods, such as adsorption and chemical precipitation, face challenges including the need for secondary treatment and large amounts of chemicals, strict operating conditions, and low purity of the resulting ammonia². Among these methods, electrodialysis, which has garnered attention in recent years, has the potential to resolve these issues. On the other hand, it faces challenges such as treatment rate, cost, and selectivity toward specific ions.

Therefore, the objective of this study is to fabricate a cation exchange membrane (CEM) equipped with a selective separation layer containing an adsorbent with high NH_4^+ adsorption performance, and to selectively separate and concentrate NH_4^+ by electrodialysis using this membrane.

2. Experimental Methods

A coating solution was prepared by mixing KZnHCF (Fuso Co., Ltd.), an NH_4^+ adsorbent, tetrahydrofuran (THF), and a binder resin. After preparing the solution, it was applied to a substrate membrane and dried for approximately 1 h to form the membrane.

Two-cell electrodialysis was performed using the fabricated NH_4^+ selective CEM (NS-CEM). A mixed solution of 0.1 [M] NaCl, NH_4Cl , and CaCl_2 was used as the feed solution, and the experiment was conducted under a constant current

of 90 [mA]. Concentration-time curves were plotted based on the concentration changes in each cell, and the permeate fluxes of Na^+ , NH_4^+ , and Ca^{2+} , as well as the ion-selective permeability coefficients $P_{\text{Na}}^{\text{NH}_4}$ and $P_{\text{Ca}}^{\text{NH}_4}$, were calculated from the initial slopes of these curves.

$$J_i = \frac{V \Delta C_i}{S \Delta t} \quad (i = \text{Na}^+, \text{NH}_4^+, \text{Ca}^{2+}); P_{\text{Na}}^{\text{NH}_4} = \frac{J_{\text{NH}_4^+}}{J_{\text{Na}^+}}; P_{\text{Ca}}^{\text{NH}_4} = \frac{J_{\text{NH}_4^+}}{J_{\text{Ca}^{2+}}};$$

J_i : Transverse flow velocity [$\text{mol m}^{-2} \text{s}^{-1}$]

V : Volume of the concentrated solution [m^3]

S : Effective membrane area [m^2]

$\frac{\Delta C_i}{\Delta t}$: Initial concentration gradient [$\text{mol m}^{-3} \text{s}^{-1}$]

$P_{\text{Na}}^{\text{NH}_4}, P_{\text{Ca}}^{\text{NH}_4}$: Ion selectivity coefficient [-]

3. Results and Discussion

(a) Figure 1(a) shows the changes in ion concentration over time during electrodialysis using a commercially available CEM, and Figure 1(b) shows the corresponding results for the NS-CEM. As shown in Figure 1(a), the commercially available CEM exhibited concentration changes ranging from 0.01 to 0.02 [M] for all ions. In contrast, the NS-CEM showed a concentration change of 0.06 [M] for NH_4^+ alone, while Na^+ and Ca^{2+} exhibited very small concentration changes ranging from 0.3 [mM] to 10 [mM]. Therefore, it was confirmed that the NS-CEM selectively permeates only NH_4^+ . Furthermore, a comparison of ion selectivity coefficients showed that for commercially available CEM, $P_{\text{Na}}^{\text{NH}_4}$ was 2.04 and $P_{\text{Ca}}^{\text{NH}_4}$ was 1.09,

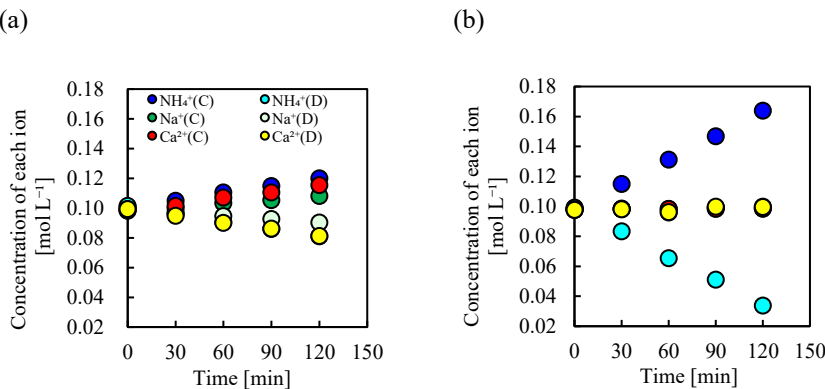


Fig. 1 Changes in ion concentration over time during ED.

Sample:(a) commercial CEM, (b) NS-CEM.

whereas for the NS-CEM, $P_{\text{Na}}^{\text{NH}_4}$ was 109 and $P_{\text{Ca}}^{\text{NH}_4}$ was 107.

4. Acknowledgments

This study is based on results obtained from a project, JPNP18016, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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SEAWATER RECIRCULATION IN REVERSAL ELECTRODIALYSIS FOR RESOURCE-EFFICIENT EFFLUENT RECLAMATION

R. Ibáñez, L. Gómez-Coma, T. Sampedro, I. Ortiz

Chemical and biomolecular Engineering Department, Universidad de Cantabria, Avda de los Castros s/n, 39005 Santander, Spain (ibanezr@unican.es)

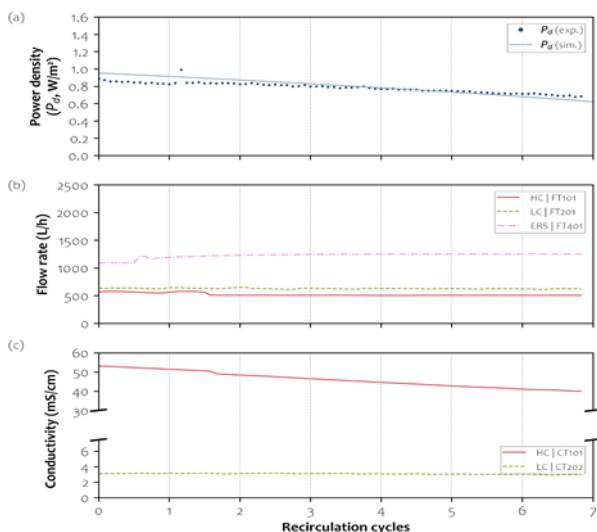
Abstract: Harvesting the energy stored in salinity gradients (EGS) through reverse electrodialysis (RED) technology emerges as one of the most promising options to support the implementation of tertiary and quaternary treatments in coastal urban wastewater treatment plants. This strategy offers a dual benefit: on the one hand, it enables the production of green energy without associated CO₂ emissions, which can help drive the installation of these treatment stages; on the other hand, the effluent quality after the process can be suitable for subsequent reuse¹. However, the efficient operation of RED systems strongly depends on the optimization of high-salinity feed management. In conventional open-loop RED operation, seawater or brine is introduced once, exploited to extract energy from the instantaneous salinity gradient, and then discharged. This approach involves large intake volumes, extensive pre-treatment requirements, high pumping energy consumption, and potentially significant concentrate disposal challenges. In this work, an experimental study was carried out in a pilot plant operating under real conditions in Comillas, Spain, using treated effluent from a coastal WWTP as the low-concentration stream and seawater as the high-concentration stream. The aim was to determine the optimal number of high-concentration stream recirculation cycles in a resource-efficient RED configuration. The pilot plant, shown in Figure 1, has a membrane area of 40.25 m² distributed across two ion-exchange membrane modules, each comprising 115 membrane cell pairs using FKS-PET-75 and FAS-PET-75 membranes.



Figure 1. Photograph of the pilot plant (left) and the RED modules (right) used in this study.

A detailed description of the complete pilot plant can be found in Sampedro et al.,². To this end, a bleed-and-make-up control strategy was designed. This strategy, activated when a minimum conductivity or open-circuit voltage threshold is

reached, preserves an adequate salinity gradient across successive RED passes, thereby sustaining high energy yields while minimizing fresh seawater intake. The proposed recirculation protocol gradually depletes the salinity difference in a predictable way, extending the use of the high-salinity feed without requiring proportional increases in seawater intake or module number. Figure 2 shows the time evolution of the first seven recirculation cycles. The figure reports the evolution of: (a) gross power density, comparing experimental data points with model predictions represented by a solid line; (b) the volumetric flow rates of the low-concentration, high-concentration, and electrode rinse solution streams; and (c) the conductivity of both feed streams throughout the recirculation sequence.



In Figure 2a, the gross power density exhibits a clear, cycle-by-cycle decline as the seawater (HC) stream is recirculated, decreasing from 0.89 W/m² at the outset to ~0.68 W/m² after seven cycles. The 24% reduction in performance correlates strongly with the progressive decrease in the conductivity of the HC stream, which dropped from an initial value of ~53 mS/cm to ~40 mS/cm, as shown in the Figure 2c.

Figure 2. Experimental evaluation of RED system performance under multiple recirculation cycles of the concentrated stream.

In addition, as also observed in Figure 2a, the experimental data are in good agreement with the predictions obtained using the model developed by Ortiz-Imedio et al.,³ confirming its ability to accurately describe RED performance under dynamic recirculation conditions and real feed-water operation. Thus, this work demonstrates that, although seawater recirculation leads to a gradual reduction in power density, the magnitude of the power loss remains moderate and predictable. These results indicate that, with appropriate monitoring and optimized hybrid operating schemes, could represent a viable operational optimization strategy for coastal RED facilities. This approach has the potential to reduce seawater intake and pre-treatment requirements while maintaining competitive energy generation performance.

Acknowledgements

The European LIFE Programme (LIFE19 ENV/ES/000143), and grant PID2023-147888OB-I00 funded by MICIU/AEI/10.13039/501100011033 and “ERDF/EU”.

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A SUSTAINABLE BIOCHAR-HYDROGEL PLATFORM DERIVED FROM MICROALGAE WASTE FOR DYE REMOVAL AND ENVIRONMENTAL SAFETY

H. Islam^{1†}, K. A. Rahaman^{1†}, S. A. Razzak², S. Uddin³

¹Department of Bioengineering, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

²Department of Chemical Engineering, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

^{1,3}Interdisciplinary Research Center for Bio Systems and Machines, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Corresponding author: Shihab Uddin

The authors did not consent to the publication of this abstract.

EFFICACY OF MONOCHLORAMINE FOR BIOFOULING CONTROL IN A PILOT-SCALE OSMOTICALLY DRIVEN MEMBRANE PROCESS

D. Jang¹, S. Kang²

¹Department of Civil and Environmental Engineering, Hanbat National University, Daejeon, 34158, Republic of Korea

²Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea

Abstract: This study evaluated the effectiveness of monochloramine (MCA) in mitigating membrane biofouling during municipal wastewater reclamation using a pilot-scale forward osmosis (FO) process. A spiral wound FO membrane (Toray FO-2540) system was operated using secondary treated wastewater as the feed solution and 0.5 M NaCl as the draw solution, with 10 ppm of MCA injected into the feed solution to compare against a control group. The results demonstrated that the MCA-injected process exhibited higher overall performance compared to the control. The chemical cleaning period, based on a 30% decline in water flux, was significantly extended from 35 days in the control to 140 days, and the chemical cleaning efficiency was enhanced from 35% to 82%. Microbial analysis and confocal laser scanning microscopy (CLSM) images indicated that the MCA membrane exhibited effective bactericidal activity and restricted the formation of extracellular polymeric substances (EPS) in the biofilm. Specifically, the concentration of loosely bound EPS (LB-EPS), which has a strong correlation with membrane fouling, was notably lower. Characterization of the foulants revealed that while the concentration of dissolved organic carbon (DOC) remained similar to the control, the properties of the foulants were altered. The proportions of microbial-oriented portions (SMP-like regions) and low molecular weight compounds—which mainly contribute to irreversible membrane fouling—were substantially decreased by the MCA injection. Furthermore, the reverse salt flux did not dramatically increase during the experiment, indicating that the FO membrane was not damaged by exposure to the MCA solution. In conclusion, chloramination is an effective strategy to inhibit bacterial growth and mitigate irreversible biofouling during wastewater treatment using an FO membrane, without causing membrane damage.

ROLE OF BIOFOULING LAYER IN THE TRANSPORT OF EMERGING CONTAMINANTS IN THE FO MEMBRANE PROCESS: HINDERER OR PROMOTER?

D. Jang¹, S. Kang²

¹Department of Civil and Environmental Engineering, Hanbat National University, Daejeon, 34158, Republic of Korea

²Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea

Abstract: The effect of a biofouling layer on the rejection of emerging contaminants (ECs) during forward osmosis (FO) was studied. The rejection of ECs and the membrane surface properties were evaluated after the formation of a biofouling layer using *Pseudomonas aeruginosa* PAO1 as a model foulant. Compared with a clean membrane, the rejection of ECs increased with the biofouling layer owing to enhanced electrostatic repulsion. However, the rejection efficiency of neutral and positively charged ECs was not significantly affected by biofouling layer formation on the FO membrane surface. The rejection of specific compounds (amitriptyline and triclosan) was significantly enhanced by biofouling. Biodegradability testing of ECs revealed that these compounds were preferentially degraded by bacteria compared to other ECs. The increased degradation of ECs by biofilms resulted in a decrease in the concentration of ECs near the membrane surface, reducing the EC diffusional transport across the FO membrane. Overall, this study suggests that biofilms, which are commonly criticized for their negative effects, could play a positive role in the transport of ECs through the FO.

RESOURCE RECOVERY FROM SEMICONDUCTOR WASTEWATER CONTAINING HIGH-CONCENTRATION AMMONIA AND FLUORIDE

S. B. Jang, J. Jung, I. S. Yoon

EHS/Infrastructure Technology Development, Samsung Electronics Co., Ltd., Hwaseong-si, Gyeonggi-do 18448, Republic of Korea

Abstract: Buffered Oxide Etchant (BOE) wastewater, generated during semiconductor oxide etching, is a highly toxic and complex stream containing extremely high concentrations of hydrofluoric acid (HF) and ammonium fluoride (NH₄F). Due to its corrosive nature and environmental risks, conventional treatment is highly challenging, making the selective recovery of fluorine and ammonia crucial for sustainable manufacturing.

Among various treatment techniques, chemical precipitation using lime (Ca(OH)₂) is commonly used to remove fluoride ions¹. However, this process generates excessive inorganic sludge and faces challenges due to unstable demand in the cement industry. To address these limitations, the recovery of fluoride in the form of cryolite (Na₃AlF₆) can be proposed as an effective strategy. It has the advantage of being able to reduce inorganic sludge and to recover fluoride as valuable crystals, cryolite, which can be sold to aluminum refining and welding rod manufacturers adding potential economic and environmental value to the treatment process.

Furthermore, to treat high-strength nitrogenous streams, conventional treatment has traditionally relied on biological nitrification and denitrification processes. While biological removal of total nitrogen (T-N) is a well-established, it has proven highly inefficient for concentrated industrial streams due to the requirement for exceptionally long hydraulic retention times and an extensive physical footprint. To overcome these inherent limitations, membrane contactor—or membrane degasifying (MDG) technology—emerges as a highly promising alternative².

Therefore, in this study, lab-scale experiments were conducted using BOE wastewater to recover fluoride via cryolite crystallization. Furthermore, a membrane contactor process model was integrated to evaluate the co-recovery potential of ammonia for a complete resource recovery strategy.

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ASYMMETRIC BIPOLAR MEMBRANES WITH MXENE-BASED WATER-SPLITTING CATALYSTS

E.-G. Jang, M.-S. Kang

Department of Green Chemical Engineering, Sangmyung University, 31 Sangmyungdae-gil, Dongnam-gu, Cheonan, Republic of Korea (solar@smu.ac.kr, eeeml.smu.ac.kr)

Abstract: Bipolar membranes (BPMs) consist of a cation-exchange layer (CEL), an anion-exchange layer (AEL), and an intermediate layer (IL), and are specialized ion-exchange membranes capable of generating acids and bases through water dissociation under a strong electric field.¹ The water dissociation performance of BPMs is strongly influenced by the properties of the ion-exchange layers, such as thickness and ion-exchange capacity, as well as by the catalytic activity of the interfacial layer. In this study, an MXene-based catalyst possessing abundant surface terminal groups ($-OH$ and $=O$)², which can promote water dissociation, was introduced into the interfacial layer. In addition, asymmetric BPMs with controlled CEL-to-AEL thickness ratios were designed to optimize the interfacial electric field distribution and enhance water dissociation performance. To improve mechanical durability for practical electrochemical applications, a polyphenylene sulfide (PPS)-based reinforcing substrate was incorporated. As a result, the tensile strength of the reinforced BPM increased by 53.6% compared to that of the non-reinforced membrane, demonstrating significantly improved mechanical stability. The fabricated asymmetric BPM was further evaluated in a direct seawater electrolysis (DSWE) system. Compared with the commercial BPU membrane from Astom, the developed BPM exhibited superior water dissociation performance, effectively suppressing the formation of inorganic precipitates caused by multivalent cations in seawater. Consequently, membrane fouling was significantly reduced, enabling stable long-term operation. These results demonstrate the potential of the developed BPM for efficient and durable seawater electrolysis applications. This work was supported by the National Research Foundation of Korea(NRF), funded by the Korean government(MEST)(NRF-2022M3C1A3081178), and by Korea Environment Industry & Technology Institute(KEITI) through Secondary Battery Saline Wastewater Treatment Technology Development Project, funded by Korea Ministry of Climate, Energy and Environment(MCEE)(RS-2026-25502999)

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SOLVOTHERMAL SYNTHESIS AND SURFACE FUNCTIONALIZATION OF ZIF-8 NANOPARTICLES WITH APTMS FOR FUTURE MEMBRANE APPLICATIONS

A. Janković¹, M. Džepina¹, D. Jozić¹, S. Perinović Jozić²

¹Faculty of Chemistry and Technology, Department of Inorganic technology, University of Split, Ruđera Boškovića 35, Split, 21000, Croatia

²Faculty of Chemistry and Technology, Department of Organic technology, University of Split, Ruđera Boškovića 35, Split, 21000, Croatia

Abstract: Zeolitic imidazolate framework-8 (ZIF-8) is one of the most extensively investigated metal–organic frameworks (MOFs) owing to its high specific surface area, well-defined microporous structure, and excellent thermal and chemical stability. These properties make ZIF-8 a promising filler for mixed matrix membranes (MMMs), where it can enhance both permeability and selectivity. However, incorporating ZIF-8 into polymer matrices is often hindered by particle agglomeration and insufficient interfacial compatibility with polymers. Therefore, surface functionalization is commonly employed to improve particle dispersion and promote stronger interactions with membrane-forming polymers.

In this work, ZIF-8 nanoparticles were synthesized by a solvothermal method using zinc nitrate and 2-methylimidazole as precursors. The synthesized material was characterized by X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM/EDS), and thermogravimetric analysis (TG). The obtained results confirmed the successful formation of the crystalline ZIF-8 structure. SEM analysis revealed particle sizes below 100 nm, with a pronounced tendency towards agglomeration. The observed morphology was taken into consideration during the design of the surface modification procedure. In order to reduce particle agglomeration and increase the availability of surface active sites, ultrasonic treatment was applied during the functionalization. Surface modification was subsequently carried out using (3-aminopropyl) trimethoxysilane (APTMS) via a one-step approach. The ultrasonic reaction was carried out at room temperature, and the obtained material was dried under vacuum at 70 °C, which allowed the introduction and retention of amino-functional groups on the ZIF-8 surface.

Keywords: ZIF-8, metal–organic frameworks, APTMS, surface functionalization, nanoparticles, XRD, SEM, FTIR.

Acknowledgment: This research is funded by the European Union – NextGenerationEU project (No. IP-UNIST-29)

MORPHOLOGY OPTIMIZATION OF CHIRAL THIN-FILM MEMBRANES

V. John¹, C. J. Hobbs¹, M. Řezanka¹, J. Čížek^{2,3}, M. Kohout⁴, P. Izák^{2,5}, F. Yalcinkaya¹

¹Institute for Nanomaterials, Advanced Technologies and Innovation, Technical University of Liberec, Studentská 1402/2, 461 17, Liberec, Czech Republic
(fatma.yalcinkaya@tul.cz)

²Institute of Chemical Process Fundamentals of the CAS, Rozvojová 135, 16500, Prague, Czech Republic

³Department of Chemical Engineering, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague, Czech Republic

⁴Department of Organic Chemistry, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague, Czech Republic

⁵Department of Physical Chemistry, University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic

Abstract: Chiral membrane separation can provide a resource-efficient route for enantiomer selectivity, but selector incorporation must not compromise the continuity of the selective layer. This work reports a morphology-driven pre-screening of thin-film membranes intended for later enantioselective separation. Enantiomeric transport and selectivity have not yet been tested. Electrospun polyacrylonitrile (PAN) nanofibers containing Fe nanoparticles (FeNPs) were used as the support. A thin film was formed from trimesoyl chloride (TMC) and an aqueous amine phase containing m-phenylenediamine (MPD) plus either diaminocyclohexane (DACH) or amino-beta-cyclodextrin (NH₂-beta-CD). For both selectors, 10-100% content in the MPD mixture was controlled by SEM. The images show the influence of concentration on film coverage, porosity, granular texture and cracking. In this study we tried to optimize defect-free composition by structural verification for subsequent D/L-tryptophan experiments.

Objective: Thin-film composite (TFC) membranes prepared by interfacial polymerization can combine a low-resistance support with a chemically tailored barrier layer. The nanoscale morphology of the active film is sensitive to the molecular structure and concentration of the aqueous-phase amine, as well as to the local reaction and transport conditions^{1,2}. The present study evaluates two prospective chiral components, DACH and NH₂-beta-CD, as partial or complete replacements of MPD in a TMC-derived thin film.

The immediate objective is not chiral separation itself, but the identification of compositions that form an intact and reproducible surface without macroscopic cracks, open gaps or excessive support exposure. This structural prerequisite is essential before using the membranes as chiral selectors.

Experimental Design: FeNP-loaded electrospun PAN nanofiber mats were used as the porous support. Interfacial polymerization was carried out using TMC in the organic phase and aqueous MPD/DACH or MPD/NH₂-beta-CD monomer mixtures. Each selector was studied at 10, 20, 30, 40, 50, 60, 80 and 100% wt. concentration in the MPD mixture under the same conditions. SEM was performed at low and high magnification to assess surface coverage, local film continuity, visible pore/open areas, particulates and crack formation.

Results and discussion. The SEM results shows distinct composition-dependent film formation. In the DACH series, 10-40% samples contain locally coated regions, although low-magnification images still show heterogeneous coverage and exposed nanofiber support in several fields. At 50% DACH, a pronounced through-layer crack is visible (Figure 1). The 60-100% DACH samples show more folded or particulate features, indicating that higher DACH content does not yield a robust continuous top layer under the current conditions.

The NH₂-beta-CD series has a more porous and nodular character. The 10% sample contains a large surface discontinuity; 20-50% formulations show cavity-like or particulate features; and 60% and 100% have macroscopic openings/cracks. At 80%, the granular surface remains discontinuous at low magnification. Therefore, DACH 50% and NH₂-beta-CD 10%, 60% and 100% are excluded from immediate downstream testing. DACH 20-40% is the most promising provisional window for replication, whereas NH₂-beta-CD requires additional control of its incorporation and film-forming conditions.

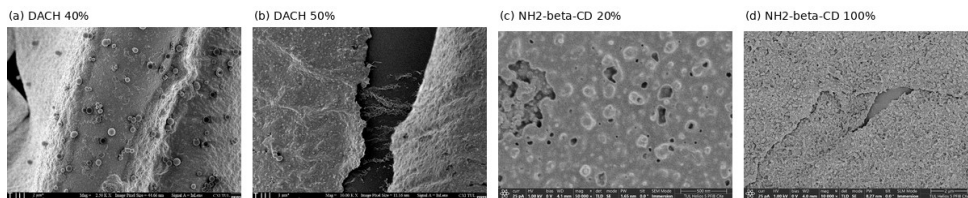


Figure 1. Selected SEM images from the monomer-composition screening: (a) DACH 40%; (b) DACH 50%, with a pronounced through-layer crack; (c) NH₂-beta-CD 20%, with cavity-like/porous surface features; and (d) NH₂-beta-CD 100%, with a macroscopic opening. Scale bars are retained from the original SEM images.

Conclusion: SEM confirms that chiral-selector content strongly affects MPD/TMC thin-film integrity on FeNP/PAN supports. These data are a structural pre-screen, not evidence of chiral separation. Selected compositions will be reproduced after pH adjustment and verified by repeated SEM, cross-sectional imaging and complementary chemical characterization before D/L-tryptophan transport and enantioselectivity measurements.

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Acknowledgement: The study was funded by the Czech Science Foundation (GACR), project number 25-15195S.

RELATIONSHIP BETWEEN MONOVALENT ANION SELECTIVITY OF ANION EXCHANGE MEMBRANES AND QUATERNIZATION CONDITIONS

M. Katsura¹, M. Tanaka², Y. Kakihana^{2,3}, M. Higa^{2,3}

¹Faculty of Engineering, Yamaguchi University (YU); 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

²Graduate School of Sciences and Technology for Innovation, YU

³Blue Energy center for SGE Technology (BEST), YU

1. Introduction

Anion exchange membranes (AEMs), a type of separation membrane, are used not only in electrodialysis applications such as salt production and seawater desalination, but also in a variety of other applications, including reverse electrodialysis power generation, which utilizes salinity gradients, and Donnan dialysis, which uses concentration gradients as a driving force for concentration and desalination of electrolytes. Generally, the membrane properties required for AEMs include low membrane resistance, and high counterion selectivity; furthermore, depending on the application, low water and salt permeability and monovalent anion selectivity will also be required. However, there have been few reports on the relationship between membrane properties and its structure¹⁾. Therefore, in this study, we fabricated AEMs with different membrane structures by varying the quaternization reaction time to increase monovalent anion selectivity.

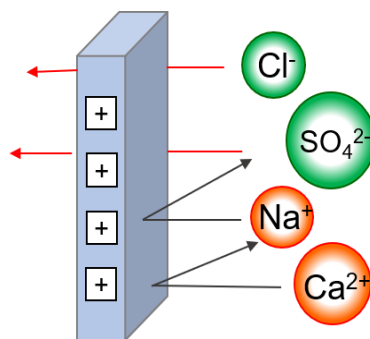


Fig. 1 Structure of an anion-exchange membrane.

2. Experimental Methods

After casting a film from a dimethylformamide (DMF) solution of chloromethylated polyether sulfone (CM-PES), the film was immersed in a 30 wt% trimethylamine solution and quaternized at 30 °C for a specified period of time. To evaluate the properties of the fabricated membrane, membrane resistance was measured and electrodialysis (ED) were performed, and the results were compared with those of a commercially available standard AEM (ASE, ASTOM Corp., Japan).

3. Results and Discussion

Fig. 2 shows the relationship between the quaternization time of the AEM prepared and the membrane resistance. This figure reveals that the membrane resistance decreases as the reaction time increases. Furthermore, membranes with reaction times of 12 hours or longer exhibited lower membrane resistance values than commercially available standard AEM, ASE, reaching a maximum of approximately one-third value of ASE. This is thought to be due to the formation of ion channels as the quaternization reaction progresses, resulting in improved ion permeability.

Fig. 3 shows the relationship between quaternization time and monovalent ion selectivity. This figure reveals that the highest selectivity is achieved at a reaction time of 15 hours. Furthermore, the selectivity of this membrane was approximately three times higher than that of ASE, demonstrating superior performance as a monovalent ion selective AEM. Ion permeability improved due to the introduction of fixed charged groups into the membrane through quaternization. On the other hand, it was shown that an excessive increase in charge density also promotes the permeation of divalent ions.

4. Conclusion

In this study, an AEM was fabricated using quaternized polyether sulfone as the matrix, and monovalent selectivity was evaluated based on measurements of basic properties. The results showed that the membrane resistance tended to decrease as the quaternization reaction time increased. In particular, membranes with a quaternization reaction time of 12 hours or longer exhibited lower membrane resistance than the commercially available standard AEM, demonstrating superior performance. Furthermore, monovalent ion selectivity improved as the quaternization reaction time increased, but decreased when the reaction time became excessively long. Future studies will investigate the optimization of quaternization reaction conditions for the fabrication of AEMs exhibiting higher monovalent anion selectivity.

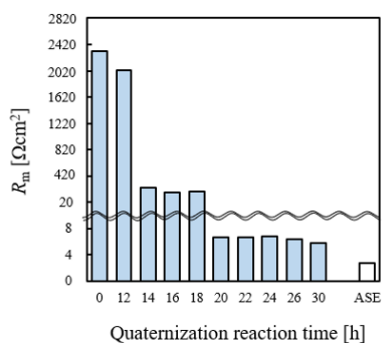


Fig. 2 The relationship between quaternization time and membrane resistance.

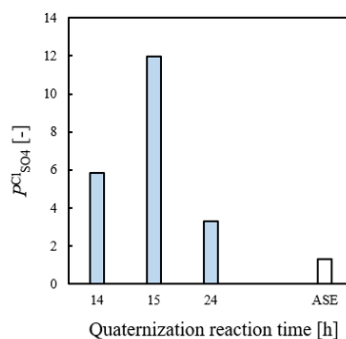


Fig. 3 The relationship between quaternization time and monovalent ion selectivity.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP26H02586.

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MOLECULAR DYNAMICS INSIGHTS INTO CO₂ CAPTURE IN PRUSSIAN BLUE ANALOGUE-MODIFIED MIXED MATRIX MEMBRANES

M. Khajavian¹, D. Kang², S.-U. Lee^{1,3}, J.-M. Lee^{1,3}, S. Lee⁴, M.-H. Hwang⁵, E. Yang^{2,**}, K.-J. Chae^{1,3,*}

¹Department of Environmental Engineering, College of Ocean Science and Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

²Department of Marine Environmental Engineering, Gyeongsang Nantional University, Gyeongsangnam-do, 53064, Republic of Korea

³Interdisciplinary Major of Ocean Renewable Energy Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, Republic of Korea

⁴Korea University Institute for Energy Technology, Korea University, 145, Anam-ro, Sungbuk-gu, Seoul 02841, Republic of Korea

⁵Graduate School of Energy and Environment (KU-KIST Green School), Korea University, 145, Anam-ro, Sungbuk-gu, Seoul 02841, Republic of Korea

*Corresponding author. Department of Environmental Engineering, College of Ocean Science and Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan, 49112, Republic of Korea. (ckjdream@kmou.ac.kr (K. J. Chae))

**Co-Corresponding author. Department of Marine Environmental Engineering, Gyeongsang Nantional University, Gyeongsangnam-do, 53064, Republic of Korea (yet83@gnu.ac.kr (Euntae Yang))

The authors did not consent to the publication of this abstract.

SYNTHESIS OF ADVANCED POLYUREA MEMBRANES FOR CRITICAL RESOURCE RECOVERY FROM ACIDIC MINE DRAINAGE

M. N. Khan, U. Khan, A. Pihlajamäki, M. Mänttari.

Department of Separation Science, LUT University, 53850 Lappeenranta, Finland

inomanzia@gmail.com

Abstract: The transition toward sustainable technology demands the efficient extraction of critical resources from harsh industrial waste streams such as acid mine drainage (AMD). To achieve this, acid-resistant polyurea thin-film composite (TFC) nanofiltration (NF) membranes were fabricated via interfacial polymerization (IP) of diethylenetriamine (DETA) and toluene-2,4-diisocyanate (TDI) on various polyethersulfone (PES) substrates. The objective was to understand the effect of substrate molecular weight cut-off (MWCO) and investigate the impact of monomer concentration on the durability and performance of the PU active layer. Fourier transform infrared spectroscopy (FTIR) confirmed the successful deposition of the PU selective layer. Formulation-A (2 wt% DETA / 0.15 wt% TDI) on UP005P, UP020P, UH030P, and UH050P substrates produced highly crosslinked selective layers with maximum Fe^{2+} rejections of 98%, 93%, 89%, and 59%, respectively. Based on a trade-off between rejection and flux, the UP020P substrate was selected for monomer concentration optimization. Decreasing the monomer concentration, formulation-B (1 wt% DETA / 0.1 wt% TDI) and formulation-C (0.5 wt% DETA / 0.05 wt% TDI) yielded Fe^{2+} rejections of 86% and 70%, respectively. These formulations achieved fluxes of $9 \text{ kg.m}^{-2}.\text{h}^{-1}$ and $189 \text{ kg.m}^{-2}.\text{h}^{-1}$, representing a 1.25 and 46.25-fold increase over the formulation-A/UP020P, while rejections decreased by only 7.5% and 24.25%. Furthermore, the PU membranes exhibited strong acid stability during a 336 h exposure test in pH 1.5 H_2SO_4 , maintaining structural integrity, MWCO, and separation performance, whereas commercial benchmark membranes (NF-270 and Desal DK) suffered an approximate 33% loss in separation efficiency under identical conditions. The enhanced acid resilience and tunable flux-rejection profiles achieved through formulation engineering highlight the potential of PU-based TFC NF membranes for selective resource recovery in highly acidic industrial environments.

Keywords: Metal ion rejection; Solvent recycling; Acid recovery; Closed-loop mine processing; Interfacial Polymerization, Acid Mine Drainage (AMD).

TESTING CUSTOM-DESIGNED 3D PRINTED PANEL REACTORS TO INCREASE THE EFFICIENCY OF BIOELECTROCHEMICAL SYSTEMS APPLYING A COMMERCIAL CATION EXCHANGE MEMBRANE

A. B. Kiszl¹, L. Koók¹, Z. Pientka², M. Otmar², A. Bahaa³, K. J. Chae³, W. Kujawski⁴, N. Nemestóthy¹, K. Bélafi-Bakó¹, P. Bakonyi^{1,*}

¹Research Group on Bioengineering, Membrane Technology and Energetics, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

²Institute of Macromolecular Chemistry, AS CR, Heyrovsky Sq. 2, 162 06 Prague 6, Czech Republic

³Department of Environmental Engineering, Korea Maritime and Ocean University, 727 Taejong-ro, Yeongdo-gu, Busan 49112, South Korea

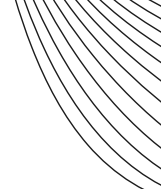
⁴Faculty of Chemistry, Department of Physical Chemistry, Nicolaus Copernicus University in Toruń, Gagarin Street 7, 87-100 Toruń, Poland

*Presenting Author (Email: bakonyi.peter@mk.uni-pannon.hu)

Abstract: Following our previous collaborative (Hungarian, Czech, Polish, Korean) research activities^{1,2}, the aim of the actual work was to develop a custom-designed, 3D printed panel reactor and its experimental testing to increase the efficiency of bioelectrochemical hydrogen production. Reactor prototypes were 3D printed from polylactic acid (PLA) in a panel configuration, which allows for flexible modification and testing of geometric parameters. The system operates in a two-chamber MEC arrangement, with a biofilm formed on carbon-based anode electrodes and a cathode electrode suitable for hydrogen evolution reaction. A polymer-based cation exchange membrane (CEM, Selemion CMVN, AGC, The Netherlands) was used to ensure ion transport. During the experiments, the effect of the electrode-membrane distance and the geometric design of the reactor chambers on the performance of the system were investigated. The operational traits were evaluated by current density measurement, coulombic efficiency (CE) calculation, hydrogen yield determination, and additional electrochemical methods. In the 3D MEC (3D printed design) system, the CE value ranged from 9-42%, while in the ICC MEC (internal cathode compartment) it was significantly lower, 11-35%. The hydrogen production efficiency ranged from 3-12% in the 3D MEC system, while in the ICC MEC system it ranged from 2-7%. The results of the research may contribute to the optimization of bioelectrochemical hydrogen production systems and the more sustainable application of hydrogen-based energy technologies.

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SURFACE MODIFICATION OF 3D PRINTED POLYMERIC MEMBRANES WITH CROSSLINKED PVA FOR WASTEWATER TREATMENT

E. Kokkinos¹, E. Paterakis¹, K. Simeonidis¹, E. Peleka¹, C. Tsiptsias², P. Samaras², T. Tsopani², A. Assimopoulou³, D. Christofilos³, K. Theodoridis³, O. Karabinaki³, A. Zouboulis¹

¹Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece (evgenios@chem.auth.gr)

²Department of Food Science and Technology, International Hellenic University, Sindos, 57400, Greece

³Laboratory of Organic Chemistry, School of Chemical Engineering, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece

Abstract: The development and application of 3D printing technology, specifically Fused Deposition Modelling (FDM), have revolutionized the fabrication of polymeric membranes, enabling highly customized architectures tailored for specific separation processes. [1] These innovative 3D printed membranes represent an increasingly significant alternative in the field of environmental engineering, offering substantial potential for complex wastewater treatment applications due to their inherent geometric versatility and cost-effective, rapid production capabilities. Despite these advantages, achieving the precise structural geometry, hierarchical pore distribution and specific surface characteristics necessary for the highly efficient removal of diverse contaminants remains a formidable engineering challenge. Consequently, the implementation of secondary surface modification strategies has become essential to refine the membrane's surface properties, optimize selectivity, and fundamentally enhance the overall separation performance in demanding industrial and environmental contexts. [2]

In this study, we investigate the systematic surface modification of 3D printed polylactic acid (PLA) membranes. To effectively overcome the limitations of standard FDM techniques regarding the production of fine, uniform pore sizes, specialized surface modification strategies were rigorously evaluated to enhance particle retention. The research specifically focused on the controlled application and structural optimization of a polyvinyl alcohol (PVA) coating, which was subsequently stabilized through crosslinking with glutaraldehyde (GA) to ensure durability and insolubility in aqueous environments. [3]

The initial 3D-printed membrane was fabricated from PLA, featuring an eight-layer complex internal configuration, external dimensions 10 x 8 cm and thickness equal to 2 mm. To secure the long-term efficiency of the PVA-based coating, an exhaustive optimization of the crosslinking protocol of the immersion technique was conducted. The identified optimal experimental conditions - consisting of 1 wt.% glutaraldehyde, 4.5 wt.% Na₂SO₄, a controlled pH of 2.5, and a consistent

treatment duration of 1.5 hours - proved highly effective, limiting the PVA mass loss to approximately 4% after 24 hours of continuous immersion in water. Comprehensive characterization of the modified membranes was performed using advanced techniques, including optical microscopy, systematic porosity determination, static contact angle measurements, and FTIR spectroscopy.



Figure 1. Optical microscopy images of the 3D printed membrane surface with a) one, b) two and c) three layers of PVA.

The application of PVA coatings influenced the membrane characteristics. Increasing the number of PVA layers from one to three resulted in a progressive reduction of porosity from 45.6% to 32.5% and a marked decrease in the static contact angle from 79.4° to 55°, clearly demonstrating enhanced surface hydrophilicity. Crucially, the modification provided the membranes with significant antifouling properties, effectively resisting the accumulation of contaminants during operation. In filtration experiments using a kaolin suspension (3 g/L) and a handmade setup that was also 3D-printed, the PVA-modified membranes exhibited a progressive increase in separation efficiency, peaking at 68% for the three-layer configuration, compared to 40% for the unmodified sample. While this enhancement in separation capacity was associated with a moderate increase in transmembrane pressure (rising from 0.40 to 0.58 bar) and a corresponding reduction in permeate flux (from 322.5 to 97.5 L·m⁻²·h⁻¹), the observed antifouling behavior significantly extends the operational lifespan of the membranes. These findings confirm that while PVA coating involves a necessary trade-off with hydraulic performance, it is a superior strategy for developing advanced, durable, and fouling-resistant 3D printed membranes.

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Acknowledgments

The research project is implemented in the framework of H.F.R.I. call “3rd Call for H.F.R.I.’s Research Projects to Support Faculty Members & Researchers” (H.F.R.I. Project Number: 24958).

ADVANCEMENTS IN SUSTAINABLE PROTON EXCHANGE MEMBRANES FOR WATER ELECTROLYZERS

F. Komers^{1,2}, D. Plachá³, L. Obalová¹, B. V. d. Bruggen⁴

¹Institute of Environmental Technology, CEET, VSB- Technical University of Ostrava, 17. Listopadu, 2172/15, Ostrava Poruba 70800, Czech Republic

²Faculty of Materials Science and Technology, VSB-Technical University of Ostrava, 708 00 Ostrava, Czech Republic

³Environmental Nanotechnology Palacký University Olomouc CATRIN-RCPTM, Šlechtitelů 241/27, 779 00 Olomouc, Czech Republic

⁴Department of Chemical Engineering, KU Leuven, Celestijnenlaan 200F, B-3001 Leuven, Belgium

Abstract: Hydrogen is widely recognized as a key energy carrier for the transition toward a low-carbon and sustainable energy system. Its ability to store energy from renewable sources and its applicability across transportation, industry, and power generation have led to a rapidly increasing global demand. Among the available hydrogen production technologies, water electrolysis powered by renewable electricity represents one of the most environmentally friendly approaches. In particular, proton exchange membrane (PEM) water electrolysis has attracted significant attention due to its simplicity, compact design, and production of high-purity hydrogen [1].

Despite these advantages, the widespread deployment of PEM electrolyzers is limited by the reliance on perfluorinated proton exchange membranes, such as Nafion. These materials exhibit excellent proton conductivity and chemical stability but suffer from high production costs, limited biodegradability, and environmental concerns associated with fluorinated polymers. Consequently, the development of sustainable and environmentally benign alternatives has become an important research objective [2].

This work focuses on cellulose-based proton exchange membranes as promising sustainable substitutes for conventional PEM materials. Cellulose is the most abundant natural polymer on Earth and offers several advantages, including renewability, biodegradability, low cost, and broad availability [1]. Furthermore, cellulose membranes exhibit high water uptake, which can facilitate proton transport, while their dense polymer structure may contribute to reduced hydrogen permeability and improved operational safety [3]. The presented research investigates the preparation and characterization of cellulose-based membranes, with particular emphasis on the relationship between membrane fabrication, structure, and transport properties. Key parameters such as water uptake, proton conductivity, hydrogen permeability, and overall suitability for PEM water electrolysis are evaluated and compared with those of commercial membranes. The

results contribute to the development of sustainable proton exchange membranes capable of reducing the environmental impact and cost of future hydrogen production technologies.

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Acknowledgement

This research was funded by MSMT, OP JTF “REFESH” project, reg. no. CZ.10.03.01/00/22_0030/0000048

This work was supported by The Ministry of Education, Youth and Sports of the Czech Republic from the project SGS - Grant Agency of the VŠB-TUO (grant no. SP2026/080).

N₂-ASSISTED MEMBRANE-SEPARATED ELECTROCHLORINATION FOR HIGH-STRENGTH SODIUM HYPOCHLORITE PRODUCTION

P. L. Koo^{1,2}, W. Y. Chia¹, T. H. Chong^{1,2*}

¹Singapore Membrane Technology Centre, Nanyang Environmental and Water Research Institute, Nanyang Technological University, Singapore

²School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

Abstract: Membrane-separated electrochlorination offers a potential route for on-site sodium hypochlorite (NaOCl) production from concentrated saline streams. However, overall product formation depends not only on electrochemical chlorine generation, but also on ion transport, hydrodynamics, gas-liquid separation and subsequent chlorine absorption. This study evaluates a membrane-separated electrochlorination system equipped with a DF2808 perfluorinated chlor-alkali cation-exchange membrane with particular emphasis on N₂-assisted chlorine transfer and the operating conditions governing high-strength NaOCl production. Synthetic NaCl solutions were electrolysed in the anodic compartment, while NaOH was circulated through the cathodic compartment. Chlorine generated at the anode was directed through a gas-liquid separator and transferred to an external alkaline absorber for conversion to NaOCl. N₂ was introduced into the separator headspace to facilitate chlorine transfer. The effects of applied current, NaCl flow rate, NaCl concentration and bromide concentration were systematically investigated under N₂-assisted operation.

Increasing the applied current from 35 to 55 A increased NaOCl concentration from 8.6 to 10.6 wt%, although the corresponding current efficiency decreased, demonstrating a trade-off between product concentration and electrical utilization at elevated current. Increasing the NaCl flow rate from 10 to 20 mL min⁻¹ decreased NaOCl concentration from 10.0 to 7.7 wt%, indicating that hydrodynamic conditions and residence time significantly influence overall product formation. Bromide addition produced a non-monotonic response, with NaOCl concentrations of 8.6, 6.7 and 8.5 wt% at 0, 50 and 100 mg L⁻¹ Br⁻, respectively. This behaviour indicates that bromide concentration alone does not directly determine the measured oxidant yield under the investigated conditions and warrants further investigation of chlorine- and bromine-containing oxidant speciation. Overall, the membrane-separated system achieved NaOCl concentrations exceeding 10 wt% under optimized operating conditions. The results demonstrate that high-strength hypochlorite production depends on the coupling between electrochemical generation, membrane transport, hydrodynamics and gas transfer rather than applied current alone. These findings establish an operating framework for N₂-assisted membrane electrochlorination and support its future application to purified desalination-derived saline streams for on-site disinfectant production.

Acknowledgement

This research is supported by the National Research Foundation, Singapore, and PUB, Singapore's National Water Agency under its RIE2025 Urban Solutions and Sustainability (USS) (Water) Centre of Excellence (CoE) Programme which provides funding to the Nanyang Environment & Water Research Institute (NEWRI) of the Nanyang Technological University, Singapore (NTU). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not reflect the views of National Research Foundation, Singapore and PUB, Singapore's National Water Agency.

OPTIMIZATION OF PARAMETERS OF EDBM PROCESS

T. Kubíčková, J. Fehér

Department of Modules and Devices, MemBrain s. r. o., Pod Vinicí 87, Stráž pod Ralskem,
PA 47127, Czech Republic

Abstract: The aim of this study was to determine the optimal conditions of the EDBM process in order to achieve high efficiency and high purity of the produced acids and bases. Membrane stacks consisting of Ralex® membranes (CM-PP, AM-PP, BM 3.1) and Ralex® membrane foils (AF, CF, BM 3.9) were tested. The membrane stacks in configurations EDBM-Z/3x10 and EDBM-H3/3x10 were subjected to batch and concentration tests with Na₂SO₄ at applied voltages of 20 V, 30 V, 40 V and 50 V. To determine the purity, samples were collected from each circuit after each test and concentrations of H⁺, OH⁻, Na⁺ and SO₄²⁻ ions were determined in laboratory. Current efficiency and purity of products increased with higher applied voltages in most cases. The exception in this correlation were tests that, for various reasons, took longer. This suggests even stronger relation between efficiency, purity and time of the test than the applied voltage.

Acknowledgements. The work was carried out within the framework of the project “A long-term concept for the development of the research organization” supported by the Ministry of Industry and Trade of the Czech Republic, using the Membrane Innovation Centre infrastructure.

EFFECT OF GLASS FIBERS ON THE MECHANICAL AND TRANSPORT PROPERTIES OF POLYMER INCLUSION MEMBRANES COMPOSED OF ALIQUAT 336 AND PVDF-HFP

L. Kukoc¹, K. Velikova², S. Perinovic-Jozic¹, M. Biocic¹, M. Gateshki³, S. D. Kolev^{2,4,5,6}, T. G. Spassov^{2,6}

¹Faculty of Chemistry and Technology, University of Split, Rudjera Boskovica 35, 21000 Split, Croatia (kukoc@ktf-split.hr)

²Faculty of Chemistry and Pharmacy, Sofia University "St. Kl. Ohridski", 1 J. Bourchier Blvd., 1164 Sofia, Bulgaria

³Malvern Panalytical B.V., Lelyweg 1, 7602 EA, Almelo, The Netherlands

⁴School of Chemistry, The University of Melbourne, Victoria 3010, Australia

⁵Department of Chemical Engineering, The University of Melbourne, Victoria 3010, Australia

⁶National Centre of Excellence Mechatronics and Clean Technologies, 8 Kliment Ohridski Blvd., 1756 Sofia, Bulgaria

Abstract: Polymer inclusion membranes (PIMs) based on PVDF-HFP as the base polymer and Aliquat 336 as the carrier in mass ratio of 6:4 with concentrations of embedded glass fibers up to 5 wt%, were successfully fabricated. Their microstructure, as well as their mechanical and thermal properties, were characterized using scanning electron microscopy (SEM), small-angle X-ray scattering (SAXS), differential thermal analysis (DTA/TG), and tensile testing. Membrane performance and long-term stability in transporting thiocyanate ions was evaluated in a two-compartment transport cell. The results showed that the membranes retained their amorphous structure even with glass-fiber loadings of up to 5 wt%. The addition of glass fibers was found to primarily enhance the elastic modulus and tensile strength, while causing a moderate reduction in plasticity without negatively affecting membrane transport properties and long-term stability. Therefore, it was concluded that the incorporation of glass fibers could improve the suitability of PIMs for industrial applications.

Acknowledgements

This research was supported by European Union-NextGenerationEU project No IP-UNIST-29.

OXIDATIVE DAMAGE IN PHOSPHATIDYLSERINE BILAYERS MODULATED BY HIGH CHOLESTEROL CONTENT: A SCANNING ELECTRON MICROSCOPY STUDY

K. Kuliš¹, M. Šerić^{2,3}, A. Bilušić⁴, M. Raguz²

¹Institute of Emergency Medicine of Split-Dalmatia County, Split, Croatia, kresokulis268@gmail.com

²University of Split School of Medicine, Department of Medical Physics and Biophysics, Split, Croatia

³Faculty of Science, University of Split, Doctoral Study of Biophysics, Split, Croatia

⁴Faculty of Science, University of Split, Department of Physics, Split, Croatia

Abstract: In this study, we investigated the properties of multilamellar vesicles (MLVs) prepared from a mixture of 1-palmitoyl-2-oleoyl-sn-glycero-3-phospho-L-serine (POPS) and cholesterol (Chol) in 10 mM 1,4- piperazinediethanesulfonic acid (PIPES) buffer, with Chol/POPS molar ratios ranging from 0 to 1.5. To prevent Chol demixing artifacts, MLVs were prepared using the rapid solvent exchange method. The vesicle suspensions were deposited onto conductive surfaces, dried, and imaged by scanning electron microscopy (SEM).

The primary aim was to examine the oxidative effects of 2,2'-azobis(2-amidinopropane) dihydrochloride (AAPH) on the membrane bilayer. A secondary aim was to assess how increasing Chol concentration influences this oxidative process.

Comparison of unoxidized and oxidized MLVs revealed clear morphological differences across all Chol/POPS ratios. Vesicles with lower Chol concentration exhibited greater damage, whereas those with higher Chol concentration were more resistant to oxidation, suggesting a protective role of Chol. Overall, SEM appears to be an adequate method for detecting oxidation-induced changes in MLV structure, including size, morphology, and lateral organization.

PARTITIONING OF COUNTERIONS AT LOW CONCENTRATIONS BETWEEN POLYELECTROLYTE HYDROGEL PHASE AND WATER PHASE

M. Lang, O. Sedláček, P. Košovan, L. Nová

Department of Physical and Macromolecular Chemistry, Faculty of Science, Charles University, Hlavova 2030/8, 128 00 Prague 2, Czech Republic (langmat@natur.cuni.cz, natur.cuni.cz)

Abstract: The partitioning of chemical substances between two different phases is one of the fundamental effects applied in many branches of chemistry. The partitioning of ions between a polyelectrolyte hydrogel and surrounding supernatant is an energy-efficient and perspective way of recycling such ions and an effective tool e.g. for water desalination as well. Analogous to membrane separation with an impermeant ion species present in one of the phases, the partition of ion species of opposite charge follows an asymmetric distribution. This distribution is usually described, in case of monovalent ions, by Gibbs-Donnan equilibrium. However, when discussing hydrogels, the two phases are the gel itself and the surrounding supernatant with the impermeant ion being the charged side chain of the polyelectrolyte. Here, the partitioning of 1+ and 2+ counterions between a strong polyacidic hydrogel based on sodium 2-acrylamido-2-methylpropanesulfonate (NaAMPS) and supernatant was studied (see Fig. 1), as well as swelling of the aforementioned hydrogel at low concentrations of the counterions in the supernatant ($10^{-8} - 10^{-3}$ mol/l).



Figure 1: Examples of partition experiments at equilibrium

The NaAMPS gel was synthesised by radical polymerization according to the reaction scheme in Fig. 2. The system behaviour should follow the ideal case, often used in simulations. During the experiments performed at low concentrations of 1+ and 2+ counterions studying the partitioning of those ions between a strong polyacidic hydrogel and 10mM NaCl water solution, it was found that the swelling of the gel is up to the volume transition concentration influenced by the presence of NaCl only. Above the volume transition concentration the effects of 2+ counterions are much more pronounced and when the NaCl effect is screened, the swelling behaviour of the studied hydrogels is universal regardless of the crosslink density

and falls onto a master curve. The concentration-independent partition coefficients of studied counterions were determined as well.

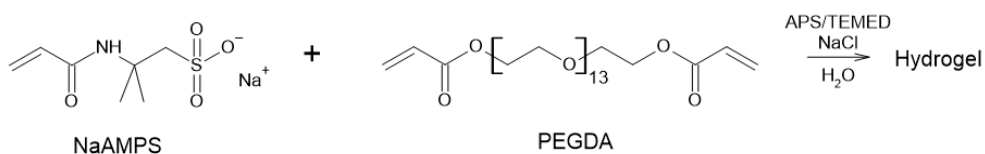


Figure 2: AMPS hydrogel synthesis reaction scheme

POLYMER BLENDING STRATEGY FOR HIGHLY DURABLE PPO-BASED ION-EXCHANGE MEMBRANES

J.-H. Lee, E.-G. Jang, M.-S. Kang

Department of Green Chemical Engineering, Sangmyung University, 31 Sangmyungdae-gil, Dongnam-gu, Cheonan, Republic of Korea (solar@smu.ac.kr, eeeml.smu.ac.kr)

Abstract: Ion-exchange membranes are key components in electrochemical energy conversion and separation processes, where high ionic conductivity, dimensional stability, and long-term durability are simultaneously required. Poly(phenylene oxide) (PPO) has attracted considerable attention as a membrane backbone owing to its rigid aromatic structure, excellent thermal stability, and mechanical robustness.¹ However, the introduction of ionic functional groups often results in excessive water uptake and swelling, leading to deteriorated dimensional stability and weakened mechanical properties. Furthermore, under highly alkaline and elevated-temperature conditions, degradation of ionic moieties and polymer backbones can significantly limit membrane durability.² In this study, a polymer-blending strategy was employed to overcome these limitations while preserving the intrinsic advantages of PPO. By incorporating a secondary polymer with complementary physicochemical properties, the membrane microstructure and phase-separated morphology were effectively tailored to regulate water management and ion-transport pathways. The optimized blend membranes exhibited balanced ionic conductivity and dimensional stability through suppression of excessive swelling while maintaining efficient ion conduction. In addition, enhanced mechanical integrity and chemical resistance were achieved through improved structural reinforcement within the membrane matrix. The resulting blend membranes demonstrated stable electrochemical performance and structural durability under harsh operating environments. Furthermore, their applicability was validated in bipolar membrane electrodialysis (BPED), highlighting their potential for energy-efficient resource recovery and sustainable electrochemical separation processes. This work presents an effective structural design strategy for developing durable ion-exchange membranes and provides insights into the design of next-generation membranes for various electrochemical and separation technologies. This work was supported by the National Research Foundation of Korea (NRF), funded by the Korean government (MEST) (NRF-2022M3C1A30811- 78), and by the National Research Council of Science and Technology (NST), funded by the Korean government (MSIT) (GTL25021-000).

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ANTHROPOGENIC CHANGES IN SURFACE WATER QUALITY: IMPLICATIONS FOR WATER TREATMENT TECHNOLOGIES

E. Łobos-Moysa¹, I. Zimoch¹, M. Zarębska², M. Ochmańska³, K. Loska¹

¹Department of Water and Wastewater Engineering, Faculty of Energy and Environmental Engineering, Silesian University of Technology, Akademicka 2A Str., 44-100 Gliwice, Poland

²Łukasiewicz Research Network- Institute of Heavy Organic Synthesis “Blachownia”, Energetyków 9 Str., 47-225 Kędzierzyn-Koźle, Poland

³Kraków Water, Senatorska 1 Str., 30-106 Kraków, Poland

Abstract: Increasing anthropogenic pressure is contributing to the deterioration of surface water quality used as a source for drinking water production. Particularly, the presence of anthropogenic micropollutants, including pharmaceuticals, pesticides, and per- and polyfluoroalkyl substances (PFAS), poses a significant challenge due to their persistence, mobility, and resistance to conventional treatment processes. The occurrence of these contaminants in source waters raises growing concerns regarding drinking water safety and highlights the limitations of traditional treatment technologies in effectively removing trace organic pollutants.

The aim of this study was to evaluate the potential of nanofiltration (NF) as an intensification of process in a conventional water treatment system. The investigations were conducted using surface water characterized by substantial temporal variability in water quality. The analyzed samples exhibited pH values ranging from 7.2 to 8.4, colour from 28 to 131 mg Pt-Co/L, and COD from 21.4 to 61.2 mg O₂/L. Chloride concentrations varied considerably, ranging from 972 to 5492 mg/L, reflecting episodic anthropogenic impacts on the studied aquatic ecosystem. Furthermore, the total concentration of 20 monitored PFAS compounds ranged from 0.02 to 3.93 µg/L.

The performance of NF was assessed with particular emphasis on the removal of organic micropollutants and compounds potentially involved in the formation of disinfection by-products. The results demonstrated that integrating NF into the treatment train substantially improved the removal of contaminants at trace concentrations, thereby enhancing the overall quality and safety of treated water. Given the increasing occurrence of PFAS and other persistent micropollutants in surface waters, advanced oxidation processes (AOPs) are also gaining attention as promising complementary technologies for future treatment systems. The findings indicate that implementing integrated treatment approaches is a viable strategy for improving the resilience of drinking water treatment plants to ongoing changes in source water quality driven by anthropogenic activities.

The research was carried out as part of the statutory activities of scientific research units.

DEHYDRATION BY PERVAPORATION OF A TERNARY MIXTURE OF PHARMACEUTICAL SOLVENTS

A. Martín-Quijano, D. González-Revuelta, D. Gorri

Chemical Engineering Department, University of Cantabria, Av. de Los Castros s/n, 39005 Santander, Spain (e-mail: gorrie@unican.es)

Abstract: The pharmaceutical industry represents one of the sectors with the highest intensity of organic solvent utilization throughout its manufacturing workflows, particularly in the synthesis of active pharmaceutical ingredients (APIs). The production of these solvents entails highly energy-intensive operations, which together with recent global market conditions, has resulted in a substantial escalation of product costs. Conventionally, solvent recovery in industrial settings is achieved through thermal separation techniques, such as distillation. However, these processes are inherently associated with significant energy demands, thereby limiting their overall sustainability and economic efficiency. The steadily increasing global demand for solvents leads to higher waste generation and disposal costs, prompting industries to consider process intensification strategies to mitigate both economic and environmental impacts.

In this context, membrane-based separation techniques have recently attracted considerable attention due to their potential to enhance process efficiency, minimize environmental impact, and enable the advancement of more sustainable and energy-efficient operations. Among these approaches, pervaporation (PV) has emerged as a particularly promising technique for the dehydration of organic solvent streams. In pervaporation, a dense non-porous membrane physically separates the liquid feed from a downstream side that is maintained under vacuum. The separation is governed by a solution-diffusion mechanism: target molecules (in dehydration applications, water) are preferentially sorbed onto the hydrophilic membrane surface on the feed side, diffuse through the membrane matrix driven by a concentration gradient, and are finally desorbed and evacuated as vapour on the permeate side due to the applied vacuum. This induces a phase change from the feed to the permeate side without requiring the bulk mixture to undergo vaporization. Crucially, pervaporation operates largely independently of vapour-liquid equilibrium constraints, making it exceptionally suitable for breaking azeotropes and separating thermally sensitive or close-boiling mixtures that conventional distillation cannot resolve efficiently.¹

In this work, the application of pervaporation is evaluated for the dehydration of a synthetic ternary pharmaceutical waste stream composed of methyl tert-butyl ether (MTBE), isopropanol (IPA), and water (85/10/5 wt.%). To this end, hydrophilic membranes are used with the objective of reducing water content of the feedstock from 5 wt.% to less than 0.1 wt.%, enabling direct on-site solvent reuse and supporting circular economy goals in pharmaceutical manufacturing.

To this end, a set of membranes manufactured by DeltaMem AG (MuttENZ, Switzerland) was selected and tested. All of them have hydrophilic characteristics and were suitable for dehydration applications. The performance of each membrane was assessed through pervaporation experiments. A laboratory-scale, custom-designed pervaporation unit previously used by the research group in other studies was employed for the experiments.² The system was operated in batch mode, with continuous recirculation of the feed solution from a 2 L feed tank. All membranes were tested under similar temperature conditions (40, 55, and 70 °C) in order to systematically evaluate the influence of temperature on their performance. On the permeate side, a high vacuum was maintained using a diaphragm vacuum pump (Vacuubrand PC 3004 VARIO). The feed flow rate through the membrane module was fixed at 2 L min⁻¹, sufficient to suppress a possible concentration polarization effect at the membrane surface and to ensure negligible liquid-phase mass-transfer resistance.

The duration of each experiment was chosen to allow the system to reach a pseudo-steady-state, thereby ensuring the reliability and reproducibility of the resulting data. Both feed and permeate samples were analyzed using a gas chromatograph equipped with a flame ionization detector (GC-FID), while the water content was determined using Karl Fischer titration.

Near-complete selectivity toward water was demonstrated by all membranes, with the PERVAP 4100 exhibiting the highest permeation flux. The MTBE and IPA concentrations in the permeate were very low, confirming that the permeate consisted of nearly pure water. This high membrane selectivity is considered critical from both an economic and environmental perspective, as it prevents loss of valuable organic solvents and minimizes the costs associated with permeate wastewater treatment. Water permeation flux was found to increase with the feed water content, consistent with the activity-driven transport mechanism, which says that the driving force across the membrane is proportional to the difference in water activity between the feed and permeate sides. Furthermore, the fluxes through the membrane increased considerably as the temperature was raised from 40 to 70 °C, since temperature is a key factor in pervaporation. These results demonstrate that pervaporation represents a technically viable, energy-efficient, and sustainable alternative for the dehydration of complex pharmaceutical solvent mixtures, contributing to a reduced environmental footprint and improved solvent circularity in industrial manufacturing.

Acknowledgements: Financial support from Grant PID2022–136553OB-I00 funded by MICIU/AEI/ 10.13039/501100011033 and by FEDER/UE. The authors are also grateful for the support of the University of Cantabria through an Industrial Doctorate project (Ayuda DI26).

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TREATMENT OF PFAS-ENRICHED NF MEMBRANE RETENTATES BY ANODIC OXIDATION

M. M. Miranda^{1,2}, F. Zouaoui², P. F. Biard², F. Fourcade², E. C. de Paula¹, M. C. S. Amaral¹, V. R. Moreira^{1*}

¹Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, MG, Brazil. *Corresponding author e-mail: victor@desa.ufmg.br

²Univ Rennes, Ecole Nationale Supérieure de Chimie de Rennes, CNRS, ISCR – UMR6226, F-35000 Rennes, France

Abstract: Pressure-driven membrane processes, particularly nanofiltration, are effective for the removal of per- and polyfluoroalkyl substances (PFAS)¹. However, these processes are non-destructive and generate a concentrated retentate stream containing PFAS, organic matter, and other co-occurring constituents. Therefore, concentrate management remains one of the main challenges to the sustainable implementation of membrane-based treatment. In this context, destructive technologies are required to close the treatment chain by degrading and, ideally, mineralizing PFAS retained in membrane retentate. Among the available options, anodic oxidation is a promising advanced electrochemical approach due to its ability to generate strong oxidizing species, including hydroxyl and sulfate radicals. In this sense, anode material is an important factor controlling PFAS degradation, mineralization efficiency, and by-products formation. Therefore, this study evaluated different anode materials, including mixed metal oxide (MMO) electrodes (Ir/TaO₂, Sb-SnO₂, TiO₂, PbO₂, Ta/Ir/PbO₂) as well as boron doped diamond (BDD), for the electrochemical destruction of PFOA, PFOS, and TFA in a synthetic membrane retentate. The anodic oxidation experiments were conducted under galvanostatic conditions in a batch reactor containing 800 mL of a synthetic membrane retentate (PFOA, PFOS, and TFA: 0.5 mg/L each; TOC: 31 mg/L), with Na₂SO₄ added as the supporting electrolyte. BDD and MMO electrodes were used as anodes, where BDD served as the cathode. The electrodes consisted of square mesh-type structures with an effective surface area of 33 cm² and an interelectrode gap of 10 mm. The electrodes were connected to a potentiostat (OrigaFlex, OrigaLys), and a current intensity of 500 mA (current density of 15.2 mA/cm²) was applied in pulse mode², consisting of 1 s current-on period followed by a 1 s rest period (1 s ON / 1 s OFF), over a total treatment time of 4 h. Samples were collected at different reaction times (0, 30, 60, 120 and 240 min) and analyzed for fluoride concentration using a fluoride ion-specific electrode (Thermo Scientific 9609BNWP), total organic carbon (TOC), TOC-VCPH analyzer (Shimadzu), and PFAS concentrations using HPLC-MS (Waters Acquity UPLC system). Most electrodes presented limited degradation (<40%), with Ir/TaO₂ showing no relevant degradation of the target PFAS (Figure 1). Among the tested materials, PbO₂ and BDD presented the highest overall performance. PbO₂ achieved approximately 45% degradation of PFOA and 60% of PFOS, whereas BDD reached around 50% degradation for both compounds. These results indicate that both electrodes can promote the degradation of long-chain PFAS, although with different apparent

efficiencies. TFA exhibited substantially lower degradation than PFOA and PFOS, with degradation values of approximately 11% and 24% using PbO_2 and BDD electrodes, respectively. This lower removal is consistent with the higher persistence of short-chain PFAS and suggests that TFA may behave both as a recalcitrant target compound and as a possible transformation product arising from the degradation of longer-chain PFAS³. Overall, the results highlight that anodic oxidation can contribute to overcoming one of the main limitations of membrane-based PFAS treatment, namely generation of a contaminated concentrate stream. However, the process requires further optimization for PFAS degradation. These findings support the integration of membrane separation and anodic oxidation as a treatment train for PFAS removal and destruction.

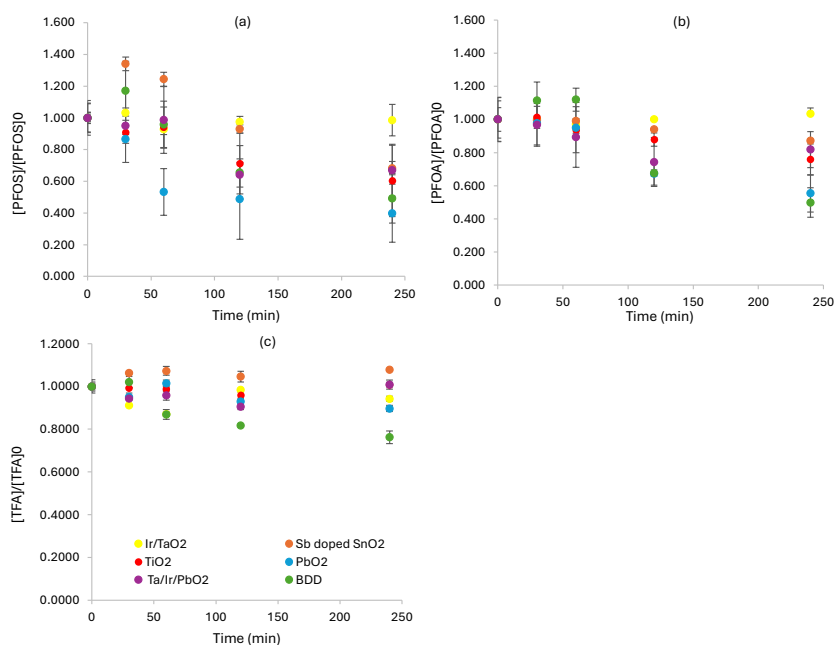


Figure 1. Kinetic monitoring of (a) PFOA, (b) PFOS and (c) TFA degradation.

Acknowledgements

CAPES – Coordination of Superior Level Staff Improvement; COFECUB – French Committee for the Evaluation of University Cooperation with Brazil. The authors would like to thank the intern Raphaël Zamponi for his support.

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EVALUATION OF MONOVALENT ION SELECTIVITY IN MEMBRANES PREPARED BY ION-TRACK GRAFT POLYMERIZATION

K. Murasaki¹, Y. Kakihana^{1,2}, M. Higa^{1,2}, S. Sawada³, K. Yoshimura³, H. Koshikawa³, T. Yamaki³

¹Graduate School of Sciences and Technology for Innovation, Yamaguchi University (YU); 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

²Blue Energy center for SGE Technology (BEST), YU

³QST, 1223, Watanuki, Takasaki, Gunma 370-1207, Japan

1. Introduction Electrodialysis (ED) is an application of ion exchange membranes. One problem with ED process is that the concentration of divalent ions such as Ca^{2+} in seawater causes scales of insoluble salts, resulting in membrane damage¹. Therefore, monovalent selective membranes, which selectively permeate monovalent ions, have been attracting attention for ED process. In this study, to achieve more precise control of the selectivity, we fabricated an anion-exchange membrane (IB- AEM) using the ion-track graft polymerization method²), which allows for the localized and high-density introduction of charged groups to create a monovalent-selective membrane with a structure different from that of commercially available membranes. We also evaluated the properties of the fabricated membranes and examined the relationship between membrane structure and membrane properties. Furthermore, we conducted a comparative study in the selectivity with a commercially available standard AEM.

2. Experimental Methods A poly(ethylene-*co*-tetrafluoroethylene) (ETFE) substrate membrane was irradiated with a 560 MeV ^{129}Xe ions at the fluence of 1.0×10^9 ions/cm². The membrane was then immersed in a 50 vol.% toluene solution of chloromethyl styrene (CMS) and subjected to graft polymerization with under an Ar atmosphere at 60 °C for a specified duration. Subsequently, quaternization was performed by reacting the membrane in a 30 wt% trimethylamine aqueous solution at 30 °C for 24 hours, thereby producing the IB-AEM. A commercial standard membrane (ASE, ASTOM Corp., Japan) was used as a reference.

Membrane resistance was determined by placing a AEM between the cell electrodes and measuring the resistance (R) at 25 °C using an LCR meter. The membrane resistance (R_m) was calculated as $R_m = R - R_0$, where R is the resistance measured with the membrane in place and R_0 is the solution resistance measured without the membrane.

For ED test, the fabricated membrane or a commercial AEM was placed in a cell equipped with Ag/AgCl electrodes. Each cell was filled with 100 mL of a 0.05

mol/dm³ or 0.5 mol/dm³ NaCl/Na₂SO₄ mixed solution, or 0.5 mol/dm³ NaCl, and an electric current of 100 mA was applied at 25 °C for 120 minutes. Sample solutions were taken at predetermined intervals, and the permeation fluxes of Cl⁻ and SO₄²⁻ (J_{Cl} , J_{SO_4}) were calculated from the concentration-time curves of the ions obtained by ion chromatography. The selective permeability of Cl⁻ relative to SO₄²⁻ ($P_{\text{SO}_4}^{\text{Cl}}$) was calculated from the permeation fluxes.

3. Results and Discussion Fig. 1 shows the relationship between membrane resistance of AEMs and polymerization time. As shown in this figure, membrane resistance decreased as polymerization time increased. This is thought to be due to the fact that an increase in polymerization time led to an increase in the amount of fixed charged groups in the membrane, thereby improving ion permeability. Furthermore, the membrane resistance of all membranes prepared in this study was lower than that of ASE, a commercial standard AEM with a membrane resistance of 2.8 Ω cm².

Fig. 2 shows the relationship between the monovalent ion selectivity coefficient ($P_{\text{SO}_4}^{\text{Cl}}$) and polymerization time. At an initial salt concentration of 0.05 mol/dm³, all of the prepared membranes exhibited $P_{\text{SO}_4}^{\text{Cl}} < 1$, indicating that the membranes displayed divalent ion selectivity. This is thought to be due to the Donnan equilibrium, whereby divalent ions with a higher valence were selectively permeated. At the initial concentration of 0.5 mol/dm³, all of the fabricated membranes had a $P_{\text{SO}_4}^{\text{Cl}}$ value greater than 1, indicating monovalent ion selectivity. This should be due to the selective permeation of monovalent ions, which have smaller hydrated ion radii. The IB-AEM with a polymerization time of 3 h exhibited a value approximately

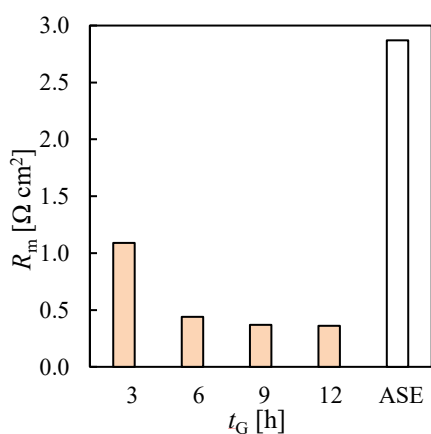


Fig. 1 Membrane resistance as a function of polymerization time of the prepared AEMs and ASE.

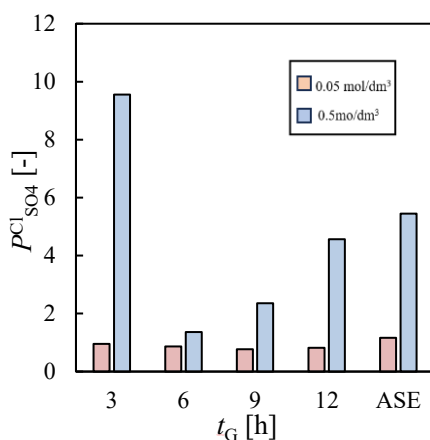
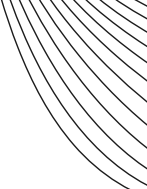


Fig. 2 Relationship between Cl⁻ ion permselectivity and polymerization time of the prepared AEMs and ASE.

1.8 times that of ASE, a commercial standard membrane.



4. Conclusion The IB-AEMs fabricated in this study exhibited lower membrane resistance compared to the commercial standard AEM and ED results showed that they selectively permeated monovalent ions in high-concentration solutions.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP26H02586.

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FROM NANOFIBER DESIGN TO PILOT-SCALE MODULES: NEEDLELESS-ELECTROSPUN MESOPOROUS ION-SIEVE MEMBRANES FOR SELECTIVE LITHIUM RECOVERY FROM DESALINATION BRINES

N. Nadzri, Y. J. Lim, Y. Liang, K. Goh, A. Goto, R. Wang

Singapore Membrane Technology Center, Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore (yujie.lim@ntu.edu.sg)

Abstract: The growing demand for lithium (Li) for energy storage technologies has intensified interest in recovering Li from unconventional resources such as seawater reverse osmosis (SWRO) brines. However, the ultra-dilute Li concentration and high abundance of competing ions present significant challenges for selective and economically viable recovery. In this study, we demonstrate the development, optimization, and scale-up of ion-sieve electrospun nanofibrous membranes for lithium extraction from desalination brines, progressing from laboratory-scale membrane design to pilot-scale module operation. Lithium ion-sieves, $\text{H}_{1.6}\text{Mn}_{1.6}\text{O}_4$ (HMO) and H_2TiO_3 (HTO), were incorporated into electrospun polyacrylonitrile (PAN) nanofibers using three membrane architectures: direct-blend, mesoporous, and electrospray configurations (Ref. [1]). Membrane morphology played a critical role in determining adsorbent accessibility, adsorption kinetics, and lithium recovery performance. Mesoporous membranes, fabricated through sacrificial polymer elution, generated accessible pore networks that enhanced Li uptake by up to 13.5% relative to ion-sieve powders, while electrospray membranes suffered from particle agglomeration and reduced adsorption capacity. Although HTO exhibited higher intrinsic Li selectivity, mesoporous HMO/PAN membranes provided the most favorable balance between selectivity, adsorption kinetics, and dynamic performance. Building on these findings, mesoporous HMO/PAN membranes were successfully scaled up using needleless electrospinning (Ref. [2]). During fabrication, spider-web-like veiling was identified as a key deposition challenge and mitigated through antistatic treatment, enabling stable production of large-format membrane sheets. The resulting membranes retained uniform HMO dispersion and an open porous nanofiber structure. Module-scale testing identified a practical residence time of approximately 1.2 h in a 1 L working-volume module, corresponding to a treatment capacity of 20 L d⁻¹. Compared with conventional packed-bed adsorbents, the mesoporous membrane configuration exhibited superior mass-transfer characteristics and dynamic adsorption performance. Laboratory-scale tests achieved an 82.7-fold Li enrichment from SWRO brine, while pilot-scale module operation produced a cumulative eluate concentration of 153.2 mg L⁻¹ over three adsorption–desorption cycles, corresponding to a 306-fold enrichment from a 0.5 mg L⁻¹ feed. High separation factors against major brine cations (Na^+ , Mg^{2+} , Ca^{2+} , and K^+) confirmed excellent lithium selectivity, and repeated cycling demonstrated robust and reversible operation. These results establish nanofiber

architecture as a key design parameter for lithium-selective adsorption and demonstrate the successful translation of electrospun ion-sieve membranes from laboratory concepts to dynamically operated pilot-scale recovery modules.

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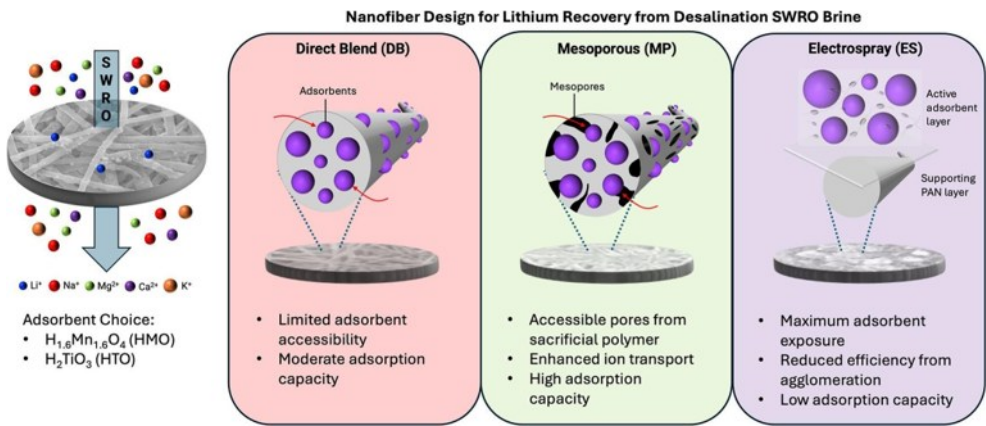


Figure 1. Nanofiber designs for lithium recovery.

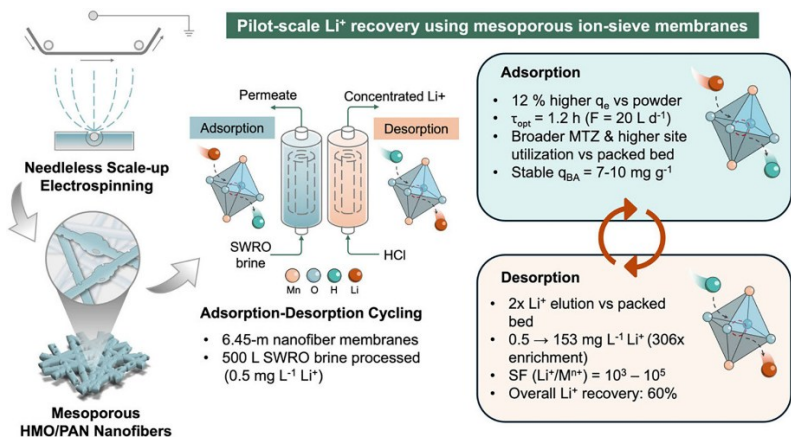


Figure 2. Pilot-scale lithium recovery using needleless-electrospun mesoporous ion-sieve membranes

ASSESSING THE POTENTIAL IMPACT OF LEAKAGE FROM SUPPORTED IONIC LIQUID MEMBRANES ON BIOELECTROCHEMICAL PERFORMANCE

K. B. Nagy, P. Bakonyi, Sz. Szakács, L. Koók

Research Group on Bioengineering, Membrane Technology and Energetics, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

Abstract: Supported ionic liquid membranes (SILMs) can be considered as promising alternatives to conventional ion exchange membranes in bioelectrochemical systems (BES)¹. However, partial leakage of the immobilized ionic liquid (IL) may compromise bioelectrochemical performance. In this study, the potential consequences of such leakage were simulated by introducing representative concentrations of 1-butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ([BMIM][NTf₂]) directly into the anolyte of operating bioelectrochemical systems. Electroactive anodic biofilms enriched in *Geobacter* (>60%) were developed at an anode potential of +0.2 V vs. Ag/AgCl, after which the effect of increasing [BMIM][NTf₂] concentrations (0–0.65 mM) was evaluated during acetate-fed operation. Increasing ionic liquid concentration resulted in a progressive decline in the maximum current density, decreasing from 7.32 A m⁻² in the control reactors to 5.52, 4.24 and 2.04 A m⁻² at 0.22, 0.44 and 0.65 mM, respectively. Non-turnover cyclic voltammetry revealed a concentration-dependent loss of anodic electrochemical activity, indicating that exposure to [BMIM][NTf₂] adversely affected the extracellular electron transfer capability of the biofilm. The findings suggest that persistent interactions between the ionic liquid and cellular components, particularly membrane-associated redox proteins such as cytochromes, are likely responsible for the observed inhibition². These results provide new insight into the compatibility of ionic liquid-based materials with bioelectrochemical technologies and highlight the importance of considering IL leakage when developing SILMs for BES applications³.

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Acknowledgement: This work was supported by National Research, Development and Innovation Office under grant number NKKP-STARTING 150013.

PERFORMANCE EVALUATION OF REVERSE ELECTRODIALYSIS USING CONDUCTIVE SPACERS

A. Nakamoto¹, Y. Sugimoto^{1,2}, M. Higa^{1,2}

¹Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

²Blue Energy Center for SGE Technology (BEST), Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

Abstract: In recent years, novel renewable energy sources have attracted increasing attention, among which salinity gradient energy (SGE) is considered a promising option. SGE is generated when two salt solutions with different salinities are mixed. One of the technologies for harvesting SGE is reverse electrodialysis (RED), which generates electricity by ion transport through alternately stacked cation exchange membranes and anion exchange membranes. Spacer nets are typically inserted between membranes to maintain the intermembrane distance and provide flow channels. However, conventional non-conductive spacers hinder ion transport and increase internal resistance due to the spacer shadow effect. To address this issue, conductive spacers have been proposed as alternatives.

In this study, conductive spacers fabricated from ion-exchange materials (such as sulfonated poly (ether sulfone)) were applied to a RED stack, and their performance was evaluated. A stack consists of 10 membrane pairs (effective membrane area: 88 cm² per membrane) was used. As feed solutions, artificial seawater (50 mS/cm NaCl solution) and river water (2 mS/cm NaCl solution) were supplied to the concentrated and dilute compartments, respectively. The linear velocity of the feed solutions was varied from 0.1 to 1.0 cm s⁻¹. Electrochemical measurements were conducted to obtain open-circuit voltage, internal resistance, gross power density, and net power density

Figure 1 shows the internal resistance of the RED stack using non-conductive and conductive spacers. The stack equipped with the conductive spacer exhibited lower internal resistance than that with the non-conductive spacer, indicating mitigation of the spacer shadow effect. As a result, higher gross power density was obtained with the conductive spacer (Fig. 2). These results demonstrate that conductive spacers are effective in improving RED performance.

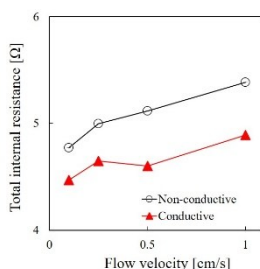


Fig. 1 Internal resistance of the RED stack with non-conductive and conductive spacers.

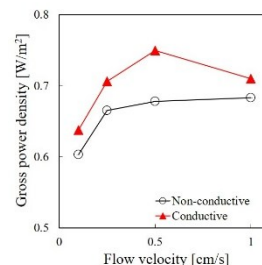


Fig. 2 Gross power density of the RED stack with non-conductive and conductive spacers.

TREATMENT OF TURBINE CONDENSATE BY ELECTRODEIONIZATION

Q. T. Nguyenová, P. Kůs, A. Sears, P. Polívka, S. Gogulin

Research Centre Řež, Hlavní 130, 250 68 Husinec-Řež, Czech Republic
(quynh.nguyenova@cvrez.cz, <https://www.cvrez.cz/en>)

Introduction: Conventional turbine condensate treatment technologies are primarily based on ion-exchange processes. However, these technologies generate significant amounts of wastewater that require further treatment and disposal. Therefore, there is growing interest in alternative "zero-waste" technologies that are not associated with the generation of fly ash or other by-products from coal-fired power plants, which are commonly used for the disposal of spent regeneration solutions.

This study aimed to evaluate the applicability of reverse osmosis (RO) and electrodeionization (EDI) for turbine condensate treatment, focusing on the removal of chloride and sulfate ions. These impurities can adversely affect the service life of power plant equipment, particularly turbine blades.

Experimental: Two types of RO membrane modules designed for seawater desalination and a laboratory-scale EDI unit were tested to determine their efficiency in turbine condensate treatment. The RO experiments were performed using Nitto Hydranautics modules, specifically the SWC5 2540-LD and SWC4 2540-26 models. The EDI unit was assembled using RALEX ion-exchange membranes, while the membrane stack was filled with mixed-bed resin.

Model solutions containing chloride and sulfate concentrations ranging from 0.5 to 60 $\mu\text{g}\cdot\text{L}^{-1}$ were used in the experiments. Throughout the study, key operational parameters, including conductivity, pH, chloride concentration, sulfate concentration, and temperature, were monitored.

Results: A series of experiments was conducted to evaluate the performance of RO and EDI in the treatment of model solutions. The results demonstrated high removal efficiencies for both chloride and sulfate ions in all tested systems. Both RO membrane modules and the laboratory-scale EDI unit effectively reduced the concentrations of these contaminants, indicating their potential suitability for turbine condensate treatment.

Acknowledgements

We acknowledge the state support of the Technology Agency of the Czech Republic within the National Competence Centre Programme II, project TN02000012 „Center of Advanced Nuclear Technology II“.

The presented results were obtained using the CICRR infrastructure, which is financially supported by the Ministry of Education, Youth and Sports - project LM2023041.

We gratefully acknowledge Nitto-Hydranautics for providing the membrane modules used in the experimental work.

PREPARATION AND EVALUATION OF K⁺ SELECTIVE CATION EXCHANGE MEMBRANES

M. Okada¹, Y. Kakihana^{2,3}, M. Higa^{2,3}, P. Durga⁴, T. Kawamoto⁴

¹Faculty of Engineering, Yamaguchi University (YU); 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

²Graduate School of Sciences and Technology for Innovation, YU

³Blue Energy center for SGE Technology (BEST), YU

⁴National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-0046, Japan

1. Introduction

Potassium is one of the three primary nutrients in fertilizers, alongside nitrogen and phosphorus, making it an essential resource in agriculture. It is also widely used in the medical field as a raw material for dialysis fluids and intravenous solutions. However, global potassium reserves are highly localized, and Japan relies heavily on imports for most of its supply, posing a significant challenge for stable procurement¹⁾. Although technologies to recover potassium from salt-production brine are currently in practical use, the supply of the brine is limited as it is a byproduct of seawater salt production process. Directly recovering potassium from abundant seawater could unlock its potential as a new domestic resource. Therefore, this study aims to selectively separate and concentrate K⁺ from seawater by electrodialysis (ED) using a K⁺ selective cation exchange membrane (KS-CEM) that incorporates an adsorbent with high K⁺ adsorption capacity.

2. Experimental

Preparation of KS-CEM A solution was prepared by wet-mixing and codispersing a binder, tetrahydrofuran (THF), and a K⁺ adsorbent, KZnHCF (Fuso Co., Ltd.). After the solution preparation, a Teflon sheet was attached to a glass plate, and the solution was dropped onto the sheet. Finally, the solution was cast using a bar coater and dried for approximately 20 minutes, after which the resulting membrane was peeled off from the sheet.

Evaluation of K⁺ Concentration Performance by ED The KS-CEM was set between two chambers equipped with Ag/AgCl electrodes. A 100 [mL] mixed solution of 0.1 [M] mixed NaCl and KCl was added to each compartment. ED test was performed by applying a direct current while stirring the solutions. During the measurement, samples were collected from each compartment at specified time intervals to analyze their concentrations. Concentration–time curves were then obtained using a calibration curve. From the initial slopes of these curves, the permeation fluxes of Na⁺ and K⁺ were calculated using Eq. (1), and the ion permselectivity coefficient was determined using Eq. (2).

$$J_i = \frac{V \Delta C_i}{S \Delta t} (i = \text{Na}^+, \text{K}^+) \dots (1)$$

$$P_{\text{Na}}^{\text{K}} = \frac{J_{\text{K}^+}}{J_{\text{Na}^+}} \dots (2)$$

J_i : Permeation flux of component [$\text{mol m}^{-2} \text{s}^{-1}$],

V : Volume of the concentrated solution [m^3],

S : Effective membrane Area [m^2],

$\frac{\Delta C_i}{\Delta t}$: Initial concentration gradient [$\text{mol m}^{-3} \text{s}^{-1}$],

P_{Na}^{K} : Ion permselectivity coefficient [-]

3. Results and Discussion

Fig. 1 shows the temporal changes in Na^+ and K^+ concentrations on the concentrate and dilute sides during the electrodialysis experiment at 90 [mA]. The K^+ concentration increased on the concentrate side and decreased on the dilute side until the end of the measurement period. In contrast, the Na^+ concentration remained almost unchanged throughout the experiment. Furthermore, the ion permselectivity coefficient of K^+ over Na^+ , P_{Na}^{K} was determined to be 8.99. These results confirm that the fabricated K^+ selective membrane successfully permeates K^+ with high selectivity.

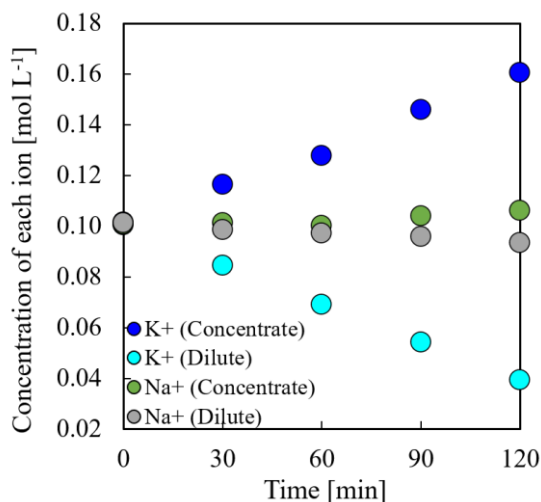


Fig. 1 Time-course of concentration changes in ED test.

Acknowledgments

This study is based on results obtained from a project, JPNP18016, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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VALORIZATION OF VINASSE BY INTEGRATED UF-NF FOR WATER REUSE AND NUTRIENT RECOVERY

P. M. de Oliveira, M. C. S. Amaral, V. R. Moreira*

Department of Sanitary and Environmental Engineering, Federal University of Minas Gerais, 6627 Antonio ^ Carlos Avenue, Campus Pampulha, MG, Brazil. *Corresponding author e-mail: victor@desa.ufmg.br

Abstract: The global expansion of ethanol production has generated a voluminous effluent whose inadequate disposal causes severe environmental degradation. This residue, however, contains valuable macronutrients (nitrogen – N, phosphorus – P, and potassium – K) that represent a sustainable alternative for crop fertilization. To enable agricultural reuse, however, the effluent must be properly treated to mitigate its harmful characteristics while preserving its nutrient content. Moreover, the substantial volume generated, approximately 15 liters per liter of ethanol¹, positions this residue not only as a fertilization source but also as a promising alternative water supply for industrial and agricultural applications. Membrane processes offer a solution, however, fouling and the difficulty of achieving high permeate flux while producing a concentrate rich in nutrients with low sodium content (which compromise soil quality) remain major obstacles². To overcome these hurdles, this work proposes an integrated UF-NF route using hollow fiber UF and flat sheet commercial nanofiltration membranes (NF90 and NFDK) designed to remove suspended solids upfront while concentrating nutrients and minimizing sodium in the retentate. Samples were characterized by Standard Methods for the Examination of Water and Wastewater for ammonium (4500-N), potassium (3500-K), phosphorus (4500-P-B) and sodium (3500-Na), while membrane surface changes were monitored via FTIR. The UF had an effective filtration area of 0.05 m², operated at 0.5 bar up to a 40% recovery rate, followed by NF membranes (NF90 and NFDK) with 0.0064 m² of effective area, operated at 6 bar with a recirculation flow rate of 1.2 L min⁻¹. Samples were collected at every 10% recovery rate increment. Permeability measurements enabled the calculation of total flux decline (FD_{Total}), with its fouling component (FD_{Fouling}) split into reversible (FD_{Rev}), irreversible (FD_{Irrev}), and concentration polarization (FD_{CP}). UF flux decline ($J/J_0 = 0.39$) and filtration resistance can be observed in Fig. 1a, resulting from cake layer formation on the membrane surface. Consequently, as the UF efficiently removed fouling precursors, the flux of NF90 ($J/J_0 = 0.13$) and NF DK ($J/J_0 = 0.11$) remained stable throughout the runs, as shown in Fig. 1b. For NF90, the retentate and permeate presented concentrations (NH₃, PO₄, K, Na in mg L⁻¹) of (3.5, 68, 1440, 67) and (0.36, 1.3, 584, 17), respectively, while for NFDK, values of (1.64, 55, 1220, 19) and (0.3, 0.7, 500, 29) were obtained for retentate and permeate, respectively. The superior concentration performance of NF90 was attributed to its smaller pore size and more negative surface charge, which intensified both size exclusion and Donnan exclusion, effectively retaining monovalent ions such as sodium while enriching potassium and phosphorus in the retentate. Furthermore, FTIR analysis (Fig. 1c) showed that functional groups associated with vinasse

deposition (highlighted in red circles) emerged after filtration but were no longer detected after chemical cleaning (ACC), confirming the effectiveness of the cleaning procedure. Regarding fouling contributions (Fig. 1d), NF90 exhibited predominantly reversible fouling ($FD_{rev} = 0.61$), manageable through physical cleaning and hydrodynamic adjustments, while NFDK showed a greater contribution from concentration polarization ($FD_{CP} = 0.29$), indicating that solute accumulation at the membrane surface played a more significant role for this membrane. Both membranes presented similar irreversible fouling (~ 0.60), yet the lower chemical cleaning demand for NF90 represents an operational advantage, extending membrane lifespan and reducing chemical consumption. In conclusion, the UF-NF system successfully converted vinasse into a nutrient-rich, low-sodium concentrate and high-quality permeate, with NF90 outperforming NFDK in nutrient concentration. Predominantly reversible fouling ensures operational sustainability, confirming the viability of this circular economy approach for vinasse valorization.

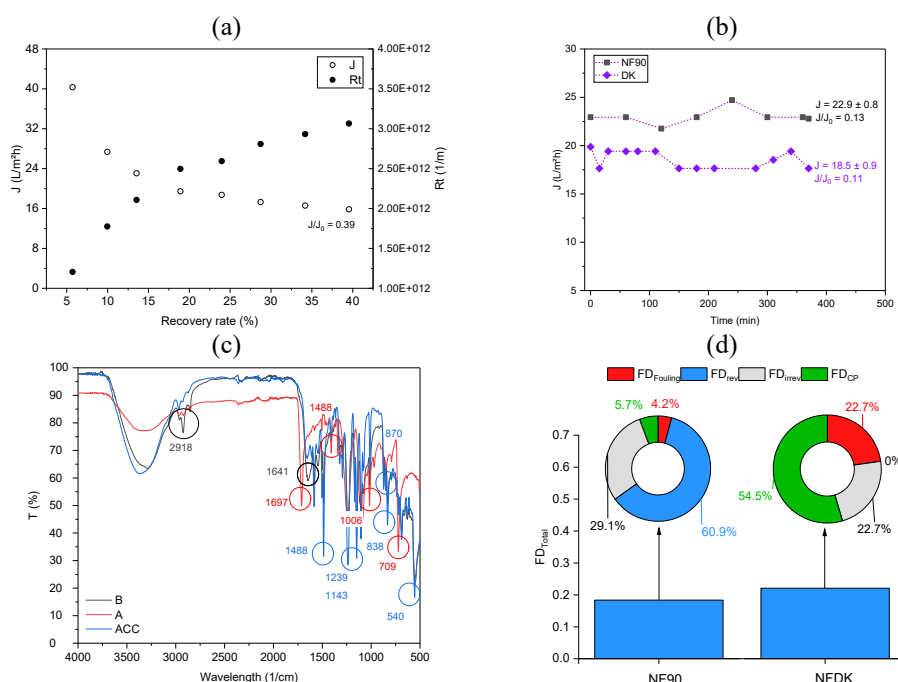


Figure 1. (a) UF permeate flux and total filtration resistance; (b) NF permeate flux; (c) FTIR spectra of the pristine NF90 (B), the membrane after the experiment (A), and the membrane after chemical cleaning (ACC); and (d) contributions of fouling to NF flux decline.

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SYNTHESIS OF CHIRAL SELECTIVE MEMBRANES FOR THE SEPARATION OF RACEMIC MIXTURES

M. Otmar, L. Brožová

Institute of Macromolecular Chemistry, Academy of Sciences of the Czech Republic,
Heyrovský Sq. 1888/2, 162 06 Prague 6, Czech Republic (otmar@imc.cas.cz,
www.imc.cas.cz)

Abstract: Chirality is a molecular property in which a molecule cannot be superimposed on its mirror image. Such molecules occur as two stereoisomers, known as enantiomers, which can exhibit markedly different biological activities despite having identical physicochemical properties in achiral environments. The efficient production of enantiomerically pure compounds remains a major challenge in the pharmaceutical, agrochemical, and fine chemical industries. As a result, considerable efforts are being directed toward the development of effective technologies for enantiomer separation.

Chiral membrane separation offers several important advantages, including low energy consumption, continuous operation, and the absence of additional separating agents, making it a highly attractive approach for enantiomer resolution. The development of advanced chiral membrane materials is therefore essential for the successful implementation of this technology¹.

In this work, enantioselective membranes were prepared from the triblock copolymer polystyrene-*block*-poly(ethylene-*ran*-butylene)-*block*-polystyrene (SEBS). This polymer was selected because it retains excellent mechanical properties even after the introduction of covalently bound chiral selectors². The membrane preparation involved chloromethylation of the styrene units in SEBS, followed by nucleophilic substitution with amino-functionalized chiral selectors. This synthetic strategy enables the stable immobilization of chiral recognition sites within the polymer matrix while preserving the structural integrity and processability of the membrane material. The resulting functionalized membranes represent a promising platform for the development of efficient enantioselective separation systems and provide opportunities for tailoring membrane performance through the choice of chiral selector and degree of functionalization.

Acknowledgment

The financial support was provided by the Czech Science Foundation, grant # 26-21718S.

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EVALUATION OF POWER GENERATION PERFORMANCE OF REVERSE ELECTRODIALYSIS USING PROFILED MEMBRANES UNDER NATURAL SALT WATER

T. Ozuru¹, Y. Shimizu², Y. Takaoka^{2,3}, Y. Sugimoto^{2,3}, M. Higa^{2,3}

¹Faculty of Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

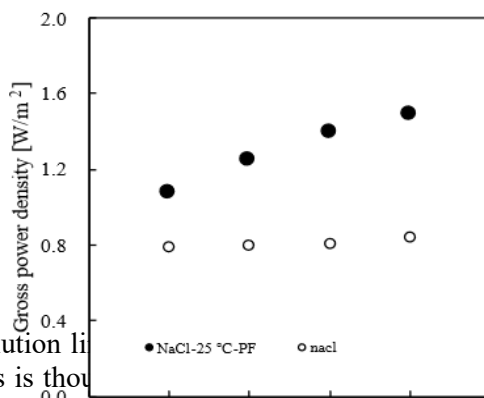
²Graduate School of Science and Technology for Innovation, Yamaguchi University, 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

³Blue Energy Center for SGE Technology (BEST), Yamaguchi University, 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

1. Introduction: Salinity gradient energy (SGE) is one of the renewable energies. SGE is generated when two salt solutions with different salinity concentrations are mixed. One technique that converts SGE into electricity using a membrane is reverse electrodialysis (RED). This method generates electricity by passing salt solutions of different concentrations between cation exchange membranes (CEMs) and anion exchange membranes (AEMs). One of the methods to reduce the internal resistance of RED and to improve output is to use profiled (PF) membrane. PF membrane does not require nonionic conductive spacers on the low-concentration flow passages, thereby reducing the electrical resistance in the low-concentration can become possible. Other factors that reduce RED output include decreased input energy recovery rate due to increased pump energy, and decreased power generation performance due to organic substances adhering to natural salt water. In this study, the goal was to improve power generation performance by using PF membranes when using various natural salt water.

2. Experiment: As the base membrane for the PF membranes, Fumasep® FKS-30 and FAS-30 (FUMATECH BWT GmbH), which do not have reinforcement, were used for the CEM and AEM. PF membranes were fabricated from these flat membranes by using the hot pressing. The RED stack alternately stacked 10 pairs of CEMs and AEMs (with a total effective membrane area of 0.06 m²). The supply solution temperature was 25°C, and high-concentration solution (0.5 mol/L NaCl aqueous solution), low-concentration solution (0.017 mol/L NaCl aqueous solution), and electrode solution (3 mol/L NaCl aqueous solution) were used. By controlling the load resistance of the RED stack under each condition, the gross power density (PD_{Gross}) was measured.

3. Result and consideration: Fig. 1 shows the relationship between linear velocity and PD_{Gross} in a RED stack stacked with flat and PF membranes.



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membranes. This is thou
need for non-ionic conductive spaces, reducing the electrical resistance in low-
concentration flow passages. Additionally as the linear velocity increased, PD_{Gross}
remained increased
Fig. 1 The relationship between linear velocity and PD_{Gross} in a RED ies, PD_{Gross}

stack stacked with flat and PF membranes.

Going fo
membranes and flat membranes when using natural salt water will be conducted.
Furthermore, we will examine structure of PF membrane that can improve net
output.

Acknowledgment

This study was supported by KAKENHI Gant-in-Aid for Scientific Research (JSPS) 26H02586.

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DEVELOPMENT OF AN ELECTROFORMATION METHOD FOR GIANT UNILAMELLAR VESICLE FORMATION USING VARIOUS DAMP LIPID FILMS

M. Raguz¹, M. Šerić^{1,2}

¹University of Split School of Medicine, Department of Medical Physics and Biophysics, Split, Croatia, marija.raguz@mefst.hr

²Faculty of Science, University of Split, Doctoral Study of Biophysics, Split, Croatia

Abstract: Giant unilamellar vesicles (GUVs) serve as suitable model system for studying cellular membrane properties, owing to their cell-like dimensions. Electroformation has become the most widely used method for GUV production since its introduction.

Traditionally, electroformation is performed by swelling a dry lipid film deposited on conductive electrodes under influence of alternating electric field. A major limitation of dry-film electroformation is the difficulty of incorporating high cholesterol (Chol) concentrations into vesicle bilayers. During dry-film preparation, Chol tends to crystallize, leading to a Chol demixing artifact that results in reduced and uncontrolled Chol incorporation into the vesicle bilayers.

To overcome this limitation, we developed a modified electroformation protocol based on damp lipid films. In this protocol, we first used the rapid solvent exchange (RSE) method to prepare multilamellar vesicles (MLVs) and avoid the Chol demixing artifact. The MLVs were then subjected to ultrasonication to generate large unilamellar vesicles (LUVs). Conductive electrodes were plasma cleaned, and the LUV suspension was deposited onto their surface by spin-coating to produce a damp lipid film. In this approach, we were unable to control the number of membrane bilayers formed on the electrode surface, but we were able to form giant unilamellar vesicles (GUVs) as in the traditional protocol.

To improve this protocol, instead of spin-coating the LUV suspension onto the electrodes, we formed multiple supported lipid bilayers on the electrode surface. Our goal was to determine whether the number of applied layers influenced GUV formation.

Using new approach, we investigated lipid mixtures of Chol/1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine prepared in 10 mM PIPES pH 7, 150 mM NaCl buffer. Electroformed vesicles were monitored by fluorescence microscopy.

STABILITY AND PERFORMANCE OF RESVERATROL-COATED ULTRAFILTRATION MEMBRANES

E. Raiskio, T. Rissanen, M. Mänttari

Department of Separation Science, LUT University, Yliopistonkatu 34, 53850
Lappeenranta, Finland (elisa.raiskio@lut.fi)

Abstract: Membrane fouling remains a major challenge in pressure-driven membrane processes used for water treatment. Surface modification of membranes using compounds derived from nature is a promising approach to improve membrane performance and reduce fouling. In previous work, the plant-derived polyphenol resveratrol was used to modify commercial polyethersulfone (PES) ultrafiltration membranes. Resveratrol was introduced to the membrane surface via adsorption and adsorption combined with UV-irradiation. The surface modifications resulted in increased membrane water permeance and hydrophilicity as well as changes in separation performance. The observed effects were mainly attributed to adsorption of resveratrol on the membrane surface. However, the stability of such coatings under realistic membrane filtration conditions remains largely unknown.

In this research, the resveratrol-modified commercial PES ultrafiltration membranes are subjected to continuous rinsing and pressurized filtration conditions. On-line Raman spectroscopy, UV/Vis extraction, atomic force microscopy, and zeta potential analysis are used to investigate the coating stability and changes in the membrane surface properties before and after filtration. Membrane performance is further evaluated by permeance and fouling experiments to determine how operational conditions affect coating retention and membrane functionality.

Preliminary results show that resveratrol remains detectable on the membrane surface after rinsing and filtration experiments. However, certain changes in membrane surface characteristics can be seen, suggesting partial desorption of the coating under operational conditions. Ongoing work focuses on quantifying coating retention and correlating stability with membrane performance. These results will improve the understanding of the long-term applicability of resveratrol-based membrane surface modifications in practical membrane operations. The results will also support the development of bio-based membrane modifications for water treatment applications.

THE DUAL AND SYNERGISTIC ROLES OF PHENOLICS IN MEMBRANE FOULING AND FOULING PREVENTION

E. Raiskio, T. Rissanen

Department of Separation Science, LUT University, Mikkulankatu 19, 15210 Lahti, Finland
(tiina.rissanen@lut.fi, www.lut.fi/en/profiles/tiina-rissanen)

Abstract: Membrane fouling is one of the major challenges limiting the use of pressure-driven membrane processes. Phenolic compounds are commonly encountered in natural waters and biorefinery process streams, where they are often associated with membrane fouling due to their tendency to adsorb onto membrane surfaces. However, selected phenolics have also demonstrated surface-modifying and antimicrobial properties that may be exploited for mitigation of fouling. This apparent contradiction suggests that phenolics can play a dual role in membrane processes. However, the mechanisms governing these opposing fouling and antifouling effects remain poorly understood.

An important unresolved question is how interactions between phenolics, membrane surfaces, foulants, and microorganisms influence membrane (bio)fouling behavior. Beyond the effects of individual compounds, synergistic interactions among phenolics may alter adsorption, coating formation, microbial attachment, and interactions of foulants and membranes in ways that cannot be predicted from the properties of single molecules alone. Such interactions may ultimately determine whether phenolics promote membrane fouling, mitigate it, or contribute to both phenomena simultaneously.

To elucidate these mechanisms, behavior of phenolic compounds and phenolic mixtures on membrane surfaces will be investigated using membrane filtration experiments, surface characterization, online Raman spectroscopy, and microbiological analyses. Particular emphasis is placed on adsorption phenomena at membrane interfaces, coating formation, biofilm development, and the potential of naturally derived phenolics for sustainable fouling control. In addition, synergistic fouling prevention approaches based on the use of phenolic-rich natural extracts will be explored.

This study is expected to provide fundamental insight into phenolic-membrane interactions and reveal how synergistic effects influence membrane fouling and its prevention. By advancing understanding of the dual nature of phenolics in membrane systems, it aims to establish new concepts for sustainable fouling control in water treatment and biorefinery applications. The work is supported by the Research Council of Finland through the FenSy project (funding decision number 375220).

EFFECT OF CERAMIC MEMBRANE MWCO ON THE EFFICIENCY OF RUBBER INDUSTRY WASTEWATER TREATMENT

M. Rajca, S. Kempa

Silesian University of Technology, Faculty of Environmental Engineering and Energy,
Department of Water and Wastewater Engineering, Poland (Mariola.Rajca@polsl.pl,
Slawomir.Kempa@polsl.pl)

Abstract: Wastewater generated during the washing of vulcanized rubber hoses represents a complex industrial effluent containing dissolved and colloidal organic matter, non-ionic surfactants, residues of a protective anti-adhesive gel, and fine elastomeric and mineral particles removed from product surfaces during washing following vulcanization. The aim of this study was to evaluate the suitability of ceramic ultrafiltration membranes for the treatment of wastewater generated during the washing of vulcanized rubber hoses. The wastewater investigated in this study originated from the washing of vulcanized rubber hoses following vulcanization carried out in steam autoclaves at a plant manufacturing rubber products for the automotive industry. Samples were collected from a combined sewer manhole receiving wastewater from six washing units, which ensured the representativeness of the collected samples. The raw wastewater was characterized by the following parameters: COD of 204 – 630 mg/L, non-ionic surfactant (NIS) concentration of 73.9 – 180.0 mg/L, TOC of 91.8–139.3 mg/L, turbidity of 38.4 – 70.3 NTU, specific conductivity of 195 – 331 $\mu\text{S}/\text{cm}$, and pH ranging from 7.3 to 7.9. Ceramic ultrafiltration membranes supplied by Intermasz-Membrane Filtration (Poland), with molecular weight cut-off (MWCO) values of 0.45, 1 and 5 kDa, were used in the study. Ultrafiltration experiments were carried out in a batch recirculation system with progressive retentate concentration. Prior to the membrane module, a 50 μm cartridge filter was installed to remove larger suspended particles and minimize the impact of the coarse fraction on the ultrafiltration process. The ultrafiltration process was conducted at a constant transmembrane pressure of 6 bar. Membrane performance was evaluated based on transport and separation properties. To enable comparison of permeate flux decline over time for the investigated membranes, flux values were normalized to a reference temperature of 20°C. Pollutant separation efficiency was assessed based on chemical oxygen demand (COD) and non-ionic surfactant concentrations. Analyses were performed using a Hach DR3000 spectrophotometer (Hach Poland) and commercial cuvette tests.

Fouling mechanisms were identified using Hermia's models by evaluating the fit of permeate flux decline data to classical pore-blocking and cake-filtration models. The results demonstrated that all investigated membranes reduced both COD and non-ionic surfactant concentrations in the permeate, with the removal efficiency depending on the membrane MWCO value (Table 1). The average permeate flux normalized to 20°C was 39.65 $\text{L m}^{-2} \text{h}^{-1}$ for the 0.45 kDa membrane, 52.64 $\text{L m}^{-2} \text{h}^{-1}$ for the 1 kDa membrane, and 116.96 $\text{L m}^{-2} \text{h}^{-1}$ for the 5 kDa membrane,

confirming an increase in hydraulic performance with increasing membrane MWCO.

A decline in permeate flux over time was observed for all membranes, amounting to 35%, 44%, and 39% for the 0.45, 1, and 5 kDa membranes, respectively. The highest susceptibility to fouling was recorded for the 1 kDa membrane.

Analysis based on Hermia's models indicated that intermediate pore blocking was the dominant fouling mechanism for all membranes, with coefficients of determination (R^2) of 0.896, 0.951, and 0.923 for the 0.45, 1, and 5 kDa membranes, respectively.

Regarding separation performance, the highest retention of non-ionic surfactants (84%) was achieved with the 0.45 kDa membrane, whereas retention values of 50% and 66% were obtained for the 1 and 5 kDa membranes, respectively. In terms of COD removal, the highest reduction (73%) was achieved using the 5 kDa membrane. The corresponding reductions reached 67% for the 0.45 kDa membrane and 64% for the 1 kDa membrane.

The obtained results confirm that the performance of ceramic ultrafiltration membranes in the treatment of wastewater generated during the washing of vulcanized rubber hoses is not determined solely by the nominal MWCO value. It is also likely influenced by the characteristics of the fouling-induced cake layer dynamically formed on the membrane surface during filtration.

The 0.45 kDa membrane provided the highest retention of non-ionic surfactants but operated at the lowest permeate flux. The 5 kDa membrane offered the most favourable compromise between high hydraulic performance and effective COD removal. Under the investigated conditions, the 1 kDa membrane proved to be the least favourable option, exhibiting the greatest flux decline, the lowest COD reduction, and the lowest non-ionic surfactant retention (Table 1).

Table 1. Performance of ceramic ultrafiltration membranes in the treatment of wastewater generated during the washing of vulcanized rubber hoses

MWCO kDa	Initial permeate flux at 20°C [L/m ² ·h]	Final permeate flux at 20°C [L/m ² ·h]	COD mg O ₂ /L			NIS mg/L		
			feed	permeate	R, %	feed	permeate	R, %
0.45	48.84	31.64	394	128	67	185	30	84
1	65.52	36.68	548	196	64	205	103	50
5	143.00	87.48	548	145	73	205	69	66

Acknowledgements: This work was supported by the Polish Ministry of Science and Higher Education within statutory funds.

REMOVAL OF PHARMACEUTICAL COMPOUNDS BY ENHANCED MIXED MATRIX MEMBRANES USING FUNCTIONALISED ADSORBENTS

D. Ramírez Espinosa, R. Jiménez-Robles, L. Martí

Decarbonization Department, Plastics Technology Centre (AIMPLAS), C/ Gustave Eiffel 4, Valencia 46980, Spain (ramjimenez@aimplas.es, www.aimplas.net)

Abstract: The increasing occurrence of pharmaceuticals in aquatic effluents represents a critical environmental issue due to their persistence, toxicity, and low biodegradability, which makes their removal by conventional treatments particularly challenging. The development of novel adsorbent materials based on mesoporous silica, such as MCM-41 and SBA-15, has gained significant attention owing to their high specific surface area, ordered pore structure, and tunable physicochemical properties, enabling efficient removal of pharmaceuticals such as diclofenac^{1,2}. Additionally, the incorporation of mesoporous adsorbents into polymeric matrices to fabricate mixed matrix membranes (MMMs) has emerged as a promising strategy to synergistically combine adsorption and filtration mechanisms, thereby enhancing the removal efficiency of low-molecular-weight pharmaceuticals while improving membrane physicochemical properties, including hydrophilicity, porosity, and permeability³. In this context, the aim of this work was to develop and evaluate MMMs that integrate functionalized silica-based adsorbents for the removal of diclofenac from a pharmaceutical effluent.

Polysulfone (PSf, M_n 22000, Sigma-Aldrich) was used as the base polymer for the preparation of the MMMs using N,N-dimethylformamide (DMF, ACS Reagent >99.8%, Sigma-Aldrich) as solvent. For the preparation of the dope solution, the inorganic filler was added to DMF at a concentration of 1%_w under stirring. Then, the pelletized PSf was added and dissolved at 110°C under continuous stirring overnight. The dope solution was casted in an automatic film applicator with a knife gap of 500 μm , and the film was let overnight for solvent evaporation at room temperature. Different fillers were used: MCM-41 (MCM, A-type, ACS Material, LLC), SBA-15 (SBA, ACS Material, LLC), activated charcoal (AC, Norit® CA1, Sigma-Aldrich) and functionalized MCM-41 (f-MCM) and SBA-15 (f-SBA). The functionalization of MCM-41 and SBA-15 was conducted following the methodology reported elsewhere^{1,2}. This functionalization was based on the grafting of amine-rich components using 3-aminopropyltriethoxysilane (APTES, 99%, Sigma-Aldrich) and polyetherimide (PEI, Aldrich) for the MCM-41 and SBA-15, respectively. The membranes (47-mm diameter) were tested in vacuum filtration tests treating a diclofenac-rich effluent from a pharmaceutical industry. Contaminant concentration in the effluents and samples from the filtration tests were determined through the analysis of the total organic carbon (TOCL, Shimadzu). Initial concentration of the effluent was 25.57 g of TOC L⁻¹.

The performance of the functionalized mesoporous silica-based adsorbent was benchmarked with the non-functionalized materials in direct adsorption tests (adsorbent load of 1 mg mL⁻¹ during 18 h). The removal efficiency of dissolved organic carbon was increased from 47% (ads-MCM) to 84% (ads-f-MCM) after the functionalization of the MCM-41 (Figure 1). Amino functionalization enhanced adsorption performance mainly by introducing positively charged sites and specific active centers that promote electrostatic interactions, ion exchange, and strong chemical affinity with diclofenac, thereby significantly outperforming unmodified mesoporous silica.

Filtration tests showed lower removal efficiencies in the first filtration cycle (1st) for all membranes than the adsorbent material in direct adsorption (Figure 1). For example, the removal efficiency of ads-SBA/PEI was 91% whilst the filtration test with mem-SBA/PEI showed a removal of 70%. This was attributed to the lower retention time in which the effluent is in contact with the adsorbent materials. In the case of the filtration, the contaminants were only in contact with the adsorbent while the effluent crossed the membrane pore structure. From this point of view, the filtration process was able to achieve high removal efficiency in an extremely low residence time. Therefore, a second filtration cycle was carried out, and significantly higher removal efficiencies than after the first filtration were observed with all tested membranes. For example, the removal with mem-SBA/PEI increased to 97% in the 2nd filtration, showing even a higher performance than the direct adsorption. This could be attributed to the micropore structure of the membrane which enhanced the contact between the contaminants and the adsorbent on the pore wall. Hence, filtration with SBA/PEI- and AC-based MMM outperformed the direct adsorption, reaching removal efficiencies of ~97%, even though MCM/APTES MMM showed a lower removal efficiency after the 2nd filtration with a value of 71%.

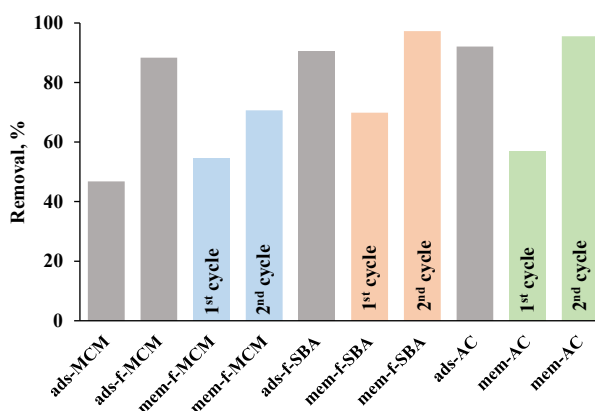


Figure 1. Removal efficiency of organic carbon from a diclofenac-rich effluent in adsorption (grey bars) and filtration tests after 1st and 2nd cycle (blue, red, and green bars) with adsorbents denoted by the prefix ads- and the membranes denoted by the prefix mem-, respectively.

The developed MMM demonstrated that the integration of amino-functionalized mesoporous silica significantly enhances diclofenac removal by combining

adsorption and filtration mechanisms, as well as an improved physicochemical interaction with the contaminants. MMM based on SBA/PEI and AC, showed great potential as efficient and scalable solutions for pharmaceutical wastewater treatment.

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CONTROLLED CHLORINATION FOR LSRRO MEMBRANE PREPARATION: EFFECTS ON OVERALL WATER RECOVERY AND MONOVALENT/DIVALENT SELECTIVITY FOR BRINE VALORISATION

G. Razi Parchikolaei^{1,2*}, M. S. Camilleri-Rumbau¹, M. Reig², C. Valderrama², X. Martínez Lladó¹, S. Casas Garriga¹

¹Eurecat, Centre Tecnològic de Catalunya, Water, Air and Soil unit (WAS), 08243 Manresa, Spain (Presenter: Ghazal.razi@Eurecat.org)

²Chemical Engineering Department and Barcelona Research Center in Multiscale Science and Engineering (CCEM), Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politècnica de Catalunya - BarcelonaTech (UPC), Av. Eduard Maristany 16, Campus Diagonal-Besòs, Barcelona 08019, Spain

The authors did not consent to the publication of this abstract.

VOLATILE CARBOXYLIC ACID SEPARATION FROM REAL FERMENTATION EFFLUENT BY ELECTRODIALYSIS

T. Rózsenszki, V. Kalauz-Simon, L. Koók, P. Bakonyi

Research Group on Bioengineering, Membrane Technology and Energetics, University of Pannonia, Egyetem u. 10, 8200 Veszprém, Hungary

Abstract: Volatile fatty acids (VFAs) represent an increasingly important product stream in anaerobic biodegradation, shifting the focus from gas generation (biogas, biohydrogen) toward organic waste valorization in biorefinery systems. As versatile intermediates, VFAs can serve as precursors for biofuels, bioplastics, medium-chain carboxylic acids, and other value-added chemicals, while their efficient separation from complex fermentation broths is a key challenge for further utilization. Therefore, in this work electrodialysis unit P EDR-Z/4x was operated with mono- and bipolar membranes (Ralex) for VFAs separation from real fermentation effluent. Based on the results, electrodialysis (ED) proved to be suitable for the separation of VFAs (61–95%), particularly in the case of shorter-chain acids (C2–C4). Caproic acid was also transported, although slowly, and part of the acid was retained in the membrane module. This may indicate partial retention within the membrane stack, possibly due to sorption/partitioning phenomena associated with the higher hydrophobicity of the longer-chain acid. However, further targeted experiments are required to distinguish between surface adsorption, membrane-phase partitioning and hydraulic hold-up effects. The fed-batch experiment showed lower specific energy consumption (0.26 kWh/kg VFA) compared with the batch experiments (0.30–0.32 kWh/kg VFA). Overall, the results indicate that continuous or semi-continuous ED operation could improve the energetic feasibility of VFA recovery from real fermentation effluents.

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Acknowledgement: This work was supported by National Research, Development and Innovation Office under grant number NKKP-STARTING 150013. Project no. 2022-1.1.1-KK-2022- 00002 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2022-1.1.1-KK funding scheme

FLOW ELECTRODE CAPACITIVE DEIONISATION (FCDI): FROM BRACKISH WATER DESALINATION TO SELECTIVE LITHIUM RECOVERY

H. Saif, J. Crespo, S. Pawlowski

LAQV REQUIMTE, Department of Chemistry, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Portugal (s.pawlowski@fct.unl.pt)

Abstract: Flow Electrode Capacitive Deionisation (FCDI) was proposed in 2013 as an alternative electromembrane technology for water treatment. We will showcase the transition of FCDI from standard brackish water desalination to the selective recovery of lithium from complex sources¹. Our comparative evaluation of FCDI configurations showed that the Single-Cycle Separate Concentrate (SCSC) mode was the most energy-efficient and stable, and it also allowed for on-site regeneration of flow electrodes. Additionally, unlike other tested modes, this mode exhibited minimal pH fluctuations, making it suitable for scalable, long-term, continuous desalination². We also demonstrated that lab-made activated carbons with smaller particle sizes (1 to 10 μm), higher surface areas, and hydrophilic surface chemistry are crucial for enhancing FCDI performance and can outperform commercial alternatives such as YP80F, YP50F, and Norit³. We will also discuss the development of lithium-selective polymeric mixed-matrix membranes based on sulfonated polyether sulfone (SPES) and hydrogen manganese oxide (HMO)⁴. Furthermore, to enhance sustainability, we will present the use of bio-derived bacterial cellulose acetate (BCA) to replace fossil-fuel-based polymers⁵. These advancements provide a clear pathway towards implementing FCDI for circular-economy applications, such as lithium recycling from end-of-life LIBs.

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CAN WE DO BETTER THAN MICHELANGELO? 3D PRINTED GASKETS VERSUS CNC MILLED GRAPHITE PLATES

H. Saif, T. Gebregeorgis, J. Crespo, S. Pawlowski

LAQV REQUIMTE, Department of Chemistry, NOVA School of Science and Technology,
Universidade NOVA de Lisboa, Portugal (s.pawlowski@fct.unl.pt)

Abstract: Flow electrode capacitive deionisation (FCDI) uses suspended carbon particles (flow electrodes) to remove ions from saline water. Traditional FCDI cells use CNC-milled graphite plates as current collectors. Just as Michelangelo sculpted David, flow electrode channels are engraved into graphite plates. However, Michelangelo created a masterpiece, whereas modern Computer Numerical Control (CNC) milling can produce only very simple shapes, usually limited to serpentine channels. Recently, it was shown that mixing in such channels is limited¹. The potential advantage of 3D printing is the ability to create channels with much more complex geometries, thus enabling better mixing of flow electrodes. In particular, the use of conductive filaments made from a mixture of polylactic acid (PLA) and carbon black, combined with the formation of microcorrugations within the flow electrode channels, increased internal mixing and led to a 25% increase in desalination efficiency². These findings highlight the importance of a comprehensive strategy to improve FCDI performance by integrating advanced manufacturing, customised designs, and material optimisation to create a scalable, sustainable desalination solution. This work provides a solid foundation enabling FCDI scale-up that can effectively address global water scarcity.

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HIGH PRESSURE CO₂/CH₄ SEPARATION USING MOF-ENHANCED PVAm/PVA FACILITATED TRANSPORT MEMBRANES

S. Sharma¹, A. Lindbråthen¹, M. Sandru², L. Deng¹

¹Department of Chemical Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway (swapnil.sharma@ntnu.no)

²SINTEF Industry, 7491, Trondheim, Norway

Abstract: Facilitated transport membranes based on polyvinylamine (PVAm) blended with polyvinyl alcohol (PVA) are promising candidates for CO₂/CH₄ separation in high pressure natural gas sweetening; however, maintaining their separation performance at elevated pressure remains challenging¹. In this work, hydrophilic MOF-808 was incorporated into PVAm/PVA as a potential water-reservoir filler to improve high pressure CO₂/CH₄ separation. Mixed-matrix membranes were fabricated by blade coating with a selective layer thickness of approximately 2 µm. Membrane fabrication parameters and operating temperature were systematically optimized, with 25 °C selected for high pressure testing. The neat PVAm/PVA membrane exhibited a CO₂ permeance of 47 GPU and a CO₂/CH₄ selectivity of 28 at 2 bar, with both permeance and selectivity decreasing as the operating pressure increased. Incorporation of MOF-808 (5 wt%) increased the CO₂ permeance to 57 GPU at 2 bar while CO₂/CH₄ selectivity remained stable across the investigated pressure range, indicating improved separation performance compared with the neat membrane. This behaviour is possibly associated with the hydrophilic nature of MOF-808, which could enhance water retention and sustain facilitated CO₂ transport at elevated pressure.

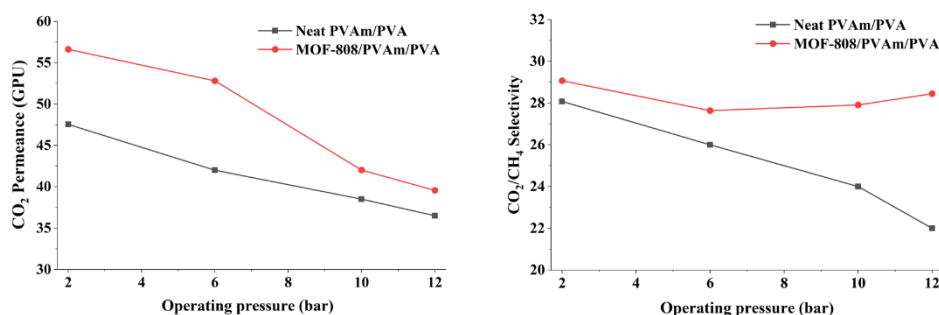


Figure 1. Effect of operating pressure on (a) CO₂ permeance and (b) CO₂/CH₄ selectivity of neat PVAm/PVA and MOF-808/PVAm/PVA membranes at 2-12 bar, 25 °C.

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EFFECT OF SOLUTION IONIC COMPOSITION ON THE POWER GENERATION PERFORMANCE OF REVERSE ELECTRODIALYSIS SYSTEMS USING PROFILED MEMBRANES

Y. Shimizu¹, Y. Takaoka^{1,2}, Y. Sugimoto^{1,2}, M. Higa^{1,2}

¹Graduate School of Science and Technology for Innovation, Yamaguchi University (YU); 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

²Blue Energy center for SGE Technology (BEST), YU

Abstract: Salinity gradient energy (SGE) generates electricity when two salt solutions of different concentrations are mixed¹⁾. Reverse electrodialysis (RED) uses ion exchange membranes (IEMs) to convert SGE to electricity. RED uses a stack consisting of two flow channels to feed to high-salinity salt solution (HS) and low-salinity salt solution (LS) between cation exchange membranes (CEMs) and anion exchange membranes (AEMs). Although seawater and river water are used in RED stacks, these solutions contain not only monovalent but also divalent ions. It has been reported that the presence of divalent ions in the solution leads to a decrease in RED power density²⁻⁴⁾. On the other hand, RED power density can be improved by reducing internal stack resistance. When flat membranes are used, spacer nets are required to maintain the distance between the CEM and AEM (Fig. 1(a)). However, the spacer nets increase the internal resistance of the RED stack. The use of profiled (PF) membranes eliminates the need for spacer nets and reduces the stack resistance⁵⁾. (Fig. 1(b)). In this study, The effect of solution ionic composition on the power generation performance of a reverse electrodialysis (RED) stack employing profiled membranes was investigated.

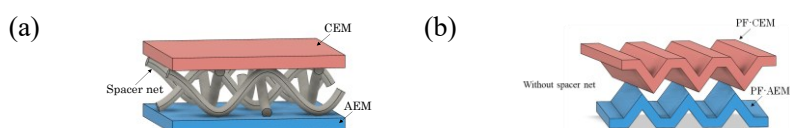


Fig. 1 Schematic diagram of RED cell with (a) flat membrane (b), novel PF membrane.

Fumasep® FAS-30 and FKS-30 were used as the flat IEMs and also used for preparing the PF IEMs by hot pressing. Two RED stacks with flat IEMs and PF IEMs were constructed. The feed solutions to the stacks were as follows: high-concentration solutions—HS-1: 0.5 M NaCl aqueous solution; HS-2: 0.45 M NaCl + 0.05 M MgCl₂ aqueous solution; HS-3: 0.45 M NaCl + 0.05 M Na₂SO₄ aqueous solution; and low-concentration solutions—LS-1: 0.017 M NaCl aqueous solution; LS-2: 0.0153 M NaCl + 0.0017 M MgCl₂ aqueous solution; LS-3: 0.0153 M NaCl + 0.0017 M Na₂SO₄ aqueous solution. The voltage and current were measured by controlling an external resistor to evaluate the power generation characteristics under various conditions.

Fig. 2 shows flow velocity dependence of maximum power density ($PD_{\max}$) of the stack with PF and flat membranes in various solutions. For all solution compositions and flow velocities, PF membranes exhibited higher values than flat membranes. This is thought to be due to the reduction in internal resistance within the stack resulting from the use of PF membranes. When solutions containing divalent ions were used, $PD_{\max}$ decreased significantly in the presence of Mg^{2+} for both PF and flat membranes, with $PD_{\max}$ reductions of 19–22 % for flat membranes and 26–31 % for PF membranes. This is thought to be due to an increase in internal resistance resulting from the fact that the hydration ionic radius of Mg^{2+} is larger than that of Na^+ , its interaction with fixed charged groups within the membrane is stronger, and its mobility within the membrane is lower^{2,3}). In the presence of SO_4^{2-} , the decrease in $PD_{\max}$ was limited to 2–6 % for flat membranes and 2–9 % for PF membranes. This is because SO_4^{2-} forms an ion pair ($NaSO$) with sodium in solution, potentially becoming a monovalent ion species⁴).

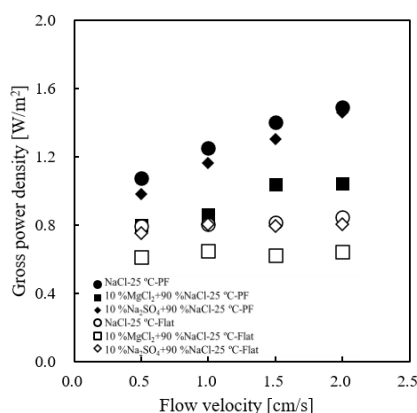


Fig. 2 Relationship between gross power density in flat and PF membranea as a function of flow velocity. Membrane distance : 380 [μ m]. solution temperature : 25 °C. Used membrane, solid symbols, PF membrane; open symbols, flat membrane. Test solutions: ●○, HS-1/LS-1; ■□, HS-2/LS-2; ◆◇, HS-3/LS-3.

Acknowledgment

This research was supported by the Cabinet Office's Strategic Basic Research Program (SIP) Grant JPJ012307 and a Grant-in-Aid for Scientific Research (JSPS) Grant 26H02586.

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MINERAL FUNCTIONALIZATION OF 3D-PRINTED MEMBRANES FOR WASTEWATER TREATMENT

K. Simeonidis¹, E. Kokkinos¹, E. Paterakis¹, T. Tsopani², E. Peleka¹, C. Tsiptsias³, P. Samaras³, A. Assimopoulou², D. Christofilos², K. Theodoridis², O. Karabinaki², A. Zouboulis¹

¹Department of Chemistry, Aristotle University of Thessaloniki, Thessaloniki, Greece
(ksime@physics.auth.gr)

²Laboratory of Organic Chemistry, School of Chemical Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece

³Department of Food Science and Technology, International Hellenic University, Sindos, Greece

Abstract: Recently, the growing transition to additive manufacturing processes for the production of custom-made parts and devices, attracted significant interest toward resolution of water membrane disadvantages. By this approach, membrane preparation turns from a random chemical precipitation procedure into a computer-aided design (CAD) manufacturing which allows full engineering and control of the printed structure. Particularly, 3D printing methods normally use eco-friendly pastes, powders or filaments supporting the solvent-free preparation of membranes, thus, significantly reducing the environmental footprint. Furthermore, 3D printing enables a unique complexity of the macroscopic and microscopic geometric features of membrane pores, channels and spacers, optimizing the hydrodynamics of filtration and controlling turbulence against fouling. Adoption of 3D printing for membrane manufacture is also compatible with decentralization practices, as soon as customized replacement membranes can be produced on-site by a simple printer within a period of few hours.

Common 3D-printed water membranes consist of synthetic polymers, which provide sufficient durability, selectivity and chemical resistance in the majority of processes¹. However, to establish good affinity to the aqueous phase, it is critical to secure a highly hydrophilic surface in order to increase contact time and prevent building up of hydrophobic organic foulants. Among the different approaches used to ensure high degree of hydrophilicity, coating of the membrane with a layer of inorganic material appears to be an efficient and low-cost method to control geometrical characteristics, porosity, permeability, surface charge and selectivity to inorganic pollutants. At the same time, adsorbed water molecules form a protective layer that repels hydrophobic organic phases and decreases the tendency for membrane fouling.

In the current study, the potential of coating a PLA 3D-printed membrane with calcium carbonate has been examined as a candidate solution to improve the operational efficiency for the removal of inorganic colloids from the flowing wastewater. The membranes were fabricated using a fused deposition modeling

printer fed with a black PLA filament (density 1.24 g/cm^3) in a flat configuration with dimensions $10 \times 8 \text{ cm}$. The obtained membrane was built by 8 layers of alternating geometries in the following sequence: 2 layers with triangular pattern, 4 layers of parallel lines, 2 layers with spiral pattern showing a filling percentage of 85 % (Figure 1a). Coating of the membrane with CaCO_3 was realized by a first step of chemical etching after immersing the membrane in a 0.1 M NaOH solution for 30 min, and then, by the deposition of concentrated aqueous dispersion of CaCO_3 having being synthesized by the precipitation of CaCl_2 after Na_2CO_3 addition. Membrane were dried at 40°C and then, the deposition procedure was repeated another two times. At the end, the CaCO_3 -coated membrane was washed with deionized water and placed in a supersonic bath to release loose captured material.

The initial porosity of the initial membrane was found to be 45.6 %, the mean roughness was above $100 \mu\text{m}$ while the static contact angle of 79.4° indicates the hydrophobic character of the PLA. After CaCO_3 deposition no significant change was observed in the porosity ($\sim 44\%$) and the mean roughness, however, the contact angle drops to around 60° as a result of hydrophilicity improvement. To evaluate the efficiency of the CaCO_3 -coated membrane, filtration experiments were carried out by the flow of a kaoline dispersion through the membrane and the monitoring of separation yield, the flux and the transmembrane pressure. In general, CaCO_3 deposition caused an increase of the transmembrane pressure by 50 % in comparison to the initial PLA membrane approaching 0.3 bar while only a small loss in the flux $<10\%$ was observed. Importantly, the CaCO_3 -coated membrane succeeded a separation efficiency of 73 % compared to the value of 40 % for the initial membrane validating the concept of mineral functionalization.

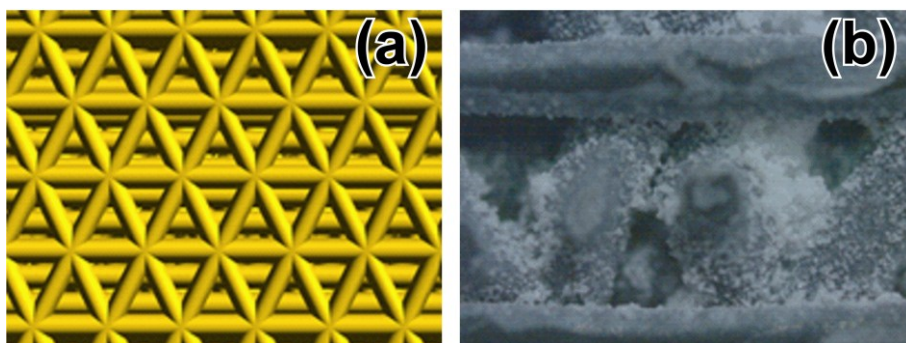


Figure 1. Digital representation of the membrane pattern (a), optical microscope image of the CaCO_3 -coated membrane (b).

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Acknowledgment

The research project is implemented in the framework of H.F.R.I. call “3rd Call for H.F.R.I.’s Research Projects to Support Faculty Members & Researchers” (H.F.R.I. Project Number: 24958).

INTERFACIAL ENGINEERING AND INTERACTION CONTROL IN ADVANCED MEMBRANE BIOPROCESSES AND BIOCATALYTIC SYSTEMS

Z. Su, J. Luo, M. Pinelo*

Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU), Søltofts Plads 228A, 2800 Kgs. Lyngby, Denmark (mp@kt.dtu.dk)

Abstract: Precision bioproduct recovery and green biomanufacturing rely heavily on controlling physical and chemical interactions at the membrane-solute interface. While conventional ultrafiltration and nanofiltration processes are often limited by concentration polarization, fouling and insufficient selectivity, membrane surface engineering provides powerful opportunities to modulate transport phenomena and process performance. In carbohydrate fractionation, membrane charge, pore swelling and molecular conformation have been exploited to enable selective separation of 3'-sialyllactose from lactose-rich streams and controlled fractionation of charged saccharides.¹ In enzymatic membrane reactors, customized multilayer architectures and immobilization strategies have enabled stable oligodextran production with reduced fouling and narrow molecular-weight distributions. For protein and peptide processing, including recovery of casein glycomacropeptide, threshold-flux operation and interaction control successfully mitigate fouling. Beyond passive separations, interfacial engineering has been extended to biocatalytic membrane systems through polyelectrolyte multilayers and metal-organic frameworks, improving enzyme retention, mass transfer and catalytic stability for sustainable resource conversion, including CO₂ valorization.^{2,3} These studies demonstrate how rational manipulation of membrane interactions provides robust pathways for efficient downstream processing, intensified biomanufacturing and next-generation membrane biocatalysis.

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PREDICTIVE MODELING OF MULTI-COMPONENT ELECTRODIALYSIS BASED ON EXPERIMENTAL PARAMETERS

Y. Suetsugu¹, Y. Sugimoto^{1,2}, M. Higa^{1,2}

¹Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

²Blue Energy Center for SGE Technology (BEST), Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

Abstract: To optimize electrodialysis for real wastewater containing multiple ionic species, a phenomenological simulator was developed. The model incorporates ion transport driven by electric current, salt leakage due to concentration gradients, and water transport using a small set of experimentally determined parameters.

Batch-mode electrodialysis experiments were conducted using ion exchange membranes (CSE and ASE) for single- and multi-component solutions. Concentration and volume changes were measured to determine water permeability, salt permeability, and ion selectivity. These parameters were then applied to flow-mode system with continuous feed under constant current conditions.

Figure 1 shows a representative batch result for a NaCl solution in batch-mode electrodialysis. In the concentrate, both concentration and volume increased over time, while both decreased in the diluate. Similar trends were observed for other electrolytes and were used to determine permeability parameters. Flow-mode electrodialysis experiments were conducted using a NaCl solution, and the results were compared with simulation results based on the parameters obtained from batch-mode experiments. The developed simulator reproduced the experimental concentration and volume changes with reasonable accuracy. The result suggests that the proposed phenomenological approach can be extended to multi-component electrodialysis systems by incorporating experimentally determined ion selectivity.

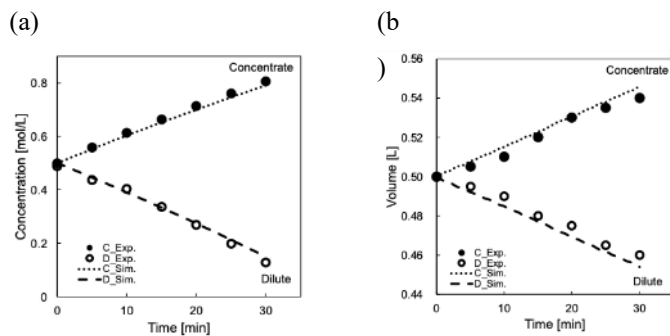


Fig. 1 (a) Concentration and (b) volume changes of NaCl solution in the batch-mode electro dialysis.

ADVANCED ION-EXCHANGE MEMBRANES FOR ENHANCED PERFORMANCE IN MEMBRANE CAPACITIVE DEIONIZATION (MCDI) TECHNOLOGY

O. Thayfi¹, Z. El Bouhali¹, R. Benhida^{1,2}, K. Khaless¹

¹Mohamed VI polytechnic University, Chemical and Biochemical Science, Green Process Engineering, Benguerir, Morocco.

²Nice institute of chemistry, University Côte d'Azur, Nice, France.

*Corresponding Author E-mail: Khaoula.KHALESS@um6p.ma

The authors did not consent to the publication of this abstract.

FABRICATION OF CHARGED MOSAIC MEMBRANES USING AROMATIC POLYMERS AND EVALUATION OF ELECTROLYTE PERMSELECTIVITY

H. Tsuru¹, S. Ishikawa², Y. Kakihana^{2,3}, M. Higa^{2,3}

¹Faculty of Engineering, Yamaguchi University (YU); 2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611, Japan

²Graduate School of Sciences and Technology for Innovation, YU

³Blue Energy center for SGE Technology (BEST), YU

1. Introduction

As shown in Fig. 1, a charged mosaic membrane (CMM) consists of cation-exchange and anion-exchange regions and can selectively permeate electrolytes. Therefore, CMMs are expected to be useful for

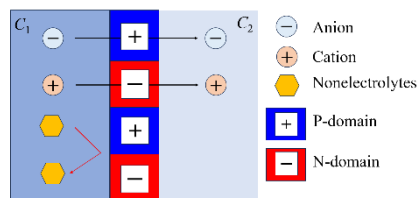


Fig. 1 Schematic diagram of a

desalination of seawater, brine, foods, and pharmaceutical products¹. However, the fabrication of practical CMMs remains challenging, and a cost-effective method for producing highly selective CMMs has not yet been fully established². In this study, aromatic-polymer-based CMMs were fabricated using a screen-printing technique, which is simple and suitable for large-area production, with the aim of establishing an easy and low-cost fabrication process for CMMs.

2. Experimental

2-1. Membrane Fabrication

The screen-printing process consisted of three steps: ink preparation, screen printing, and post-treatment. First, cationic ink (a precursor of positively charged groups) and anionic ink were prepared using aromatic polymers (chloromethylated poly(ether sulfone) and sulfonated poly(ether sulfone), respectively) to form fixed charged groups. To distinguish the cation-exchange and anion-exchange layers, a red dye (Lacquer, Nippon Home Products Co., Ltd.) and a blue dye (T-JET Blue 210, Mino Group Co., Ltd.) were added to the respective inks. Next, each ink pattern was sequentially printed onto a substrate using a film, a nonwoven fabric, a screen mask, and the prepared inks. Finally, a quaternization treatment was performed to introduce positively charged fixed groups into the printed regions, thereby forming a CMM.

2-2. Characterization of the Fabricated CMM

Membrane potential measurements were conducted to investigate the charge structure of the fabricated membranes. For comparison, the membrane potentials of the commercial cation-exchange membrane Neosepta® CSE and anion-exchange membrane Neosepta® ASE (Astom Corp., Japan) were also measured as control. For membrane potential measurements, the membrane was fixed between two cells using a holder. KCl solutions of 0.1 mol dm^{-3} and 0.5 mol dm^{-3} were introduced into the respective cells. After stirring for 10 min, the membrane potential was measured using a KCl salt bridge, and the membrane potential value (ϕ) was determined.

3. Results and Discussion

3-1. Charged structure of the fabricated CMM

A surface photograph of the CMM fabricated by the screen-printing method is shown in Fig. 2. The blue regions correspond to the anion-exchange layers (P layers), whereas the red regions correspond to the cation-exchange layers (N layers). Both layers were successfully formed in a regular striped pattern. The widths of the N and P layers were confirmed to be $500 \mu\text{m}$ each, and the membrane thickness was $35 \mu\text{m}$.

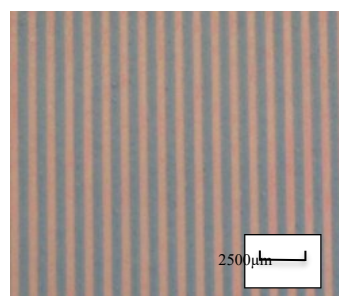


Fig. 2 Surface photograph of dyed CMM. Blue and red regions correspond to N

3-2. Membrane potential of the CMM

In a CMM where the charge densities of the N and P layers are equal, the potentials generated in the two layers cancel each other, and the membrane potential theoretically becomes zero¹. The membrane potential of the fabricated CMM was measured to be 6.1 mV. In contrast, the membrane potentials of CSE and ASE were 36.28 mV and -35.29 mV , respectively. These results indicate that the membrane potential of the fabricated CMM was much closer to 0 mV than those of CSE and ASE, suggesting that the fabricated membrane possesses the characteristics of a charged mosaic membrane.

Future work will focus on evaluating water permeability and ion transport properties through diffusion dialysis. Furthermore, the performance of the fabricated CMM will be compared with that of conventionally fabricated CMMs, and the optimization of a large-area fabrication process for practical applications will be investigated.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP26H02586.

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TREATMENT OF TEXTILE RINSING WATER – THE USE OF ELECTROCHEMICAL PROCESSES

M. Tykva, L. Šeda

Department of Technology, MemBrain s.r.o., Pod Vinicí 87, 471 27 Stráž pod Ralskem,
Česká republika

Abstract: Industrial wastewater from textile facilities poses a significant technological challenge due to the high levels of organic contamination, dyes, salts, or pigment metals which are typically present. Textile wastewater is difficult to treat primarily due to its content of persistent dyes, high salinity, and variable composition. Membrane processes, e.g. nanofiltration, reverse osmosis, or electrodialysis are promising technologies for the separation of ionic components, water recycling, and the concentration of salts or metals; however, their efficiency may be limited by the presence of organic substances, colloids, and substances that cause fouling of ion-exchange membranes, thereby reducing their separation capabilities¹⁻³.

This study focuses on the validation and optimization of selected electrochemical and oxidative pretreatment processes as a preparatory step prior to final treatment by membrane processes. Specifically, electrocoagulation, electrooxidation, and UV oxidation were tested on actual rinse water from the textile industry, which contained high concentrations of organic dyes. The objective was to reduce color, the concentration of organically bound carbon represented by COD-Cr and TOC, and the content of metal ions originating from the metal center of the dye molecules.

Obtained results show that a properly designed combination of electrocoagulation and advanced oxidation processes can significantly improve the quality of the feedwater for following membrane processes. Through subsequent treatment including electrodialysis, we were able to meet the limits set for discharging of the mentioned wastewater into the sewage system. AOP pretreatment of the feedwater for electrodialysis significantly reduces the risk of membrane fouling, stabilizes operation, and opens up possibilities for recycling industrial rinse water in facilities with high organic loads.

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EFFECT OF MXene LOCALIZATION ON THE PFAS REMOVAL PERFORMANCE OF PAN-DERIVED CARBON NANOFIBER MEMBRANES

K. Ulucan-Altuntas^{1,2}, T. Akca^{1,2}, Y. Sorkhe³, A. Uzunoglu³, I. Koyuncu^{1,2}

¹Department of Environmental Engineering, Istanbul Technical University, Ayazaga Campus, 34469 Istanbul, Türkiye

²National Research Center on Membrane Technologies (MEM-TEK), Istanbul Technical University, Istanbul, Türkiye

³Department of Material Engineering, Istanbul Technical University, Ayazaga Campus, 34469 Istanbul, Türkiye
(kualtuntas@itu.edu.tr, www.mem-tek.org, www.cevre.itu.edu.tr/en/home)

Abstract: Per- and polyfluoroalkyl substances (PFAS) are persistent contaminants of increasing concern due to their high chemical stability, mobility, and resistance to conventional water treatment processes. Carbon nanofiber (CNF) membranes derived from polyacrylonitrile (PAN) offer a promising platform for PFAS removal owing to their porous fibrous network, chemical stability, and tunable surface chemistry^{1,2}. In this study, MXene-combined PAN-derived CNF membranes were prepared to evaluate how the localization of MXene influences PFOA removal performance. Electrospun PAN nanofiber membranes were thermally stabilized and carbonized under an inert atmosphere to obtain CNF membranes^{3,4}. Three membrane configurations were comparatively investigated: bare PAN-derived CNF membranes, MXene-incorporated CNF membranes in which MXene was embedded within the electrospun fiber matrix, and MXene dip-coated CNF membranes in which MXene was mainly introduced onto the membrane surface. The membranes were evaluated in terms of morphology, structural integrity after thermal treatment, and PFOA removal behavior in aqueous solution. The comparative results indicate that MXene modification changes the membrane surface characteristics and affects the interaction between PFOA and the carbonaceous fibrous structure. Bare CNF and MXene-modified CNF membranes were compared to evaluate the influence of MXene incorporation strategy on PFOA removal. Particular attention was given to the difference between MXene embedded within the fiber matrix and MXene introduced onto the membrane surface by dip-coating. This study provides a preliminary assessment of MXene distribution as a design parameter for PAN-derived CNF membranes in PFAS removal.

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SUSTAINABLE FABRICATION OF MIXED MATRIX MEMBRANES INCORPORATING TEA/COFFEE WASTE USING GREEN SOLVENTS FOR REMOVAL OF CADMIUM IONS FROM WASTEWATER

S. Ur Rehman¹, D. Lemmens¹, U. Ahmad¹, M. Jamal¹, B. Van der Bruggen^{1,2,*}, A. H. Al-Marzouqi³

¹Department of Chemical Engineering, ProcESS-Process Engineering for Sustainable System, KU Leuven, Celestijnenlaan 200F, Leuven B-3001, Belgium
(saifurrehman.saifurrehman@kuleuven.be,
https://scholar.google.com/citations?hl=en&view_op=list_works&gmla=ACrTK9Xd9x7QFXQGBQCPmm5R2srO5wjsg-pK6cnIz3pC3bpnuS83c41ETzbgiM-GukrkN-cC1bQAYB-wwA8ZcPPovxhrl4n3jJZXxVmOZXs&user=jReh0soAAAAJ)

²Department of Chemical and Biochemical Engineering, Korea University, 145 Anam-Ro, Sungbuk-Gu, Seoul 02841, Republic of Korea

³Chemical and Petroleum Engineering Department, UAE University, Al Ain, United Arab Emirates

Abstract: The world is moving towards green chemistry and sustainable approaches to avoid early end of the natural reserves¹. This study based on the volarization of tea and coffee waste by incorporating these materials into the membranes as filler because of their porous nature and existence of diverse functional groups. Polysulfone and polyethersulfone were used as alternative polymers and the membranes were casted on polypropylene support via phase inversion technique. There are various organic solvents that are being used for the synthesis of membranes but these solvents are harmful for the environment. The replacement of these solvents with the green solvents is the requirement of the modern age². Therefore, the green solvents like dimethyl sulfoxide (DMSO), N-butyl pyrrolidone (NBP), Cyrene and ASTROBIOTMNS6 were used for the development of mixed matrix membranes (MMMs) in different combinations. The membranes were characterized by Fourier transform infrared spectroscopy (FTIR), contact angle measurements and were tested to trace out hydrophilicity, leaching ratio, pore size, porosity, pure water flux, wastewater flux and rejection of Cd(II) ions. The membranes were found to be hydrophilic in nature with the leaching ratio of <1.5% and the flux was increased up-to 9-folds in comparison with pristine membrane leads to the less rejection of Cd(II) ions due to the flux-rejection trade-off³. The rejection can be increased by applying post-treatment like interfacial polymerization of membranes to optimize the aforementioned trade-off.

Table title:

1. Combinations of solvent, polymer and filler in membrane compositions

Figure captions:

1. Testing the solubility of different polymers in the green solvent
2. Images of real time Tea/Coffee based membranes
3. FTIR of membranes
4. Contact angle measurements of membranes
5. Water uptake (hydrophilicity:%) of membranes
6. Leaching ratio of membranes
7. Water flux through the membranes
8. Rejection of Cd(II) ion

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PREPARATION OF HOMOGENEOUS ION-EXCHANGE MEMBRANES FOR ELECTRODIALYSIS BASED ON FUNCTIONALIZED SULFONE POLYMERS

R. Válek¹, L. Martinko¹, M. Petrovič²

¹MemBrain, Pod Vinicí 87, Stráž pod Ralskem, Czech Republic

²Czechiachem Pharma, Academy of Sciences of the Czech Republic, Heyrovský Sq. 2, 162 06 Prague 6, Czech Republic

Abstract: Homogeneous ion-exchange membranes are being developed at MemBrain as tailored materials for electrodialysis. This work presents two complementary preparation routes based on aromatic sulfone polymers. Cation-exchange membranes are prepared from commercially available sulfonated polyethersulfone (Konishi), in which fixed sulfonic acid groups provide cation-exchange functionality. The polymer is processed into casting solutions and converted into membranes by solution casting under controlled film-forming conditions. The anion-exchange route starts from polysulfone, which is first chloromethylated to introduce reactive benzyl chloride groups. The chloromethylated precursor is then quaternized with tertiary amines, including 1,4-diazabicyclo[2.2.2]octane (DABCO) and triethylamine, to form fixed quaternary ammonium sites. The effect of functionalization chemistry and casting-solution composition on membrane formation is assessed qualitatively. Prepared membranes are characterized by key electrochemical methods, particularly ionic conductivity and permselectivity, while analytical techniques (XPS) verify the degree of chloromethylation and support structure-property interpretation. This synthesis and casting strategy provides a flexible platform for homogeneous cation- and anion-exchange membranes and enables correlation of polymer chemistry, membrane morphology, and ion-transport behaviour in electrodialysis-relevant systems.

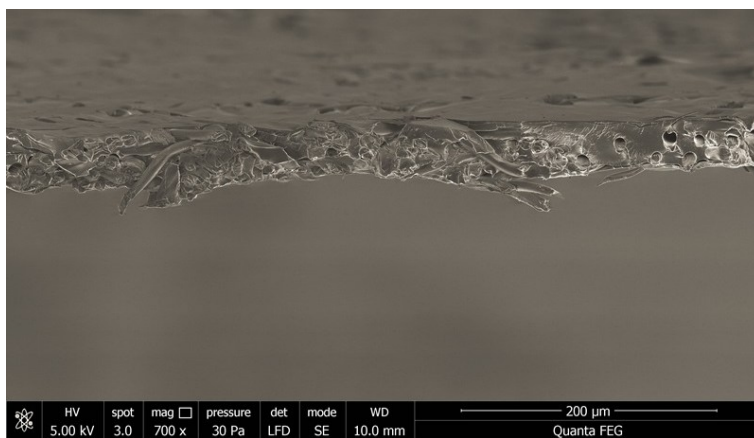


Fig. 1. Cation exchange membrane reinforced by nonwoven fabric

3D-PRINTED ION-EXCHANGE MEMBRANES: ACHIEVING COMMERCIAL PERFORMANCE WITH A NEAR-ZERO-WASTE APPROACH

M. Venu, C. Galinha, J. Crespo, S. Pawlowski

LAQV REQUIMTE, Department of Chemistry, NOVA School of Science and Technology,
Universidade NOVA de Lisboa, Portugal (s.pawlowski@fct.unl.pt)

Abstract: Electromembrane processes, such as electrodialysis, flow electrode capacitive deionisation, and reverse electrodialysis, play a vital role in applications ranging from water desalination and recovery of critical raw materials to sustainable power generation. The most common arrangement of electromembrane stacks is a plate-and-frame configuration, in which spacers separate flat ion exchange membranes (IEMs) to create internal channels. Several recent studies have shown that replacing flat IEMs with profiled IEMs can offer advantages, such as higher mass transfer and lower pressure drop, thereby overcoming the limitations caused by concentration polarisation, fouling, and the spacers' shadow effect. We developed a pioneering approach to the preparation of ion-exchange membranes by fused deposition modelling (FDM) 3D printing, a solvent-free, cost-effective, and customisable technique. Unlike traditional methods, FDM allows for the precise design and fabrication of both flat and profiled membranes. The 3D-printed membranes were functionalised into cation-exchange membranes by sulfonation and into anion-exchange membranes by chloromethylation followed by amination. The electrical resistance and permselectivity of the obtained membranes are comparable to commercial alternatives¹. The ability to fabricate tailor-made membranes via FDM 3D printing without solvents or extensive manual effort represents a significant step forward in manufacturing profiled ion-exchange membranes for diverse electromembrane processes.

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EXPERIMENTAL AND NUMERICAL ANALYSIS OF HOLLOW FIBER MEMBRANE CONTACTOR FOR AIR DEHUMIDIFICATION

G. Viano¹, M. Malaguti², S. Díaz-Quezada², C. Quist-Jensen², A. Ali^{1*}

¹AAU Energy, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg Øst, Denmark

²Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark

Abstract: Rising global demand for indoor climate control has exposed the energy inefficiencies of conventional vapor-compression air conditioning, which requires overcooling air below its dew point and subsequent reheating to manage relative humidity. Membrane-based liquid desiccant dehumidification offers a compact, sustainable alternative by driving continuous moisture absorption across a porous interface. However, significant knowledge gaps remain regarding the relationships between component-level transport dynamics, air-state evolution, and system applicability across diverse climatic conditions.

To resolve these relationships, this study investigates the thermodynamic behavior and practical feasibility of a hollow-fiber membrane contactor system using an integrated experimental and mechanistic modeling framework. Experiments were conducted using hollow fiber membrane modules with active membrane surface areas of 294 and 599 cm². Multiple liquid desiccants (NaCl, CaCl₂ and LiCl) were evaluated under various solution temperatures, concentrations, and flow rates. In parallel, a concurrent 1D heat and mass transfer model was developed and validated against the experimental data, exhibiting high predictive accuracy with Mean Absolute Percentage Errors (MAPE) of 4.0% for outlet air temperature, 12.5% for relative humidity, and 14.8% for vapor flux.

The validated model enabled mapping of air-state trajectories on psychrometric charts across representative climatic scenarios. Results demonstrate high performance in hot, humid climates, where LiCl solutions achieved supply air relative humidity as low as 45%. Shorter modules yielded superior localized vapor fluxes due to stable vapor pressure gradients, whereas larger membrane surface areas maximized total moisture absorption. Importantly, the psychrometric mapping revealed operational boundaries dictated by desiccant water activity, solution cooling limits, and regeneration constraints. These findings establish clear design parameters for optimizing hollow-fiber membrane modules to achieve high-efficiency latent load management in next-generation HVAC architectures.

EFFECT OF HALIDES ON THE BEHAVIOR OF A HETEROGENEOUS ANION-EXCHANGE MEMBRANE

L. Vobecká, V. Láznička, D. Krzecio, Z. Slouka

Department of Chemical Engineering, University of Chemistry and Technology in Prague,
Technická 3, Prague, 16628, CZ (linhartl@vscht.cz)

Abstract: Ion-exchange membranes are key components of electromembrane separation processes such as electrodialysis and electrodeionization, where their performance is governed not only by membrane structure but also by the properties of the transported ions. In this work, we investigate the influence of anion identity on the behavior of an anion-exchange membrane using sodium salts with different counter-ions, namely F^- , Cl^- , NO_3^- , Br^- , SO_4^{2-} , and I^- . The membrane response was characterized by current–voltage curves, chronoamperometry, chronopotentiometry and particle image velocimetry in a custom electrochemical cell allowing simultaneous electrochemical measurement and optical observation of transport phenomena near the membrane surface.

The obtained current–voltage curves exhibited the typical underlimiting, limiting and overlimiting regions for most electrolytes. The curves differed in limiting current, underlimiting slope, overlimiting slope and the width of the limiting plateau, demonstrating a clear dependence of membrane behavior on electrolyte composition. The NaI system deviated from this behavior, most likely due to membrane degradation induced by iodide ions. Particle image velocimetry confirmed the presence of gravitational convection for all investigated anions, with characteristic velocities on the order of tens to hundreds of micrometres per second. The intensity of gravitational convection generally increased with increasing anion molar mass, although chloride and sulfate represented notable exceptions. In the sulfate system, enhanced convection was attributed to the double charge and strong hydration of SO_4^{2-} , which promote pronounced concentration and density gradients near the membrane surface.

Electroconvection in the overlimiting region was relatively weak compared with behavior previously observed for cation-exchange membranes and was absent for NaBr and NaI. Distinct central vortices were observed mainly for NaCl and Na_2SO_4 , correlating with stronger overlimiting transport. These results show that counter-ion properties significantly influence interfacial transport phenomena at anion-exchange membranes and suggest that gravitational convection may be exploited for future intensification of electrodialysis and related membrane separation processes.

CHARGE-REGULATED POLYELECTROLYTE COMPLEX MEMBRANES VIA SALINITY-INDUCED AQUEOUS PHASE SEPARATION FOR ELECTRODIALYTIC $\text{Li}^+/\text{Mg}^{2+}$ SEPARATION

Q. Xu^{1,2}, J. Lin³, P. Luis^{1,2,4}

¹Institute of Mechanics, Materials and Civil Engineering - Materials & Process Engineering (iMMC-IMAP), Université catholique de Louvain (UCLouvain), Place Sainte Barbe, 2 bte L5.02.02-B, 1348 Louvain-la-Neuve, Belgium

²Research & Innovation Centre for Process Engineering (ReCIPE), Université catholique de Louvain (UCLouvain), Place Sainte Barbe, 2 bte L5.02.02-B, 1348 Louvain-la-Neuve, Belgium

³Chinese Academy of Sciences Ganjiang Innovation Academy, Ganzhou, China

⁴WEL Research Institute, Avenue Pasteur, 6, 1300 Wavre, Belgium

Abstract: The surging global demand for lithium requires a paradigm shift toward highly efficient and sustainable extraction technologies, particularly for salt lake brines characterized by high magnesium-to-lithium ($\text{Mg}^{2+}/\text{Li}^+$) ratios^[1]. However, efficient $\text{Li}^+/\text{Mg}^{2+}$ separation is critically impeded by the difficulties in separating these similar ions, and the conventional fabrication of polymeric separation membranes heavily relies on large quantities of toxic, unsustainable organic solvents^[2]. Herein, we report an entirely green, organic solvent-free strategy for fabricating charge-tunable polyelectrolyte complex (PEC) membranes via salinity-induced aqueous phase separation (APS)^[3]. By utilizing poly(sodium 4-styrenesulfonate) (PSS) and poly(diallyldimethylammonium chloride) (PDADMAC) in a fully aqueous system, we engineered an electro-driven membrane platform tailored for highly selective electrodialytic $\text{Li}^+/\text{Mg}^{2+}$ separation^[4]. Through precise control of the aqueous phase inversion process, we achieved optimal regulation of the membrane's structural properties and surface charge. Striking a balance between high separation efficiency and eco-friendliness, this tailored design is integrated with a multi-stage gradient electrodialysis process to preferentially drive monovalent Li^+ transport while effectively hindering multivalent Mg^{2+} migration. Unlike traditional membranes, our engineered PEC membranes achieve exceptional $\text{Li}^+/\text{Mg}^{2+}$ selectivity and efficient lithium recovery with reduced energy consumption, all while generating zero organic waste during fabrication. This work provides a facile, safe, and scalable strategy for constructing high-performance ion-selective membranes, offering a profoundly sustainable pathway for green lithium extraction from complex brine streams.

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CHEMICALLY ROBUST HOLLOW FIBER THIN-FILM COMPOSITE MEMBRANES BASED ON POLYUREA SELECTIVE LAYERS FOR NANOFILTRATION UNDER EXTREME pH CONDITIONS

Q. Xue, Y. J. Lim, R. Wang

Singapore Membrane Technology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, 637141, Singapore
(qiang.xue@ntu.edu.sg)

Abstract: The development of nanofiltration (NF) membranes with high stability under extreme pH conditions is crucial for applications such as metal ion removal from acidic or alkaline wastewater. However, most conventional polyamide-based thin-film composite (TFC) membranes suffer from chemical degradation, limiting their long-term reliability. Herein, we report hollow fiber TFC membranes featuring a chemically robust polyurea selective layer, synthesized via interfacial polymerization (IP) reaction between polyethyleneimine (PEI) and toluene diisocyanate (TDI). The optimal membranes exhibit a high water permeance of $16.8 \text{ Lm}^{-2}\text{h}^{-1}\text{bar}^{-1}$ and a MgCl_2 rejection of 94.4%, outperforming recently reported flat-sheet polyurea NF membranes. More notably, the membrane maintained excellent rejection after 45 days of continuous exposure, reaching 91.6% in acidic solution and 93.9% in alkaline solution, demonstrating superior chemical durability in both environments. This work not only introduces a mechanically robust membrane architecture, but also provides a promising platform for developing NF membranes suited to harsh industrial separation processes.

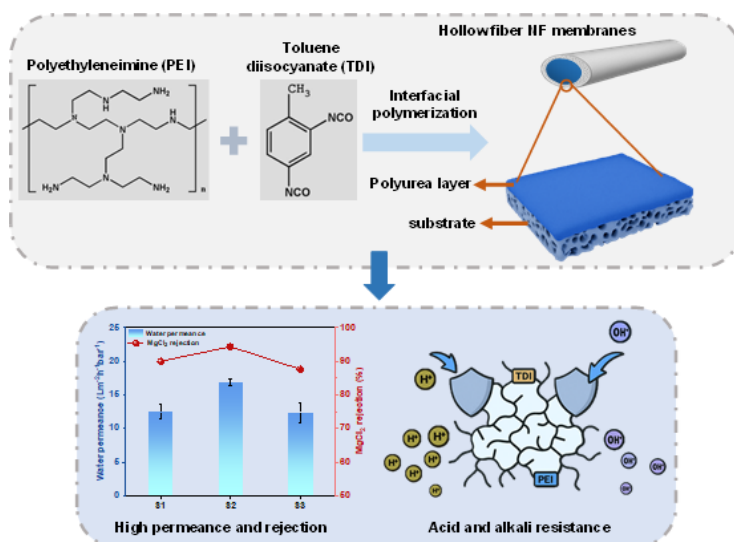


Figure 1. Preparation process and performance of acid- and alkali-resistant hollow fiber polyurea nanofiltration membranes.

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TAILORED NANOPOROUS MEMBRANE ENABLES ONE-STEP AND HIGHLY EFFICIENT ELECTRODIALYTIC DYE/SALT FRACTIONATION

Z. Yu^{1,2}, W. Ye³, P. Luis^{1,2,4}

¹Institute of Mechanics, Materials and Civil Engineering - Materials & Process Engineering (iMMC-IMAP), Université catholique de Louvain (UCLouvain), Place Sainte Barbe, 2 bte L5.02.02-B, 1348 Louvain-la-Neuve, Belgium

²Research & Innovation Centre for Process Engineering (ReCIPE), Université catholique de Louvain (UCLouvain), Place Sainte Barbe, 2 bte L5.02.02-B, 1348 Louvain-la-Neuve, Belgium

³Jiangxi University of Science and Technology, Ganzhou, China

⁴WEL Research Institute, Avenue Pasteur, 6, 1300 Wavre, Belgium

The authors did not consent to the publication of this abstract.