Network Young Membrains Meeting 2022

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WELCOME

Dear Young Membrains, welcome to the Network Young Membrains 19th edition.

After Sweden, United Kingdom, and Spain (see the NYM timeline), for the second time the meeting has come to Italy. It is a big honor for us to welcome you and to host this renowned conference in Naples, one of Italy's most beautiful cities. NYM 2022 is organized by the Institute on Membrane Technology of the National Research Council of Italy (CNR-ITM) under the *motto* **"The Colors of Membranes".**

This motto for the #NYM2022🏳️‍🌈 wants to represent, with several colors, different membranes related topics: energy, health, green processes, water treatment, gas separation, modeling.

Moreover, the rainbow colors recall the "peace flag" since we fully believe that membranes must not only separate but also unite and build bridges between the different communities, as well as bringing a message of peace.

This year we are very glad to welcome more than 50 international participants that will actively join the event giving oral presentations covering different topics of membrane science and technology.

Four plenary lectures will be held by distinguished speakers in the field: Dr. Francesco M. Benedetti, Dr. Rocio Semino, Dr. Cejna Anna Quist-Jensen and Dr. Valentina Tortelli.

The scientific program goes along with a social event and the visit to Cannon Artes, a company specialized in engineering and manufacturing of water and wastewater treatment plants through membrane-based operations. All the activities are intended to stimulate debates among participants and to exchange knowledge and skills.

Special thanks go to the European Membrane Society which is sponsoring four Awards of 250€ each for the best oral presentations given during NYM2022

The organization team thanks all the participants for attending the event and all the people who contributed to the success of the conference and in particular to Dr. Alberto Figoli and Dr. Lidietta Giorno for their constant and precious support.

Stay tuned and join the Young Membrains community following NYM social media:

Twitter (https://twitter.com/NMembrains)

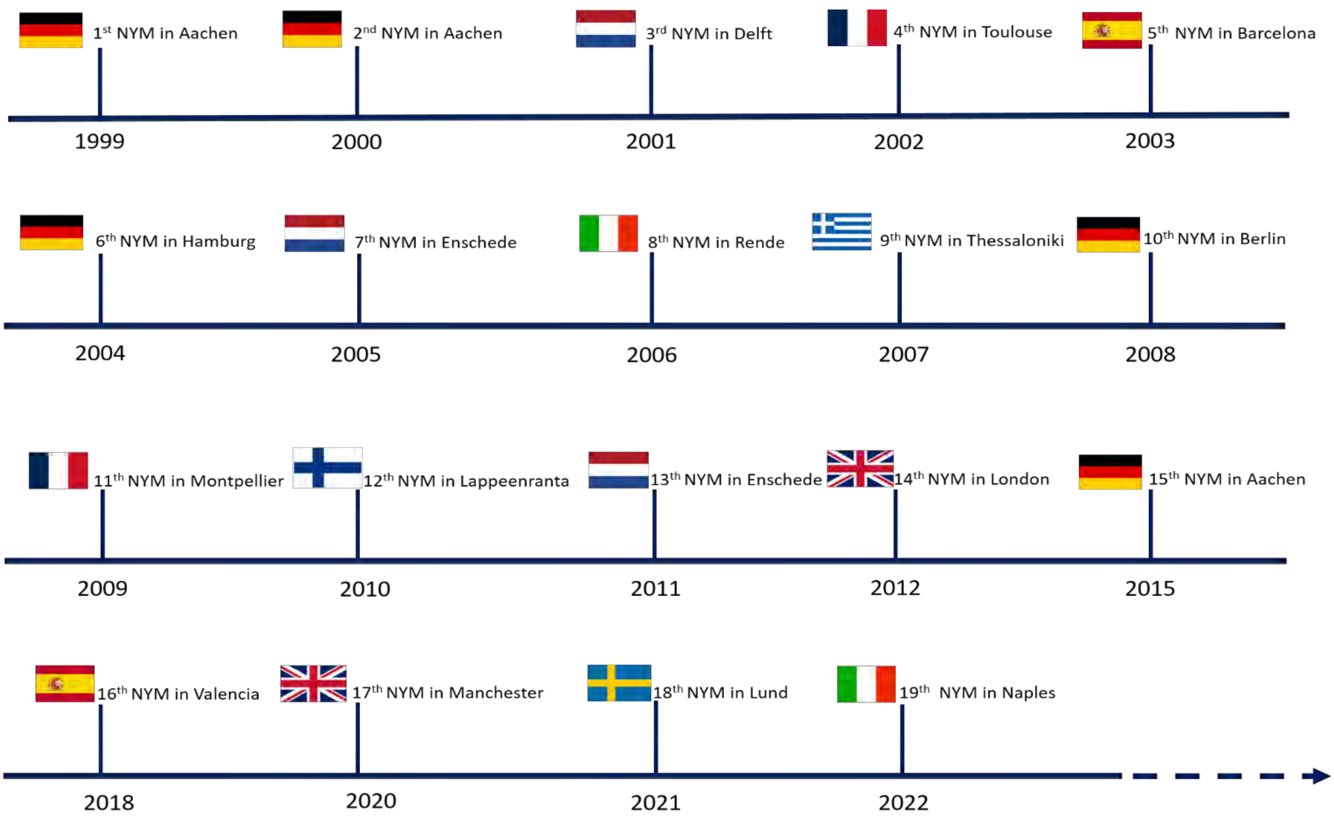
Instagram (https://www.instagram.com/network_young_membrains/)

Facebook (https://www.facebook.com/search/top/?q=NYM2022)

Aims and scope of NYM

The aim of NYM is to bring together creative people, who are currently researching membrane technology at university or in industry as PhD or Master-students. The network is meant to create a communication platform on which membrane researchers can exchange ideas. This will serve to enhance knowledge and abilities as well as to build useful contacts in the field of membrane technology. All participants have the opportunity to present their own field of research and get informed about different projects based on similar or different membrane topics.

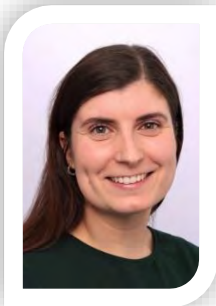
Chronology of the NYM meetings



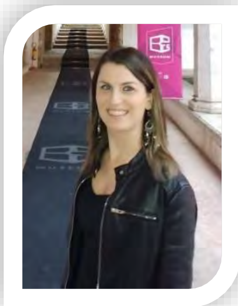
Keynote Speakers

Dr. Francesco M. Benedetti
Co-Founder and CEO, Osmoses, Inc

Dr. Rocio Semino
Associate Professor, Sorbonne University



Dr. Cejna Anna Quist-Jensen
Associate Professor, Aalborg University

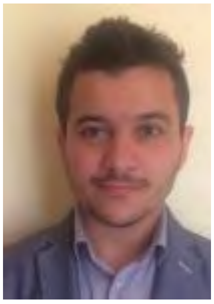


Dr. Valentina Tortelli
Technologist, CNR-ITM

The NYM2022 Organizing and Scientific Committee

Giuseppe Vitola

Serena Regina



Alessio Fuoco

Elisa Esposito

Francesco Galiano

Francesca Russo

Program

Thursday, 17th November 2022 *Session 1*			
14:00	14:30	**Welcome Message**	
14:30	15:00	**Francesco M. Benedetti** *Starting a company from a research project*	
15:00	15:13	**Akkoyunlu Burcu** *Membrane bioreactors to produce polyhydroxyalkaonate (PHA) from gaseous feedstocks*	Green processes
15:13	15:26	**Alcalde Berta** *Polymer inclusion membranes for the extraction of antibiotics from water*	Water treatment
15:26	15:39	**Andrea Torre Celeizabal** *Chitosan based composite membranes for CO_2/CH_4 separation. Experimental and model evaluation*	Gas separation
15:39	15:52	**Anna Volz** *A tunable fabrication method towards catalytic polymer-based porous multi-composite membranes with promising properties for pollutant degradation and hydrogen production*	Membrane preparation
15:52	16:05	**Mohammadamin Esmaeili** *Antifouling recycled-membranes modified by polyelectrolyte multilayer in pulp and paper*	Water treatment
16:05	16:18	**Eryildiz Bahriye** *Fate, environmental impact and treatibility of antiviral drugs*	Energy
16:18	16:31	**Bastian Kirkebæk** *3D printing in the field of membrane distillation and membrane crystallization*	Membrane preparation
16:31	16:44	**Carmen M. Sánchez-Arévalo** *An integrated membrane process to recover polyphenols from wet olive pomace*	Green processes
16:44	16:57	**Anastasiia Lopatina** *Effect of low concentrations of lithium chloride additive on cellulose-rich ultrafiltration membranes performance*	Water treatment
Coffee break			

Thursday, 17th November 2022

Session 2

17:30	17:43	**Gabriela Santos Medeiros** *Gas transport properties of hollow fibers membranes for CO_2 separation based on poly(ether-block-amide) copolymers*	Gas separation
17:43	17:56	**Giuseppe Di Luca** *Bio-sustainable membranes for potential water treatment applications*	Membrane preparation
17:56	18:09	**Taqwa Zouaoui** *Graphene based membranes to massively reduce energy in the oil, gas and chemical industry*	Energy
18:09	18:22	**Hao Boyuan** *Organic liquid mixture separation using fluorinated covalent organic framework (COFs) supported crosslinked polyvinylidene fluoride (PVDF)*	Water treatment
18:22	18:35	**Dániel Gardenö** *Synthesis and characterization of membranes based on carbon-based 2D materials for H_2 separation from gas mixtures*	Gas separation
18:35	18:48	**Sascha Fahlberg** *Efficient and sustainable membrane platform development for microfiltration applications*	Modelling

Friday, 18th November 2022

07:30	**Visit to Cannon Artes S.p.A.**

13:30	**Lunch**

Friday, 18th November 2022 *Session 3*			
14:30	15:00	**Rocio Semino** *Modelling interfaces and self-assembly of porous materials*	
15:00	15:13	**Chunchun Ye** *Development of efficient aqueous organic redox flow batteries using ion-sieving sulfonated polymer membranes*	Energy
15:13	15:26	**Vatsha Banele** *Organic solvent separation using a hybrid of size-controlled porous organic polymer and polyethersulfone membrane*	Water Treatment
15:26	15:39	**Sneha De** *Investigation of spray-coated novel low-fouling layer with PBM materials on UF PES membranes*	Membrane preparation
15:39	15:52	**Tomislav Horvat** *Performance optimisation of curly hollow membrane modules using CFD*	Modelling
15:52	16:05	**Triantafyllia Grekou** *Post-synthesis modification of silica membranes for enhanced CO2 capture from flue gas streams*	Gas separation
16:05	16:18	**Madenli Evrim Celik** *Polyphenol recovery by ceramic membranes*	Green processes
16:18	16:31	**Joona Nieminen** *Emerging prospects of charge-enhanced ultrafiltration membranes*	Water treatment
16:31	16:44	**Jan Cizek** *Preparation of enantioselective membranes through simple functionalization by chiral ionic liquid*	Membrane preparation
16:44	16:57	**Shahla Radmehr** *Studying the effects of single and mixed algae strains on performance of algae-sludge membrane bioreactors*	Green processes

Coffee break

Friday, 18th November 2022

Session 4

17:30	17:43	**Lettieri Melania** *Functionalizing polyether-ether-ketone polymer for preparing more performing pervaporative dense membranes*	Membrane preparation
17:43	17:56	**Mutto Abeer** *Membranes for bio-fuel recovery: deciphering membrane permeation in multicomponent pervaporation*	Green processes
17:56	18:09	**Ilaria Rizzardi** *Hydrophobic membrane bubble free aerator applied in MABR for simultaneous ammonia and COD removal*	Water treatment
18:09	18:22	**Enise Pekgenc** *Development of biocatalytic membrane systems for the control of biofouling in reverse osmosis and ultrafiltration membrane systems*	Green processes

20:00 Social dinner

Saturday, 19th November 2022
Session 5

08:30	09:00	**Cejna Anna Quist-Jensen** *Membrane crystallization - Potential, process, and membrane design*	
09:00	09:13	**Vadim Ippolitov** *Cellulose membranes in the treatment of Deep Eutectic Solvents (DESs)*	Green processes
09:13	09:26	**Kulkarni Akshay** *Coating of polymer membranes with photoactive nanoparticles and studies on degradation of water pollutants*	Water treatment
09:26	09:39	**Virginia Guiotto** *F-MOF-based matrix mixed membranes for an energetically favourable separation of CO_2*	Gas separation
09:39	09:52	**Martinez Malinalli Ramirez** *Polyolefin membranes fabricated with bio-based solvents: from plastic waste to value-added materials*	Membrane preparation
09:52	10:05	**Martina Gaglianò** *Phenolic compounds enhancement and sugar reduction in apple juice by diananofiltration*	Green processes
10:05	10:18	**Pegah Hajivand** *Olefin/paraffin separation by MOF-based mixed matrix membranes*	Gas separation
10:18	10:31	**Sven Johann Bohr** *From hollow fibre to flat sheet - How to develop membranes with similar properties and different shapes*	Membrane preparation

Coffee break

Saturday, 19th November 2022
Session 6

11:00	11:13	**Sorcha Daly** *Membrane fouling during continuous production of lactic acid with cell recycle*	Green processes
11:13	11:26	**Keskin Başak** *Precious metal recovery applications of polymer inclusion membranes*	Water treatment
11:26	11:39	**Xiong Chen** *Porous PVDF membrane with controllable wetting property in oil water emulsion separation*	Membrane preparation
11:39	11:52	**Maria Francesca Vigile** *Polymerizable bicontinous microemulsion as anti-fouling coatings for PES and PVDF membranes for wastewater treatment*	Water treatment
11:52	12:05	**Rebecca Esposito** *Rheology of polytriazole/ZIF-8 solutions and dynamics of mixed-matrix composite films*	Membrane preparation
12:05	12:18	**Sven Kroß** *Polymeric fluorine-free ionomers and their complexes with polyelectrolytes for thin-film composite nanofiltration membranes*	Water treatment
12:18	12:31	**Merve Yilmaz** *Life cycle environmental and economic assessment of AnFOMBRs and AnMBRs*	Modelling
12:31	13:00	**Valentina Tortelli** *HORIZON Europe MSCA for Young Researchers: Focus on Postdoctoral Fellowships and Career Opportunities*	

13:00	**13:30**	**Final remarks, prizes, and closure of NYM 2022**
13:30		**Lunch**

Abstracts

Membrane bioreactors to produce polyhydroxyalkaonate (PHA) from gaseous feedstocks

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Polyhydroxyalkanoate (PHA) is a promising alternative to petroleum-derived plastics due to their comparable physical and chemical properties and biodegradability. Many microorganisms can produce PHA as an intracellular energy and carbon storage material. Microorganisms such as *Cupriavidus necator* can metabolize CO_2 as a carbon source and produce PHA when a mixture of H_2, CO_2 and O_2 gas is supplied. Thus, it is possible to produce PHA directly from CO_2 which would reduce greenhouse gas emissions. However, the optimum gas composition ratio for cell growth is 7:2:1 for H_2:O_2:CO_2 which is within the gas-explosion range [1]. To eliminate the explosion risk, the oxygen concentration should be maintained below the lower explosion limit however this limits the growth and productivity due to oxygen limitation. Furthermore, gas fermentation faces substrate limitation due to the low solubility of gases in the culture medium. Membranes have the potential to achieve high gas transfer efficiencies at low gas supply rates due to the high specific surface area available for transfer. Thus, membrane bioreactors are promising reactor systems for gas fermentation processes. This project demonstrates the applicability of membrane bioreactors to deliver gaseous substrates to produce PHA. To accomplish this, membrane bioreactors were constructed using 50 ml centrifugal tubes and gas-permeable polydimethylsiloxane membrane fibres with 760 µm outer diamater. The obtained membrane bioreactors are operated in batch mode where membranes are used for supplying gasesous substrates to maximize yield. The specific surface area for gas transfer is adjusted by optimizing the number of fibers used. The effect of operational conditions such as recirculation and gas flowrate is studied. Later, a fed-batch strategy is used to maximize PHA production by applying nitrogen limitation. PHA content within the biomass is increased from 8 ± 2% to 22 ± 2%. This is expected to be increase further by optimizing the conditions.

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Acknowledgements

Authors would like to thank BiOrbic Research Center funded under the Science Foundation Ireland Research Centres Programme and European Regional Development Fund.

Polymer inclusion membranes for the extraction of antibiotics from water

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The presence of organic pollutants in natural waters is a risk to ecosystems and living beings' health. Nowadays, wastewater treatment plants are not designed to completely remove these compounds, therefore, there is a need to monitor their presence in the water. One possible approach is the use of polymer inclusion membranes (PIMs), which are non-porous functionalized liquid membranes that are flexible, stable, and versatile. PIMs have been used in many applications such as sample pre-treatment [1]. These membranes consist of two main elements; a base polymer and a carrier, and sometimes a plasticizer is added to increase membrane softness and flexibility [2].

This study was focused on the optimization of the design of a PIM for the extraction of organic compounds from aqueous samples, specifically the antibiotics sulfathiazole, sulfamethazine, and sulfamethoxazole. The membranes were prepared using three different polymers, specifically CTA, PVC, and PVDF-HFP, and two anion-exchangers as carriers, methyltrioctylammonium chloride and trihexyl(tetradecyl)phosphonium chloride.

The effect of the water matrix was investigated by performing experiments with tap, bottled, and synthetic water where 5 mg L-1 of each antibiotic were added. It was demonstrated that the extraction efficiency of the antibiotics was affected by the water matrix. The effect of the membrane composition and the addition of a plasticizer in the membrane formulation were also studied, and it was found that antibiotic extraction was more efficient with a high concentration of carrier and that the plasticizer presence did not really affect the extraction efficiency. The membrane with the highest extraction was composed of PVC and trihexyl(tetradecyl)phosphonium chloride achieving quantitative extractions for all antibiotics studied in bottled water. Other parameters such as kinetics or pH effect were investigated.

In conclusion, it has been demonstrated that the use of a PIM effectively allowed the extraction of the three antibiotics studied from water samples.

References

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Acknowledgements

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Chitosan based composite membranes for CO_2/CH_4 separation. Experimental and model evaluation

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Climate change due to greenhouse gases emissions is one of the greatest challenges to address. One possible solution is the use of renewable energies such as biogas. In order to obtain biomethane from this source, to be used for energy production is vital to separate CH_4 from CO_2. Although membrane technology is commercially used as one of the efficient technologies for biogas upgrading, the sustainability of the fabrication can still be improved by using renewable and environmentally friendly materials [1].

For the replacement of synthetic polymers, biopolymers, which are obtained from natural sources, can be used. Chitosan (CS) is a non-toxic, hydrophilic, multi-functional, biodegradable and biocompatible polymer from abundant natural sources, with good adhesive and film forming properties. The primary amine and hydroxyl goups are responsible of its high affinity for CO_2, which is reinforced in humid conditions [2]. The trade-off between this facilitated transport and mechanical resistance can be enhanced by blending with non-toxic fillers and polymers [3].

This work analyzes the gas permeation performance of CS-based mixed matrix composite membranes. CS was hybridized with [emim][acetate] non-toxic ionic liquid (IL) and different inorganic fillers such as layered materials with high area/volume (AM-4) and zeolites that may enhance the properties of both materials on membrane gas separation. The CO_2 permeance and CO_2/CH_4 mixture selectivity at different feed concentrations was obtained to focus in different processes. Figure 1 shows the model validation for a CS:PVA/PES membrane regarding purity and recovery of the permeate stream. In addition, an optimization model is proposed to identify the optimal membrane design and operation conditions.

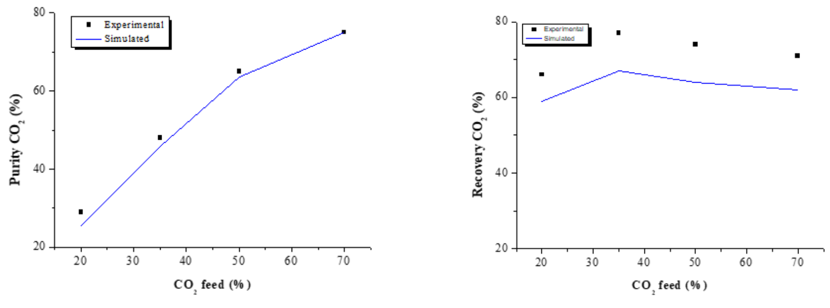

Figure 1. Experimental and simulated CO_2 permeate purity (a) and recovery (b) as a function of CO_2 feed concentrations for a CS:PVA/PES membrane.

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A tunable fabrication method towards catalytic polymer-based porous multi-composite membranes with promising properties for pollutant degradation and hydrogen production

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Porous catalytic composite materials are fundamental for promising solutions to current challenges such as green energy production or pollution reduction. A prerequisite are methods for incorporating multiple different functional components into a stable material that exhibits good mass transport properties.

Here, we present a new approach for the fabrication of catalytically active multi-composite membranes that incorporate nickel nanoparticles, carbon nanoparticles and a cationic ionomer. Based on the film casting and subsequent phase separation of solutions of the matrix material polyethersulfone in presence of all other components, we were able to prepare porous membranes with tuneable morphology and chemical compositions. Via elemental analysis a complete integration of the components was confirmed, and additional EDX mapping and SEM images showed a homogeneous distribution of the different components. We further managed to control the pore structure and pore size distribution by using different phase separation conditions and additives. The composite membranes exhibit a high porosity of over 70% and an extraordinarily high stability in 6M KOH and at elevated temperature over 30 days. All these properties make our new membranes promising candidates for various catalytic applications. We could show high activity for the reduction of p-nitrophenol in water in batch mode and observed a significant synergy between the different components. We found that at constant nickel catalyst content anisotropic morphologies as well as an increase in carbon or ionomer content led to higher catalytic activity. Additionally, we used our materials as flow-through membrane reactors for p-nitrophenol reduction and achieved an about 1000fold increase in activity compared to the batch mode as well. Based on the promising results in this model study, ongoing work is devoted to tune the novel membranes for a catalytic membrane contactor for hydrogen recovery from the storage material $NaBH_4$ and as catalytic electrodes for hydrogen production via water electrolysis.

Antifouling recycled-membranes modified by polyelectrolyte multilayer in pulp and paper industry

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Despite the mature and widespread implementation of RO, it possesses a variety of downsides to overcome, beyond reducing energy consumption, such as discharging brines and managing the large amounts of waste produced by discarded membrane modules. The latter disadvantage is attributed to the short life expectancy of RO membrane modules (5-8 years on average). It is worth mentioning to this end that, an enormous global amount of 14,000 tonnes of membrane modules is discarded each year [1]. When taking into account the types of membranes commonly used in RO, degradation of the PA active layer can easily convert a dense membrane into a porous material, which is mainly refers to NF and UF membranes, depending on the level of PA layer degradation. Thus, to meet the European Union's objectives in moving toward a circular economy system and greener chemistry through its contribution to waste reduction, the sustainable management of end-of-life is economically and environmentally more preferable than a commonly disposed approach to landfill. Herein, the main effort has been devoted to developing a new approach in which the chemical conversion of the PA layer to the UF/NF membrane is much faster, along with a minimum amount of oxidation reagents. Moreover, due to the complexity of biorefineries' streams, the converted membranes were further modified with layer-by-layer deposition techniques to tackle membrane fouling, which is still one of the main bottlenecks, diminishing the flourishing of the membranes' wider applicability in pulp and paper industries. The results of the current study reveal the promising potential of LBL techniques combined with the recycling of End-of-Life membranes for developing and antifouling UF/NF membranes, which can be successfully implemented in biorefinery industries.

References

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Acknowledgements

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Fate, environmental impact and treatibility of antiviral drugs

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A novel coronavirus (COVID-19) linked to respiratory diseases in humans was discovered in China, Wuhan in December 2019. In March 2020, WHO recognized the new coronavirus (COVID-19), also known as Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2), as a worldwide pandemic, based on its fatal effect [1]. COVID-19 as of September 2022 >603.711.760 people have been infected, and > 6.484.136 have died according to World Health Organization (WHO). There are several drugs i.e., favipiravir, remdesivir, hydroxychloroquine, azithromycin, chloroquine and molnupiravir for treatment of COVID-19 [2].
These antiviral drugs are common in wastewater due to the use of personal care items and pharmaceuticals in the home, as well as in the pharmaceutical industry and hospital waste. These antiviral drugs and their metabolites, which can reach environmental waters, may pose a high risk in terms of ecotoxicology, especially for the aquatic system. In addition, the presence of such high levels of antiviral drugs in environmental waters can lead to the development of antiviral drug-resistant viral strains in the bodies of specific wild animals, which are natural reservoirs of viruses. Therefore, it is of great environmental importance to monitor the fate of these drugs and to carry out their treatment [3].
The purpose of this study is to evaluate the environmental impact of antiviral drugs in the increasing COVID-19 pandemic in the world. In this context, it is aimed to examine the treatability of antiviral drugs that cause harm to the environment in wastewater using different treatment technologies. In addition, the transformation products of antiviral drugs that may occur after treatment and whether they are harmful to the environment will be analyzed. Finally, the changes in the microbial community and presence of SARS-CoV-2 will be examined.

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3D printing in the field of membrane distillation and membrane crystallization

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Membrane crystallization (MCr) and Membrane distillation (MD) are membrane technologies with applications in various fields including water and wastewater treatment, in food and pharma applications etc. The membrane performance is strongly linked to the physical properties of the membrane such as porosity, morphology and topology [1]. Therefore, control of these parameters is of great interest. For instance, complex topological shapes can mitigate fouling and reduce wettability of the membrane and hereby result in increased membrane permeability [2,3]. However, in membrane manufacturing, there is a lack of methods to generate structures more complex than flat sheets or hollow fibers. 3D printing is a potentially new method for creating these new membranes with complex topology and shape [4]. However, 3D printing has some limits when it comes to resolution, processing speed and overall cost [5]. Nevertheless, resent efforts have been made to increase resolution, produce new polymer types and increase processing speed making it more and more feasible to generate membranes via 3D printing and thereby narrowing the gap between 3D printing and membrane manufacturing. In this study, we have shown how membranes can be fabricated through 3D printing and how the performance of the membranes can be alternated depending on the 3D printing procedure.

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Acknowledgements

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An integrated membrane process to recover polyphenols from wet olive pomace

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The processing of olives by the two-phase methodology results in the obtention of the praised virgin olive oil. Together with this appreciated product, tons of residues are also generated. The most abundant by-product is the wet olive pomace (also called *alperujo*, which is the Spanish term), which consists of a semi-solid combination of the olive pulp, seeds, skin and vegetation water.

The high organic load of the wet olive pomace is of concern due to its environmental impact. However, this residue contains high concentrations of antioxidant molecules from the olive fruit. Among these molecules, the phenolic compounds stand out because of their interesting properties, related to health benefits and cosmetic applications.

To extract the polyphenols from the wet olive pomace, an aqueous, ultrasound-assisted solid-liquid extraction (at 40ºC, during 45 min) was performed. Afterwards, this extract was purified and concentrated through an integrated process based on ultrafiltration and nanofiltration.

During the first stage, the UH030 membrane (Mycrodin Nadir) was employed to purify the compounds of interest through an ultrafiltration process, at a transmembrane pressure (TMP) of 2.5 bar and a cross-flow velocity of 1.5 $m \cdot s^{-1}$. Satisfactory results were obtained, as the rejection of the chemical oxygen demand was very high (90 ± 16%), whereas the phenolic compounds were obtained in the permeate stream at a higher purity degree (rejection of total phenolic content was 18 ± 2 %). Membrane cleaning was performed several times during the process to preserve the permeate flux.

In a second stage, the permeate stream from the ultrafiltration was submitted to a nanofiltration process with the NF270 membrane (Filmtec). Several TMPs were studied, in the range 5 - 9 bar. At a volume reduction factor of 2.5, the membrane rejected the phenolic content in 60 – 80%, achieving the concentration of these compounds, previously purified.

Effect of low concentrations of lithium chloride additive on cellulose-rich ultrafiltration membranes performance

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Wood is a vast source of cellulose, the most abundant and greatly potential biopolymer. Cellulose demonstrates attractive mechanical properties, moderate thermal and chemical stability, and remarkable hydrophilicity. However, the number of pretreatment operations involved in the production of pure cellulose from wood biomass, as well as the utilization of hazardous and expensive solvents, makes the process of cellulose purification a rather unsustainable one. The novel solvents, e.g., ionic liquids (ILs) and deep eutectic solvents (DESs), give the possibility to dissolve and purify cellulose from wood biomass. This possibility shows cellulose-based membranes from the waste and side-streams of the forest industry as one of the interesting new products for biomass-based industries. The hydrophilic cellulose membrane has big global market potential in different sidestream treatment and water purification applications as well.

Based on the results discussed in our previous study [1], it was decided to focus on the investigation of DES-treated and bleached membranes performance depending on the amount of LiCl, used as an additive that was previously reported to promote pore formation and improve permeability. The concentration range for LiCl was kept low in order to study the effect of low concentrations and possibly suggest the sustainable concentration of additive.

It was found that interactions between LiCl and biomass are more complex than it was reported for petroleum-based polymers and cellulose acetate cases. Results showed that the effect of LiCl on the formation of the membrane is dependent on its concentration in the casting solution. Up to 0.4% concentration LiCl acts like a suppressor of macrovoids, resulting in dense membranes with fine pores. On the contrary, going to 0.5% concentration and higher, LiCl acts like a pore former, resulting in a large amount of macrovoids and much higher thickness. With 0.4% LiCl concentration in the casting solution, the final membrane shows the best overall performance in terms of pure water permeability and PEG 35 kDa retention.

Figure 1. The pure water permeabilities (blue) and PEG 35 kDa retentions (green) of the tested membranes, all measured in the Amicon ultrafiltration cell at 25°C and with a mixing rate of approximately 300 rpm.

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Gas transport properties of hollow fibers membranes for CO_2 separation based on poly(ether-block-amide) copolymers

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The high rate of carbon dioxide emissions at the atmosphere has been increased over the last decades leading to a high impact on the global warming. One of the main causes of such effect comes from emissions of flue gases from thermal power plants [1]. Therefore, the use of separation membrane technology for CO_2 capture has been widely explored. The final performance of such membranes technology is directly influenced by the membrane material, its structure, thickness, configuration and design of membrane modules [2].
The top-down approach is one of the methods used to fabricate a specific membrane configuration. Tested hollow fibers for this purpose were made with polysulfone (PSF) and polyacrylonitrile (PAN). In this work, the surface conditions of polymeric hollow fibers were examinated to improve an efficient gas separation, specifically for CO_2/N_2. Surface variables such as the pore size distribution and fabrication process parameters of hollow fibers were investigated. The BET isotherms of different PSF and PAN membranes prepared under different processing conditions shows that a wide distribution of pore size and large pore sizes inhibited an efficient performance of the gas separation. The SEM microscopy testify the big porous size on the surface of polysulfone fibers, however the hollow fibers prepared from PAN shows a smoother surface and an asymmetric porous structure.
The PAN fibers were selected for gas separation performance, due to the better structure and chemical stability to different solvents. In order to achieve a smooth surface without defects for selective layer, polydimethylsiloxane was used and a defect free gutter layer was provided. Hollow fibers were also coated only with PEBAX, poly (ether block amide), as selective layer, in different concentrations. The influence of different concentrations was explored allowing a good separation of CO_2/N_2 33.

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Bio-sustainable membranes for potential water treatment applications

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The demand for fresh water, due to the global increase in population and related activities, industry, agriculture and livestock breeding represents a great challenge for our modern society. The scarcity of water due to climate change, and the degradation of the quality of fresh water available, requires the increasing use of efficient and clean purification technologies [1]. In this context, membrane processes play a fundamental role in the separation and purification of water streams. However, the production of polymeric membranes is currently dependent on petroleum polymer materials (such as PVDF, PES, etc.), moreover, it involves the use of large volumes of very toxic solvents (such as DMF, NMP, DMAc, and THF). The use of fossil resources is responsible for global warming and ongoing climate change. Furthermore, the wastes generated by the production and by the final disposal of the membranes can have a negative impact on operational safety, costs, on the environment and human health [2]. For these reasons, the membrane production processes cannot be considered fully sustainable. In this framework, it is necessary to find an eco-friendly solution and more sustainable materials for the production of polymeric membranes. The aim of this research project is to produce bio-polymeric membranes using green solvents and bio-polymers to be specifically applied in water treatment applications. Bio-derived polymers such as cellulose and its derivatives, polyhydroxyalkanoates, and polyphuronoates [3] are some of the candidate materials to be investigated. In combination with them, a new class of green solvents, with low toxicity and good biodegradability, such as methyl lactate, ethyl lactate, triethyl phosphate (TEP), dimethyl sulfoxide (DMSO) and methyl 5-(dimethylamino)-2-methyl-5-oxopentanoate (Rhodiasolv PolarCleanPolarclean), can be used for producing completely sustainable membranes.[4,5] In this work, the strategy and the first results obtained in the preparation of cellulose acetate (CA) membranes, using ethyl lactate as a solvent and water as a non-solvent, is reported. The membranes were produced by a combination of vapor induced phase separation and non-solvent induced phase separation (VIPS-NIPS method) and NIPS method, using water as a non-solvent. The polymer concentration was varied from 8 to 16% and polyvinyl pyrrolidone (PVP) was used as a porogen additive in order to promote the formation of a porous morphology. The preliminary data collected indicated the possibility of preparing micro-porous membranes in CA using ethyl lactate as a solvent using traditional phase-inversion membrane preparation techniques and with CA concentrations of 8 and 10%. The newly developed membranes were further investigated in order to study their properties and performance in terms of physical-chemical properties, resistance to fouling and permeability. Process and preparation parameters such as composition of the polymer blend and pre-evaporation steps before coagulation in water were also studied in order to evaluate their impact on the final membrane morphology and properties.

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Graphene based membranes to massively reduce energy in the oil, gas and chemical industry

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Graphene, a two dimensional single atomic carbon layer, is an attractive material for thin film and membrane applications. Graphene oxide (GO) membranes made by assembling small GO flakes have demonstrated great potential in gas and liquid separation. For upscale applications, GO membranes in hollow fibre geometry are of particular interest due to the high surface area per volume and easy-assembly features at module level.

In our research group, ceramic hollow fibres (CHFs) have been developed for various membrane processesses. They are an excellent substrate candidate for GO membranes due to its robust mechanical property and inert chemical nature which enables them to work under extreme conditions. However, our studies revealed that GO membranes on CHFs are unstable in dry-state, mainly due to drying-related shrinkage [1]. We reserved graphene oxide hollow fibre (GOHF) membranes in water after initial drying to avoid further shrinkage and the formation of defects. Though such a strategy worked well to preserve the microstructure of GO-membranes, it limits the GO-membranes only to water-related applications. In another approach, GOHF membranes were stabilized by using a porous poly(methyl methacrylate) sacrificial layer, which created a space between the HF substrate and the GO membrane that allows stress-free shrinkage. Defect-free GOHF membrane was successfully determined and the membrane was stable in a long-term gas tight stability test [1].

In this study, in order to employ the developed GO-membranes for solvent permeation, a post treatment of the stabilized GO hollow fibre membranes is being carried out which induces mild reduction that would lead to some controlled pore formations. These modifications enhances the performance of GOHF membranes in solvent nanofiltration while still maintaining the molecular sieve property of GO membranes. Solvents such as ethanol, toluene and benzene containing nutural dyes with different MWCOs are being tested and will be reported at the conference.

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Organic liquid mixture separation using fluorinated covalent organic framework (COFs) supported crosslinked polyvinylidene fluoride (PVDF)

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Organic liquid separation is an essential industrial process for recycling valuable organic solvents from organic solvent mixtures. To achieve the goal, some traditional separation processes such as distillation, etc can be employed, but consume 10%-15% of the world's energy [1] Alternatively, membrane processes can separate organic liquid mixtures more energy effectively [1]. Covalent organic frameworks (COFs), a crystalline porous polymer made of regularly extended and covalently connected network is a promising candidate for an exquisite selective layer due to its ordered pore structure and uniform pore channels which are optimal for the transportation of solvent molecules. However, COFs have not been extensively applied in the field of membrane separation yet. The aim of the research is to develop a new organic liquid mixture separation membrane which consists of a fluorinated COF layer with high crystallinity and optimum pore size supported by crosslinked polyvinylidene fluoride (PVDF) which can provide excellent chemical stability and high pressure resistance. A new COF TpPa-CF_3 was synthesized by the polymerization of 1,3,5- trimethylresorcinol (Tp) and 2,5-Diaminobenzotrifluoride (Pa-CF_3), and the crystallinity was confirmed by XRD. A ultrathin film of TpPa-CF_3 was fabricated onto the top of crosslinked PVDF support through liquid-liquid interfacial polymerization (IP) for a thin film composite (TFC) membrane. Compared with a conventional COF TpPa, this new COF showed improved hydrophobicity with the average water contact angle of 92° due to the presence of the hydrophobic side groups -CF_3 in Pa-CF_3, leading to a higher permeation of non-polar solvents. Meanwhile, the introduction of the side groups can also slightly reduce the pore size which should be smaller than the reported pore size of 1.8 nm for COF TpPa [3]. This kind of hydrophobic COF membrane showed a good performance in the separation of various organic liquid mixtures.

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Synthesis and characterization of membranes based on carbon-based 2D materials for H_2 separation from gas mixtures

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This research explored the effects of combining two promising carbon-based materials, graphene oxide (GO) and single-walled carbon nanotubes (SWCNT), with various inorganic additives. Fabricated GO-SWCNT composite membranes were tested for effective H_2 separation from permanent gases. The GO-SWCNT composites benefit from unlimited permeability-selectivity performance [1], while polymer-based commercial organic membranes usually suffer from the trade-off effect. However, the better separation performance of inorganic membranes is usually offset by their problematic scaling-up, fragility and complicated preparation. To mitigate unwanted issues, such as fragility and lack of reproducibility, the influence of the SWCNT as support and modification of GO skin layer by adding selected polyvalent metal ions on the overall separation properties was investigated. A GO modification was performed by adding selected polyvalent metal ions into the GO solution before filtration to evoke recently reported interactions of ions with the GO structure [2]. Doped GO sheets become connected via intermolecular bonds that make the material more ordered and stable [3]. Prepared composite membranes were further characterized using analytical methods (SEM, XRD, XPS, FTIR-ATR, Raman, BET) to reveal the effect of the additives on the structure of materials and transport properties. The gas permeability and selectivity of the membranes were tested for single and binary gas mixtures using a permeameter connected to a GC. Combining bivalent metal ions with a graphene oxide provided enormous H_2 permeability > 30.000 Barrer with excellent H_2/CO_2 and H_2/N_2 selectivity (above 4.7 or 2.8, respectively), both above the corresponding 2008 Robeson upper bounds. Obtained results thus significantly exceed the separation characteristics of the vast majority of published membrane materials. Achieved results demonstrate the uniqueness of the prepared composite materials and the possibility of tailoring their permeability and selectivity.

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Efficient and sustainable membrane platform development for microfiltration applications

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Most porous polymeric membranes are made from polymer solutions (casting solutions) where membrane formation is based on phase separation. There are four main mechanisms for phase separation: vapor-induced phase separation (VIPS), non-solvent-induced phase separation (NIPS), evaporation-induced phase separation (EIPS) and thermal-induced phase separation (TIPS). Often, the precipitation casting process consists of a combination of two mechanisms VIPS and NIPS. This provides the possibility to vary the resulting membrane structures and thus the membrane properties in many ways.
In addition to the specified process parameters, the resulting membrane properties are also dependant on the composition of the casting solution. To influence the thermodynamics and kinetics of membrane formation, various solvents and additives are part of the casting solution in addition to the membrane-forming polymer.
In this work different green solvents like Cyrene or Methyl lactate are tested to develop a sustainable cellulose acetate microfiltration platform. One target is to create high performance membranes with tailored structures.
Therefore, the membrane casting process (VIPS + NIPS) is developed on a laboratory scale casting line. Here the most important process parameters can be investigated and a pre-development for production scale is conducted efficiently.
To deepen the understanding of membrane formation phase diagrams [1] are developed. The deepened understanding of the membrane formation process allows a more effectively process development.

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Development of efficient aqueous organic redox flow batteries using ion-sieving sulfonated polymer membranes

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Redox flow batteries (RFBs) based on low-cost aqueous organic electrolytes have great potential for grid-scale long-duration energy storage1-3. One key challenge for the new-generation of organic RFBs using two different electrolytes is the cross-mixing of active species through the membrane, leading to rapid battery performance decay4, 5. Here we report new size-selective ion-exchange membranes, based on the sulfonation of a spirobifluorene based polymer of intrinsic microporosity (sPIM-SBF), that feature sub-nanopores and show exceptional performance in aqueous organic RFBs. The spirobifluorene unit allows exquisite control over the degree of sulfonation of the PIM in order to optimize the rapid transport of small cations, whilst the ion exchanged subnanometer pores effectively prohibits the crossover of large anions and anionic organic molecules via size sieving and Donnan exclusion. The high selectivity towards anionic species mitigates crossover-induced capacity decay. Importantly, these cation exchange membranes demonstrate ultrahigh conductivity for aqueous salt electrolytes at near-neutral pH, in which both a redox-active anthraquinone and ferrocyanide show long-term stability. The new PIM membranes significantly boost battery energy efficiency and peak power density and enable stable operations of concentration-optimized RFBs over 2000 charge and discharge cycles, allowing the prediction of several decades of useful performance under ideal operating conditions. Our membrane design strategy may inspire the development of a new generation of ion-selective membranes for a wide range of electrochemical processes for energy conversion and storage applications.

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Organic solvent separation using a hybrid of size-controlled porous organic polymer and polyethersulfone membrane

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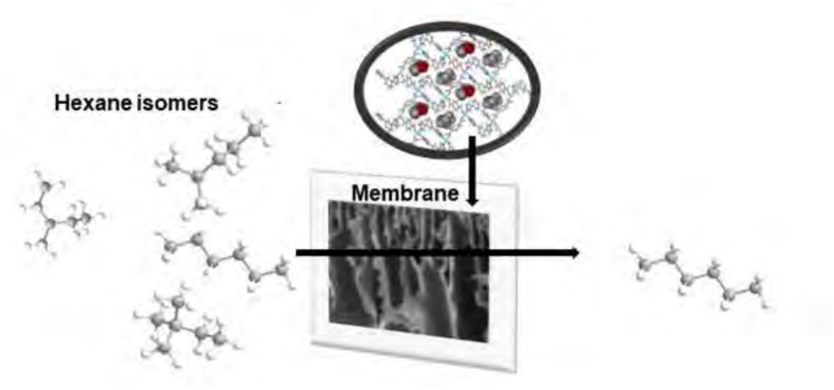
Materials research for fabricating Mixed matrix membranes (MMM) are considered a promising strategy for both aqueous solutions and organic solvents separations. Traditional polymeric membranes are commercially used for solute-solvent separations and are susceptible to low chemical stability when exposed organic solvent separation [1,2]. Separating alkane isomers, which is extremely difficult due to their similar physiochemical properties, is of great benefit to the production of gasoline [1]. This has prompted researchers to construct rigid and tunable pore size materials for incorporation into membrane matrix to create advanced membranes. Here, we report the synthesis and incorporation of a new interdigitated two-dimensional (2D) porous coordination polymer: $[Zn(1,3\text{-}H_2BDP)_2(BDC)_2]DMF$ (PCP) into a polyethersulfone matrix via phase inversion method. The loadings of PCP were varied from 0 and 8% to produce MMM0-MMM8. The membrane surface and cross-sectional pores increased as loadings of PCP increased. The contact angle measurements also revealed an increase in hydrophilicity as the PCP loadings increased. The membrane flux and selectivity were performed using a dead-end filtration cell as shown in the Scheme 1. The gas chromatography (GC) was used to quantify the hexanes in the permeate solutions. The selectivity coefficients showed a preference for linear hexane (nHx) over 2,3-dimethylbutane (2,3DMB) hexane, with selectivity coefficients ranging between 1.0 and 1.2 in all membranes (MMM0-MMM8).



Scheme 1. Hexane isomers separation using a flat-sheet hybrid membrane.

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Investigation of spray-coated novel low-fouling layer with pbm materials on uf pes membranes

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Commonly employed membrane technology for industrial and municipal wastewater treatment is ultrafiltration (UF) by membrane bioreactors (MBRs) which are equipped with polyethersulfone (PES) membrane modules. The function of the porous PES membranes is to act as rejection barrier for suspended particles and micropollutants. During MBR operation these rejected impurities eventually deposit on the membrane surface causing significant membrane fouling with passage of time. The membrane fouling of commercial grade Microdyn UP150P PES membrane was studied in a side-stream module by fouling propensity tests with 0.1 g/l humic acid solution as model foulant. A solution to mitigate the severe membrane fouling was proposed by spray-coating the PES membrane with anti-fouling layer of polymerisable bicontinuous microemulsion (PBM) materials, followed by 1 minute of ultraviolet (UV) radiation exposure to complete the polymerisation process. The enhanced PBM spray-coated membrane exhibited 25% lesser decline of permeability than commercial PES membrane during critical flux determination. The commercial and PBM-coated membranes were also used to treat low-strength model domestic wastewater in Sartorius AG's Biostat® lab-scale side-stream MBR for further investigation of membrane fouling by focusing on three key parameters – permeate flux, transmembrane pressure (TMP) and permeability. The PBM-coated membranes enabled better flux control accompanied with higher TMP and better rejection rate than commercial PES membrane. The PBM-coated membranes were characterised by FTIR-ATR spectroscopy and contact angle measurements. The PBM-coated membranes are being further enhanced by addition of copper nanoparticles which will be studied for anti-bacterial and anti-viral properties.

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Performance optimisation of curly hollow membrane modules using CFD

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Converting waste greenhouse gases such as CO_2, CO, and CH_4 into valuable products is an exciting opportunity that is gaining attention as we move from the linear economy to a more circular economy. Gas fermentation using bacteria as bio-catalysts is increasing in popularity as the reaction does not require extreme operating conditions and expensive catalysts [1]. One major drawback of gas fermentation is that it is limited by gas to liquid mass transfer resulting in low productivity. This problem can be overcome by using membrane modules to increase gas to liquid mass transfer. The relationship between the membrane bioreactor system hydrodynamics and performance is examined in this study. The effect of curly hollow fibre membranes on the mass transfer compared to the straight membrane systems is investigated. Studies show that different configuration of fibres enhances flux from 53% to 92% depending on the module [2].

In this project, there are three levels of investigation. The first one examines a single curly fibre (0.76 mm diameter) in a small tube (8 to 12 mm diameter). The second study compares multiple curly fibres in a small tube (8 to 12 mm) and multiple curly fibres (61 fibres) in a large tube (50 mm diameter). The experimental set-up is simulated using OpenFOAM software and the model validation is underway. Preliminary results from the single fibre systems showed that there is a range where the peak of the residence time distribution (RTD) curve is decreasing at a significant rate. It was also discovered that, at higher flow rates, the decrease in the peak of the RTD curve is not as large compared to that at lower flow rates.

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Post-synthesis modification of silica membranes for enhanced CO_2 capture from flue gas streams

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Carbon Capture, Utilization, and Storage (CCUS) technologies are about to play a key role in realizing the European Union's ambitious decarbonization objectives while can offer low-carbon energy security in Europe, in the short term. Membrane-based separations are low cost and green alternative routes to conventional post-combustion carbon capture technologies. Microporous silica membranes are among the most studied inorganic membranes, and they still attract growing attention due to their low cost and ease of production. Amorphous silica membranes have already been commercialized for small–scale pervaporation applications but they are also considered as promising potential candidates for various gas separation applications. Therefore, the scope of this work is to evaluate the performance of commercial silica membranes for gas separation applications, specifically for CO_2 capture from flue gas streams, and further increase their efficiency by implementing post-synthesis, tailor-made modification treatments, and adjusting the separation's operational parameters to decrease the energy cost. The developed experimental protocols that involve in situ Chemical Vapor Deposition (CVD) and Atomic Layer Deposition (ALD) focus on precise pore size control and surface chemistry adjustment. Namely, the modification treatments make use of several silanes to simultaneously narrow the membrane's pore size and enhance silica's affinity for CO_2 by incorporating surface functional amine groups. The effectiveness of the applied modification protocols is tested by single gas permeation, relative permeability, and CO_2/N_2 separation experiments while Fourier transform infrared spectroscopy (FTIR) is employed to verify the functional group attachment on the pore surface. Evidently, several treatment protocols are developed showing promising results, leading to modified membranes with improved separation performance. The latter is attributed to a molecular sieving effect along with contributions from CO_2 preferential surface diffusion through the functionalized rigid pores.

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Polyphenol recovery by ceramic membranes

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Phenolic compounds are bioactive phytochemicals naturally found in plants. The chemical structures of these reagents comprise a hydroxyl group directly attached to one or more aromatic benzene rings. Many phenolic compounds, such as flavonoids, anthocyanins, and carotenoids, are found in various foods, such as herbs, vegetables, and legumes. Phenolic compounds function as antioxidants with mechanisms that include both free radical scavenging and metal chelation. Polyphenols have been shown to have benefits in the prevention of cardiovascular diseases, cancer, diabetes, neurodegenerative conditions, aging, and skin-related problems. It also has a significant prebiotic effect. They increase the rate of beneficial bacteria in the gut, which is essential for overall health, weight management, and disease prevention. Polyphenols are considered functional foods as they have a variety of health benefits beyond basic conventional nutrition. Functional foods have emerged as the second largest usage area of polyphenols in the industry after functional beverages. In addition to using polyphenols in producing functional foods, beverages, and nutritional supplements, polyphenols are also used in cosmetics, paints, and animal foods. The use of polyphenols is becoming a growing market. Using polyphenols in different industries makes it attractive to recover polyphenols from wastewater. Hence, polyphenol recovery by ceramic membranes was investigated in this work. Quercetin was selected as a model polyphenol. Quercetin filtration efficiency and fouling resistance were also investigated. Polyphenol filtration flux is shown in Figure 1. As it is shown in the figure there is no fouling in 4 hours of quercetin filtration with ceramic membranes.

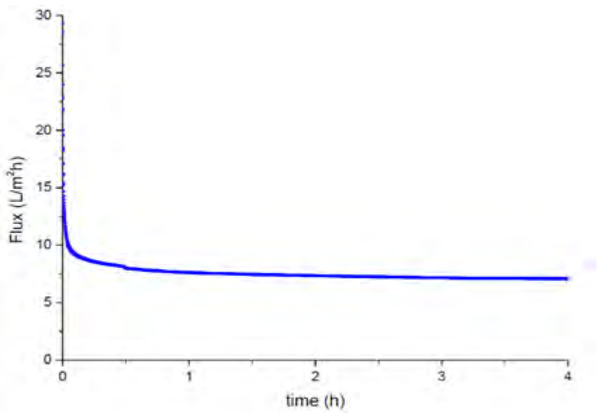

Figure 1. Polyphenol filtration flux.

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Emerging prospects of charge-enhanced ultrafiltration membranes

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Surface charge has a great influence on how a membrane functions. It is known to affect especially the membrane fouling tendency, and rejections of charged compounds. Typically these effects are studied on nanofiltration membranes, which are in many instances highly dependent on charge characteristics, but we aim to show that these considerations can be applied for the UF class as well. In practice, the surface charge is often considered more or less a fixed property of a polymeric material, which is then used as the basis for membrane material selection for a specific application. Our investigations intend show that membrane surface charge can be modulated in a controlled manner and that it can be highly beneficial even for more open membranes.

Different polymers are susceptible to different modifying reactions. For instance, TEMPO-mediated oxidation has appeared to be a well-controlled way of adjusting the surface charge of cellulosic membranes. This property of cellulose is based on the abundant primary -OH groups, which can be oxidized to dissociable and charge-asserting carboxylic acid groups. By furthermore adjusting the extent of the surface modification, the properties of the membrane can be tailored to ones needs. In the case of TEMPO oxidized cellulosic membranes, high oxidant exposure does intensify the surface charge, but seems to degrade the top-layer material, so it is important to know the practical limits of the modification. [1]

Some of the most intriguing outcomes of the charge enhancing surface functionalization we have observed include increased rejections of charged compounds and improved adhesion of charge-dependent coating materials, i.e., polyelectrolytes. In the upcoming research, we plan on studying the phenomena related to charge-assisted layer-by layer coating. Additionally we investigate the possible applications of charge-enhanced or coated membranes.

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Preparation of enantioselective membranes by simple functionalization with charged chiral selectors

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Many chiral drugs and food supplements were developed and are still sold as racemic mixtures of both enantiomers. However, to maximize the positive effects of these drugs, minimize side effects connected to the administration of the unwanted enantiomer and to mitigate the environmental issues caused by the excess of unmetabolized drugs in wastewater, it is highly desirable to use enantiomerically pure compounds. To this day, production of many racemic compounds remains very difficult or expensive. With the advantage of continuous operation and easy scalability, membrane processes could provide a robust solution to this issue.

In practice, preparation of enantioselective (chiral) membrane usually involves a multistep chemical treatment process, that is not only complicated, but also time demanding. In this work, we present a simple method for chiral membrane preparation through electrostatic interaction between regular membrane with charged surface and ionic chiral selector [1]. Cationic or anionic derivatives of chiral selectors, such as cyclodextrins, can be combined with oppositely charged membranes (such as anion- or cation-exchange membranes) through a simple one step dip-coating process. Here we discuss the feasibility of this preparation procedure as well as stability of the functional layers. Transport of chiral compounds through the functionalized membranes was examined by performing diffusion experiments with several model racemic mixtures.

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Acknowledgements

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Studying the effects of single and mixed algae strains on performance of algae-sludge membrane bioreactors

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In this study, five microalgae strains were collected from local water bodies in Finland and were mixed with activated sludge and cultivated in local municipal wastewater; and used in batch trials (phase I) to assess their nutrient removal capability. The efficacy of these local strains was compared to well-known wastewater treatment algae strains *Chlorella vulgaris* and *Euglena gracilis*. Two microalgae strains (*Chlamydomonas* sp. and *Selenastrum* sp.) and their mixture were chosen for further exploration during phase II, by inoculation in the conventional sludge membrane bioreactors (CMBRs).

The results of phase II revealed that coexistence of single algae strains and their mixtures with activated sludge minimizes membrane fouling, promotes microbial growth, changes microbial diversity, and improves nutrient removal compared to the CMBR (nutrient and TOC removal of CMBR: TOC: 90%, NH_4-N: 70%, PO_4-P: 22%). The *Chlamydomonas* sp. reactor (TOC: 93.2%, NH_4-N: 76%, PO_4-P: 34%) and the mixed *Chlamydomonas* sp. + *Selenastrum* sp. reactor (TOC: 91.4%, NH_4-N: 80%, PO_4-P: 32%) provided higher TOC and nutrient removal, and biomass and chlorophyll-a growth compared to the *Selenastrum* sp. reactor. The *Selenastrum* sp. reactor and the mixed *Chlamydomonas* sp. +*Selenastrum* sp.reactor, on the other hand, had less membrane fouling than the *Chlamydomonas* sp.reactor. This study suggested that inoculating CMBR with a mixture of algae strains could improve CMBR performance more than single algal inoculation by taking advantage of multiple strains' benefits at the same time. Furthermore, sequencing analysis showed that the microbial community changed by inoculating algae which benefits the CMBRs. In addition, different algael cells inoculation affect sludge properties, fatty acids profile, and oxygen consumption profile with/without presence of nitrification inhibitors.

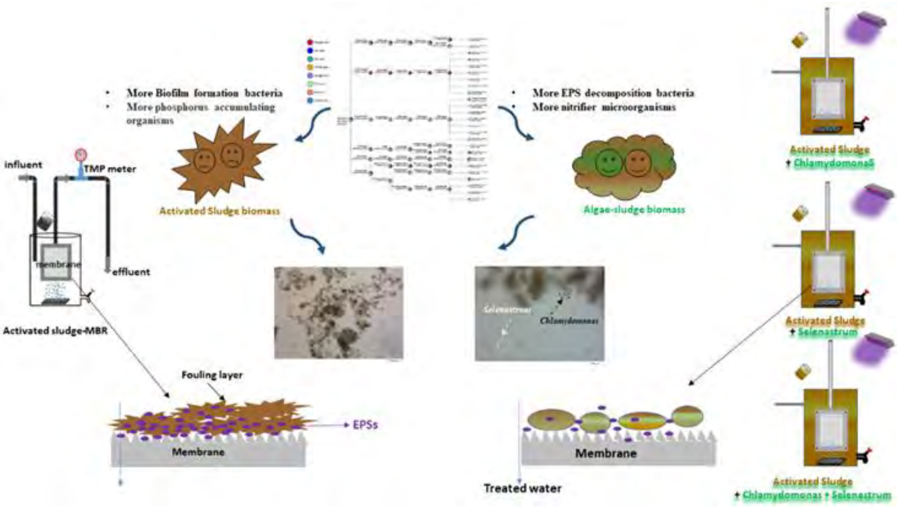

Figure 1. Schematic of conventional MBR and algae-sludge MBRs.

Functionalizing polyether-ether-ketone polymer for preparing more performing pervaporative dense membranes

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Pervaporation is considered a competitive technology compared to traditional separation processes (e.g., distillation) for the removal and purification of volatiles from liquid matrices. Through the use of dense membranes, pervaporation is able to separate liquid mixtures at the azeotropic point that cannot be resolved using common column distillation. The separation principle is based on the different solubilisation and diffusion of the species to be separated with the polymeric material of which the membrane itself is made of [1].
The driving force in this process is the chemical gradient that is created between the two sides of the membrane by applying a partial pressure difference that can be achieved, at the permeate side, by using a vacuum pump or a gas flow [2]. Aim of this work is to chemically functionalise the polymer polyether-ether-ketone (PEEK) in order to make it more processable. PEEK is a semi-crystalline polymer that possesses high chemical and thermal stability. Therefore, it can be used as a high-temperature structural material and as electrical insulator [3].
Several PEEK functionalisations are, therefore, proposed by changing the ketone group into an imine, or by reducing the ketone group to an alcohol, or by changing the ketone group into an acetal.
Membranes will be produced by common phase inversion techniques such as non-solvent induced phase inversion (NIPS) and temperature induced phase inversion (TIPS). In this regard, the polymer will be solubilised in a suitable solvent in order to obtain a stable and homogeneous polymer solution. The solvents chosen will fall either among those traditionally already used in membrane preparation or in a new class of 'green' and more compatible solvents with the aim of achieving a more sustainable membrane preparation.
The produced dense membranes will be finally applied in pervaporation for the separation of different azeotropic mixtures.

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Membranes for bio-fuel recovery: Deciphering membrane permeation in multicomponent pervaporation

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The increased pollution and environmental hazards associated with the use of conventional fossil fuels have encouraged attention towards biofuels as a supplementary energy source. These fuels, which mostly include bioalcohols like ethanol, butanol,etc, are derieverd from fermentation of agricultural and other lignocellulisc biomass and can not lead towards a more eco-friendly fuel economy but also serve as an useful way to deal with large amout of agricultural and food wastes in a sustainable manner. However, the biofuel industry is still plauged by the challenges of cost effective and sustainable downstream recovery of these fuels from complex fermentation broths. Membrane based processes like pervaporation not only provide mild conditions feasible for in situ seperation of biofuels (a pleasant exception withen the many alternatives for bio-refining) but can also serve as an effective alternative to energy insentive distellation pocesses if the selectivity of the process is enhanced. However, selectivity in pervaporation, besides being dependent on membrane materials, is a function of both operating conditions as well as feed composition.Fermentation broths are often complex multicomponent mixture with multiple organic compounds in variable compositions. An understanding of their effects on the final membrane performance would help to optimize the fermentation process itself, with the aim of maximizing bio-fuel recovery and predicting membrane selectivity as a function of broth composition. In our study, we used Acetone-Butanol-Ethanol fermation broth model solutions to study the effect of various factors that effect pervaporation.Besides varying feed operational conditions, special notice was taken of the various compositional factors, interactions and coupling withen different components.Experiments were carried out in both traditional OVAT scheme and a statistical DOE model designed to undertand the various thermodynamic and kinetic interactions and coupling effects that become important in multicomponent organophilic pervaporation process[1].

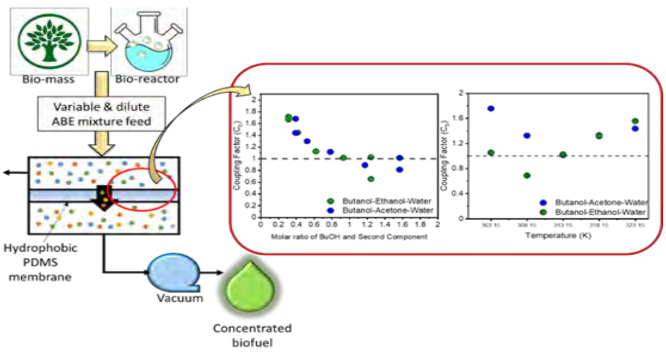

Figure 1. Multiple components in fermentation broths lead to coupling effects which are functions of broth composition and temperature.

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Hydrophobic membrane bubble free aerator applied in MABR for simultaneous ammonia and COD removal

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High chemical oxygen demand (COD) and ammonia concentrations in wastewater are a serious environmental risk and have to be reduced before disposal [1]. Biological processes are an interesting option since they are economically sustainable, versatile and "green". The microorganisms in such systems could be present in suspended growth forms, as in the activated sludge process, or in the attached growth form as in biofilm reactors (MBfR) [2]. MBfR has several advantages compared with the traditional systems thanks to flexible procedures, smaller space demand, lower hydraulic retention time, higher biomass retaining time, low sludge production, higher concentration of biomass in a thin layer. The membrane aerated biofilm reactor (MABR) is a promising type of MBfR in which a gas permeable membrane act as a support for the biofilm and as a supplier of oxygen. The amount of oxygen provided could be controlled by adjusting several operative conditions that play an important role in bubble free aeration process [3]. Considering these aspects, the aim of the work is the study bubble free aeration, performed with hydrophobic membranes, for the development of a MABR. To this end the work was divided in two phases: a) the study of the effect of operative parameters (e.g. air and liquid flowrates, air pressure inside the fibers and membrane characteristics) on the mass transfer coefficients (K_La) in aeration and b) the exploitation of these results in MABR technology. Membrane modules were prepared using polypropylene membranes and the study of the K_La was performed using sodium sulphite method. Accurel S6/2 was selected to MABR preparation which was applied to the treatment of a synthetic wastewater containing both organics and ammonia. A good removal of COD was achieved with a simultaneous slower conversion of ammonia.

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Development of biocatalytic membrane systems for the control of biofouling in reverse osmosis and ultrafiltration membrane systems

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The number of studies with a biotechnological approach to prevent and control the biofouling problem in membrane processes is increasing day by day. Biocatalytic (enzymatic) membranes are one of these biological strategies. In these systems, which benefit from the biocatalytic properties of enzymes, biofilm formation mechanisms are broken down by enzymes to offer an effective and environmentally friendly solution. Also, it is crucial to do research on the stability and activity of the enzymes used in these systems. The aim of the study is to find a solution to the biofouling problem by preventing the formation of the biofilm in the membrane processes. In this context, the lactonase enzyme from *Bacillus sp*., isolated from various environmental sources in Turkey, will be purified. This purified enzyme will be immobilized on reverse osmosis and ultrafiltration membranes with different techniques to obtain biocatalytic membranes, and enzyme activity and stability as well as its biofouling effect will be investigated. As a result of the study, a system that will save energy by preventing the formation of a biofilm layer on the surface of the produced membranes, reducing biofouling and preventing the decrease in flux values over time, will be put forward.

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Cellulose membranes in the treatment of Deep Eutectic Solvents (DESs)

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Deep Eutectic Solvent (DES) is a mixture with melting point much lower than the melting points of its constituents. Some properties of DES, such as nonvolatility, thermal stability and low toxicity make DES a perspective green solvent. The DES made by mixing Choline Chloride and Lactic Acid in 1:10 molar ratio has been used in many different studies focusing on the biomass treatment and it has been proved that this DES is possible to use in recovery of lignin from biomass. However, there is still only limited amount of information available about the possibilities to purify the spent DES for recycling even though that is crucial to arrange when the use of DES is implemented in large scale. Membrane filtration is an attractive tool for the purification of DES, because it does not require phase conversion and it allows to purify a target solution while concentrating valuable compounds in retentate fraction at the same time. Cellulose demonstrates very poor solubility in the DES made of Choline Chloride and Lactic Acid (1:10 molar ratio). Thus, in theory, DES purification with cellulose membranes should be feasible. Due to that in this study the aim is to get improved understanding on the possibilities to use commercial cellulose membranes in purification of the spent DES (Choline Chloride : Lactic Acid 1:10). The results achieved by so far have shown that the RC70PP (Alfa Laval, cut off 10 kDa) and the 5kD Disc (Millipore) can be used in fractionation of the spent DES. The use of these membranes in series enables the removal of 95% of the water insoluble compounds in the spent DES. [1] Current experiments are focused on the long-term stability of the cellulose membranes in the spent DES. They have already shown that there are no significant changes in the performance of the RC70PP or the 5kD Discs after four week exposure (PEG retention and pure water flux). The possible changes in the membrane characteristics (chemical structure, charge, physical structure) will also be studied.

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Coating of polymer membranes with photoactive nanoparticles and studies on degradation of water pollutants

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Introduction of Endocrine Disruptive Chemicals into the water bodies is an emerging threat to humans and the environment. Conventional water treatment processes are inadequate to remove these chemicals. In order to degrade the emerging water pollutants like Bisphenol A (BPA), Bismuth based photoactive nanoparticles were synthesised, characterised and used to modify Polyethersulfone (PES) ultrafiltration membranes. The structure, morphology, composition and surface charge of synthesised particles were characterised by XRD, SEM, EDX and zeta potential. A photocatalytic batch test with suspended nanoparticles under VS light irradiation was performed to evaluate their photocatalytic activity and found that 90-100% degradation of BPA was possible. Photoactive nanoparticles were introduced to PES polymer dope solution to cast particle embedded membranes. Layer by Layer technique was employed using cationic and anionic polyelectrolytes to coat the Carboxylated PES membrane with photoactive nanoparticles. Both the types of functionalised membranes were characterised and checked for their photocatalytic activity and fouling resistance. Only 25-30% degradation of BPA was possible using the modified membranes. Optical Coherence Tomography (OCT) equipment was used for real-time observations of the development of the biofouling layer on the surface of particle modified membranes. E. Coli bacteria in the LB nutrient solution was used in this experiment, and the fouling layer was analysed using the OCT equipment during the experiment. After the experiment, SEM and EDX analysis of the used membranes was carried out to check the antibacterial properties of photoactive nanoparticles.

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F-MOF-based Matrix Mixed Membranes for an energetically favourable separation of CO_2

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Excessive emission of greenhouse gases is responsible for the global climate change. Unfortunately capture and separation of such gases are difficult and expensive [1]. Since 1970, polymeric membranes have been used for separation of gas mixtures offering satisfactory results at low energy costs. The key parameters for a good-quality membrane are the permeability and selectivity which are trade-off parameters, and thus related to an upper bound that must be achieved to have satisfying results [2]. Recently, Mixed Matrix Membranes (MMMs) have emerged as a new generation of promising materials for gas separation. MMMs combine the strength points of polymers with the highest adsorption capacity of porous fillers. This work presents an Italian project named doMino concerning the synthesis and advanced characterization of a new generation of MOF-based MMMs for CO2 separation. Novel MOFs containing per-fluorinated linkers are synthesized and deeply characterized. Structural and adsorptive properties are evaluated via spectroscopic techniques (IR and Raman but also SSNMR) coupled with volumetric and microcalorimetric analysis. MMMs are prepared by mixing Hyflon AD60x and novel F-MOF, specifically F4_MIL140(Ce) and F4_UiO66(Ce), at different concentrations as self-standing dense films and tested in terms of gas transport properties. Spectroscopy techniques are used to understand the properties of the final MMMs, and volumetric analysis at low pressure (up to 1 bar) allows evaluating which are the most promising MMMs that present better properties than their neat polymers, exploiting the great adsorption capacity of new F-MOFs.

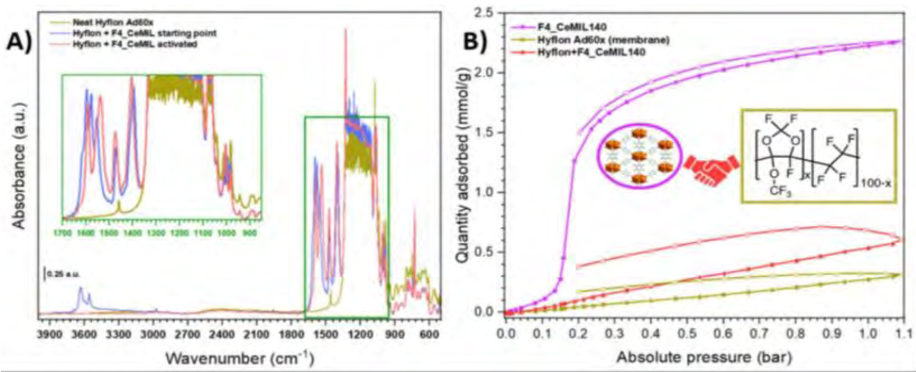

Figure 1. A) FTIR spectra of neat Hyflon membrane and MMM containing F4_CeMIL140 before and after activation; B) CO_2 isotherms at 303K of both single hyflon and F4_CeMIL140 and coupled in the MMM.

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Polyolefin membranes fabricated with bio-based solvents: From plastic waste to value-added materials

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The utilization of non-renewable solvents and plastic pollution are two sustainability challenges that can be addressed from the membrane field. In recent years, alternative raw materials such as bio-based solvents and plastic waste have been proposed for membrane fabrication. In this work, two bio-based and renewable solvents are employed to dissolve polypropylene (PP) and low-density polyethylene (LDPE). The thermal properties and phase separation behavior of solutions prepared with LDPE and PP were studied, from which phase diagrams were obtained. Liquid-liquid phase separation and spherulitic morphology were observed for the studied systems. Polypropylene membranes were obtained by thermally induced phase separation (TIPS) process employing commercial polymer and analogous plastic waste. The influence of the quenching media during TIPS and polymer content was evaluated in terms of morphology, mechanical and thermal properties, and water contact angle on the resulting membranes. Their underoil contact angle (above 150°) allowed them to be used for water-in-toluene emulsions separation, where around 95% water rejection and an average of 99.97% toluene purity were obtained.

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Phenolic compounds enhancement and sugar reduction in apple juice by diananofiltration

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Apple is one of the most consumed fruits in the world because of its availability throughout the year in various products, including fresh fruit, juice and concentrate [1]. Epidemiological studies have shown that apple consumption as fresh fruit can prevent chronic heart and vascular diseases, diabetes, respiratory and pulmonary dysfunctions, obesity, and cancer, among others [2]. All these quality properties are ultimately based on the metabolic composition of the fruit. On the other hand, processing steps for producing ready-to-drink apple juices, including juice extraction and clarification, harm the health-promoting compounds of apples, and clear apple juice has been associated with adverse effects, mainly related to its high fructose and low fiber content [2]. Partial removal of sugars in apple juice without compromising its biofunctional properties represents a significant technological challenge [3].
In the present work, apple juice was initially characterized using Nuclear Magnetic Resonance (NMR) and Mass spectrometry (MS) coupled with HPLC-UV. Three different spiral-wound nanofiltration (NF) membranes with a molecular weight cut-off (MWCO) range of 200–500 Da were tested to reduce the sugar content of the juice and preserve its phenolic composition. In addition, a combination of diafiltration and batch concentration processes was investigated. For all selected membranes, the permeate flux and recovery rate of glucose, fructose, and phenolic compounds were evaluated in both diafiltration and concentration processes. Among the investigated membranes, a thin-film composite membrane with an MWCO of 200–300 Da provided the best results in preserving phenolic compounds in the selected operating conditions. More than 70% of phenolic compounds were recovered in the retentate stream, while the content of sugars was reduced by about 60%.

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Olefin/paraffin separation by MOF-based mixed matrix membranes

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Here we propose a method to separate propane/propylene mixtures by membrane operations. The traditional methods for these separations are among the most energy-intensive industrial separation processes because of the massive scale and because of the high energy requirement for cryogenic distillation and pressure-swing processes. Membrane separation with facilitated transport membranes has been proposed as an alternative, but these membranes have the disadvantage that they tend to be unstable and lose their efficiency over time [1]. In the present paper we will discuss the possibility of propane/propylene separation using mixed matrix membranes based on various metal organic framework (MOF) filllers from the MIL family and the ZIF family, dispersed in a suitable polymeric matrix, such as 6FDA-based polyimides. The membranes will be prepared by the solution casting and solvent evaporation method. Single gas permeation measurements are planned by the time-lag method in a fixed volume setup, yielding the single propane and propylene permeabilities and diffusivities, and the corresponding ideal selectivities. For a general characterization of the membranes, light gases (He, H_2, N_2, O_2, CH_4 and CO_2) will be tested as well to obtain deeper insight into the gas transport mechanism. The study of propane/propylene mixed gas permeation with an innovative permeation setup, based on the continuous online analysis of the permeate composition by a quadrupole residual gas analyser will be discussed, with special attention for the deconvolution of the signal of propylene permeating through the membrane and propylene formed by fragmentation of propane. This instrument has also the unique possibility to determine besides the permeability also the diffusion coefficients of the individual gases in the mixture from their permeation transient [2,3]. The effect of the MOF type and concentration, the gas composition and the feed pressure on the separation performance of the investigated membranes will be discussed.

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From hollow fibre to flat sheet – How to develop membranes with similar properties and different shapes

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A brief comparison of hollow fibre modules and spiral wound flat sheet modules shows that both technologies have low investment costs and high maintenance costs due to high fouling tendency and poor cleaning possibility. So why do hollow fibres not have a higher market penetration considering their 10-fold higher packing density? Amongst other things, hollow fibre applications need additional feed conditioning to prevent blocking and they exhibit comparatively poor heat recovery.
Both types of module design are applied in membrane distillation (MD). MD in turn is usually coupled with other processes as it makes do with waste heat. In our case, a reverse electrodialysis (RED) pilot plant employs a solar powered MD step that takes effluent from a mining operation to produce clean water and a concentrated brine that feeds the RED process.
In order to meet the harsh requirements of the aforementioned process, the MD unit preferably employs flat sheet membranes in multi-envelope spiral-wound modules over hollow fibre modules. Therefore, the properties of proven lab-scale PVDF hollow fibres are being transferred onto PVDF flat sheet membranes, in order that the membranes have similar properties that result in comparable membrane process parameters (e.g. retention, permeation rate) and only differ in shape. All relevant process parameters of the dry-jet wet-spinning process are identified and translated into those of a vapour-assisted non-solvent induced phase separation process. A DoE approach ensures an efficient technology transfer from the lab-scale hollow fibre production to a large-scale flat sheet membrane production.

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Membrane fouling during continuous production of lactic acid with cell recycle

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Introduction: Two major challenges facing our planet are inherently linked: the decline of our natural resources and the accumulation of plastic in our environment. Both of these challenges can be tackled simultaneously thanks to engineering. Waste that was once allowed to accumulate in our environment now has the potential to be reused as something of value that is not harmful to the planet. For example, whey permeate from the dairy industry can be converted to lactic acid and then polylactic acid, a biodegradable plastic. This is conventionally done using batch fermentation, however, integrating membranes with the bioreactor can facilitate a more efficient continuous process, the focus of this study. Membrane fouling is a serious challenge that is under reported in the literature.

Materials and methods: The use of cell recycle via membranes in fermentation processes can increase cell density and lactic acid yield, [1]. The continuous fermentation of Lactobacillus lactis to produce lactic acid with hollow fibre ultrafiltration membranes for cell recycle is examined in this study with a particular focus on membrane fouling and mitigation.

Results: Preliminary results show that higher recycle flowrates can help delay flux losses due to membrane fouling. Cell recycle at a flowrates of 0.09, and 0.14 L/min resulted in a 97% and 70% decrease in flux after just 5 minutes respectively. Cell recycle at a flowrate of 0.18 L/min managed to maintain the flux for over an hour. This is an opportunity for research in the optimal flowrate required to maintain performance.

Future work: Further work is required to examine damage, if any, to cells caused by cell recycle flowrate. The optimum flowrate must be identified, and an effective fouling control strategy developed. Technoeconomic analysis will be undertaken to compare the continuous process to the batch process.

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Precious metal recovery applications of polymer inclusion membranes

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Polymer inclusion membranes are used to remove metal ions, small molecules, inorganic anions, etc. from aqueous solutions. Polymer inclusion membranes consist of three main materials [1]. These are base polymer, plasticizer and carrier [2]. Polymers used in the structure of polymer inclusion membrane are generally thermoplastics that soften with heat and become elastic. Plasticizers are used to make the polymer both softer and more flexible. It also increases the chemical and mechanical stability, allowing metal species to be trapped and transported across the membrane. Carriers are often used to transport target material by polymer inclusion membranes. In addition, these carriers depend on the control of the transport rate, the selectivity and stability of the polymer inclusion membranes [3]. These materials were mixed in the appropriate solvent using the base polymer, carrier and plasticizer and kept on the glass plate for slow evaporation. Palladium has recently become popular in a variety of industrial applications, including fuel cells, electronics, electroplating, catalysis, jewelry, and investment vehicles [4]. Due to their rarity and high cost, palladium recovery has become essential. It is frequently employed in numerous traditional and innovative palladium recovery techniques [5]. Adsorption and extraction experiments will be carried out with the fabricated membranes and the removal efficiency of precious metals which are palladium, gold and silver etc. will be investigated. In our studies, pH, temperature, contact times and membrane contents will be changed and the membrane performance will be obtained. According to adsorption experiments, the optimum membrane will be selected for extraction parts. After the adsorption tests, extraction experiments will be performed by changing concentration of receiving phase, concentration of precious metal in feed phase and membrane contents. Some parameters such as permeability coefficient, intial flux and recovery factor will be calculated by using system.

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Porous PVDF membrane with controllable wetting property in oil water emulsion separation

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There is an urgent problem [1] in oil water emulsion pollution due to the massive oil leakage and oily wastewater, and membrane technology could play a significant role in the separation of oil water emulsion. The porous polyvinylidene difluoride (PVDF) membrane fabricated via vapor induced phase separation method was coated with dopamine, and it was grafted with poly(N-isopropylacrylamide) (PNIPAm) [2] on the polydopamine layer. Due to the function of surface chemistry and microstructure, [3] the PVDF membrane showed thermal responsive property in contact angle (31 to 37 °), in the meantime the water permeance increased from 1100 to 2000 $Lm^{-2}h^{-1}bar^{-1}$ as the temperature raised from 25 to 45 °C. The PVDF membrane was applied to separate n-hexane-in-water emulsion with good permeance (600 $Lm^{-2}h^{-1}bar^{-1}$) and high oil rejection (99.8%), and it showed an excellent antifouling property attributed to the same permeance and oil rejection even in three subsequent oil water emulsion separation cycles. Therefore, the PVDF membrane with controllable wetting property could show good potential in the oil water emulsion separation.

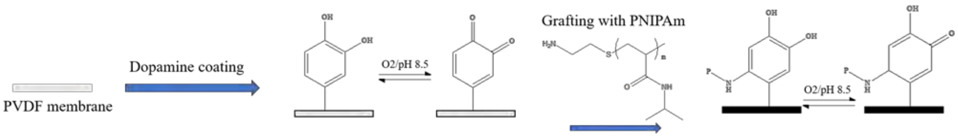

Figure 1. The modification process of the PVDF membrane.

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Polymerizable bicontinous microemulsion as anti-fouling coatings for PES and PVDF membranes for wastewater treatment

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Vietnam is one of the protagonists of the emerging markets universe and its economic growth is mainly based on the activity of exporting, such as fish and shellfish processed by seafood industries. To convert fishery products in exportable products, different steps are required responsable of the production of huge quantities of wastewater. A promising choice to purificate sewage is represented by membrane bioreactors (MBR) due to the combination of a microfiltration or ultrafiltration membrane with a biological process. The main drawbacks that limit membrane technology's widespread use, are represented by the phenomena of fouling and biofouling. In this work, the surfaces of porous membranes were modified following the procedure described by Galiano et al. [1] with a polymerizable bicontinuous microemulsion (PBM)[1,2], in order to mitigate this problem and to employ them in MBR systems for the treatment of very polluted wastewaters in a successful way. The PBM solution was cast on the surface of commercial ultrafiltration polyethersulfone (PES) and polyvinylidene fluoride (PVDF) membranes thus allowing the polymerization on their surface. Pure water permeability and humic acid (HA) filtration tests (100 mg/L) (Figure 1) were carried out on both coated and uncoated membranes. After fouling, PBM membranes were washed and subjected to pure water permeability tests to assess their permeability regain. For PBM surface-modified membranes, the results revealed a better permeability and a higher HA rejection as well as a lower fouling tendency and a complete regain in permeability owing to their hydrophilic and smoother surface. The anti-fouling properites of coated membranes can be attributed to their intrinsic properties such as high hydrophilicity, nanostructures morphology and low surface roughness.

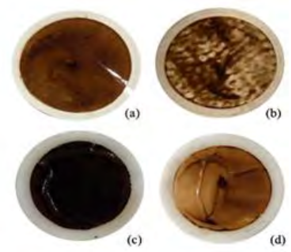

Figure 1. Comparison, after treatment with humic acid, between (a) commercial flat PES membrane, (b) PBM PES-membrane, (c) commercial flat PVDF membrane and (d) PBM PVDF-membrane.

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Rheology of polytriazole/ZIF-8 solutions and dynamics of mixed-matrix composite films

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Mixed matrix membranes are expected to reach high selectivity and permeability, combining polymers properties and metal-organic fillers, overcoming the permeability-selectivity trade-off in gas separation [1]. However, the problem with mixed matrix membranes is the poor adhesion between the filler and the polymer; this creates cavities around particles, providing a preferred route for the permeate, indicating an increasing permeability without reaching the expected selectivity. Meanwhile, excessively strong interactions increase the rigidity of the polymer around the filler affecting the permeability. Quantification of the polymer/filler adhesion is essential, but it is usually confirmed only after the membrane performance testing [2].
Solution rheology is a tool for identifying polymer-filler pairs with good interaction in this work. The investigated system was polytriazole with and without hydroxyl functionalization (PTA-OH and PTA) and ZIF-8. ZIF-8/PTA-OH forms stable gels even with small filler content, while analogous systems with PTA do not form gel [3]. Since a significant increase in viscosity was observed even with 3% filler, rheology is highly sensitive for identifying the best polymer/filler pairs. The investigations were supported by spectroscopic methods, electron microscopy, and dynamic mechanical analysis of the final membrane. While small ZIF contents lead to sensitive changes in the solution viscosity, only minor changes in the FTIR and NMR spectra were detected for the same system. The good adhesion between PTA-OH and ZIF-8 could be seen by SEM, confirming the formation of cavities in membranes prepared with PTA, while they were practically absent in membranes prepared with gelling PTA-OH/ZIF-8 systems. The separation performance of the optimized membranes is under investigation using different gases such as CO_2, CH_4, and N_2.
To sum up, the methods described in this work can be extended as useful tools in the development of composites such as mixed-matrix membranes applied to a large variety of currently available metal−organic frameworks and polymers.

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Polymeric fluorine-free ionomers and their complexes with polyelectrolytes for thin-film composite nanofiltration membranes

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Selectivity in terms of ion and micropollutant rejection of nanofiltration (NF) membranes is a crucial factor for the performance of NF applications, such as wastewater treatment. Membranes based on a commercial fluorine-free ionomer may extended the available selecitivity spectrum as well as stability compared to common NF membranes [1]. Herein, the fabrication of a tunable and highly stable ionomer NF membrane by coating the negatively charged blockcopolymer Nexar on a support membrane with ultrafiltration characteristics is reported. The support membrane is prepared from L-PAN (93 % polyacrylonitrile, 7 % vinylacetate comonomer) via film casting and phase inversion. The nanoscale morphology of the Nexar film can be tuned by the solvent system of the casting solution [2]. In order to increase separation performance of the thin-film composite NF membranes beyond state-of-the-art (cf. [1]), different solvent systems are investigated. Low Nexar layer thickness (> 1 µm) as pre-requisite for high permeance of the membrane is controlled by dip-coating. The filtration performance of the new membranes in terms of solute rejection (Na2SO4, NaCl, CaCl2, sucrose) and permeance is competitive with established NF membranes. Subsequently, in analogy to recent other work with Nafion as part of the selective layer [3], a polyelectrolyte complex membrane is prepared by impregnating the fluorine-free Nexar layer with the polycation polyethyleneimine to further tune membrane separation performance.

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Life cycle environmental and economic assessment of AnFOMBRs and AnMBRs

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LCA (life cycle assessment) has huge importance in evaluating the environmental performance of new technologies and processes concerning various categories of environmental concern (Corominas et al., 2020). While some LCA studies on WWT (wastewater treatment) processes were run to determine the impacts of the entire treatment plants, some were conducted as decision support tools for WWTP management. Additionally, LCA studies have encompassed various scales and levels, including nutrient removal, configurations (primary, secondary, or tertiary processes), integrated resource recovery, and water reuse technology. In addition to those, the solids handling and disposal subjects, which are substantial in terms of the toxicological effects of heavy metals, take part in some studies (Foley et al., 2010; Rahman et al., 2016). Overall, LCA studies on WWT systems provide many advantages, such as a better understanding of environmental and cost-friendly options, showing contamination reduction options, and helping to decide water reusability alongside process safety and environmental security (Parra-Saldivar et al., 2020; Sabeen et al., 2018). On the other side, a new anaerobic forward membrane bioreactor (AnOMBR) has been created that uses FO (forward osmosis) membrane as the separation membrane in anaerobic membrane bioreactors. AnOMBR has received greater attention because it maintains AnMBR's strong energy production capacity and fixes its flaws. (Ansari et al., 2017). It is planned to make life cycle assessments, life cycle cost analysis, and sensitivity or uncertainty analysis of AnMBRs and AnFOMBRs in this doctoral thesis under different operation conditions, dissolved methane recovery options, and reuse of treated wastewater alternatives. It is planned to use Ecoinvent, and many literature data from AnMBR and AnFOMBR studies will be used as LCA data. Also, it is planned to use Simapro 9.4 as LCA program and Monte Carlo simulations for sensitivity analysis.

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