NYM

Network Young Membrains Meeting

September 4-6, 2024
UCT Prague, Czech Republic

BOOK OF ABSTRACTS

2024

20th anniversary

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NETWORK YOUNG MEMBRAINS MEETING 2024

September 4 – 6, 2024

University of Chemistry and Technology Prague

Czech Republic

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WELCOME

Dear Young Membrains,

It is our pleasure to welcome you in Prague at the 20th anniversary of the Network Young Membrains Meeting.

From Naples in Italy, the place of the last NYM Meeting in 2022, we move to the very heart of the Europe, to the city of a hundred spires. We are thankful to all of you joining us and helping the NYM going on. Since the first NYM in 1999, this event has always been about connecting students and young researchers from all around the world to share ideas, support each other and build the community around the one common topic, which is membrane technology. We believe this year's NYM is going to continue in this tradition and provide you with motivation, new ideas and new connections for future collaborations.

This year, we are going to hear three plenary speakers from various areas of membrane research and application. Prof. Karel Friess, a well-established researcher with academic background will speak about the development of advanced gas separation membranes and how to take an advantage of the difficult path that a researcher does often step on. Dr. Daniel Bousa, founder and CEO of ART CARBON® company will take us through what it takes to turn an idea into a business. And finally, Tomáš Kotala, a senior researcher from MemBrain company will introduce us to the world of machine learning, artificial intelligence and its involvement in the innovative, state-of-the-art membrane science.

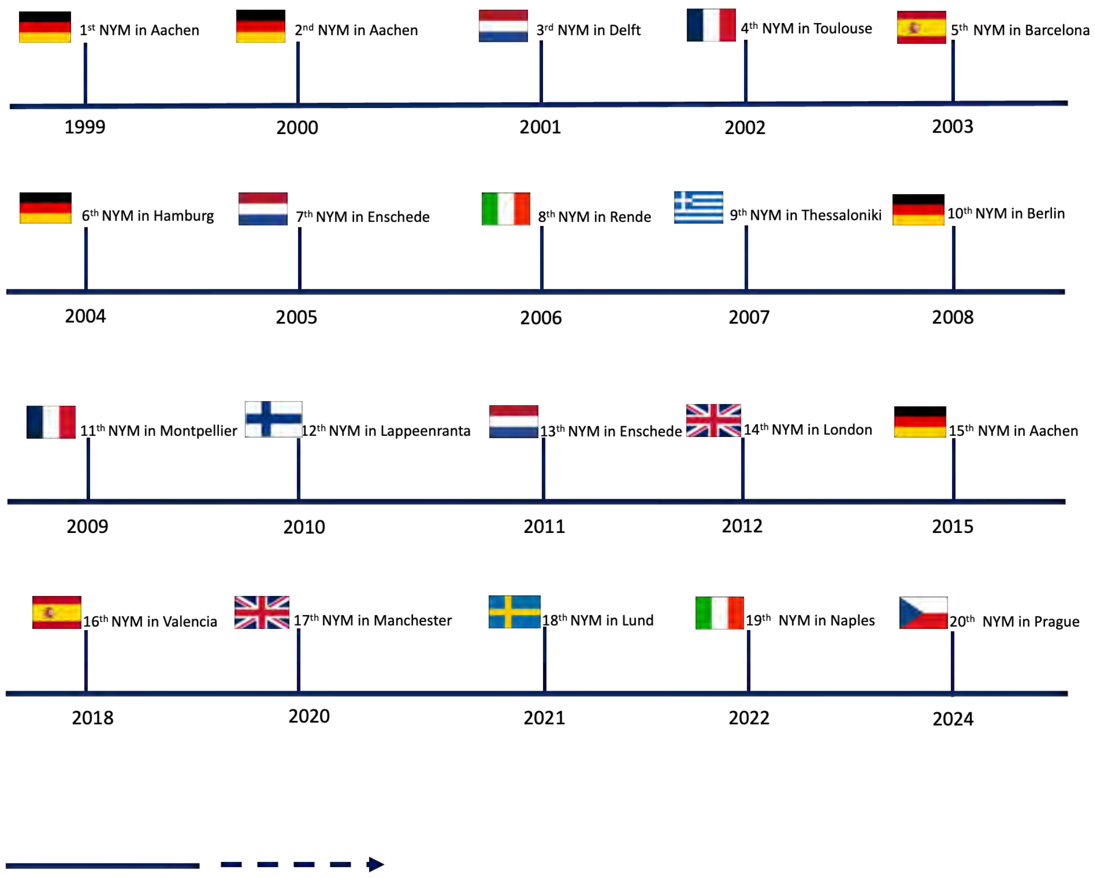
This year's NYM is organized by AMCA and the Czech Membrane Platform, an organization that associates experts on membrane technology. It takes place in the beautiful premises of the University of Chemistry and Technology Prague, a home to the chemical sciences. Special thanks go to the European Membrane Society for sponsoring the students' awards given for the best oral and poster presentations on the NYM 2024. The quality of the works will be assessed by a commission consisting of experts in the fields of membrane processes.

We hope you enjoy this year's Meeting. Let's present, discuss, inspire and get inspired!

Jan, Jana, Dániel and Kirill

NYM 2024 Organizing Committee

NYM TIMELINE



TIME SCHEDULE

Wednesday, September 4

11:00 – 13:15 Registration

13:15 – 16:15 Oral Presentations

16:30 – 18:30 Poster Session

Thursday, September 5

7:30 – 14:00 Excursion – MemBrain

15:00 – 17:15 Oral Presentations

19:00 – 21:30 Social event – dinner (Restaurant Lávka)

Friday, September 6

9:00 – 13:45 Oral presentations

13:45 – 14:30 Closing + Awards

SCIENTIFIC AND EVALUATION COMMITTEE

Karel Friess
Department of Physical Chemistry, University of Chemistry and Technology Prague

Tomáš Kotala
MemBrain, s.r.o.

Zdeněk Slouka
Department of Chemical Engineering, University of Chemistry and Technology Prague

Pavel Izák
Institute of Chemical Process Fundamentals of the CAS

ORGANIZING COMMITTEE

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Rudolf Kinc	AMCA

PLENARY SPEAKERS

Karel Friess
Professor at University of Chemistry and Technology Prague

Daniel Bouša
Founder and CEO of ART CARBON®

Tomáš Kotala
Senior researcher at MemBrain, s.r.o.

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PLENARY LECTURES

ADVANCED MIXED MATRIX MEMBRANES FOR GAS SEPARATION - HOW TO ACHIEVE YOUR GOAL WHILE LEARNING FROM MISTAKES (AND STAYING OPTIMISTIC)

Karel Friess[1*]

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Keywords: gas separation, mixed matrix membranes, molecular engineering
Presentation form: Plenary lecture

Abstract: This work presents a novel approach to fabricating highly efficient mixed matrix membranes (MMM) for gas separation. By integrating the principles of molecular engineering (MLE), in-situ chemical bonding between the additive and the polymer or carbon membrane, and the influence of an external magnetic field on the deposition of magnetic nanoparticles, we have achieved a notable enhancement in the permeability and separation performance of the membranes. The central concept of this work is the MLE, which involves the deliberate preparation of the morphology of MMM materials at the molecular level.

In comparison to unfilled polymers or polymer MMMs prepared by the conventional method, which involves the random distribution of the additive in the polymer matrix, the materials developed by our research group based on PMMA, CTA, PVDF, and PEBAX exhibited a notable enhancement in gas permeability and optimal selectivity. This notable enhancement can be attributed to the uniform and regulated dispersion of the nanoadditives (MOF, ZIF, etc.), which prevents aggregation or sedimentation, as well as their structural and intrinsic characteristics. The obtained permeability and selectivity results exceed the upper limits set by Robeson in 2008 and 2015 for various gas pairs.

The aforementioned successes are accompanied by unsuccessful attempts to prepare MMMs membranes during the years 2009 to 2019. These apparent failures have allowed us to gain insight into the fundamental factors of the MMMs fabrication process and develop the presented methodology for overcoming the bottlenecks of the preparation of MMMs.

Acknowledgments
The financial support of the Czech Science Foundation (Grant No. 19-14547S and 24-11041S), the Ministry of Education, Youth and Sports of the Czech Republic (MEYS, Project LTA USA 19038) and the Specific University Research (MEYS Projects No. 21-SVV/2022, 2023 and 2024) is gratefully acknowledged.

STORY OF ART CARBON: FROM LAB TO THE BUSINESS

Daniel Bouša[1*]

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Keywords: art carbon, water purification, carbon nanotube
Presentation form: Plenary lecture

Abstract: ART CARBON is an innovative company focused on the development and commercialization of carbon nanotube (CNT) based adsorbent materials for water purification. The CEO and founder Daniel Bouša, Ph.D., has transferred his experience from academic field of research to business with an aim to solve practical problems in water management. The company has developed a patented a unique composite material that combines CNTs with a special fiber support, which provides rapid adsorption, passive antimicrobial properties, and easy in-situ recovery. This material is certified for drinking water treatment according to the Norm EN 12873-3.

Major applications include swimming pool water recycling (ACPool), catalytic degradation of bound chlorine (ACDeC) and removal of pesticides and other contaminants (AC Process). Regeneration of the material is via an alcohol-based reagent with multiple downstream treatment options, minimizing operating costs (OPEX) and capital costs (CAPEX). ART CARBON also offers a compact solution for home water filtration (AQUA VIVA) that ensures high efficiency thanks to fast adsorption and resistance to bacteria.

Founded in 2017, the company has expanded its activities internationally over the years, including installations in Europe and Asia. Its journey illustrates the importance of linking scientific research with commercial applications, with ART CARBON continuously innovating its technology for a more sustainable water management for a better future.

References

https://www.art-carbon.cz

INNOVATING MEMBRANE SCIENCE: USING MACHINE LEARNING AND AI FOR FUTURE ADVANCEMENTS

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Keywords: nanofiltration, bipolar electrodialysis, machine learning, personal knowledge management
Presentation form: Plenary Lecture

Abstract

Integrating machine learning (ML) into membrane science has revolutionised the field. Presented examples focused particularly on pressure and electro-membrane separation processes like nanofiltration (NF) and bipolar membrane electrodialysis (EDBM). This plenary lecture explored the transformative impact of ML on membrane technology, highlighting key case studies and theoretical frameworks that underscore its potential. The final remarks focused on personal knowledge management systems and research tactics.

The first example is covering ML in NF. Nanofiltration (NF) is essential in water and wastewater treatment and is characterised by its ability to selectively remove contaminants based on size and charge. Traditional approaches to predicting membrane performance in NF have relied heavily on manually measuring and obtaining datasets for different experimental setups. Complex interactions require the collection of large datasets. ML offers nowadays a robust alternative to scientists by leveraging big data and advanced algorithms to enhance predictive accuracy and process efficiency. A notable case study from 2022 in this field of application involves predicting organic contaminant rejection by NF and reverse osmosis (RO) membranes using interpretable ML models [1]. This study utilised a dataset comprising 2102 data points, encompassing 52 NF and RO membrane types and 276 contaminants. Key inputs influencing NF performance included membrane properties (e.g., molecular weight cut-off, contact angle, charge), contaminant characteristics (e.g., molecular weight, size, McGowan volume, compound charge), and operational parameters (e.g., pH, pressure, concentration, temperature, flow rate). The data analysis strategy employed a 20:80 split for training and testing, with four ensemble ML models—Random Forest (RF), Gradient Boosting Decision Trees (GBDT), XGBoost, and LightGBM—being evaluated. XGBoost emerged as the most effective model, achieving optimal results with only ten input parameters. The use of Shapley Additive Explanations (SHAP) facilitated model interpretation and feature selection, demonstrating the potential of ML to streamline NF processes and enhance contaminant rejection prediction efficiency.

The second example covered EDBM, another area where ML has shown significant promise to speed up research progress. EDBM converts ionic species, which is vital in resource recovery applications. Traditional membrane separation processes, including EDBM processes, are often constrained by their reliance on static models and limited real-time monitoring capabilities. The application of ML in EDBM involves dynamic modelling using Nonlinear Autoregressive Exogenous (NARX) Recurrent Neural Networks [2]. This approach predicts key outputs such as voltage drop, base, acid, and salt conductivity based on initial NaCl, NaOH, HCl concentration, water dilution flow rate, and current density. ML-driven EDBM models can optimise operational parameters, reduce energy consumption, and improve overall process efficiency by incorporating real-time data and adaptive algorithms. The next steps could include training ML models with the hardness of feedwater below 50 ppm, membrane ageing, organic contamination, CIP frequencies, temperature, etc.

The final remarks include personal knowledge management, competitive intelligence (CI) and research strategies. The Bates taxonomy, developed by Marcia J. Bates, provides a comprehensive framework for information research tactics, which remains relevant in ML and competitive intelligence [3]. Bates' taxonomy categorises research tactics as structured terms and is effective for information retrieval. The following prompt can be used in available large language models: please act as [role] and help me develop a blooming leaf research tactic based on Terms from Marcia J. Bates' taxonomy for a specific keyword

[specify]. Please provide five examples of Superordinate Term, Neighbour Term, Synonymous Term, and Specific Term related to the keyword. Then, create a structured query based on these terms that I can copy and paste into [search tool] to find relevant research articles. The result is an advanced search query, which can then be parsed into search tools like Google Scholar, Scopus or Web of Science to retrieve relevant research articles. The proposed approach allows PhD students to enhance the depth of competitive intelligence efforts. Utilising a personal knowledge management system (e.g. obsidian.md) is another way to level up research skills. These innovations underscore the transformative potential of ML and generative AI to drive future advancements in membrane technology and competitive intelligence.

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.

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ABSTRACTS

COMPARATIVE STUDY OF NITROGENOUS COMPOUNDS REMOVAL FROM BRACKISH WATER BY BATCH AND SINGLE-PASS MULTISTAGE ELECTRODIALYSIS SYSTEMS

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Keywords: Electro-membrane process, physico-chemical water treatment, desalination, specific energy consumption (SEC)

Presentation form: Lecture

Abstract: Increasing population and socio-economic growth have put high demand on global potable drinking water [1]. Desalination of brackish water (1-10 g/L of TDS) is seen to be a practical technique for supplying potable drinking water. Brackish waters are not only affected by salt concentrations but at times are polluted with nitrogenous (N) compounds such as nitrate, nitrite, urea, and ammonium. High levels of N-compounds in groundwater have given rise to significant environmental and public health issues. Electrodialysis (ED) is able to remove such contaminants and different configurations such as batch and single-pass, are yet to be evaluated as this will aid develop a deeper understanding of each configuration advantages and limitations in treating N-compounds contamination in different water sources.

Experimental data was collected with a single-pass multistage electrodialysis (SPM-ED) system, while data from a batch electrodialysis (B-ED) system was adapted from Ramos *et al.*[2] for comparison. Firstly, LCD for the SPM-ED system was performed at different salinities (0.58-10 g/L NaCl) to avoid working over LCD and prevent possible membrane deterioration. To investigate how salinity could impede the transport of N-compounds, different salinities (0 to 10 g/L + 1 mM $NaHCO_3$) were mixed with 100 mg/L N-compound solution at pH 8 and a flow velocity of 3 cm/s. To study the extent to which an electric voltage could affect electromigration of the N-compounds, experiments were conducted at different electrical voltages at 5-25 V for the first stack while fixing the voltage for the second stack at 5 V.

Increasing the salinity of the feed solution affected the removal of N-compounds in SPM-ED and B-ED due to competition between Na^+, Cl^- and N-compounds. Removal was higher in SPM-ED (99-97%) than in B-ED (94-92%) at lower salinity (0-2.5 g/L). At higher salinity (5-10 g/L), B-ED showed higher removal (91-89%). An increase in electrical potential has a significant influence on N-compound removal in B-ED than SPM-ED as an upward trend was observed. The B-ED values (42-96%) were lower than what was observed in SPM-ED (87-94%). This was attributed to the fact that, at low electrical potential (5-10 V), the applied voltage in B-ED was not enough to overcome the stack resistance. For energy consumption, increasing the electrical potential and salinity increased the SEC in both systems (Fig. 1). The SEC in B-ED (0.4-7 kWh/m^3) was higher than SPM-ED (0.2-2 kWh/m^3).

For N-compounds removal, removal efficiency was ~ 5% higher in SPM-ED than B-ED at varying salinities and at low voltages, removal efficiency in B-ED was ~ 45% lower than SPM-ED. SPM-ED SEC was lower than B-ED (~ 5 kWh/m^3) and this translates that to remove N-compounds from brackish water, while desalinating concurrently, SPM-ED is more energy and current efficient.

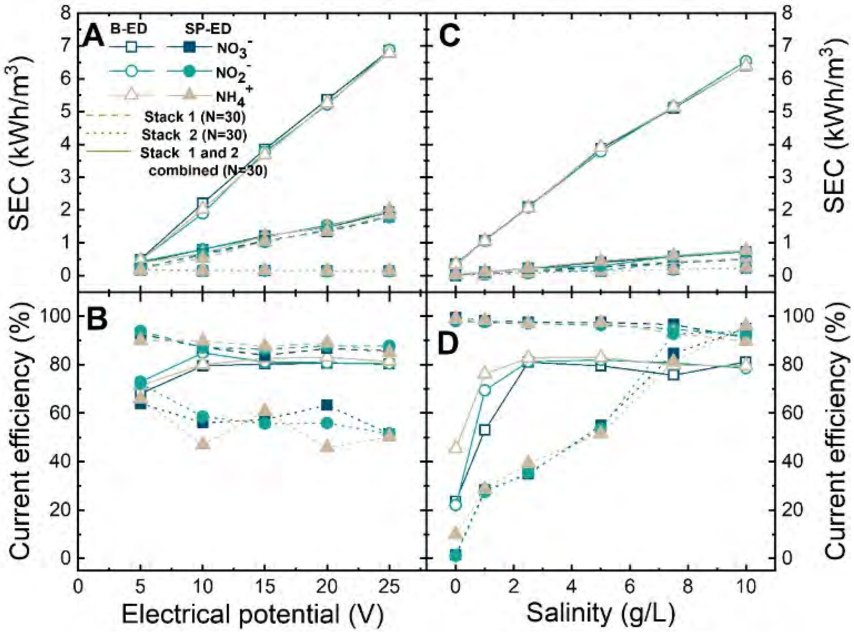

Fig.1 Comparison of SEC and CE for SPM-ED and B-ED

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REVERSE OSMOSIS VERSUS NANOFILTRATION FOR THE REMOVAL OF DISSOLVED CONTAMINANTS IN WATER REUSE APPLICATIONS

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Keywords: potable water reuse; nanofiltration; reverse osmosis; trace organic compounds; salinity; energy consumption.

Presentation form: Lecture

Abstract: The increasing demand for drinking water has led to the adoption of unconventional water sources, such as water reuse. Reverse osmosis (RO) and Nanofiltration (NF) membranes proved to be effective barriers against trace organic contaminants for potable water reuse applications. However, the use of RO is being challenged by NF, primarily due to NF's potential to achieve similar contaminant rejections as RO but with higher productivity and lower energy requirements. This study compares NF with RO membranes on contaminant rejections and energy consumption for potable water reuse applications. RO (BW30XFR) and dense and loose NF (NF90 and NF270) membranes were tested in bench-scale, and RO (TW30) and NF (NF9) were tested in engineering scale systems utilizing UF-filtered reclaimed wastewater. The lowest solute rejection was observed using NF270. There was no difference between NF90 and BW30XFR in terms of divalent ion rejection, but NF90's total organic carbon and monovalent ion rejections were lower. Both NF90 and BW30XFR highly rejected negatively charged TOrCs, while rejections were lower for neutral and positively charged compounds. Furthermore, all compounds were highly rejected in the engineering-scale system by NF9 and TW30. The results highlight the potential of dense NF membranes as an energy-efficient barrier for contaminant removal.

INTEGRATION OF CORNCOB AS BIO-ADSORBENT AND MEMBRANE FILTRATION FOR REMOVAL OF MICROPOLLUTANTS FROM WATER

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Presentation form: Lecture

Author did not agree to publish the abstract

GREENER HOLLOW FIBER MEMBRANE WITH POLYELECTROLYTE LAYER

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Keywords: backwashing, green solvents, polyelectrolyte, single step.
Presentation form: Poster

Abstract body: Hollow fiber membranes (HFM) offer a higher surface area-to-volume ratio, improved packing density, and reduced fouling compared to flat sheet modules. The Layer-by-Layer deposition of polyelectrolytes on porous hollow fiber membranes based on a blend of polyether sulfone (PES) and sulfonated polyether sulfone (SPES) has proven to create nanofiltration membranes and has recently been commercialized [1]. Low molecular weight cut-offs (MWCO) are of special attention, since they offer the possibility to retain micropollutants while the hollow fiber module design offers easy cleaning via backwashing. However, the multi-step coating procedure is cost and time consuming. Additionally, the fabrication of the porous hollow fiber membrane involves the usage of reprotoxic petrochemical solvents which don't follow the principles of green chemistry.

The 'chemistry in a spinneret' technique has shown to create hollow fiber membranes comprising a polyelectrolyte dual layer in a single-step process. The negatively charged porous structure based on SPES forms simultaneously to a first charged layer on the inner side of the fiber through the use of a positively charged polyelectrolyte in the bore. A second charged layer is then added by immersing the freshly formed fiber into a coating bath containing another charged polyelectrolyte. This work is geared towards the fabrication of composite HFM with a polyelectrolyte selective layer using environmentally friendly solvents. Herein the 'Chemistry in a spinneret' approach is used to synthesize HFM with a polyelectrolyte inner layer, by using bio-based and non-toxic solvents. Additionally, polyelectrolyte pairs such as poly(allylamine hydrochloride) (PAH) and poly(styrene sulfonate) (PSS) which have shown to create low molecular weight cut-offs [2] are used in the bore and coating bath. We aim to showcase the greener single step fabrication of hollow fiber nanofiltration membranes for the removal micropollutants from water.

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MUSSEL-INSPIRED SUPERHYDROPHILIC AND ANTIBACTERIAL MEMBRANES FOR EFFECTIVE GRAVITY-DRIVEN SEPARATION OF OIL-IN-WATER EMULSIONS

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Keywords: Superhydrophilic membrane, Mussel-inspired polydopamine coating, Cu nanoparticles, Oil-in-water emulsions, Antibacterial
Presentation form: Lecture

Author did not agree to publish the abstract

MIXED MATRIX ENANTIOSELECTIVE MEMBRANE BASED ON CHIRAL ION-EXCHANGERS

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Keywords: enantiomer, chiral separation, chiral membrane, ion exchange
Presentation form: Poster

Abstract: Enantiomers are molecules that share the same chemical formula but in space form mirror images of each other. Their reactions with other chiral molecules can be remarkably different, which is crucial mainly for pharmaceuticals and agrochemicals. However, industrial-scale synthetic production of enantiomerically pure compounds is not always available. Separation of racemic mixtures using membranes is promising thanks to the easy scalability and continuous operation of membrane processes. The mechanism of enantiomeric separation on an enantioselective membrane is, however, highly specific and still requires extensive research on the molecular level. In this work, we verify the enantioselectivity of a chiral ion-exchange membrane by applying the principles known from ion-exchange membrane processes and chiral ion-exchange chromatography.

The mixed matrix chiral membrane was prepared by mixing a suitable polymer (Matrimid® or ethylene-co-vinyl alcohol EVAL™ EVOH) with silica particles coated with a chiral anion-exchange type selector based on Cinchona alkaloids [1]. The membranes were prepared from N-methyl-2-pyrrolidone or dimethyl sulfoxide by the solvent evaporation method. Prepared membranes were tested in diffusion cells to measure the permeability and selectivity of N-(3,5-dinitrobenzoyl)-leucine and N-(3,5-dinitrobenzoyl)-aspartic acid as a chiral acidic analytes. Various experimental conditions including changes in feed concentration, pH and acetate/formate (buffer) concentrations were tested to describe the separation process both in batch and continuous modes.

We observed high selectivity reaching over 90 % enantiomeric excess in permeate. In diffusion mode, however, the selectivity decreases over time, depending on the amount of acid and buffer present in the solvent. Comparison of the fluxes of individual enantiomers over time reveals that the flux of the less retained enantiomer remains almost constant during the experiment, while the flux of the enantiomer more attracted by the chiral selector increases, lowering effectively the enantiomeric excess measured in permeate. The decline of the enantiomeric excess is sharper in experiments with a higher amount of the buffer/acid, indicating oversaturation of the positively charged selector by the counterions provided by the buffer/acid. In the batch mode, sorption and desorption cycles are present, revealing the chromatographic behavior of the membrane. In continuous mode, the cyclic behavior is less pronounced, leading to a steady state with low effective separation.

Acknowledgments

Financial support obtained from the Czech Science Foundation, projects 23-06152S, is gratefully acknowledged.

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ENHANCING SEPARATION PERFORMANCE OF CELLULOSE MEMBRANE VIA SEQUENTIAL SURFACE MODIFICATIONS

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Presentation form: Lecture

Abstract: Cellulose membranes inherently possess hydroxyl groups that can be functionalized to alter the membrane surface properties, such as surface charge. One promising route is TEMPO-mediated oxidation to selectively oxidize C6 primary hydroxyl groups into carboxylates to impart negative surface charge on cellulose surface [1]. Furthermore, layer-by-layer (LbL) assembly presents a versatile and tunable technique to sequentially coat the TEMPO-oxidized cellulose membranes with oppositely charged polyelectrolytes to further improve its separation properties [2]. However, the intricate interactions among several factors such as ionic strength, pH, physicochemical properties of polyelectrolytes and the substrate can complicate the multilayer membrane structure and functionality [3]. Salt annealing has shown to mitigate these functional and structural complexities of the LbL coated multilayer membrane, enhancing the overall separation efficiency [4].

This study examined the sequential surface modifications of commercial cellulose ultrafiltration membranes to enhance its surface properties and separation performance. The methodology involved TEMPO-mediated oxidation, followed by LbL polyelectrolytes coating, and subsequent salt annealing.

TEMPO-mediated oxidation of cellulose membrane significantly increased its negative surface charge, as indicated by zeta potential change from -35 to -80 mV at pH7. This modification resulted in modest increase in sulfate rejection from 3 to 20%, while chloride rejection remained below 1%. Additionally, water permeance improved from 63 to 74 L/m^{2}hbar. Next, the TEMPO-oxidized cellulose membrane was sequentially coated with poly(diallyl dimethylammonium chloride) (PDADMAC) and poly(sodium 4-styrene sulfonate) (PSS) (PSS-terminated). It resulted in notable decline in water permeance, from 74 to 33 L/m^{2}hbar and marginal increases in salt ion rejection rates compared to the TEMPO-oxidized cellulose membrane substrate. Moreover, LbL coated multilayer membrane surface appeared coarse and irregular, characterized by polymer clusters. Subsequent cyclic salt annealing of the multilayer membrane with 2M NaCl solution for 30 minutes followed by additional PSS monolayer deposition led to compact and smoother multilayer membrane surface. The negative surface charge of the multilayer membrane progressively improved with each salt annealing cycle, reaching -80 from -68 mV by the fourth annealing cycle. Although water permeance of salt annealed multilayer membrane slightly decreased to 20 L/m^{2}hbar, sulfate rejection significantly improved, reaching 80% after only two annealing cycles. However, chloride rejection remained modestly low at around 5%.

Overall, the findings of this study suggest that an integrated multi-step surface modification approach is a promising strategy to improve the properties and performance of ultrafiltration cellulose membranes.

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DEVELOPING NOVEL LOW-FOULING UF PES MEMBRANES FOR MBR APPLICATIONS

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Keywords: Ultrafiltration (UF), polyethersulfone (PES) membrane, polymerizable bicontinuous microemulsion (PBM), spray-coating, membrane bioreactor (MBR)
Presentation form: Lecture

Abstract: The deposition of submicron particles on the membrane surface of a commonly used ultrafiltration polyethersulfone (UF PES) membrane during membrane bioreactor (MBR) operation cause significant membrane fouling with passage of time. So, novel membranes were developed by spray-coating an anti-fouling layer of polymerizable bicontinuous microemulsion (PBM) materials to enhance the active filtration surface of commercial grade UF PES membrane (Microdyn® Nadir UP150P).

Membranes coated by conventional casting coating technique and by innovative spray coating technique were tested at lab-scale. The enhanced membrane with coated PBM layer was characterized by infrared spectra (ATR-FTIR), electron microscope imaging (SEM and AFM), surface charge (zeta potential) and surface wettability (contact angle) measurements. The fouling propensity of the membranes were tested using 100 mg L^{-1} humic acid solution (model foulant) in a cross-flow module and in Sartorius AG's Biostat® lab-scale side-stream MBR to treat model low-strength domestic wastewater using activated sludge. Permeate flux, transmembrane pressure (TMP) and permeability were monitored to observe the fouling propensity while conducting flux-step tests.

The spray-coated PBM membranes exhibited 25 % lesser decline in permeability than commercial PES membrane during critical flux determination. The PBM-coated membranes enabled better flux control accompanied with higher TMP and better rejection rate. Performance of the enhanced membranes were also assessed with constant flux experiments to treat model wastewater (such as high-strength olive mill wastewater) in lab-scale MBR. The composition of the PBM is being further studied to incorporate nanoparticles to add anti-bacterial and anti-viral properties to the enhanced membranes.

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SOLAR POWERED MEMBRANE BIOREACTORS – A PROMISING TECHNOLOGY FOR WATER REUSE IN EAST AFRICA

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Keywords: Membrane bioreactor (MBR), solar powered, wastewater treatment and reuse

Presentation form: Poster

Abstract: MBR technology has achieved rapid growth in a number of practical small- and large-scale applications worldwide due to its high effluent quality (for water reuse) and small footprint. However, its application in Sub-Saharan Africa has been limited [1]. Very few MBRs installed in Africa were mainly imported as costly units from developed countries and they are not well suited for local application. The installation and operation of solar powered pilot MBRs in Kisumu (Kenya) and Kampala (Uganda) takes an integrated approach by providing sustainable, cost-effective, and robust solution for wastewater treatment and reuse that meets the demand for clean water for a variety of applications as a promising example of the water-energy nexus approach.

The results from two operational pilot plants in Kenya (Kisumu) and Uganda (Kampala) are presented here. The installation and operation of a pilot MBR (3-4 m^3/day) in Kisumu, studied within the EU funded project VicInAqua, provides solution for water sanitation that meets the demand for clean water in fish processing industry, aquaculture, and irrigation [2, 3]. Another MBR plant (7-8 m^3/day) to treat hospital wastewater was installed in Kampala, within the DBU (German Federal Environmental Foundation) funded project Reuse4Hos, to provide reusable water for toilet flush and irrigation [4].

The semi-autonomous energy system consisting of a 14.3 kWp photovoltaic (PV) system and a 30 kWh lithium battery storage was installed in Kisumu to ensure maximum system security despite the frequent power outages. Approximately 40 % degree of autonomy has been achieved. The scalable pilot plant can be adapted to all local fish species and will contribute to sustainable fish production and job creation in the local fish industry. The MBR in Uganda was installed using mainly locally available components (tanks, pumps, aerators etc.). A granular activated carbon (GAC) filter was installed downstream to remove pharmaceutical residues/micropollutants. The pilot plant was powered by 7 kWp solar modules, 3.55 kWh supercapacitor battery such that surplus energy was stored in the battery or fed into the grid of the hospital. Based on the promising results in Kenya and Uganda, the EU project PrAEctiCe was launched to design a new upscaled solar powered MBR (production capacity of 20-25 m^3/day of treated water) and install at the existing VicInAqua pilot site in Kenya to provide clean water for the expansion of the aquaculture production.

Acknowledgments

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SOPHIA: SUSTAINABLE OFF-GRID TECHNOLOGIES FOR DRINKING AND DEIONISED WATER FOR HOSPITALS IN AFRICA

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Keywords: Drinking water, ultrafiltration (UF), membrane capacitive deionisation (MCDI), deionized water

Presentation form: Poster

Abstract: Sub-Saharan Africa has about 100,000 health facilities of which approximately 26 % have no access to electricity and only 28 % of health care facilities, on average, had reliable electricity among the 8 countries reporting data [1]. So, the medical health care has to cope with the poor electricity and water supply in the remote and rural areas of Africa with no cooling facilities. The European Union's (EU) Horizon 2020 project 'SophiA – Sustainable Off-Grid Solutions for Pharmacies and Hospitals in Africa' aims to enable African people in rural and remote areas access to safe and clean drinking water, steam and cooling of food and medicine [2]. It will be demonstrated at 4 health facilities - Burkina Faso, Cameroon, Uganda and Malawi such that different climate and geographical regions are covered. The concept of containerized water treatment system is based on 2-stages of low-pressure technologies – ultrafiltration (UF) to address microbial safety and membrane capacitive deionization (MCDI) for water softening and deionization.

SophiA water treatment and refrigeration systems will be built in two 40-foot containers such that one container provides water treatment and steam generation while the other container provides refrigeration for medicines. Both will be fully solar powered with battery backup for seamless operation. The water treatment container mainly employs 2 technologies – UF and MCDI (Figure 1). The first stage of treatment comprise polyethersulfone (PES) based UF module manufactured by Martin Systems GmbH to remove the suspended particulates and biological contaminants to produce hygienically safe drinking water. The total dissolved solutes (TDS) are then removed by the novel MCDI technology to produce deionized water.

The modules were tested in the laboratory of Karlsruhe University of Applied Sciences (HKA), Germany. Removal of suspended impurities (model bentonite) was achieved by the UF PES module. Removal of 90 % TDS for deionized water (electrical conductivity < 15 µS/cm) and removal of excess fluoride for drinking water were achieved by the commercial (C12) MCDI module. The assembly of the water systems was completed in South Africa and shipped to the first demo site in Burkina Faso where it was commissioned to produce drinking water and deionized water for steam production.

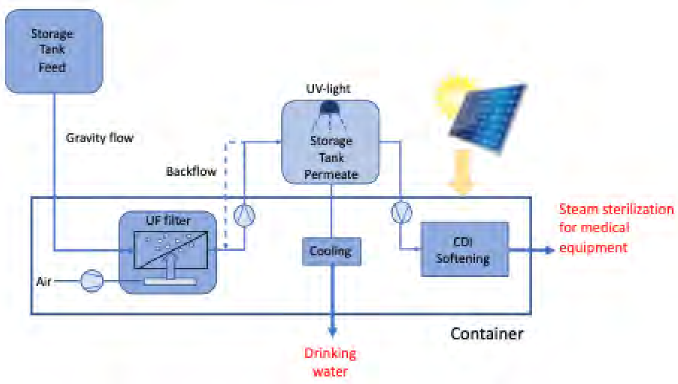

Figure 1. Safe water concept of SophiA

Acknowledgments

The on-going project SophiA has been funded by the European Union HORIZON 2020 programme under the grant agreement number 101036836.

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DEVELOPMENT OF LOW-RESISTANCE/HIGH SELECTIVE CATION-EXCHANGE MEMBRANES FOR REVERSE ELECTRODIALYSIS USING EXPERIMENTAL AND MATHEMATICAL MODELLING TOOLS

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Presentation form: Poster

Abstract: Hypersaline brine has negative impacts on the environment, if discharged as it is. On the other hand, it may represent a valuable resource for energy generation and raw materials recovery. The main aim of this work will be the development of a low resistance and high permselective cation-exchange membrane for recovery of Lithium and harvesting of energy from the brine for "green" electric energy production. Lithium recovery will be performed via Donnan Dialysis (DD), i.e. a separation process that utilizes counter-diffusion of two or more ions through an ion-exchange membrane to achieve a separation [1]. Driving force for transport is the gradient of activities of individual ions across the DD membrane. Energy harvesting will be performed via Reverse Electrodialysis (RED), which exploits the Gibbs energy of mixing brine and seawater. More specifically, the energy is generated by mixing two solutions of different concentration of dissolved salts (ions) (5 M brine and 0.5 M seawater), separated by a cation- and anion-exchange membrane [2], where the salt concentration gradient across the membranes is the main driving force. In principle, the RED process is like the electrodialysis one, but operated spontaneously in reverse regime. The study will include both an experimental campaign, i.e. preparation and testing of the membranes, and a mathematical modelling of the ions transport across them, to permit a deeper understanding of transport mechanism and a prediction of their behavior and main characteristics. Combining these two research approaches represents a very effective way of new material investigation and development. About the membranes to be newly developed, they are novel sulfonated thin films incorporating metal-organic-frameworks (MOFs) highly selective to monovalent alkali metal ions (i.e. ZIF-8, H-KUST-1, UiO-66), including Li. The methodology of membrane development will be optimization of sulfonation degree, determined by elemental analysis and 1H NMR, of polymers (polysulfone, poly-ethersulfone, etc.) as a function of mechanical properties and permselectivity after preparing mixed matrix membrane via phase inversion by blending MOFs in polymer-solvent-[co-colvent] solution. Incorporation of MOFs into the membrane creates nanochannels with dimensions improving the separation of Li ions and cavities, which can increase transport of Li ions [3].

Finally, the membranes will combine the benefits of sulfonated films and MOFs, leading to optimal properties for DD and RED, such as high selectivity (combining size-sieving, electrostatic repulsion, etc.), dispersibility, stability and ionic conductivity [4], [5]. Modeling is based on Poisson-Nernst-Planck model, where Nernst-Planck and Poisson equation are coupled and local violation of electroneutrality is explicitly allowed [6].

Acknowledgements

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MICROPOLLUTANT REMOVAL USING COMBINED TECHNOLOGIES: A CASE STUDY ON PFAS AND PHARMACEUTICALS

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Keywords: wastewater treatment, pharmaceutical removal, PFAS removal, nanofiltration, adsorption
Presentation form: Lecture

Abstract: The presence of micropollutants, such as pharmaceuticals and Per- and Polyfluoroalkyl Substances (PFAS), in wastewater raises significant environmental and health concerns. PFAS are persistent organic pollutants that have been widely detected in various environmental matrices, including groundwater, due to their extensive use in industrial and consumer products [1]. On the other hand, pharmaceuticals, including antibiotics, hormones, and painkillers, are commonly found in wastewater due to their widespread use and incomplete removal by conventional treatment processes [2].

In the first study, combined technology for PFAS removal from groundwater was tested. The designed technology consists of nanofiltration (with ultrafiltration as a mechanical pretreatment) and subsequent treatment of the retentate with concentrated contaminants by ion exchange resins. Two types of resins were selected as separation material. Different contact times in column tests were tested, and long-term tests were performed to determine sorption capacity. From the results, it can be concluded that PFAS from nanofiltration concentrates (retentates) can be treated very efficiently by sorption on the tested ionexes, with an initial efficiency over 99% even for a concentrate with a PFAS concentration of 1 800 ng/L.

In the second study, combined technology for pharmaceutical removal was designed. Due to the apparent dominance of introducing pharmaceuticals into the environment from surface sources [2], the technology aims to eliminate or reduce the introduction of these substances from the effluents of biological wastewater treatment plants. The multistage technology consists of heterolytic catalysis, microbial degradation and adsorption on activated carbon.

The initial step was the advanced oxidation process (AOP) column tests with heterogeneous catalysts. Two pre-selected catalysts were tested with the effluent from the municipal WWTP as a feed. The next step was a moving bed bioreactor (MBBR) for biosorption and biological removal of the biodegradable micropollutants and oxidized products. The final step was adsorption on a granular activated carbon (GAC) in dynamic column tests at contact times of 5 and 10 minutes. Different types of AC and GAC were tested, and long-term dynamic tests for 6 months with two different types of GAC were performed. These steps have been implemented as a pilot technology at WWTP. The pilot technology achieved high removal efficiency so that the concentration of analyzed pharmaceuticals decreased below detection limits.

In conclusion, this work demonstrates the potential of integrating advanced technologies to remove micropollutants from water sources. The successful removal of PFAS and pharmaceuticals highlights the effectiveness of these combined technologies.

Acknowledgments

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POTENTIAL USE OF ELECTRODIALYSIS FOR REMOVAL OF SALTS FROM ACIDIC WASTEWATER

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Keywords: electrodialysis, acid wastewater, chemical industry

Presentation form: Lecture

Abstract: The aim of this experiment was to test the suitability of using electrodialysis technology on acidic industrial wastewater to reduce the current problems with the current method of wastewater treatment. The selected industrial effluents originated from organic synthesis utilizing sulfuric acid. In principle, these effluents can be characterised as approximately 1 % w/w sulphuric acid with the addition of other ions and remaining organic content.

Experimental testing of the electrodialysis process was carried out on the laboratory unit P EDR-Z/10-0.8. In addition, pilot testing on-site was carried out on a P1 EDR-Y/50-0.8 pilot unit. The experiments were split into two different variants of the electrodialysis process for the treatment of chosen wastewater.

The first way of configurations the ED process was "Desalination" tests, which produced the expected results. The selected membrane process effectively transported sulphates from outflow of water already treated by current technology back into the incoming acidic effluent. The average quality of the diluates achieved in these tests was: conductivity below 1 mS/cm with sulphate content below 300 mg/L.

The second operation of the ED process "Concentration" has produced outstandingly good and positive results. By using electrodialysis to concentrate the feed water solution, an increase in sulphate concentration was achieved. The concentrates from these tests contained an average of 48 g/L of sulphate. The concentration of the solutions was selected so that the resulting quality of the solutions would not prevent reuse. The dilute solutions contained an average of 1,6 g/L sulphate and a conductivity of 6,8 mS/cm.

The outcomes of these experiments have shown that the above electromembrane process can be used in practice with very good results. The great benefit, and it should be noted that in the membrane process, little seen, is that a process has been found in which both components - diluate and concentrate - can be used. Thus, there is no need to find suitable solutions to deal with the resulting stream that is not consumable or difficult to process.

ENHANCED CO_2 SEPARATION USING MAGNETICALLY ALIGNED MIXED MATRIX MEMBRANES INCORPORATING MOF NANOPARTICLES AND PEBAX COPOLYMER

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Keywords: Metal-organic frameworks (MOFs), Mixed matrix membranes (MMMs), CO_2 capture
Presentation form: Poster

Abstract: Post-combustion CO_2 capture is a crucial approach to mitigating climate change [1], with membrane technologies providing a cleaner and more cost-effective solution. [2] Mixed matrix membranes (MMMs), which integrate inorganic and polymeric materials, have shown significant potential for efficient CO_2 separation from gas mixtures. Pebax membranes, composed of rigid polyamide (PA) and flexible polyethylene oxide (PEO) segments, are highly selective for CO_2 due to PEO's strong affinity for it. Additionally, metal-organic framework (MOF) nanoparticles, particularly UiO-66-NH_2, enhance MMM selectivity without sacrificing permeability due to their basic nitrogen atoms, which effectively bind CO_2 molecules.

In this study, we synthesized and characterized a mixed matrix membrane based on Pebax1657 and UiO-66-NH_2 for CO_2 separation from CO_2/N_2 and CO_2/CH_4 gas mixtures. Incorporating 10 wt% MOF significantly improved CO2 permeability and selectivity compared to the neat Pebax1657, as demonstrated against the 2008 CO_2/N_2 Robeson upper bound (Figure 1). Attempts to exceed 10 wt% MOF concentration were limited by nanoparticle aggregation. To overcome this, we introduced $MnFe_2O_4$, which reduced MOF aggregation and enhanced membrane performance under higher loadings. The magnetic alignment of UiO-66-NH_2@$MnFe_2O_4$ nanoparticles during membrane casting led to superior gas separation efficiency compared to random polymer-MOF systems. This enhancement is due to improved gas permeability facilitated by the magnetic nanoparticle networks.[3] The inclusion of $MnFe_2O_4$ mitigated MOF aggregation, allowing for higher loadings and increased gas separation efficiency, surpassing the 2008 Robeson upper bound for CO_2/CH_4 and CO_2/N_2 gas pairs.

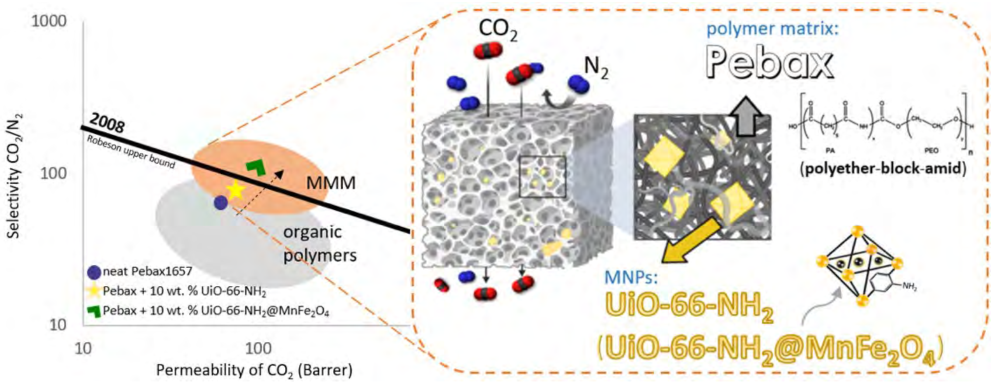

Figure 1: The 2008 Robeson upper bound for CO_2/N_2 and illustration of MMM.

Acknowledgments

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AN ALTERNATIVE APPLICATION OF 2D CARBON-BASED MEMBRANES FOR EFFICIENT H_2 SEPARATION FROM GAS MIXTURES

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Keywords: graphene oxide; gas separation; inorganic; membrane; carbon material; liquid separation
Presentation form: Poster
Abstract: Nowadays, there is a strong ongoing green transition regarding energy sources, where hydrogen is becoming more and more dominant due to its properties and ability to store energy. However, most of the hydrogen produced globally comes from fossil energy sources, which are non-renewable resources. Up to 95% of hydrogen is produced by steam reforming from natural gas [1]. Unfortunately, this product needs further purification to be used as a fuel.

In this work, we explored the effects of combining graphene oxide (GO) and single-walled carbon nanotubes (SWCNT) with various inorganic additives in order to create a membrane that is stable at high temperatures and can potentially further purify the industrially produced hydrogen via membrane separation. The SW-GO composites benefit from the unlimited permeability-selectivity performance, while polymer-based commercial organic membranes usually suffer from the trade-off or plastification effects. Further on, due to the outstanding properties of these 2D materials, other applications were also investigated, including air separation (O_2/N_2), waste-water processing, and a process concept for combining a membrane module with liquid chromatography for polyethylene glycol (PEG) rejection.

According to our previous work, GO was synthesized by a modified Tour method [2]. SWCNTs in a high-purity powder form were purchased from Tuball®. In order to improve the performance, further modifications were performed by adding selected polyvalent metal ions into the GO solution before filtration to evoke recently reported interactions of ions with the GO structure. Due to this phenomenon, the doped GO sheets connect via intermolecular bonds, making the material more ordered and stable [3]. The composite SW-GO membranes were created by a vacuum filtration method and then tested for gas separation with an integral permeameter for single gasses and a permeameter connected to a GC for binary mixtures. PEG rejection was investigated in a membrane cell connected to HPLC. The membranes were carefully picked according to their pore size to create a treated mixture, that has higher PEG content for a smoother separation for the HPLC. Material characterization was conducted with multiple commercial methods, such as FTIR, Raman, XRD, SEM, TGA, XPS, CO_2 sorption capacity measurements, BET porosity analysis.

Fabricated GO-SWCNT composite membranes were tested for effective H_2 separation from permanent gases (CO_2, CH_4, N_2). Tailoring the GO layer thickness and composition via bivalent metal ions provided enormous H_2 permeability > 35000 Barrer with excellent H_2/CO_2 and H_2/N_2 selectivity (above 6.4 or 3.8, respectively), surpassing the corresponding Robeson upper bounds. A rough cost analysis was also performed to compare the material cost with the commercially available polymeric membranes. The results demonstrate the uniqueness of the prepared composite materials, which exceeded the performance of most published membrane materials.

Acknowledgments

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PREPARATION AND CHARACTERIZATION OF MIXED MATRIX MEMBRANES BASED FOR CO_2 SEPARATION

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Keywords: Polyimide, 6FDA, CO_2 separation, MMM, UiO-66, ZIF-8

Presentation form: Poster

Abstract: Membrane technologies provide an alternative approach to traditional gas separation methods. CO_2 separation from gas mixtures is essential in applications such as biogas purification and raw natural gas processing. The addition of fillers to polymeric materials enhances their gas separation capabilities, thereby increasing the overall efficiency of the process. This study focuses on the development of novel mixed matrix membranes (MMMs) based on 6FDA-BisP incorporating fillers such as UiO-66 and ZIF-8. The characterization of the prepared MMMs and their nanoparticles was carried out using methods such as XRD, BET, FTIR, TGA, DSC, SEM and EDS. The effect of filler type and mass content on the separation properties and membrane morphology was investigated. Permeation tests were performed using a CO_2/CH_4 gas mixture at different ratios (1/1; 3/1; 1/3) and pressures (2, 4, 6 and 8 bar).

The 6FDA-BisP polyimide was synthesized using a conventional two-step polymerization process. First, diamine and dianhydride were reacted in a polar solvent under a nitrogen atmosphere to form a poly(amic acid) (PAA) solution. In the second step, the PAA was thermally imidized at 250°C. Dense membranes were prepared from 1 wt.% solution using chloroform as solvent. The obtained solution was stirred on a magnetic stirrer for 24 h. The homogeneous solution was then poured onto a Petri dish and dried under laboratory conditions for 2 days. Finally, the membranes were dried at 110 °C for 24 h.

The chemical composition, thermal stability and morphology of the prepared particles and membranes were analyzed using FTIR, TGA-DSC, EDS, SEM and XRD techniques. The effects of different fillers, feed mixture compositions and pressures (ranging from 2 to 8 bar) on the separation efficiency of the membranes were also investigated. The thickness of the prepared membranes ranged from 20 to 25 µm. For a 6FDA-BisP matrix polymer with 15 wt% ZIF-8 filler, the permeability increased by 335 % compared to the pure membrane while maintaining the original selectivity. Similarly, a membrane with 15 wt% UiO-66 particles showed a 155 % increase in permeability with no change in selectivity. The highest permeability, 135 Barrer with a selectivity of 43, was observed in the membrane with 15 wt% ZIF-8 particles.

EFFICIENT WATER- ISOPROPANOL SEPARATION THROUGH LOW-TEMPERATURE CROSSLINKING NANOPOROUS GRAPHENE OXIDE (NPGO) BASED MEMBRANES

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Keywords: GO-NPGO Membrane, Pervaporation, Low-Temperature cross-linkages
Presentation form: Lecture

Abstract: The oxygen-rich functional groups on the Graphene Oxide (GO) plane are prone to expansion induced by hydration, leading to the instability of mass transfer channels in aqueous solutions [1]. In this study, a method (as shown in Fig. 1) was employed to create in-plane nanoscale pores and establish Low-Temperature cross-linkages, enabling the precise control of both in-plane pore size and interlayer distance in layered GO membranes. By introducing additional mass transfer channels, the transport path was significantly shortened, leading to enhanced flux, and simultaneously achieved precise sieving of isopropanol and H_2O, maintaining a high retention rate.

The introduction of Low-Temperature cross-linkages increases the degree of cross-linking between GO and NPGO. Compared with uncross-linked GO, by controlling different cross-linking times and temperatures, the degree of cross-linking between NPGO and GO increases rapidly, and the density of the membrane increases accordingly. The interception rate of isopropanol is greatly improved, but it is accompanied by a certain decrease in permeability. Subsequently, under the premise of introducing NPGO, the permeability can be maintained while ensuring the interception rate.

After XRD and XPS testing, under different temperatures and cross-linking times, GO and NPGO have different cross-linking degrees, and the GO layer spacing changes accordingly, which is very beneficial to the screening of isopropanol and H_2O. And after cross-linked, its unique porosity can increase the flux while ensuring that the interception rate remains unchanged. This is because NPGO provides longitudinal water channels, which is conducive to large-scale water penetration.

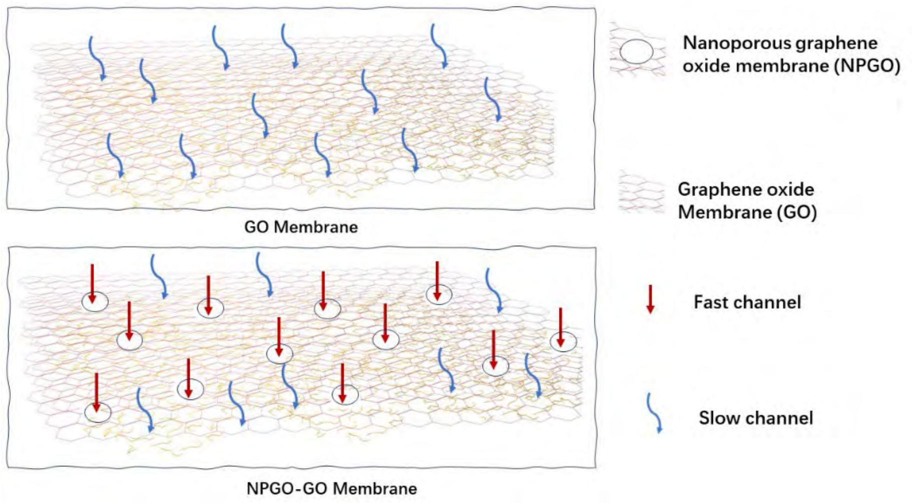

Fig. 1: GO membrane and NPGO-GO membrane

Acknowledgments

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EXPLORING POLY(CAPROLACTONE) AS A POLYMER MATRIX FOR IONIC LIQUID-FUNCTIONALIZED MEMBRANES FOR METAL EXTRACTION

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Keywords: Functionalized membrane; poly(caprolactone) (PCL); ionic liquids; metals extraction.
Presentation form: Lecture

Abstract: Functionalized polymeric membranes offer an attractive and straightforward solution to address the urgent demand for sustainable metal extraction methods. They can efficiently extract raw materials from waste sources and fulfill the imperative need to protect the environment from toxic elements. However, for these membranes to be considered a viable solution for industry applications, enhancements in their formulation are required.

In the case of polymeric membranes including an specific extractant (as PIMs), the polymers traditionally used are cellulose triacetate (CTA) and poly(vinyl chloride) (PVC). They are dissolved in a suitable organic solvent, such as chloroform and tetrahydrofuran (THF). However, to enhance sustainability and avoid harmful solvents, a shift towards utilizing more eco-friendly alternatives is mandatory. This is the case of the polymer poly(caprolactone) (PCL), a biodegradable and flexible polyester used, for example, in medical applications (Vera et al. 2019).

In this study, we investigate the possibility to use PCL as a polymer with different ionic liquids (ILs) as extractants: the commercial Aliquat 336 and the task-specific IL trioctylmethylammonium thiosalicylate (TOMATS). Both PCL and the ILs were dissolved in THF, and the membrane was obtained after the evaporation of the solvent. The resulting membranes were then characterized by scanning electron microscopy (SEM) with an energy dispersive X-ray spectroscopy (EDX) detector. The morphology of PCL-based membranes showed the presence of pores while the most common polymers used to prepare functionalized membranes, cellulose triacetate (CTA) and poly(vinyl chloride) (PVC), provide dense membranes. The incorporation the IL into PCL matrix was confirmed by the presence of the characteristic atoms of the IL by EDX.

The prepared PCL membranes were investigated for the extraction Pd and Cd in chloride media. The extraction studies were done using a 4 cm^2 membrane immersed in 25 mL 5mg L^{-1} Cd or Pd, both in 0.1M chloride solution. In the case of Cd, the membrane has shown to effectively remove the metal from a 0.5 NaCl media. Studies on membrane stability and reusability are under investigation.

The extraction of Pd was evaluated using the PCL-TOMATS membrane. It was found that the extraction was quantitative after 3h, and the metal could be recovered from the membrane using a 0.3M thiourea solution in 0.1M HCl. Moreover, a novel configuration was investigated for the extraction of Pd. The PCL membrane was place in a filtering system and was used to successfully retain Pd while the solution was filtered. Afterwards, the metal was recovered using the thiourea solution.

Acknowledgments

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POLYMERIC FLUORINE-FREE IONOMERS AND THEIR COMPLEXES WITH POLYELECTROLYTES FOR THIN-FILM COMPOSITE NANOFILTRATION MEMBRANES

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Keywords: ionomer, polyelectrolyte complex, nanofiltration membrane
Presentation form: Lecture

Abstract: Selectivity in terms of ion and micropollutant rejection of nanofiltration (NF) membranes is a crucial factor for the performance in applications, such as wastewater treatment. Membranes based on commercially available fluorine-free ionomers may extend the available selectivity spectrum and provide higher stability compared to conventional polyamide-based NF membranes [1].

Herein, the fabrication of a tunable and highly stable ionomer NF membrane by coating the negatively charged block copolymer Nexar on several support membranes, from regenerated cellulose (RC) or polyacrylonitrile (PAN), with ultrafiltration (UF) characteristics is reported. The aim of this project is to tune the coating conditions (dip coating) and the solvent systems (cf. [2]) to increase the separation performance of the resulting thin-film composite (TFC) NF membranes beyond state-of-the-art [1].

Prefunctionalization of the support membrane to introduce positively charged groups [3,4] was found to be critical for a defect-free and stable lamination with the negatively charged ionomer and may also yield a kind of polyelectrolyte complex membrane. The nanoscale morphology of the Nexar film can be tuned by the solvent system of the coating solution. A mixture of toluene and 1-propanol was identified as the solvent that results in superior morphology and performance compared to other solvents. Low Nexar layer thickness was accomplished by dip coating conditions. Alternative casting methods, e.g. casting with a doctor knife, were investigated. NF characterization of an exemplary new membrane (0.8 µm Nexar film thickness on aminated PAN support) revealed rejections for Na_2SO_4 of 95 %, for NaCl of 75 % as well as for sucrose of 99 %, and a pure water permeance of ~ 2.5 LMH/bar. To further tune the performance, a thinner selective film (>0.1 µm) is fabricated, and the feasibility of post-treatment methods is examined. In addition, research is also devoted to deeper understand the morphology of the Nexar film. In addition, in analogy to recent other work with Nafion as part of the selective layer [5], a polyelectrolyte complex membrane is prepared by combining the fluorine-free Nexar layer with a polycationic polymer (e.g. polyethyleneimine) to further tune membrane separation performance.

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REACTION-TRANSPORT PHENOMENA AT ION-EXCHANGE MEMBRANES IN DC ELECTRIC FIELD

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Keywords: electrodialysis; concentration polarization; desalination; natural convection

Presentation form: Lecture

Abstract: The availability of safe drinking water is a pressing global issue, with challenges ranging from desalinating sea and brackish water in coastal areas to treating contaminated freshwater sources. Membrane processes play a vital role in addressing these challenges, with reverse osmosis dominating conventional water desalination. However, electromembrane processes, particularly electrodialysis, are emerging as promising alternatives for smaller desalination plants and industrial applications, prioritizing the production of ultrapure water over potable water.

Despite its potential, electrodialysis faces limitations, namely concentration polarization, which is an intrinsic phenomenon occurring on the membranes used in the process when under DC bias. A deeper understanding of reaction-transport phenomena associated with this phenomenon is essential to designing and optimizing more efficient electrodialysis devices. Surprisingly, solute-induced natural convection emerges as a potential solution to, at least partly, alleviate the problems stemming from concentration polarization.

In the first part of our study an electrochemical cell for microscale study of reaction-transport phenomena on ion-exchange membranes was initially designed and constructed. The cell allowed us to perform an in-depth experimental study analyzing the behavior of a heterogeneous cation-exchange membrane in a set of KCl solutions with different concentrations. The direct observation of the membrane-electrolyte interface showed that natural convection occurs in the system due to concentration polarization, inducing gradients in solution density on both the diluate and concentrate sides of the systems. This study also proved that natural convection initiates in the underlimiting regime and gains strength throughout the limiting and overlimiting regimes. The motion is upward-directed alongside the ion-exchange membrane on the diluate side and downward-directed on the concentrate side. The developed natural convection showed a strong impact on mass transfer. The system qualitative features are conserved for all concentrations tested; however, they have a significant impact on the quantitative characteristics. On normalizing the measured electrochemical characteristics by the limiting current density obtained for each concentration, we proved natural convection gains significant strength with increasing concentration, completely dictating the limiting and overlimiting convection pattern at the membrane for the highest concentration.

In the second part of the study, we modeled the convective streaming developing in the underlimiting region of the studied cation-exchange membrane in COMSOL Multiphysics. We compared the simulation results to the experimental ones to underpin our study with theoretical foundations. The results showed good agreement, validating the formulated mathematical model for simulating the electrodialysis systems in the underlimiting regime.

DEVELOPMENT OF MACROVOID-FREE HOLLOW FIBER PES MEMBRANES BY USING DOE AND THE GREEN SOLVENT *N,N*-DIMETHYLLACTAMIDE

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Keywords: Design of Experiment, DoE, green solvent, membrane preparation, hollow fiber membranes, PES, sponge-like structures, membrane structure

Presentation form: Lecture

Abstract body: Membrane technology, recognized for its energy efficiency, finds diverse applications across industries, including wastewater purification, seawater desalination, and hemodialysis. Among the established techniques for crafting polymeric membranes, phase inversion stands out as the most prevalent in both industrial and academic settings. This method involves dissolving the polymer in a suitable solvent to create a homogeneous polymer solution. Unfortunately, many solvents utilized in membrane fabrication are highly toxic, subject to strict industrial regulations. Notably, environmentally harmful solvents like NMP (derived from fossil sources) contribute significantly to the environmental footprint of membrane production, accounting for 40–60% of the overall impact.[1] Adapting green solvents (derived from bio-based sources) presents a promising avenue to mitigate the environmental impact by up to 35% [1].

The preparation of hollow fiber membranes is influenced by numerous parameters, necessitating an examination of their impact on membrane properties when employing novel green solvents. In this context, the highly efficient Design of Experiments approach proves to be particularly fitting. By leveraging statistical methods, it minimizes the required number of experiments, facilitating the study of various parameters and their effects on membrane characteristics.

In this study, poly (ether sulfone) (PES) hollow fiber membranes were prepared utilizing *N,N*-dimethyllactamide as an environmentally friendly solvent. The study revealed that the molecular weight of the pore forming additive played a pivotal role in influencing the membrane structure and subsequently its performance. Specifically, the use of a higher molecular weight poly (vinylpyrrolidone) (PVP) facilitated the preparation of hollow fiber membranes with a sponge-like structure (exceeding 99% of the cross-section area). This sponge-like configuration contributed to enhanced mechanical stability. Both the PES and PVP content within the dope solution played a role in influencing mechanical stability and the resulting structure.

Furthermore, the study demonstrated the necessity of a minimal viscosity in the dope solution to achieve sponge-like membranes. This critical viscosity was attained through adjustments in the PES/PVP content and the molecular weight of the PVP. The incorporation of sufficient amounts of additional solvents such as isopropanol, ethanol, glycerol, or *N,N*-dimethyllactamide in the bore liquid was found to enhance membrane performance. However, these solvents were not imperative for the preparation of sponge-like fibers.

Adjusting the molecular weight cutoff (MWCO) and permeance of the resulting membranes was achieved by post-treatment with sodium hypochlorite. It enabled a significant increase in permeance and alteration of the MWCO. This study offers valuable insights into optimizing the preparation and performance of PES hollow fiber membranes using a green solvent with potential applications in science and industry.

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FACILE FABRICATION OF POLYPEPTIDE-BASED ANTIBACTERIAL TIGHT-ULTRAFILTRATION MEMBRANE FOR SUSTAINABLE HIGH-SALINITY TEXTILE WASTEWATER MANAGEMENT

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Keywords: Tight ultrafiltration membranes, Polypeptide, High-salinity textile wastewater, Antibacteria
Presentation form: Lecture

Author did not agree to publish the abstract

ENHANCING MICROBIAL RESISTANCE OF CELLULOSIC ULTRAFILTRATION MEMBRANE VIA POLYELECTROLYTE COATINGS

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Keywords: cellulosic membrane, polyelectrolytes, municipal wastewater, PVAm
Presentation form: Lecture

Abstract: Membrane technology is playing an increasingly important role in water treatment, but with the membrane material choice itself the process can be made more sustainable. Renewable cellulose is a promising option to use for membranes, as it provides them great properties such as hydrophilicity, and high selectivity [1]. The most significant problem with cellulosic membranes is biodegradation resulting from microbes [2], which prevents the large-scale use of cellulosic membranes in applications such as wastewater treatment.

Large-scale use of cellulosic membranes could be possible with different kinds of coatings that help to protect the membrane. Polyelectrolytes are one option that can be utilised in coatings on membrane and in this paper two different polyelectrolyte pairs have been explored: PDADMAC/PSS (Poly(diallyldimethylammonium chloride)/poly(styrene sulfonate)) and PVAm/PAA (polyvinylamine/poly(acrylic acid). PDADMAC/PSS coatings have been explored quite extensively in literature, but PVAm/PAA coatings on the other hand haven't been investigated as widely, especially in filtration membranes. A special characteristic of the PVAm/PAA coating that can be seen in literature is its possible antimicrobial property [3].

The filtration properties of PDADMAC/PSS and PVAm/PAA coated membranes were assessed with the measurements of pure water permeance and neutral solute rejections. Nonetheless, the main purpose of this paper was to improve the microbial resistance of cellulosic membranes using these two different polyelectrolyte coatings. The effectiveness of the coatings was tested with wastewater exposure tests where coated membranes and noncoated control membranes were held in wastewater for 5 days. The filtration properties and changes in pore size were monitored daily to see the effect caused by coatings.

When the filtration properties of PDADMAC/PSS and PVAm/PAA coated membranes were compared, it was noticed that with the same number of bilayers PVAm/PAA coating made the membrane's cut-off tighter than PDADMAC/PSS coating. The results from the wastewater exposure tests showed a positive result from both coatings on the durability of the cellulosic membranes. Pure water permeance of noncoated membrane increased over 100 L/(m^2 h bar) during the wastewater exposure, but the pure water permeance of PDADMAC/PSS coated membranes decreased 20 L/(m^2 h bar) while PVAm/PAA coated membranes' pure water permeance stayed stable.

Altogether, from these two polyelectrolyte coatings the PVAm/PAA coating was seen to be better at maintaining the membrane's filtration properties and pore size. Later, the protective mechanism provided by these coatings has been further investigated.

In the future, possibilities offered by PVAm/PAA and other coatings will be investigated further with the goal of finding a coating that enables the use of cellulosic membranes in wastewater processing.

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GAS SEPARATION PERFORMANCE AND STABILITY OF COMPOSITE HF MEMBRANES FOR CO_2/N_2 AND CO_2/O_2 SEPARATION

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Keywords: membrane gas separation, thin film composite membranes, aging
Presentation form: Lecture

Abstract: Membrane separation technology (MST) offers an efficient, easy-to-operate, and low-energy alternative to traditional methods. For large-scale applications, hollow fiber membranes (HFMs) are advantageous due to space and weight savings. These membranes typically consist of a support layer and an active layer for gas separation

In this study, various composite hollow fibers (HF) were prepared using a polyacrylonitrile (PAN) porous support and coated with an active layer of PEBAX®, a block copolymer extensively studied for gas separation due to its PEO soft blocks, which enhance CO_2 permeability[1]. Ensuring the stability of these membranes is crucial for industrial applications[2].

The physical aging of hollow fibers are generally not widely explore, therefore the stability of PEBAX® composite hollow fibers was assessed through single gas transport properties for CO_2, O_2, and N_2 over time. It was observed that the thin layer exhibited unstable performance over time. Initially, the CO_2 permeance was 328 GPU with a CO_2/N_2 separation factor of 40 on the first day, indicating a defect-free selective layer. However, after 24 days, the CO_2 permeance declined to 48%, and the CO_2/N_2 selectivity dropped to 14. A similar trend was observed for CO_2/O_2 separation, with the separation factor decreasing from 20 to 10. To address this instability, a strategy involving a gutter and protective layer was employed to provide a more stable defect-free membrane.

Small-angle X-ray scattering (SAXS) and atomic force microscopy (AFM) were employed to investigate the structural changes and morphology of the membrane over time due to physical aging. The SAXS analysis did not reveal any significant alterations in the crystallinity of the thin active layer. However, the AFM observations indicated changes in the block chains, suggesting a redistribution of free volume within the membrane. Initially, a more homogeneous distribution of the blocks was observed, and after 30 days, a more defined and phase-separated morphology emerged, confirming the rearrangement of the macromolecules.

This study highlights the challenges and potential solutions in developing stable composite hollow fiber membranes for CO_2 capture. While PEBAX®-coated hollow fibers initially show high CO_2 permeance and selectivity, physical aging significantly reduces both over time. These findings emphasize the need for improved membrane design and material selection to enhance long-term performance and stability.

Acknowledgments
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HOLLOW FIBER MEMBRANES FOR HARSH CONDITIONS VIA CHEMISTRY IN A SPINNERET

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Keywords: Chemistry in a spinneret, non-aqueous interfacial polymerization, thin film composite (TFC) membranes

Presentation form: Poster

Abstract: Membrane processes such as nanofiltration, gas separation, reverse osmosis mainly use thin film composite membranes. A majority of the composite membranes available are produced using interfacial polymerization (IP) on flat sheets and are based on polyamides which have limited chemical and thermal stability. Hollow fiber membranes have several advantages over flat sheets such as high packing density, high surface area to volume ratio, and they are self-supporting. But the fabrication of thin film composite hollow fiber membranes via IP is a time consuming process. Moreover, the success rate of defect free layers via IP on the inner surface of hollow fibres is low [1]. This can therefore be done using the so-called chemistry in a spinneret technique where one monomer is added in the dope solution and another in the bore fluid. When these solutions are extruded through a spinneret a porous support structure is formed via the phase inversion process and a selective layer is formed in the lumen side by a crosslinking reaction of the monomers in a single step [2,3].

This study aims at combing the principles of chemistry in a spinneret and non-conventional interfacial polymerization by including phosphonitrilic chloride trimer (HCCP) in the bore fluid and an aromatic alcohol in the dope solution with DMSO as the solvent. The addition of KOH to the dope solution then deprotonates the alcohol, thereby enhancing its nucleophilicity to react with the phosphorous atom of HCCP [4]. The inert polymer from the polymer solution forms the porous support structure, while the polycondensation reaction between the alcohol and HCCP forms the selective polyphosphazene layer. The resulting membranes are then anticipated to have applications in separation tasks with harsh conditions such as high temperature gas separation and organic solvent nanofiltration.

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RAWMINA: INTEGRATED INNOVATIVE PILOT SYSTEM FOR CRITICAL RAW MATERIALS RECOVERY FROM MINES WASTES IN A CIRCULAR ECONOMY CONTEXT

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Keywords: Mine Waste Valorization, Critical Raw Materials, Adsorption, Nanofibers, MOFs, membrane
Presentation form: Poster
Abstract: Critical Raw Materials (CRMs) are crucial to Europe's economy. They form a strong industrial base, producing a broad range of goods and applications used in everyday life and modern technologies. CRMs are needed for significant economic and strategical sectors, as for example manufacturing batteries, metals, electronic and medical devices, automotive, defense or renewable energy sectors. However, limited supply and difficult substitution to CRMs is a growing concern within the EU. RAWMINA aims to develop and to demonstrate the RAWMINA pilot system: an industrially scalable and flexible innovative pilot in continuous operation for Mine Waste (MW) valorization, achieving 95 % recovery rate and 95 % selectivity for CRMs (Co, Sb, Ge and W), and 80 - 90 % recovery rate and 95 % selectivity for Au, Ag and Fe-based high-value products, whilst reutilizing 90 % of water. RAWMINA will implement and standardize an innovative energy, water- and cost-effective pilot system able to treat up to 100-150 kg MW/day on an industrial demonstration (TRL7) including efficient and robust process control. To achieve these aims, RAWMINA's activities include MW sampling, MW dressing and characterization, upscaling of innovative technologies such as continuous bioleaching, iron removal with magnetic separation and CRMs selective recovery through a combination of nanofibrous composite materials and electrocoagulation processes. The novel nanofiber composite materials (NCMs) with selectivity towards Co, Sb, Ge and W will include tailored-made membranes made of polymeric nanofibers produced by electrospinning and centrifugal spinning processes. Different particles and MOFs have been synthetized and their adsorption capacity towards the target CRMs has been evaluated. The most promising particles and MOFs have been incorporated into polymeric nanofibers and the adsorption and desorption capacities of these materials has been evaluated.

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FROM MEMBRANE SURFACE ACTIVATION TO CHARGE-ASSISTED COATINGS: NOVEL INSIGHTS AND APPLICATIONS

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Keywords: water purification, cellulosic membrane, surface modification, coating
Presentation form: Lecture
Abstract body: Increasing global population produces more and more wastewaters that need to be purified. Furthermore, the existing the freshwater resources are becoming progressively scarcer as the climate change makes the world hotter and dryer. Membrane technology is thus becoming more prevalent by the year, as the need for water purification technologies increases. Membrane technology itself has some definitive drawbacks that ought to be addressed, such as the tendency of membranes to foul and lose performance over time. Furthermore, high costs stemming from the energy consumption and the replacement of End-of-Life elements are somewhat hindering the wide implementation of membranes. Herein, membrane surface modification is studied from different aspects with the aim of improving membrane properties and longevity.

Effects of membrane surface charge enhancement and consequent coating on the filtration properties are investigated. Surface charge enhancement methods on different membrane materials are studied, with a main focus on TEMPO-mediated oxidation of cellulosic ultrafiltration membranes. The charge-enhanced membranes have some desired properties over the unmodified membranes, such as simultaneously increased water permeance and salt retentions.[1] Another interesting outlook of charge-enhancement is the improved adhesion of coatings. With the help of charge-adhesion, for instance, polyelectrolytes and microfibrillar cellulose were successfully coated on top of the oxidized membranes. The coatings were used, for instance, for improving the durability of cellulosic membranes in production of drinking-quality water from natural surface water. Furthermore, the microfibrillar coatings facilitated an interesting filtration phenomenon, where certain solutes larger than membrane cut-off value could be permeated based on their molecular morphology.[2]

Surface charge enhancement and coating seem viable techniques for upscaled industrial use as well. Our results indicate that similar strategy of consequent oxidation and coating can be used for converting End-of-Life polyamide desalination membranes into repurposed nanofiltration elements inside the modular structure. Such approach could make membrane technology more feasible for different applications, as the costs would be significantly lowered, and the resulting membranes are, in some cases, even better than commercial alternatives.

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SOLAR FUELS PURIFICATION USING PERVAPORATION WITHIN NEFERTITI PROJECT

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Keywords: pervaporation, mixed matrix membranes, metal-organic frameworks
Presentation form: Lecture

Abstract: The NEFERTITI project aims at achieving an innovative highly efficient photocatalytic system that will simultaneously convert CO_2 and H_2O into solar fuels (ethanol). The solar fuels produced require a purification step, and membrane-based separation process, such as pervaporation (PV) is proposed. PV processes allow the economic and efficient separation of azeotropic mixtures, specifically compared to more energetic intensive traditional separation processes such as evaporation and distillation.

Ethanol dehydration via pervaporation processes can be found integrated in industrial sites, where commonly polymeric PVA (poly(vinyl alcohol)) based membranes are used. On the other hand, organophilic membranes have been used to recover ethanol from diluted aqueous solutions. Different hydrophobic polymers such as PDMS (polydimethylsiloxane) or Pebax® (Polyether block amide) can be used for the development of selective layer for these organophilic membranes. However, the selective recovery of ethanol from water is still challenging due to the low membrane selectivity. Furthermore, membrane stability is also affected by the permeation of organic vapors, which inflict physical aging of the membrane.

Next generation membranes consider the incorporation of nanoparticles (NPs) to maximize the membrane perm-selectivity [1]. The combination of selective nanoparticles with a polymeric matrix constitutes a different type of membrane, called mixed-matrix membranes (MMMs). Different types of NPs can be incorporated, such as traditional inorganic materials as silica and zeolites, or more recent and emerging as Metal-Organic Frameworks (MOFs) [2], among others. However, a crucial aspect in their viability and defect-free preparation are the homogenous dispersion of the filler in the polymeric matrix and the compatibility polymer/filler.

In NEFERTITI project, it is aimed to develop nanoparticle enhanced mixed matrix membranes for obtaining increased separation factors for solar fuels with acceptable permeation rates and good stability.

Acknowledgments
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INTENSIFICATION OF SEPARATION PROCESSES IN ELECTROMEMBRANE SYSTEMS

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Keywords: electrodialysis; concentration profiles; desalination

Presentation form: Poster

Abstract: The reaction-transport processes occurring within the diluate channels of electrodialysis devices result in the establishment of complex fields of relevant quantities, such as ion concentration, electric potential, and temperature. These quantities vary in all three spatial dimensions. Simplifying assumptions that permit the use of 2D or 1D models do not adequately capture the full complexity of these processes. Consequently, we conducted experimental analyses of electromembrane systems for the desalination of aqueous solutions.

In our initial study [1], we constructed a milifluidic electrodialysis system with a single diluate channel equipped with ports for measuring electric potential profiles. Measurements revealed significant variations in electric potential across the diluate channel, with the largest drops occurring on membranes with ion-depleted zones, especially under high current loads leading to near-complete desalination. The observed increase in resistance and potential fluctuations indicated the onset of overlimiting convection, although we could not reconstruct potential profiles within ion-depleted layers due to the resolution limitations of our method.

In our subsequent study [2], we modified our milifluidic cell to measure spatial concentration profiles under single-path electrodialysis conditions. This experiment demonstrated that low current loads generated linear concentration profiles along the diluate channel, whereas high current loads induced nonlinear profiles characterized by rapid initial concentration drops. A significant vertical concentration gradient was observed due to natural convection, while no major concentration changes were detected across the channel. Natural convection velocities were quantified and found comparable to pressure-driven flow velocities.

Building on our previous research, we designed and tested a novel electrodialysis unit that leverages natural convection to enhance desalination performance. The unit features a modified diluate channel with one inlet and two outlet streams, resulting in improved performance. Experimental results confirmed that this new design achieves higher desalination efficiency, with one output solution surpassing theoretical predictions. This improvement is attributed to the strategic use of natural convection within the diluate channel. Continuing our research, we aim to explore the impact of natural convection on desalination efficiency under various operational conditions. By enhancing the understanding of these complex reaction-transport phenomena, the optimization of electrodialysis for industrial applications can be significantly improved.

Acknowledgments

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THIN FILM COMPOSITE NANOFILTRATION MEMBRANES BY COATING ANIONIC AND CATIONIC IONOMERS ON POLYACRYLONITRILE MEMBRANES

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Keywords: Nanofiltration membrane, Ionomer, Polyelectrolyte
Presentation form: Poster
Abstract: The effective filtration of ions and organic pollutants, together with their selective retention, is crucial for nanofiltration membranes, especially for applications in wastewater and treatment, including resource recovery. Materials like polyelectrolytes or ionomers (amphiphilic charged polymers) offer promising alternatives to state-of-the-art polyamide-based NF membranes, providing comparable membrane performance, while demonstrating significantly higher stability, for example against oxidizing agents like active chlorine. The aim of this study is the development of thin film composite NF membranes with adjustable membrane performance and a selective barrier film made from fluorine-free ionomers, for partial desalination and removal of organic micropollutants of urban and industrial wastewater.

Highly stable thin film composite NF membranes are fabricated, which are adjustable in terms of separation selectivity and permeance. Commercially available ionomers, like the negatively charged Pemion or the positively charged Fumion and Aemion, which all had been established for fuel cell or water electrolysis technologies, are used to establish a NF-selective film. This is achieved by first preparing a polyacrylonitrile (PAN) membrane with ultrafiltration (UF) properties [1] and subsequently coated it with an ionomer solution by frame casting. A crucial aspect for achieving a defect-free, negatively charged, and stable Pemion ionomer film is the premodification of the PAN UF membrane with ethylenediamine (EDA) [2] leading to positively charged groups on the surface and thereby to attachment by a polyelectrolyte complex [3]. For further coating, Pemion is dissolved in an alcohol mixture and poured onto the PAN membrane in a horizontally oriented metal frame. After evaporation of the solvent at room temperature the membrane is ready for use.

A suitable PAN support membrane was established in laboratory scale and the upscaling of the manufacturing process to large area of non-woven supported membrane was successful. This resulted in a PAN membrane with a sufficiently high pure water permeance of 600 $L/m^2 \cdot h \cdot bar$ and a MWCO of 45 kDa. The effective premodification of the PAN membrane with EDA was successfully proven by a positive zeta potential and the stability of coated anionic ionomer films. As a first prototype, a composite with a defect-free and homogeneous 450 nm thick Pemion film on EDA-modified PAN membrane was obtained. The NF characterization of that membrane revealed rejections for Na_2SO_4 of 85 %, NaCl of 60 %, for sucrose of 50 % and for glucose 40 %, with a pure water permeance of 2 $L/m^2 \cdot h \cdot bar$.

Further optimization like increasing the permeance by reducing ionomer thickness by alternative coating methods such as dip-coating or electro-spraying, are currently under investigation. Other ongoing studies explore the coating of positively charged ionomers (Fumion and Aemion) in combination with adapted modification of the PAN support membrane. Thereby, the specific influence of a cationic or anionic film, along with the impact of the support membrane, on ion selectivity, micropollutant rejection and permeance of the novel thin film composite membranes are examined.

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STUDY OF THE IMPACT OF AMINE MODIFICATION OF BIOCHAR FOR SELECTIVE CO_2 ADSORPTION

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Keywords: Biochar, Adsorption
Presentation form: Lecture

Abstract: Biochar is a carbon-rich material obtained by the pyrolysis of plant matter in an oxygen-free environment. [1] Its high porosity makes it excellent for various applications, one of which is addressing climate change. [2] Biochar is part of the carbon removal techniques targeting CO_2. However, due to biochar's high adsorption properties, it usually cannot selectively target CO_2, and modifications are needed to expand its potential. [3]

In this study, we report the modifications of biochar with monoethanolamine and N-methyldiethanolamine, respectively, and their effect on gas sorption properties at 300 K and 315 K from 1 to 7 bar. The studied gases were CO_2, CH_4, N_2, O_2, C_3H_6, C_3H_8, and C_4H_{10}. The unmodified material showed high sorption for all gases, especially for CH_4 at both temperatures. The modified materials exhibited a decrease in sorption for all gases, with the exception of CO_2 at 300 K, which significantly exceeded that of CH_4, shifting the separation factor for CH_4/CO_2. At 315 K, both modified materials showed a rapid decrease in CO_2 sorption, while the sorption of other gases remained stable. This confirms that the modified materials' sorption of CO_2 was driven by the interaction of CO_2 with the NH_2 groups, which is exothermic.

Acknowledgments
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ENZYME-FUNCTIONALIZED POLYMER MEMBRANES FOR ENHANCED PROTEIN RECOVERY FROM MICROALGAE

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Keywords: enzyme immobilization, algae filtration, fouling, protein recovery
Presentation form: Poster

Abstract: Microalgae are a promising source of nutrients and chemicals with a very high production yield compared to corn or rape. Moreover, they don't require arable lands or fresh water. Several microalgae strains are already used as cosmetic ingredients or food sources "generally recognized as safe" (GRAS) for the US Food and Drug Administration (FDA). In the European Union some strains are included in the list of authorized foods. Currently, obtaining valuable biomolecules such as proteins from microalgae is limited. To fully exploit the potential of microalgae, cell disruption followed by efficient separation of their ingredients is required. Most biomolecules contained in green microalgae or disrupted cells are assembled into complex structures or aggregates which need to be dissociated to enable a recovery of selected biomolecules, and furthermore, to avoid membrane fouling in the filtration sequence.[1] For this purpose, digestive enzymes are immobilized on polymer membranes by electron beam grafting. The resulting enzymatic membranes will be investigated for their potential to break up agglomerates during the filtration of algal extracts to maximize protein recovery.

Polymer microfiltration membranes are grafted with Lipase and Trypsin by electron beam-induced grafting.[2] The resulting enzymatic membranes are used in sequential filtration of extracts of *Tetraselmis chui*. The protein concentration in the filtrate is quantified by bicinchoninic acid (BCA) test. Membrane fouling as well as biomolecule agglomerates are investigated by fluorescence spectroscopy. The general membrane characteristics are monitored in terms of water contact angle, water permeance, scanning electron microscopy and porosimetry.

The enzymes Lipase and Trypsin are tested individually and in combination for their ability to improve algae filtration efficiency in terms of protein recovery in the filtrate. The optimal enzyme loading is used for membrane functionalization by electron beam grafting. Different algae filtration conditions are investigated and optimized using a design of experiments approach. A highly efficient enzymatic membrane is identified and further investigated to understand the beneficial effect regarding reduced membrane fouling and/or degradation of biomolecule aggregates. This work confirms the successful use of enzymatic lysis in combination with membrane filtration to harvest valuable biomolecules such as proteins from a complex mixture of algae extract in a simple filtration procedure.

Fig.1: Filtration of microalgae using an enzymatic membrane in a stirr cell.

Acknowledgments

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ENCAPSULATED IONIC LIQUIDS IN PEBAX® MEMBRANES FOR INDOOR AIR QUALITY.

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Keywords: gas permeability, carbon sub-microcapsules (ENILs), volatile organic compounds (VOCs).
Presentation form: Poster

Abstract: The World Health Organization (WHO) reports that over 3.2 million deaths globally were attributed to domestic air pollution in 2022 [1] and that approximately 2.4 billion individuals face hazardous levels of household air pollution [2]. The major sources of indoor air pollution are inorganic gases (such as CO_x, H_2S, and SO_x) and volatile organic compounds (VOCs) such as toluene, benzene, and formaldehyde. Several technologies could potentially address the issue, including filtration, adsorption, ionization, ultraviolet disinfection, and UV-photocatalytic oxidation. However, they are constrained to specific pollutants, may produce more harmful byproducts than the original substances, are typically energy-intensive and space-consuming setups, resulting in the disposal of hazardous residues into the environment, and ultimately could stand impractical on a wider application. Novel technologies and purportedly eco-friendly solvents are being suggested, yet none has attained the requisite level of development for practical implementation on an industrial scale. Among those, ionic liquids (ILs) have attracted special interest due to their high affinity and selectivity with VOCs. Nevertheless, employing ILs alone poses notable impediments primarily associated with their transport properties. To address this challenge, we propose the encapsulation of ILs within carbon sub-microcapsules (ENILs) to reach nearly instantaneous absorption kinetics. However, the size and weight of ENILs pose a barrier to their direct utilization, hindering their application in conventional separation units. Yet, by integrating the encapsulation of ILs and their subsequent incorporation into membrane matrices, it is possible to leverage the absorption capacity and selectivity of green solvents while benefiting from the modularity, compactness, and easy scalability of membrane technology, thus envisioning a sustainable separation approach. Here, we propose the development of ENILs supported in polymeric membranes of PEBAX® as a new practical technology to tackle the abovementioned problems. The polymeric selective thin layer containing ENILs boosts the permeability and selectivity due to enhanced gas transport properties related to the tunable compatibility of ILs and the contaminants while removing the need for regeneration steps/units.

Acknowledgments

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THE EFFECTS OF OVERLIMITING PHENOMENA ON ELECTRODIALYSIS

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Keywords: electrodialysis, natural convection, electroconvection, water-splitting

Presentation form: Poster

Abstract: Electrodialysis is a green industrial separational process used for water desalination and wastewater processing. Nowadays, electrodialysers are operating in underlimiting regime and therefore are not productive enough compared to competing methods such as reverse osmosis. Our intention was to determine whether overlimiting phenomena could be used to locally increase the rate of desalination in underlimiting region. A series of experiments were performed on a continuous mini-electrodialyser with a single desalination channel observed by a camera mounted on a microscope to observe natural convection, electroconvection and water-splitting. The rate of water-splitting was determined by measuring the pH difference during the experiments and electroconvection was studied by tracking polymeric particles. As for natural convection, the desalination channel was placed in vertical direction and changes in system performance were analyzed. The results can be summarized as follows: electroconvection and water-splitting do not take place in underlimiting region, while natural convection can significantly change flux characterization and therefore the performance of the electrodialyser. In a horizontal set-up, the flux is laminar, in a vertical set-up with the downward forced flow, the central stream is twice as strong and for the vertical-up system the fastest stream is slower than for horizontal set-up and is located closer to cation-exchange membrane.

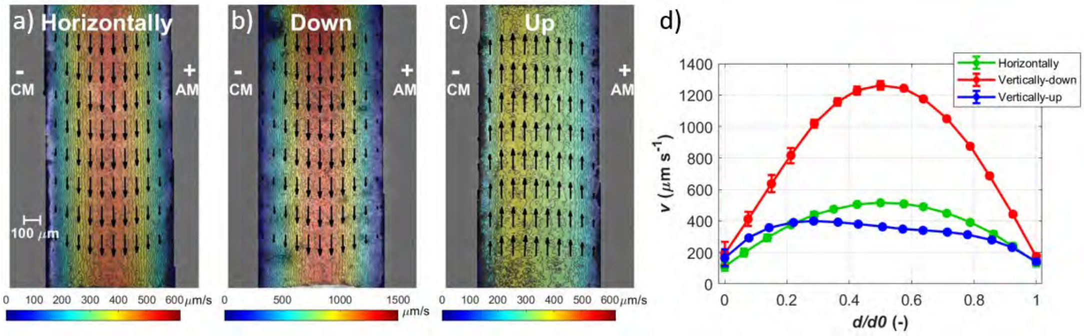

Fig. 2 a-c: Evaluated velocity fields in the desalination channel for horizontal, vertical-down and vertical-up set-ups using particle image velocimetry, left side is cation-exchange membrane and right side anion-exchange membrane, d) velocity profiles on relative channel width for all three set-ups. Zero is close to cation-exchange membrane, one is near anion-exchange membrane.

Acknowledgments

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FABRICATION OF PROFILED ION-EXCHANGE MEMBRANES FOR HARVESTING ENERGY FROM SALINITY GRADIENTS

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Keywords: 3D printing, Ion-exchange membranes, Reverse electrodialysis
Presentation form: Lecture
Abstract: Reverse electrodialysis (RED) is an electromembrane process that converts salinity gradient energy to electricity by controlled mixing of dilute and concentrated saline streams. The possibility to exploit the electrochemical energy content of desalination brine by RED is based on the evidence that the amount of extractable energy significantly increases when using concentrate ionic solutions due to higher salinity gradient and lower Ohmic resistances[1]. Within the scope of the project EXBRINER (https://exbriner.unical.it/), at which water and brines are obtained after processing steps such as nanofiltration and membrane distillation, the use of RED will be studied to recover the spent energy by mixing/diluting the produced monovalent brine with seawater or brackish water before its disposal. However, the efficiency of RED is affected by several factors, including the design of the stack, the membrane properties and the fouling of the membranes[2]. This project explores the fabrication of low-cost ion exchange membranes by 3D printing with conductivity and selectivity comparable with commercial membranes. By optimising the topography of membranes, creating so-called profiled membranes, fluids distribution in the channels can be improved, leading to the reduction of concentration polarization and fouling[,4]. Our research aims to enhance ion transport and membrane mechanical stability by optimising membrane composition and printing parameters. Thus, a thermoplastic polymer is extruded into 1.75 mm filaments which are further 3D printed as a profiled membrane with designed topography. The 3D printed membranes are then functionalised to produce cation- and anion-exchange membranes (by sulfonation and amination, respectively). The introduction of such innovative membrane manufacturing methodologies makes it simpler to create profiled ion-exchange membranes for use in energy recovery systems such as RED.

Acknowledgements

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POROUS CONTACTOR MEMBRANE FOR CATALYTIC H_2 GAS RELEASE FROM LIQUID CHEMICAL STORAGES

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Presentation form: Lecture

Abstract: As a clean energy carrier, hydrogen can play a lead role for a more sustainable future, but storage and transportation remain challenging. Liquid chemical storages (e.g. NH_3BH_3(aq)) are a promising approach but lack efficient on-demand hydrogen gas release methods. In this project, we investigate a novel approach, which utilises a catalytic membrane contactor for the H_2 gas release from aqueous NH_3BH_3 (Figure 1). A porous polymer-based catalytic membrane is continuously contacted with NH_3BH_3(aq) feed in cross flow, to facilitate the controlled release of H_2 gas. Its pore structure ensures liquid distribution to as many catalyst sites as possible while at the same time directing the generated gas towards the permeate side for direct use.

Based on a method established in an earlier study[1], we fabricated porous polymer-based multi-composite catalytically active membranes by film casting *cum* non-solvent induced phase separation (NIPS) of the matrix polymer polyethersulfone (PES), containing nickel nanoparticles as catalyst and carbon particles or a cationic ionomer as additives to alter the pore properties. By this approach we obtained several porous catalytic membranes, with differing hydrophobicity and pore size gradients. With these, we assessed the feasibility of our novel approach and investigated the interplay of transport processes in the membranes and catalytic conversion. In detail, we studied a batch reaction where the catalytic membranes are fully immersed in NH_3BH_3 (aq) and the transport of both, liquid substrate and gaseous product, can occur in all directions. To investigate directional transport the membranes were sealed on one surface, forcing the transport of NH_3BH_3 in water and gaseous H_2 through the same pore pathways, but in opposite direction. Lastly, we established a set up for continuous H_2 formation from NH_3BH_3 using catalytic contactor membranes (Figure 1).

In the batch experiments we found that the cumulative catalytic H_2 generation is foremost influenced by the membrane hydrophobicity.[2] The kinetic behaviour revealed that the reaction rate drastically decreases after a certain amount of H_2 gas is produced, which we could relate to accumulation of gas inside the porous membranes. Studies in the directional setup showed that the orientation of the anisotropic pore structure and specific pore size gradients promote higher cumulative H_2 generation rates and that the favoured transport direction could be altered by specific membrane design and fabrication. With the crossflow setup we saw that the membranes hydrophobicity influenced liquid entry, while the interplay of pore size gradient and wetting characteristics affected liquid distribution within the pores, thereby impacting catalyst utilization and H_2 release rate.

We could achieve continuous catalytic H_2 gas generation and transport to the permeate side with efficiencies that were clearly dependent on the orientation of the pore size gradient. This demonstrates the potential of our novel approach toward porous catalytic membranes for the use in a H_2 gas release system from liquid chemical storage.

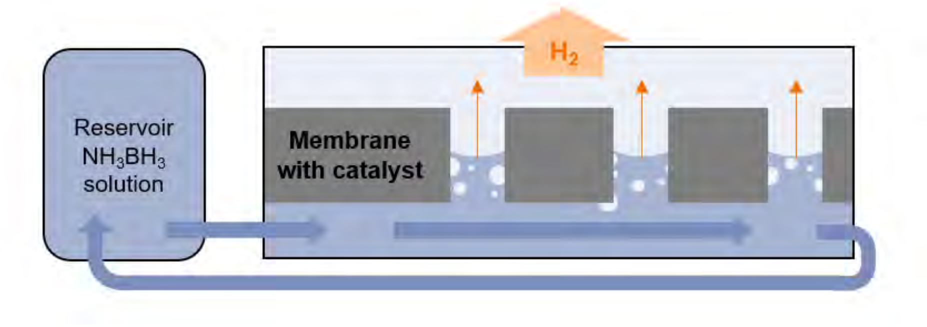

Figure 3: Catalytic liquid/gas membrane contactor design concept

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PAA-MODIFIED CNT MEMBRANE FOR ENHANCING FLUX IN MEMBRANE DISTILLATION

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Keywords: Carbon nanotubes; Polyacrylic; Polydopamine; Membrane distillation; Temperature Polarization
Presentation form: Lecture

Author did not agree to publish the abstract

CRITICAL IMPACT FACTORS IN THE DESIGN OF LOW-FOULING HYDROGEL COATINGS FOR HIGH PERFORMANCE ULTRA- AND MICROFILTRATION MEMBRANES

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Keywords: Membrane modification, Low fouling
Presentation form: Lecture

Abstract: In addition to the actual production of biopharmaceuticals, downstream processing plays an equally important role. A major problem in the purification of biopharmaceutical products, that are mainly functional proteins, is the occurrence of fouling during filtration, resulting in efficiency losses and additional costs. Membrane surface modification with tailor-made hydrogel layers is an effective approach to reduce fouling in protein filtration and thus increase membrane performance in biopharmaceutical processes. The efficacy of the hydrogel layer on membrane improvement is highly dependent on the hydrogel's properties, including its physical and chemical characteristics, which are influenced by the selection of monomers and crosslinkers as well as polymerization conditions. The aim of this study is to investigate the effects of various parameters on the hydrogel coating and to understand and utilize their impact onto fouling and permeability of the modified membranes.

Commercially available polyethersulfone (PES) microfiltration (0.2 µm) and ultrafiltration (300 kDa) membranes were modified through UV radiation-initiated cross-linking radical polymerization using a type I photoinitiator. Two different UV wavelength ranges were used to irradiate the membranes to evaluate the influence the hydrogel-modified membranes. Furthermore, the effects of irradiation time, membrane orientation to the UV source, photoinitiator concentration and composition of the monomer/crosslinker system were investigated. Degree of hydrogel grafting, nonspecific protein adsorption, adsorption of nonionic surfactants, membrane permeability and protein filtration were investigated.

It was shown that the choice of monomer/crosslinker system and the ratio of the components, the orientation of the membrane to the UV source and UV irradiation parameters play a crucial role for obtaining an optimal membrane, considering the trade-off between increasing fouling resistance and decreasing permeability. Under optimal conditions, protein adsorption was reduced by 96% compared to the virgin membrane at a loss of 59% of the permeance. It was also shown that the modification significantly reduced fouling during protein filtration. These results provide valuable insights into the relationships between modification parameters, hydrogel structures and protein adsorption, which may be useful for accelerating the design and identification of low-fouling membranes.

In ongoing experiments, it is investigated whether the very promising results can be transferred to electron beam as an alternative irradiation method for the initiation of cross-linking radical polymerization toward antifouling hydrogel coating on ultra- and microfiltration membranes and whether hollow fiber membranes can also be modified in a similar way.

INVESTIGATION OF 2D CARBON-BASED MEMBRANES FOR SEPARATION OF POLYDISPERSE PEGS BY COUPLED ULTRAFILTRATION AND CHROMATOGRAPHY

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Keywords: Liquid separation, ultrafiltration, polyethylene glycol, 2D materials, chromatography

Presentation form: Lecture

Abstract: The synthesis of polymers like polyethylene glycol (PEG) in general yields products with a more or less broad molar weight distribution (MWD). This challenges applications that require well-defined properties, such as in chemical analysis or (bio)pharmaceutical productions. Achieving improved products with narrower MWDs will require a size-selective separation.

For PEGs this challenging task can be resolved by using reversed-phase high-performance liquid chromatography (RP-HPLC) [1], also at a preparative scale [2]. However, owing to the difficulty of the separation, performance of conventional chromatographic processes remains limited. To tackle this, a modelling framework was developed that allows optimizing process setup and operating conditions to maximize performance of various advanced configurations of combined chromatographic columns. The results indicate a significant potential of some of the investigated processes. A key finding here is that the overall process performance can be greatly enhanced when performing a relatively coarse pre-separation followed by a finer chromatographic „polishing“ step.

Membrane filtration appears to be a promising approach for such a pre-separation. However, this requires membranes with very sharp retention properties. A particularly attractive option are 2D carbon-based materials such as graphene oxide (GO) and carbon nanotubes (CNTs). These materials, known for their utility in gas separations and other applications such as wastewater treatment or salt rejection, offer significant potential for tailoring pore sizes. [3] The latter property is indeed desirable when aiming at precise cuts within the MWDs of PEG.

In the presentation we give an overview on the achievable performance of (membrane-based) pre-separation in conjunction with chromatographic fractionation of PEGs, specifically demonstrating limitations and required membrane properties. Moreover, we demonstrate synthesisis of membranes with different compositions of GO and CNTs, and their further modification by various inorganic additives. The membranes were then evaluated regarding their performance in separating PEG mixtures via ultrafiltration, and compared to commercially available PES membranes.

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OSMO4LIVES: GIVING FOUR LIVES TO OSMOTIC MEMBRANES WITH INNOVATIVE RECYCLING PROCESSES

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Keywords: chemical attack, compaction, drying, storage, recycling, reverse osmosis membranes
Presentation form: Lecture

Abstract: Membrane processes are key elements for water reuse and desalination, and for the last one, reverse osmosis (RO) is the fastest growing technique taking the lead position. The aim of this work is to boost membrane technology towards the circular economy and eradicate the single use that membranes currently have. Research carried out over the last decade has been focused on restoring end-of-life (EoL) RO membrane performance or their recycling through transformation into ultrafiltration (UF) and nanofiltration (NF) membranes[1]. Still, how an RO membrane is affected by oxidizing agents and/or by drying conditions is one of the topics that is still not fully understood. This lack of knowledge, along with the need to push membrane recycling concept towards the circular economy, is being studied in this project.

On one hand, Osmo4Lives propose to better understand how dense membrane (FO, RO) and especially their polyamide (PA) layer are affected by oxidizing agents, industrial use and drying. To achieve this first objective, new and used RO membranes have been tested to evaluate the impact of drying conditions (solvents, temperature, time…) on membrane characteristics and the impact of rehydration (solvent, time…) to recover initial conditions after drying. Solvent oxidization to remove the active layer (PA layer) have been performed in order to better understand the impact of chemical attack and to evaluate how drying and ageing is affecting to the different membrane layers. Membrane coupons were tested and characterized before and after applying any treatment using a standard saline solution (2g/L NaCl)[1]. Results of this part show that an important loss of permeability occurs because of drying with a reduction of permeability around 78% for BW and 35% for SW. An important achievement has been founded showing that drying on the PA layer can be partially recover by ethanol, while drying on the polysulfone (PSf) has a permanent impact. Industrial use has been also observed as a negative factor reducing the permeability by 40% and 51% respectively. That confirms that compactions occur at industrial scale. Finally, oxidizing test showed no impact of pH on membrane characteristics for membrane stored without chlorine confirming the relatively high tolerance to basic and acidic pH of the PA layer. In presence of chlorine, permeability increases, and rejection losses were observed for coupons soaked in solutions at pH 6,8 and 13. This occurs because of the prevalent from of OCl^- which promotes the hydrolysis of the amide C−N bond on the PA layer[3]. At pH 1 solution no permeability change was observed, explained because of the prevalence of Cl_2 which do not interact with the PA layer.

On the other hand, the recycling and validation of EoL RO membranes have been carried out. An 8" spiral wound EOL RO membranes converted into UF- and NF-like membranes were tested on a gravity-driven membrane (GDM) system[4] as a tertiary WW treatment. The GDM system allows filtration using

solely the gravity-force generated by a water height pressure differential without the need of a pressure pump. Results demonstrate that both, UF and NF-like membranes, can be installed in the system with a relaxing and flushing sequence needed achieving a permeability of 12,2 and 3,4 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ respectively.

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