INNOMEM

OITB catalogue

Training & technology transfer

The project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement N° 862330.

Structure of the catalogue and material providers

Educational and training material provided by OITB members

Material and relevant links accessible through the INNOMEM website in the training & technology database (.zip file)

Technology & promotional material

- Demonstrational and promotional videos on membrane technology

Courses & lecture material

- Membrane related courses and lecture material

Research output

- Relevant research papers on membranes and the INNOMEM project

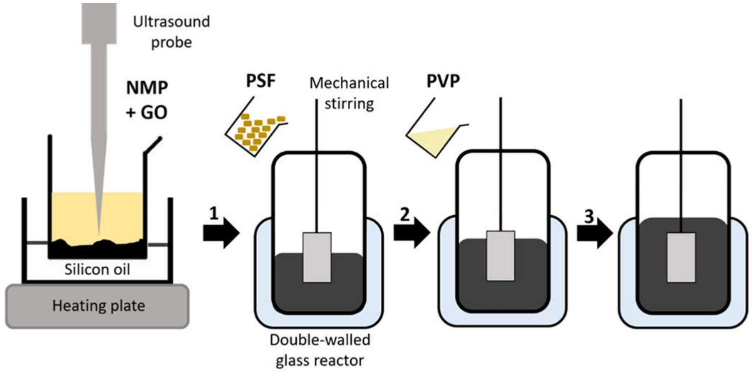
INNOMEM CATALOGUE

Technology & promotional material

Technology & promotional material

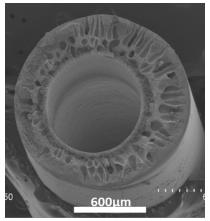
HOLLOW FIBER SPINNING LINE DEMO VIDEO - SHOWCASE 3 (Mixed matrix membranes for liquid and gas separation)

- Production of mixed matrix hollow fiber membranes for water treatment membranes for **POLYMEM** in Showcase #3 using a spinning pilot line (PL 8) located at **UM** (**University of Montpellier)**.

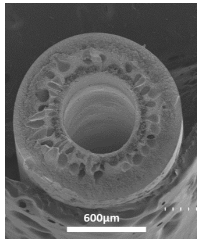


1. GO dispersed in NMP for 2h using electronical ultrasound probe at 50°C
2. Step by step addition of PSF into the double-walled glass reactor with mechanical stirring and 50°C heating
3. Step by step addition of PVP and heated mechanical stirring until obtention of an homogeneous polymer solution

Simple extrusion with GO



Co-extrusion with GO



- Graphene oxide is previously dispersed in the solvent that is used to prepare the polymer solution. Hollow fiber membranes are spun through a single spinneret or a dual layer spinneret.

- Video location: Training & technology database (.zip)

Technology & promotional material

HOLLOW FIBER SPINNING LINE DEMO VIDEO – SHOWCASE 6 (Functionalized polymeric HF membranes for aqueous applications)

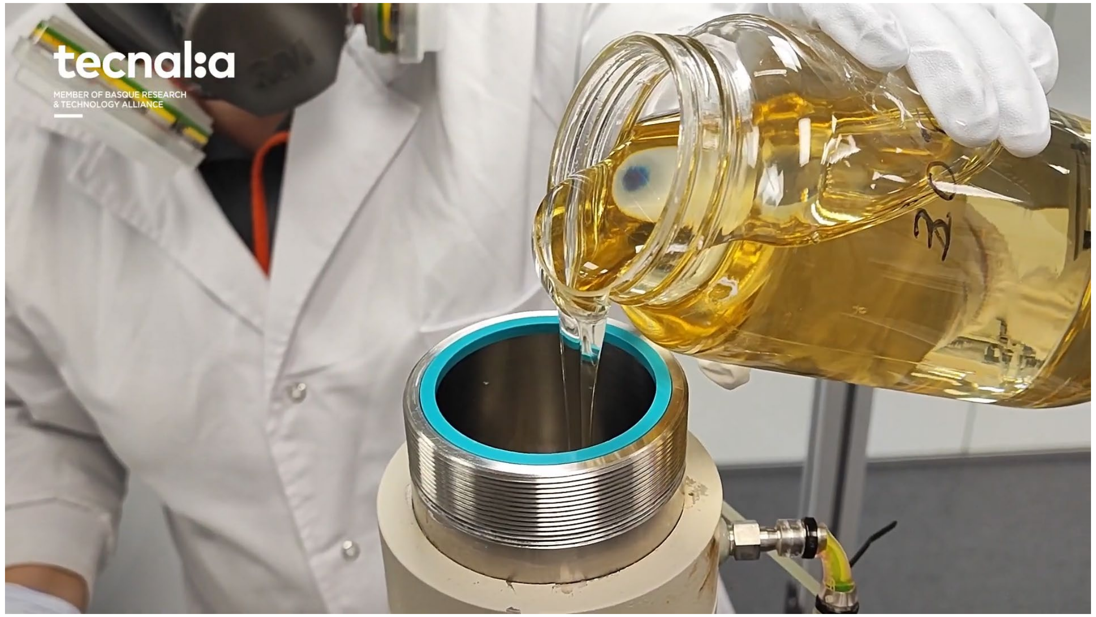
- Production of membranes for **NXF** in Showcase #6 - Functionalized polymeric hollow-fiber membranes for aqueous applications occurs in a spinning pilot line (PL 10) located at **EMI Twente**.

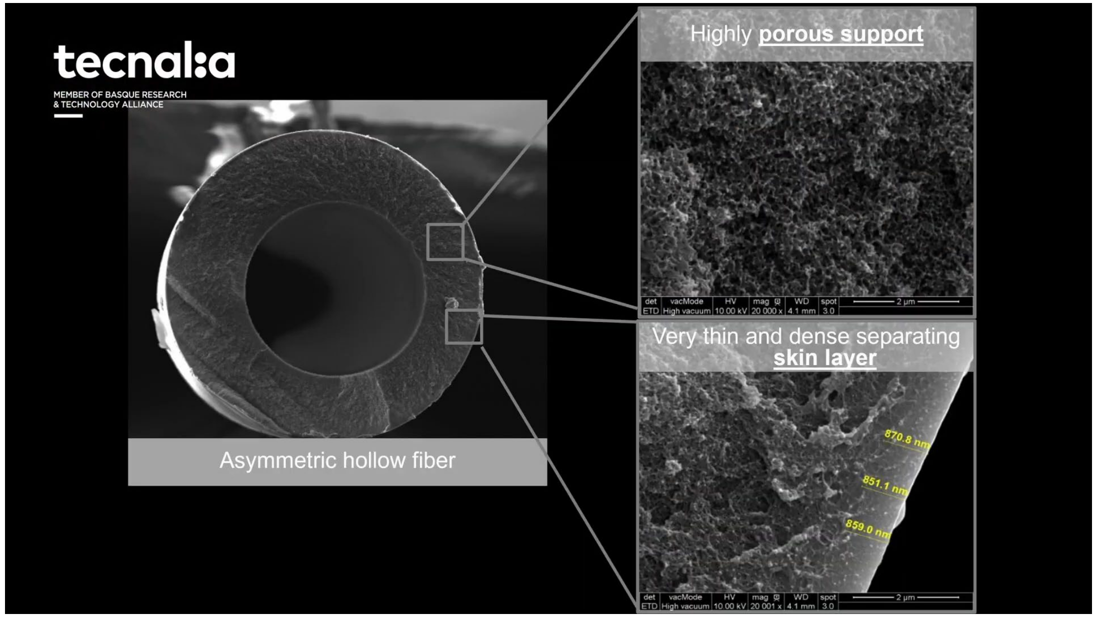
- Hollow fiber membranes are spun and treated in-line by the electron beam to enhance membrane properties. Due to the non-solvent induced phase separation (NIPS) process the hollow fiber is formed in the coagulation bath. It is washed to remove any remaining solvent. After washing, the fiber is guided through the electron beam multiple times to expose the membranes to electron beam irradiation to enhance the properties of the membranes to be subsequently collected by the collection wheel.
- Video location: Training & technology database (.zip)

Technology & promotional material

POLYMERIC MEMBRANE PRODUCTION FOR GAS SEPARATION

- Development and characterization of novel polymeric membranes for gas separation at **TEC**.





- Video location: https://www.youtube.com/watch?v=ImXnWDJcRCs

Technology & promotional material

EINDHOVEN UNIVERSITY OF TECHNOLOGY

METALLIC MEMBRANE PRODUCTION FOR GAS SEPARATION

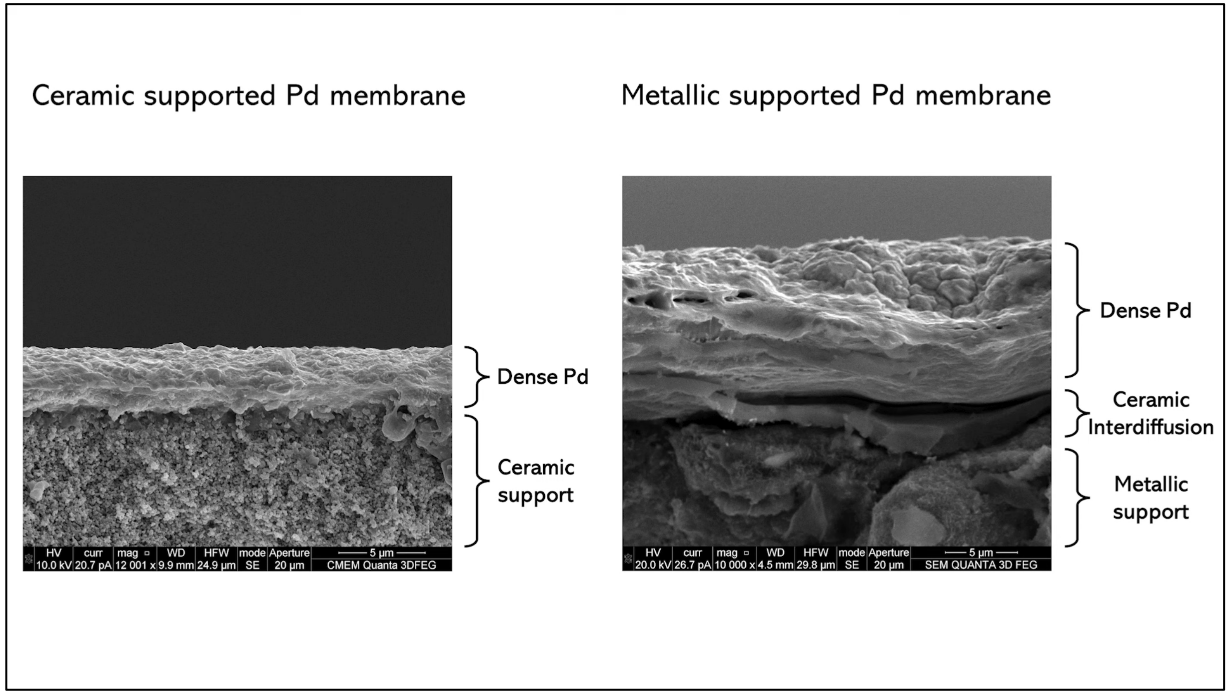
- Step-by-step production of H_2 selective metallic (Pd-based) membranes at **TUE**.

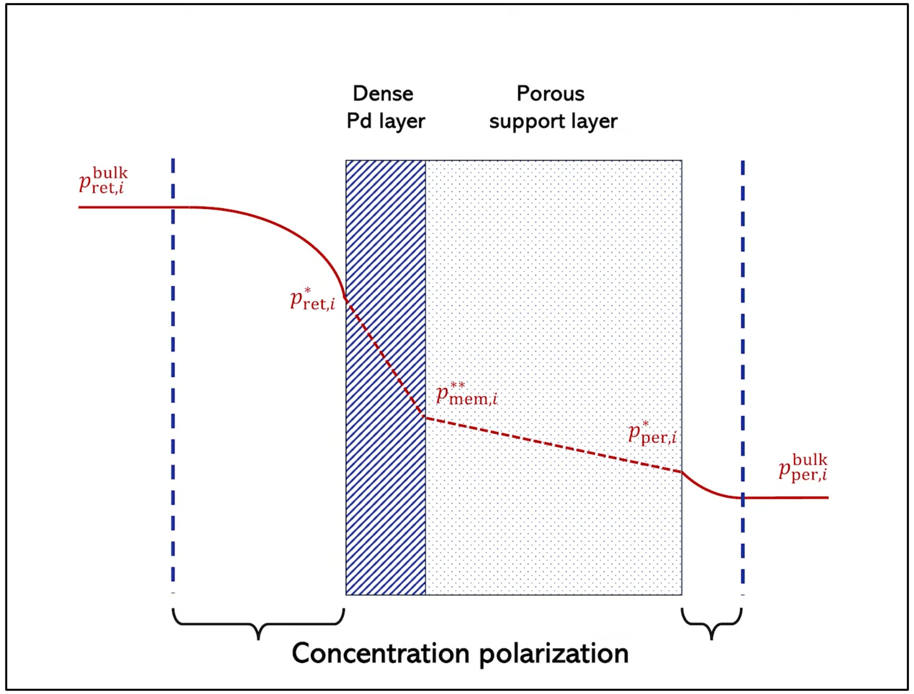
- Video location: https://www.youtube.com/watch?v=Ih6zTFUnFqc

Technology & promotional material

METALLIC MEMBRANE MODELLING

- Mass transport mechanisms and mathematical model development of H_2 selective metallic (Pd-based) membranes at **TUE**.





- Video location: https://www.youtube.com/watch?v=m7fm8eZVGEo

Technology & promotional material

VITO MEMBRANE TECHNOLOGY GROUP PROMO VIDEO

- **VITO** develops membranes and membrane processes to make industrial production more efficient, faster and greener.

- Video location: https://vimeo.com/106285920

INNOMEM CATALOGUE

Courses & lecture material

Courses & lecture material

MEMBRANE COURSE – VITO

Intensive 2-3 day membrane workshop by **VITO**

- 7th edition: June 11 & 18, 2009 at VITO
- 8th edition: February 26 & 28, 2013 at VITO
- 9th edition: May 10-11, 2017 at VITO
- 10th edition: September 26-28, 2022 in Antwerp (Radisson Blu Astrid hotel) including site visit at VITO

For more information on future editions, contact:

Pieter van de Zande - pieter.vandezande@vito.be

Courses & lecture material

MEMBRANE COURSE - VITO 2017

Chemistry

MEMBRANE TECHNOLOGY COURSE

PRINCIPLES & PRACTICES

10-11 May 2017

VITO, Mol

Membranes play an essential part in optimizing industrial processes. New membrane development and applications contribute to a more sustainable production environment, using less and alternative resources, requiring less energy and producing 'cleaner' waste streams. As an expert in membrane technology, VITO wants to share its expertise in the field, and give theoretical as well as practical insights in a 2-day intensive training course.

Why participate?

- Intensive 2-day course brought by experts in the field of membrane research & development
- Get an overall insight in the basics of membrane technology, downstream processing using membranes, electroseparation, advanced product recovery
- Learn how industrial (bio)processes benefit from the integration of advanced membrane technology
- Visit the VITO lab, demo and pilot installations
- Network with other professionals and graduates in the field

Who should attend?

Industrial professionals with a technical or scientific background or graduates in science or engineering looking for more insights in theory and advanced applications membrane technology brings to optimizing processes.

We hope to welcome you at this 9th edition of the course, exceptionally organised in collaboration with the H2020 project ButaNEXT.

Programme

Day 1: Wednesday May 10th 2017

09.00 Registration and coffee

MODULE 1: Membrane technology: principles and process operation

09.30 Basic principles of membrane technology
- Overview membrane processes
- Materials
- Basic principles and terminology
- Filtration parameters

10.00 Process operation and techno-economics
- From module configuration to process design
- Membrane fouling, scaling and cleaning
- Practical aspects and points of attention in process operation

11.00 Break

11.15 Case studies @ VITO
- From lab-scale feasibility studies to pilot-scale tests and industrial implementation
- Techno-economic calculations
- Calculation exercises

12.30 Lunch

MODULE 2: Pressure driven separations: principles and applications

13.30 Pressure driven membrane processes
- Technologies: micro-, ultra-, nano-filtration, reverse osmosis
- Applications: process and drinking water production, wastewater treatment and reuse, process applications, ...

14.15 Combination of pressure driven membrane filtration with bioprocesses
- Technologies: (reverse) membrane bioreactors, enzyme membrane reactors
- Applications: biomass retention, biomass harvesting, product fractionation, ...

15.00 Break

MODULE 3: Electroseparations: principles and applications

15.15 Electrodialysis

16.15 Capacitive deionization

17.00 Closure

Day 2: Thursday May 11th 2017

09.00 Arrival and coffee

MODULE 4: Downstream processing: membrane development and applications

09.15 Solvent filtration
- Technologies: organic solvent nanofiltration, pervaporation
- Applications: in-process recovery of solvents or products, product purification, ..

10.15 Thermal membrane processes
- Technologies: membrane distillation
- Applications: desalination, concentration, energy, ..

10.45 Break

11.00 Visit of labs and pilot hall

12.30 Lunch

13.00 Registration additional participants for Module 5

MODULE 5: Advanced product recovery (in collaboration with ButaNEXT project)

13.30 Process intensification in biocatalytic processes
- Background and rationale
- Approaches and concepts

14.00 Case study: *in situ* product recovery in butanol fermentation
- Configurations and set-ups
- Lab-scale feasibility and optimization tests
- Pilot-scale tests
- Techno-economics

15.00 Break

15.15 Process intensification by hybrid separation processes
- How to determine feasible combinations?
- Systematic design and evaluation

16.00 Process intensification in chemistry and pharma
- Clever ways to integrate membranes in chemical, catalytic and enzymatic processes
- Benefits and techno-economics
- New developments

16.45 Discussion

17.00 Conclusions followed by drinks and networking

Registration

The number of places is limited.
You can register via https://apps01.vito.be/vitoevents/inschrijving/MembraneTechnologyCourse2017.aspx
You will receive a confirmation of your registration.

Price

575€ VAT incl.

What is included in the price?

2-day course, handouts, participant list, coffee breaks and lunches, networking drink on May 11.

Questions?

For all questions about the programme, please contact
Metin Bulut at VITO
metin.bulut@vito.be
Tel.: +32 14 33 56 51

Location

Lakehouse VITO/SCK
Boeretang 201
2400 MOL
Belgium

Roadmap: www.vito.be/contact
GPS: Gravenstraat-Boeretang

Courses & lecture material

MEMBRANE COURSE - VITO 2017

Day 1

09:00 Registration & coffee

MODULE 1: Membrane technology: principles and process operation

09:30 Basic principles of membrane technology
Metin Bulut, VITO

10:00 Process operation and techno-economics
Metin Bulut, VITO

11:00 Break

11:15 Case studies @ VITO
Metin Bulut, VITO

12:30 Lunch

MODULE 2: Pressure driven separations: principles and applications

13:30 Pressure driven membrane processes
Chris Dotremont, VITO

14:15 Combination of pressure driven membrane filtration with bioprocesses
Heleen De Wever, VITO

15:00 Break

MODULE 3: Electroseparations: principles and applications

15:15 Electrodialysis
Wim De Schepper, VITO

16:15 Capacitive deionization
Joost Helsen, VITO

17:00 Closure

Day 2

PROGRAM DAY 2: THURSDAY, MAY 11TH 2017

09:00 Arrival and coffee

MODULE 4: Downstream processing: membrane development and applications

09:15 Solvent filtration
Pieter Vandezande, Anita Buekenhoudt, VITO

10:15 Thermal membrane processes
Kris De Sitter, VITO

10:45 Break

11:00 Transfer to VITO premises and visit of labs and pilot hall

12:30 Lunch

MODULE 5: Advanced product recovery (in collaboration with ButaNEXT project)

13:30 Process intensification in biocatalytic processes
Heleen De Wever, VITO

14:00 Case study: in situ product recovery in butanol fermentation
Wouter Van Hecke, VITO

15:00 Break

15:15 Process intensification by hybrid separation processes
Mirko Skiborowski, TU Dortmund

16:00 Process intensification in chemistry and pharma
Dominic Ormerod, VITO

16:45 Discussion

17:00 Conclusions followed by drinks and networking

Courses & lecture material

MEMBRANE COURSE - VITO 2022

Day 1 – 26.09.2022

12:00 - 13:15	Lunch
13:15 - 13:30	**Welcome** *Roel Vleeschouwers, Business Development Manager*
SESSION 1:	MEMBRANE TECHNOLOGY: PRINCIPLES AND PROCESS OPERATION
13:30 - 14:20	**Introduction and basic principles** *Pieter Vandezande, Senior Research Scientist* • Basic principles and terminology • Benefits and triggers • Overview membrane processes • Materials, membranes/modules and unit operations • Performance parameters
14:20 - 15:20	**Process design and operation** *Pieter Vandezande & Sara Salvador Cob, Senior Research Scientists* • From module configuration to process design • Membrane fouling and cleaning • Practical aspects and points of attention
15:20 - 15:40	Coffee break
SESSION 2:	PRESSURE-DRIVEN SEPARATION PROCESSES: PRINCIPLES AND APPLICATIONS
15:40 - 16:50	**Pressure-driven membrane processes** *Sara Salvador Cob, Senior Research Scientist* • Technologies: micro-, ultra-, nanofiltration, reverse osmosis • Applications: process and drinking water production, water production, wastewater treatment and reuse, process applications, etc.
16:50 - 18:00	**Industrial applications and case studies VITO** *Pieter Vandezande & Sara Salvador Cob, Senior Research Scientists* • From lab-scale feasibility studies to piloting and industrial implementation • Techno-economic evaluation • Calculation exercises

Day 2 – 27.09.2022

08:30 - 08:45	Arrival and coffee
SESSION 3:	SOLVENT-BASED SEPARATION PROCESSES: PRINCIPLES AND APPLICATIONS
08:45 - 09:40	**Organic solvent nanofiltration** *Anita Buekenhoudt, Senior Research Scientist* • Molecular scale membrane processes for chemical process intensification • Benefits, drivers and unit operations • Membranes, market and technology readiness • Advanced membrane design/tailoring • Challenges and trends
09:40 - 10:35	**Solvent-based membrane processes for chemical process intensification** *Dominic Ormerod, Senior Research Scientist* • Industrial reference applications in chemical, pharma and food industries • Product purification and concentration, solvent recovery, catalyst recovery, etc. • Recent case studies VITO • New developments
10:35 - 10:55	Coffee break
10:55 - 11:40	Invited speaker 1 **Module options for scaling up OSN flat sheet membranes for commercial plants** *Robin Wilmshöfer, BORSIG Membrane Technology GmbH, Germany*
11:40 - 12:30	**Pervaporation** *Pieter Vandezande, Senior Research Scientist* • Basic principles, membranes and technology readiness • Application for solvent reclamation: dehydration, water treatment, organic/organic separations, etc. • Industrial reference and emerging applications
12:30 - 13:30	Lunch
13:30 – 18:00	Departure to VITO, Mol (in group, by bus), **Site visit Mol,** transport back to Antwerp
19:00	Dinner (optional)

Day 3 – 28.09.2022

08:30 - 08:45	Arrival and coffee
08:45 - 09:30	Invited speaker 2 **Advanced Organic Solvent Nanofiltration in food & pharma industry: from scratch to production scale within 3 years** *Roman Goy, DSM, Switzerland*
09:30 - 10:15	Invited speaker 3 **Created value by deploying membrane technology: An industrial perspective** *Daniel Bergmair, Evonik GmbH, Germany*
10:15 - 10:35	Coffee break
SESSION 4:	OTHER MEMBRANE PROCESSES AND APPLICATIONS
10:35 - 11:30	**Electro-membrane processes** *Wim De Schepper, Senior Research Scientist* • Basic principles, drivers and technology readiness • Electrodialysis and Capacitive deionization • Industrial applications and VITO cases
11:30 - 12:20	**Membrane contactor processes** *Kris De Sitter, Senior Research Scientist* • Basic principles, drivers and technology readiness • Membrane distillation and extraction • Industrial applications and VITO cases
12:20 - 13:20	Lunch
13:20 - 14:20	**Membranes for bioprocesses** *Heleen De Wever & Yamini Satyawali, Senior Research Scientists* • Intensification of biocatalytic processes • Integrated product recovery • Industrial applications and VITO cases
14:20 - 14:35	**Conclusions and closure of plenary programme**
SESSION 5:	INTERACTIVE WORKSHOPS (OPTIONAL)

Radisson Blu Astrid,
Antwerp (Belgium)

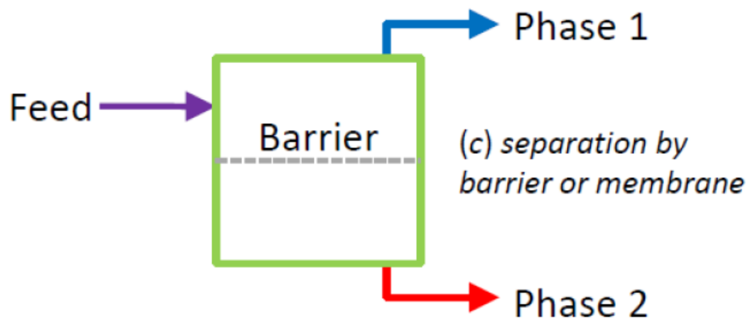
10th Membrane Technology Course:
Membranes for sustainable industrial processes

Courses & lecture material

MEMBRANE TECHNOLOGY LECTURE SERIES – ASTON UNIVERSITY

Lecture series on membrane technology in the course Advanced Mass Transfer at AU

- Lecture 6 - General features of membrane and membrane separation
- Lecture 7 - Transport (liquid application) through porous membranes
- Lecture 8 - Transport (gas) through dense membranes
- Lecture 9 - Dense membrane for liquids
- Lecture 10 - Dialysis and pervaporation



Lecture location: Training & technology database (.zip)

For more information on this course, contact **dr. Zhentao Wu**

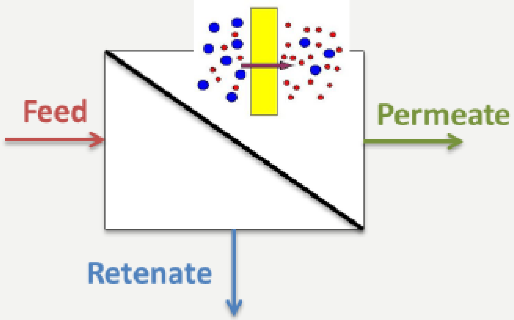
- E-mail: z.wu7@aston.ac.uk
- Department: Chemical Engineering, School of Engineering and Applied Science, Aston University

Lecture 6 - General features of membrane and membrane separation - Overview

➢ General features – brief introduction

What is a "Membrane"?

Membrane is a ***selective barrier*** *allowing something to pass through but stopping the others*



What can it do?

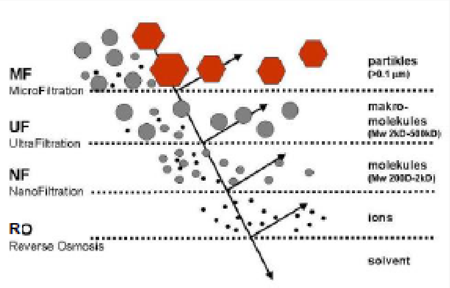
& More

How does this "selective barrier" work?

Driven by Pressure
or
Concentration

Size exclusion

Solution diffusion



How to evaluate a membrane ?

- **Permeation**
- **Selectivity**

Lecture 7 - Transport (liquid application) through porous membranes - Overview

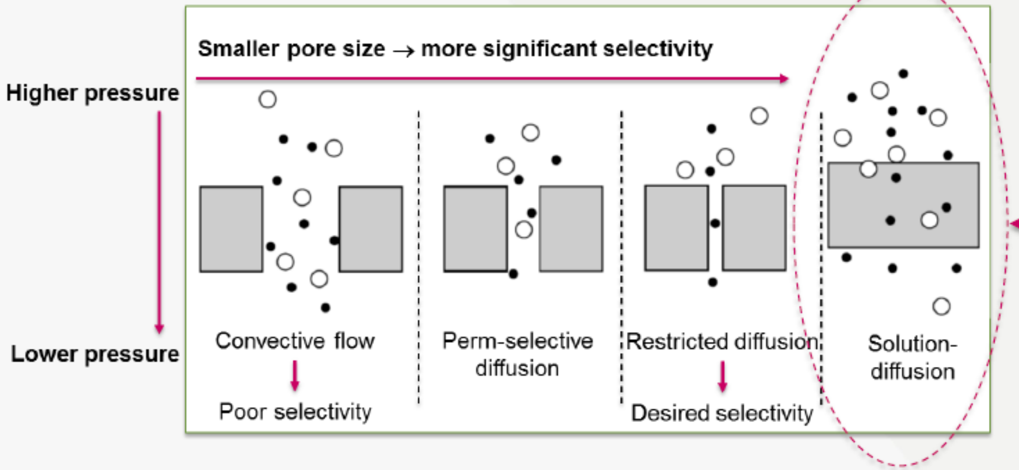
Filtration – transport through porous membranes

- Darcy's law
- Filtration resistance model
- Cake formation model

Lecture 8 - Transport (gas) through dense membranes - Overview

Gas separation-Transport through **dense** membranes

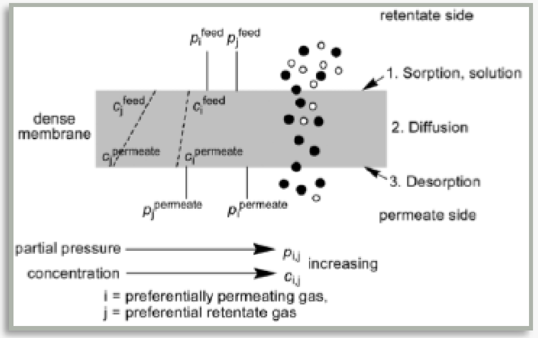
- Mass transfer and separation selectivity
- Module modelling for Perfect mixing and ideal Crossflow patterns
- Cascade arrangement

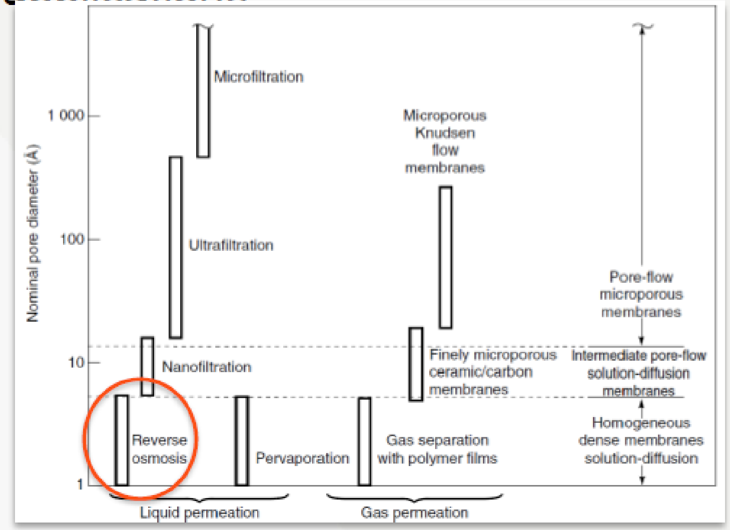


For liquid and gas diffusion through porous membranes, please refer to the recommended books

Lecture 9 - Dense membrane for liquids - Overview

- Osmosis and osmosis pressure
- Forward osmosis and applications
- Reverse osmosis mass transfer through membranes
- Concentration polarization
- Reverse osmosis process and applications

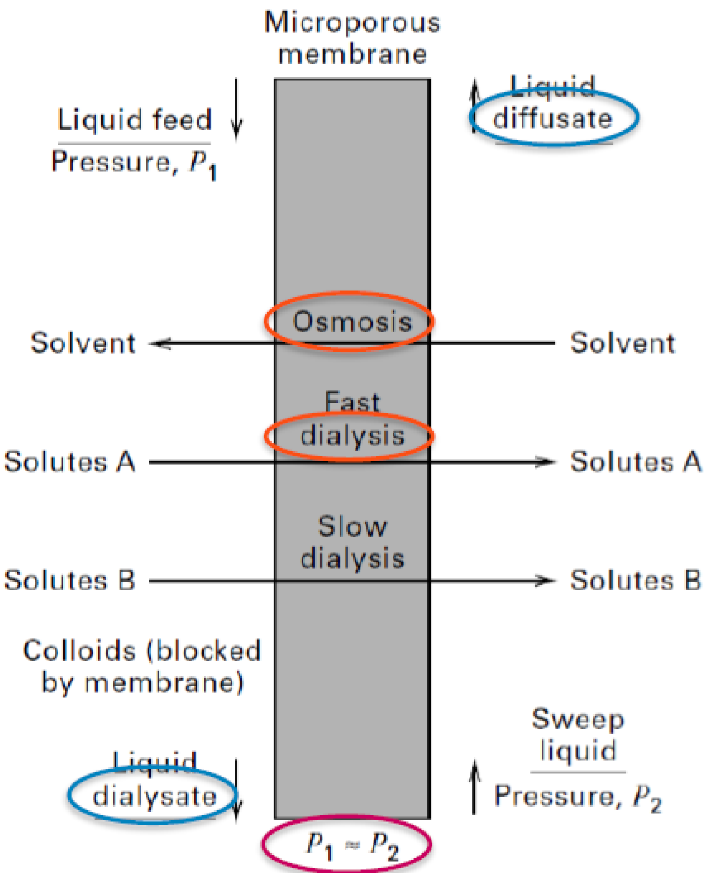




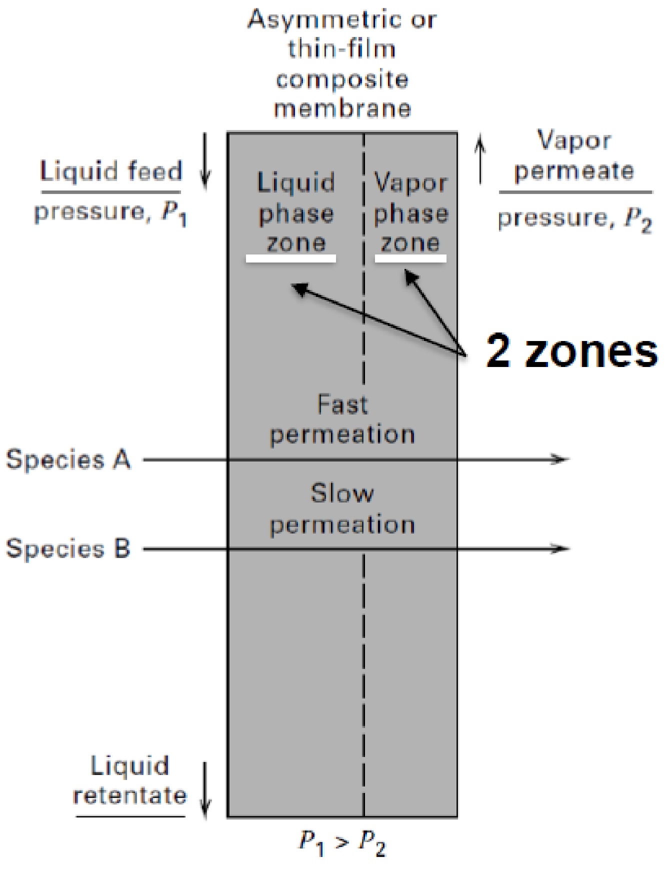
Lecture 10 - Dialysis and pervaporation - Overview

- Dialysis
- Pervaporation
- Exercise

Dialysis



Pervaporation



Courses & lecture material

MEMBRANE TECHNOLOGY LECTURE – CNR-ITM LECTURE APPLICATION OF MEMBRANES

- PhD course at the University of Calabria - SIACE Doctorate School
    1. Introduction
    2. Fundamentals of gas separation and membrane reactors
    3. Membranes for gas separation and membrane reactors
    4. Process intensification and Membrane Engineering
    5. Membrane-assisted processes examples
        - Hydrogen separation, purification, upgrading.
        - Hydrogen production
        - CO_2 separation
        - CO_2 conversion by catalytic and photocatalytic membrane reactors
        - Recovery of water vapour from waste gaseous streams
- Other activities: Dissemination activities for SuperscienceMe - at elementary, middle, and high schools.

For more information, contact **dr. Giuseppe Barbieri**:

- E-mail: g.barbieri@itm.cnr.it
- National Research Council of Italy - Institute on Membrane Technology, Rende (CS)

Courses & lecture material

SEPARATION TECHNOLOGY LECTURE SERIES – HEREON

Gas Separation and Pervaporation for Biorelated Systems at HEREON

1. Introduction
2. Mass transfer through dense, polymeric membranes
3. Membrane modules
4. Modelling and simulation
5. Process examples
    a) Gas permeation: biogas processing
    b) Gas permeation: CO2 separation
    c) Pervaporation: production of aroma compounds

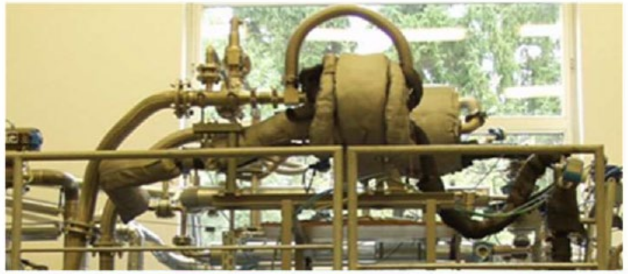
Lecture location: Training & technology database (.zip)

For more information, contact **dr. Torsten Brinkmann** :

- E-mail: torsten.brinkmann@hereon.de
- Department: Institute of Membrane Research, Hereon

Hereon GP Pilot Plant

Hereon VP Pilot Plant



Courses & lecture material

SEPARATION TECHNOLOGY LECTURE SERIES – HEREON

Vapour Permeation and Pervaporation

1. Introduction
2. Fundamentals of pervaporation and vapour permeation
3. Membranes for pervaporation and vapour permeation
4. Membrane modules
5. Process examples

Lecture location: Training & technology database (.zip)

For more information, contact **dr. Torsten Brinkmann**

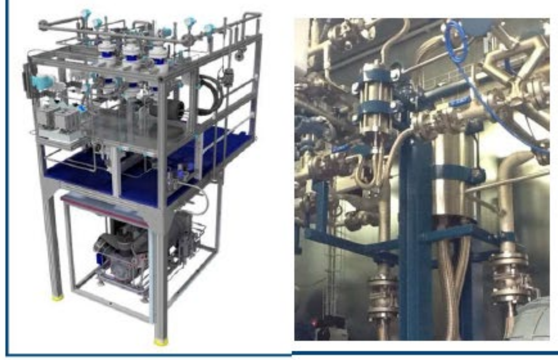
- E-mail: torsten.brinkmann@hereon.de
- Department: Institute of Membrane Research, Hereon

Membrane process development: entire R&D pathway

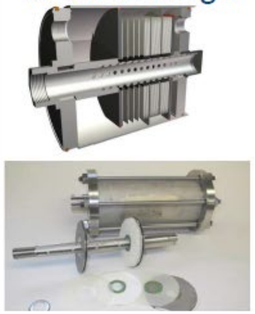
Lab. scale investigations
- Polymer synthesis
- Polymer modification
- Permeation behaviour

Pilot scale membrane production

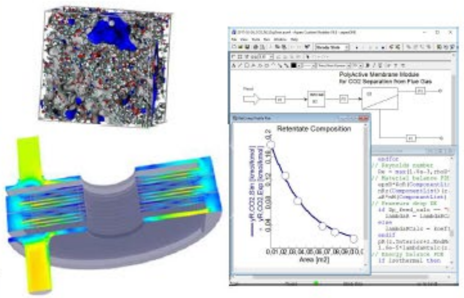
Pilot plants



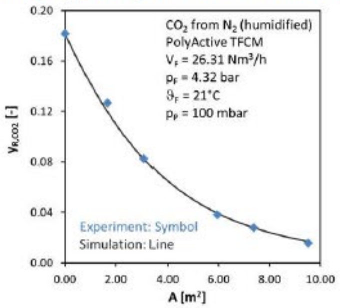
Module design



Modelling and simulation



Comp. pilot plant/simulation



Courses & lecture material

SEPARATION TECHNOLOGY BSC. LECTURE SERIES – TUE

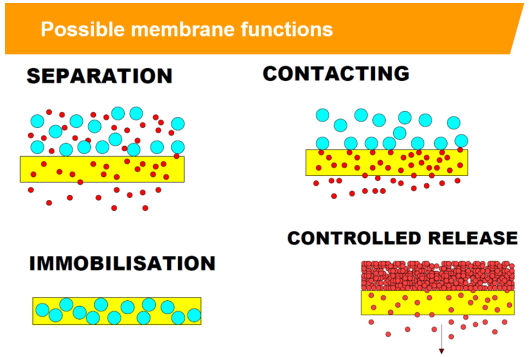
Membrane separations

- Membrane: Why?
- Membrane: What?
- Membranes: How many?
- Membrane separation: How?
- Membrane production
- Membrane modules
- Application of Membranes in Water treatment
- Novel possible Applications (membrane reactors)
- Conclusions

Lecture location: Training & technology database (.zip)

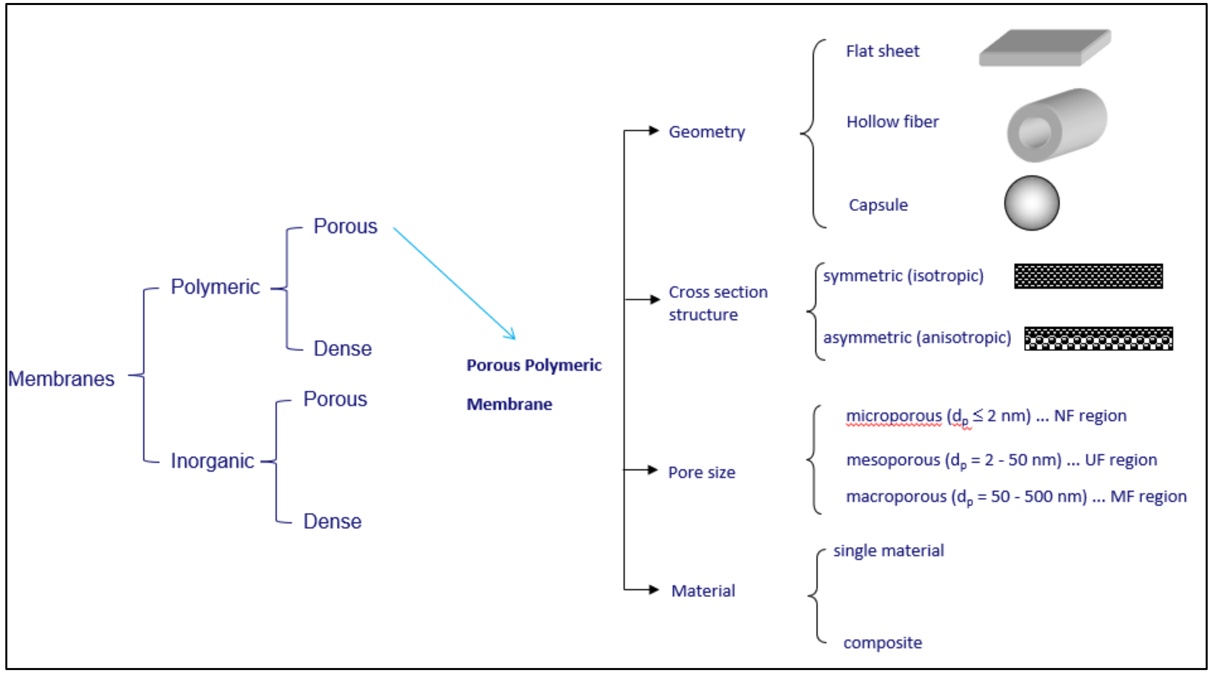
For more information, contact **dr. Fausto Gallucci**:

- E-mail: f.gallucci@tue.nl
- Department: Inorganic Membrane and Membrane Reactors, Chemical Engineering, Technical University of Eindhoven



Learning objectives

- Be able to describe what is a membrane
- Be able to select a specific membrane for a given process
- Be able to calculate the membrane flux and membrane area required for a separation
- Be able to describe the membrane production processes
- Be able to describe membrane fouling and concentration polarization phenomena



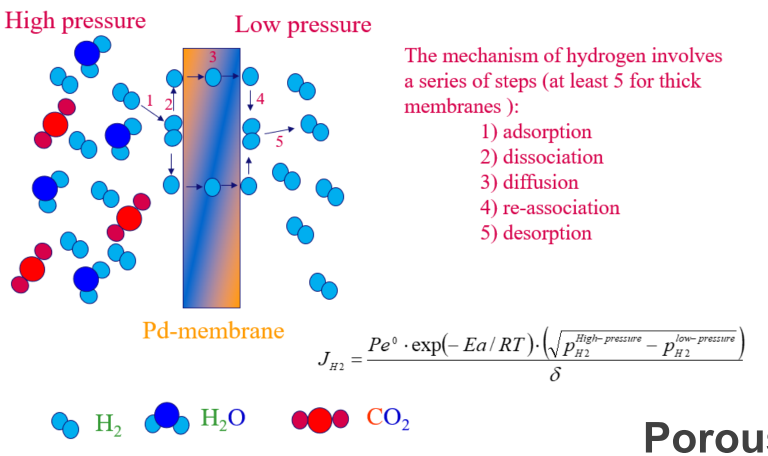
Courses & lecture material

ADVANCED SEPARATION TECHNOLOGY MSC. LECTURE SERIES – TUE

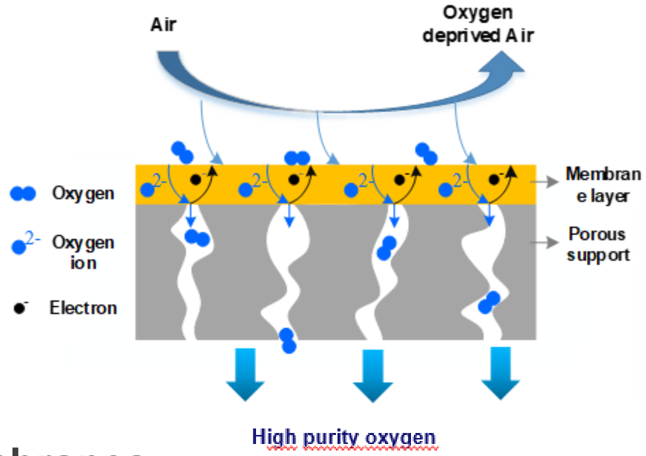
Inorganic membranes

- Dense Membranes for O2 and H2
- Zeolite membranes
- Carbon membranes

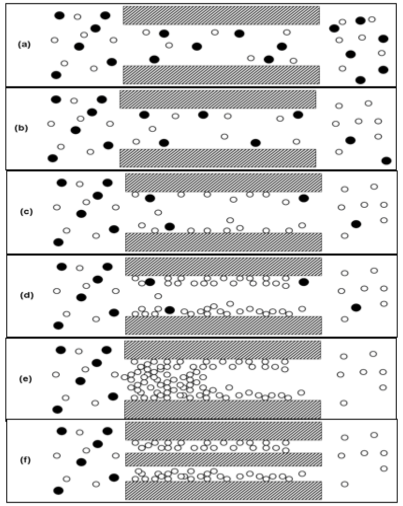
Palladium based membranes



Perovskite based membranes



Porous membranes



Poiseuille (viscous) mechanism

Knudsen mechanism

Surface diffusion

Multi-layer diffusion

Capillary condensation

Molecular Sieving

Lecture location: Training & technology database (.zip)

For more information, contact **dr. Fausto Gallucci**:

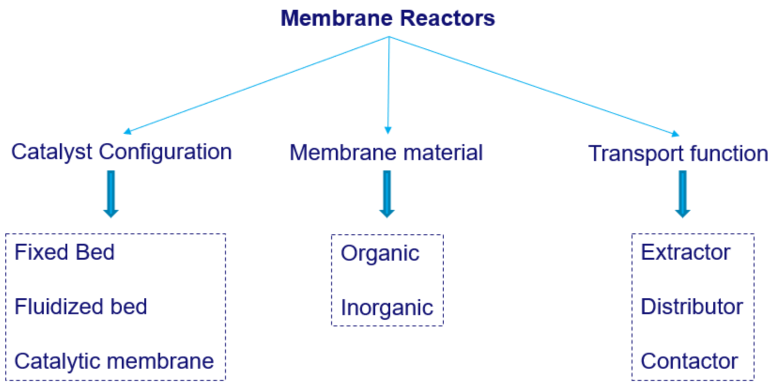
- E-mail: f.gallucci@tue.nl
- Department: Inorganic Membrane and Membrane Reactors, Chemical Engineering, Technical University of Eindhoven

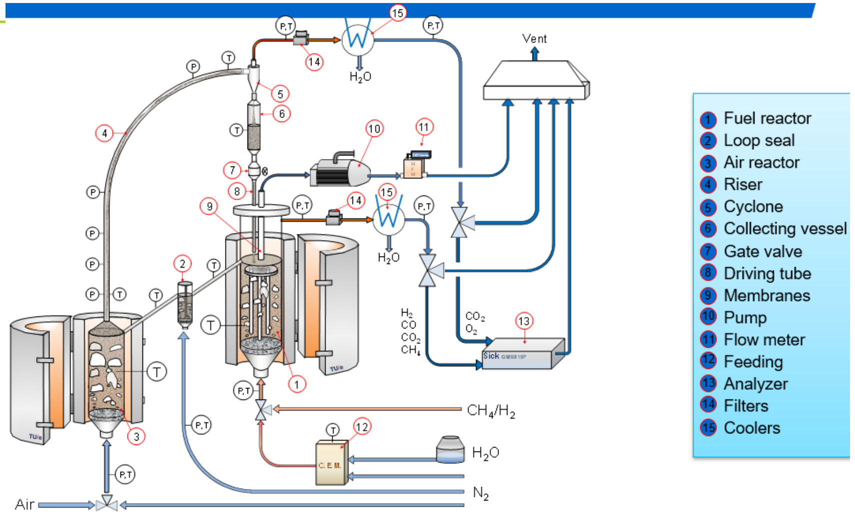
Courses & lecture material

ADVANCED SEPARATION TECHNOLOGY MSC. LECTURE SERIES – TUE

Membrane reactors

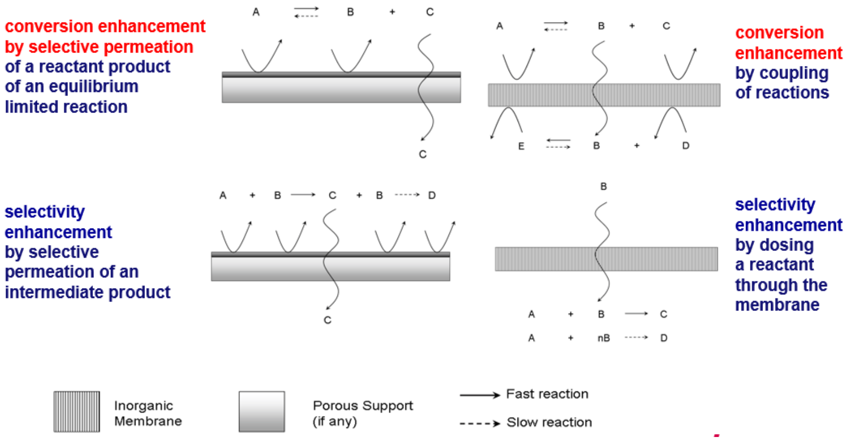
- Membrane reactor concept
- Examples
- Membrane reactors types
- Membrane Reactor Modeling





Membrane reactor concept

Main application opportunities of inorganic membrane reactors



Lecture location: Training & technology database (.zip)

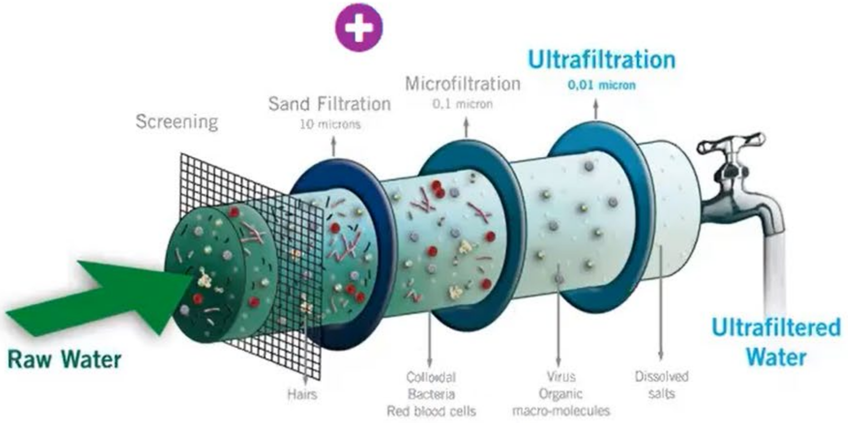
For more information, contact **dr. Fausto Gallucci**:

- E-mail: f.gallucci@tue.nl
- Department: Inorganic Membrane and Membrane Reactors,

Chemical Engineering, Technical University of Eindhoven

Courses & lecture material

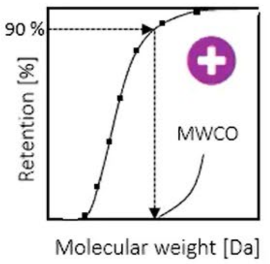
ULTRA- AND MICROFILTRATION VIRTUAL LAB TOUR VIDEO – RWTH

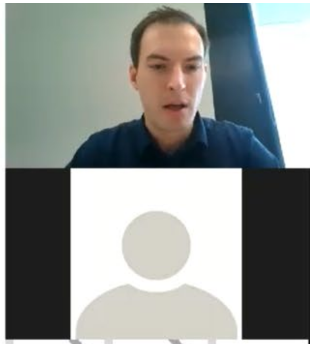


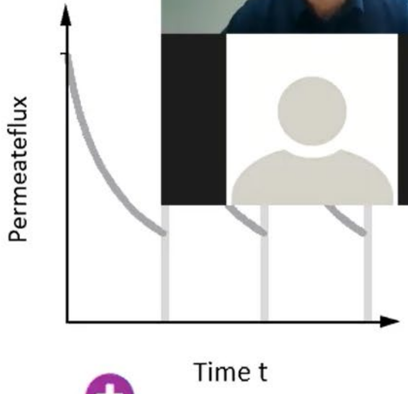
Permeability

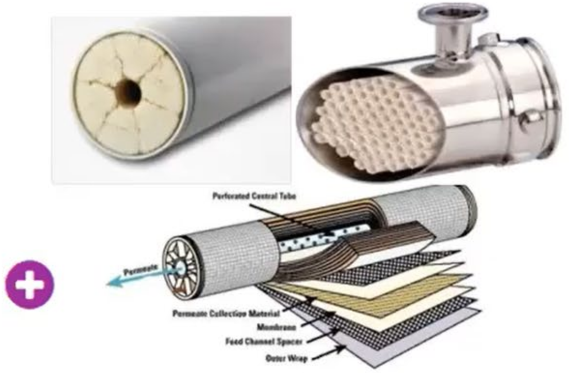
$$Q = \frac{L}{m^2 \cdot h \cdot bar} = [\frac{LMH}{bar}]$$

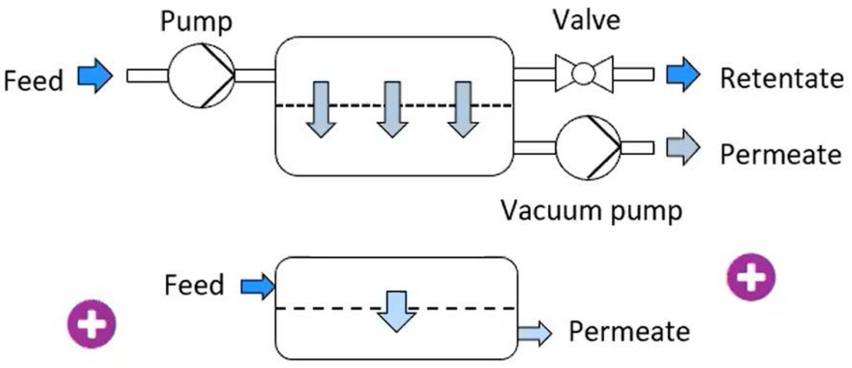
Molecular weight cut-off (MWCO)











Lecture video location: Training & technology database (.zip)

INNOMEM CATALOGUE

Research output

Research output

RESEARCH PAPERS – SHOWCASE 3 (Mixed matrix membranes for liquid and gas separation)

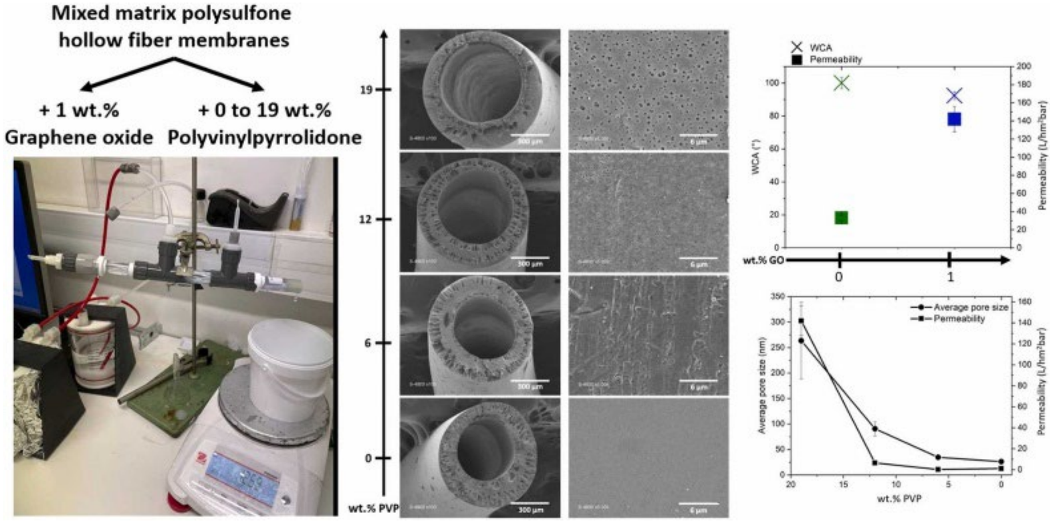
- **Polymeric hollow fiber (HF) mixed matrix membranes (MMMs): Mutual effect of graphene oxide (GO) and polyvinylpyrrolidone (PVP) on nano-structuration**

J. Casetta, E. Virapin, C. Pochat-Bohatier, M. Bechelany, P. Miele, Polymeric hollow fiber (HF) mixed matrix membranes (MMMs): Mutual effect of graphene oxide (GO) and polyvinylpyrrolidone (PVP) on nano-structuration, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 681, 2024, 132805, https://doi.org/10.1016/j.colsurfa.2023.132805

Summary: Hollow fiber (HF) membranes were fabricated using polysulfone (PSF) and 1.0 wt.% graphene oxide (GO) synthesized through Hummer's method. The outcomes highlighted favorable mechanical and thermal characteristics thanks to a good dispersion of GO. The addition of GO leads to the formation of larger pores. Results showed that a porogent agent is still necessary to favor the porous structure of the membrane because GO cannot substitute it.

Highlights

- Polysulfone mixed matrix membranes were synthetized by spinning process.
- Successful dispersion of 1 wt% Graphene Oxide (GO) was evidenced.
- GO modified membranes exhibited larger pore sizes and a fourfold rise in permeability.
- GO cannot substitute a porogen agent like polyvinylpyrrolidone.
- GO potentially stabilizes polymer lean-phase growth to form larger pores.



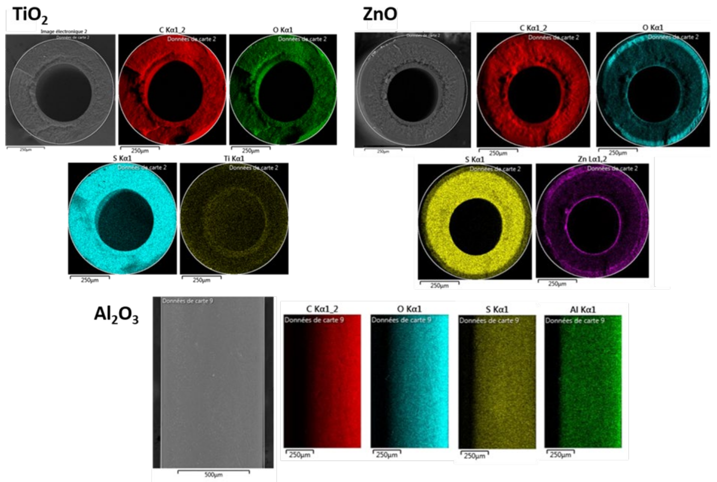
Research output

RESEARCH PAPERS – SHOWCASE 3 (Mixed matrix membranes for liquid and gas separation)

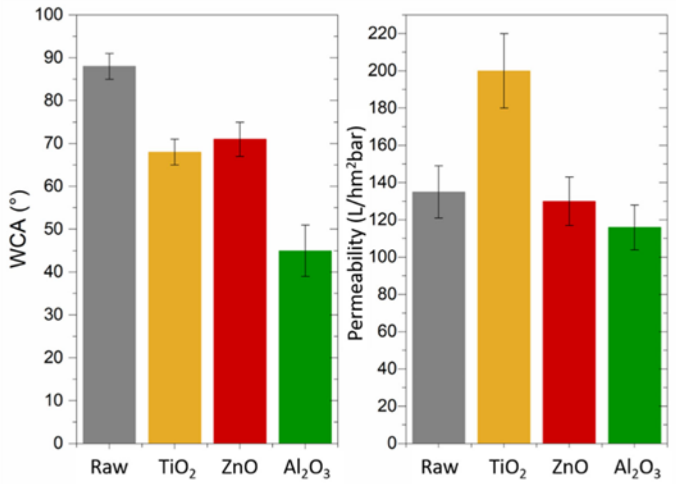
- **Enhancing Water Treatment Performance of Porous Polysulfone Hollow Fiber Membranes through Atomic Layer Deposition**

J. Casetta, C. Pochat-Bohatier, D. Cornu, M. Bechelany, P. Miele, Enhancing Water Treatment Performance of Porous Polysulfone Hollow Fiber Membranes through Atomic Layer Deposition. Molecules 2023, 28, 6133. https://doi.org/10.3390/molecules28166133

Summary: Atomic layer deposition (ALD) stands as a distinctive technology offering exceedingly even and uniform layers of coatings, like oxides that cover the surfaces of objects with three-dimensional (3D) shapes, porous structures, and particles. In the context of this study, the focus was on titanium dioxide (TiO_2), zinc oxide (ZnO), and alumina (Al_2O_3), which were deposited on polysulfone hollow fiber (HF) membranes via ALD using $TiCl_4$, diethyl zinc (DEZ), and trimethylamine (TMA), respectively, and H_2O as precursors. The morphology and mechanical properties of membranes were changed without damaging their performances. The deposition was confirmed mainly by energy-dispersive X-ray spectroscopy (EDX).



EDX mapping of TiO_2, ZnO (cross section) and Al_2O_3 (surface) modified PSF HF membranes.



Water Contact Angle (WCA) and Water permeability of raw and TIO_2-, ZNO-, and Al_2O_3 modified membranes

Research output

RESEARCH PAPERS – SHOWCASE 3 (Mixed matrix membranes for liquid and gas separation)

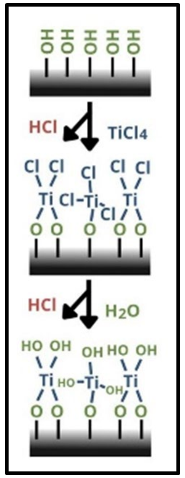
- **Atomic layer deposition of TiO_2 on porous polysulfone hollow fibers membranes for water treatment**

J. Casetta, D. Gonzalez Ortiz , C. Pochat-Bohatier, M. Bechelany, P. Miele, Atomic layer deposition of TiO_2 on porous polysulfone hollow fibers membranes for water treatment, Separation and Purification Technology 312 (2023) 123377 https://doi.org/10.1016/j.seppur.2023.123377

Summary: Titanium dioxide (TiO_2) was deposited on polysulfone hollow fibers (HF) membranes via Atomic layer deposition (ALD) using $TiCl_4$ and H_2O as precursors. Membranes obtained with increasing number of deposition ALD cycles were tested until the pores were totally blocked. The morphology, structure and mechanical properties of membranes were not altered. The deposition was confirmed by scanning electron microscopy (SEM), Energy-dispersive X-ray spectroscopy (EDX) and X-ray Photoelectron Spectroscopy (XPS) analyses. The deposition of TiO_2 enhanced by 50% the water permeability and by 20% the fouling resistance of the PSF HF membranes until only 20 ALD cycles. This is accompanied by an increase of hydrophilicity and a pores size reduction.

Highlights

- TiO_2 thin layer deposition on porous polysulfone hollow fiber via ALD was developed.
- The deposition was confirmed by different physicochemical characterizations.
- The mechanical properties were not altered.
- The surface modified membranes exhibited enhanced hydrophilicity.
- BSA protein rejection and water permeability were increased after 10 ALD cycles.



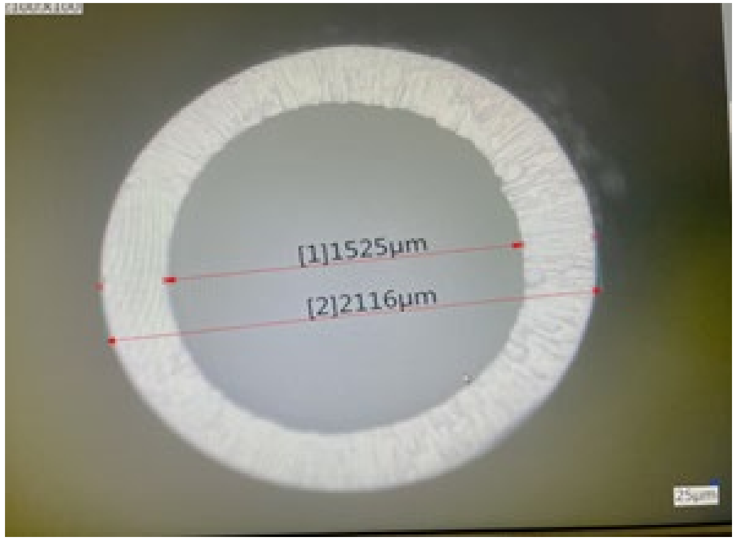
Research output

RESEARCH PAPERS – SHOWCASE 5 (Micro-Tubular And Micro-Monolith Ceramic Membranes)

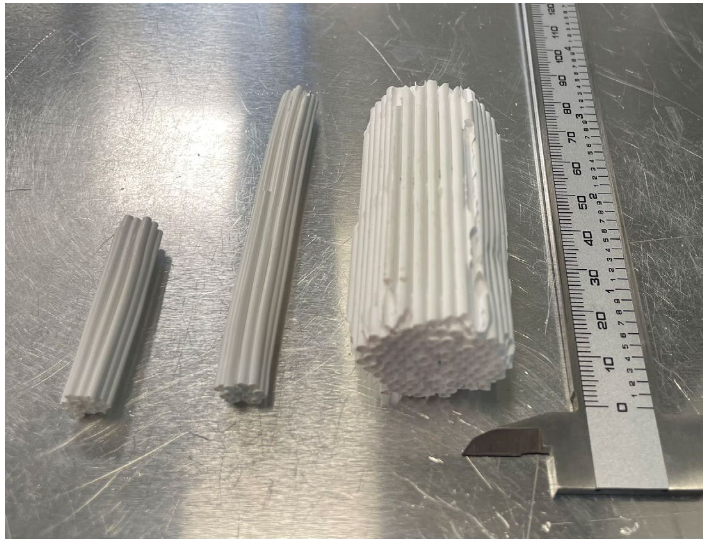
- **Re-invent the catalytic converter with micro-structured hollow fiber substrate**

Peng Yan, Victor M. Candelario Leal, Mahesan Subramaniam, Zhentao Wu, and Kang Li, Re-invent the catalytic converter with micro-structured hollow fiber substrate, Conference book of 16th International Conference on Catalyst in Membrane Reactors (ICCMR16-2023)

Summary: A micro-structured hollow fiber substrate is developed as a catalytic converter; state-of-the-art catalyst are developed and incorporated into innovative substrate; the monolith with various lengths or diameters are successfully manufactured; the final catalytic converter based on innovative substrate and advanced catalyst is much smaller than conventional one



Innovative micro-structured ceramic hollow fibre substrate



The monoliths assembled from innovative micro-structured hollow fiber substrate

Research output

RESEARCH PAPERS – SHOWCASE 5 (Micro-Tubular And Micro-Monolith Ceramic Membranes)

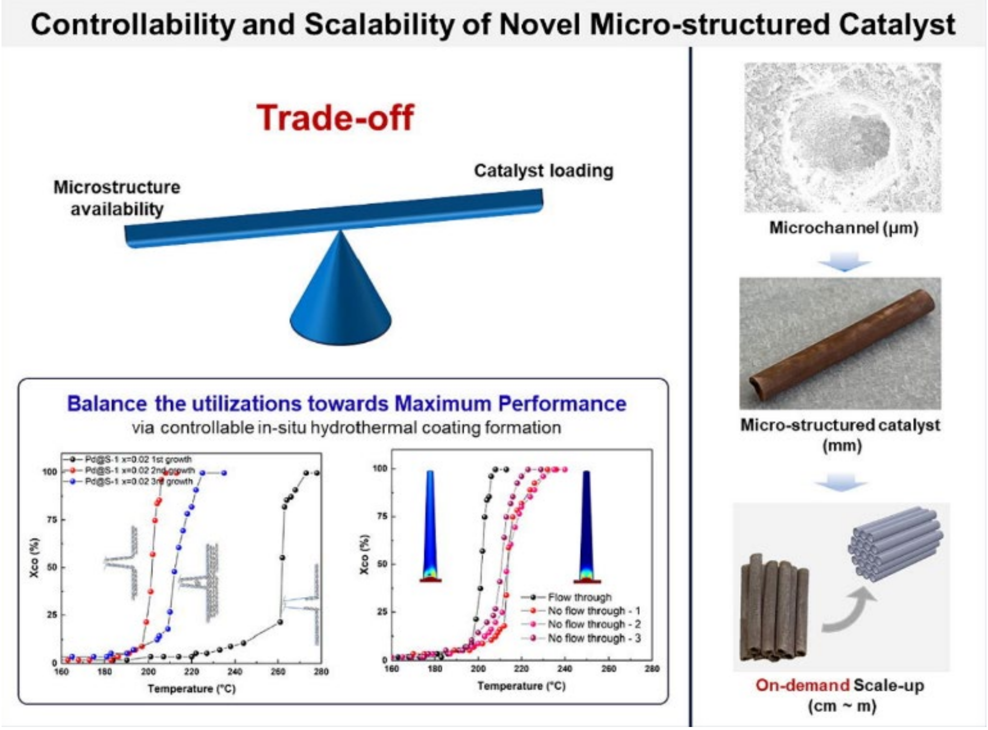
- **Readily scalable and controllable micro-structured catalyst with encapsulated Pd@Silicate-1 towards sustainable catalytic emission control**

P. Yan and K. Li, "Readily scalable and controllable micro-structured catalyst with encapsulated Pd@Silicate-1 towards sustainable catalytic emission control," Chemical Engineering Science, p. 120037, Mar. 2024, doi: 10.1016/j.ces.2024.120037.

Summary: In-situ hydrothermal coating method is developed to achieve tunable incorporation of Pd@S-1 catalyst into micro-structured confined space, and the trade-off between catalyst loading and confined micro-structures' availability towards the best performance is revealed, e.g. 10 ~ 50 °C lower T50 with balanced control. Moreover, systematic experiments and CFD simulations prove that (1) flow-through flow pattern, rather than flow-over, in confined space enables better catalyst utilization and performance (>10 °C lower T50), thus optimal micro-structure design is proposed; (3) a loosely bundled scale-up method is the best.

Highlights:

- Trade-off phenomenon is identified in novel micro-structured catalyst.
- Controllable catalyst loading in micro-structured confined space is achieved.
- Flow-through flow pattern intensifies catalytic performance over the flow-over pattern.
- In-parallel loosely bundled method is proposed to on-demand scale-up.



Research output

UNIVERSITÄT DUISBURG ESSEN

EVONIK Leading Beyond Chemistry

RESEARCH PAPERS – SHOWCASE 9 (Anion-conducting membrane to be used in alkaline water electrolysis to produce H2)

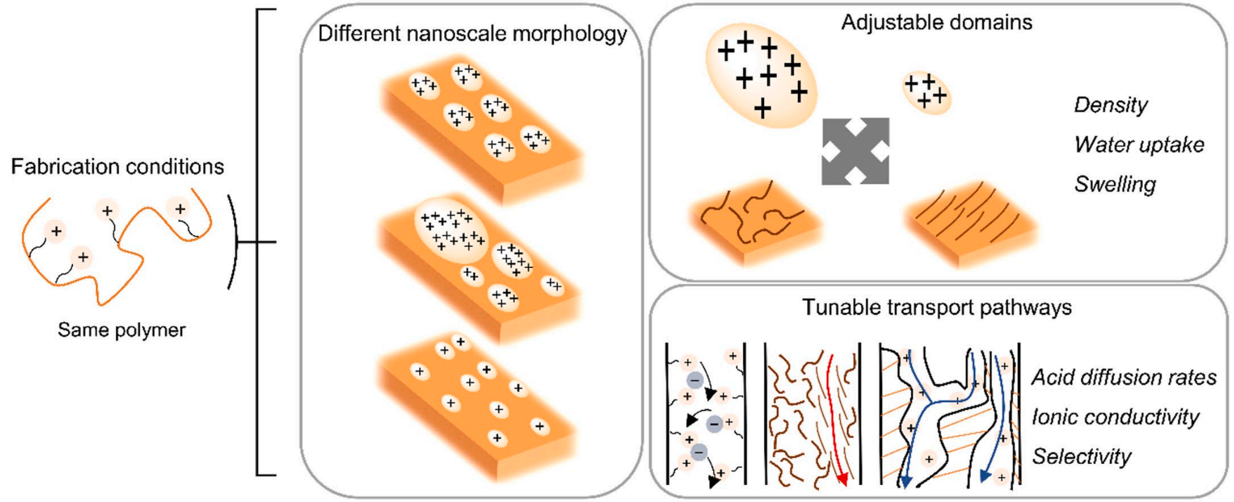
- **The influence of anion-exchange membrane nanostructure onto ion transport: Adjusting membrane performance through fabrication conditions**

L. Fischer, S. S. Hartmann, A. Maljusch, C. Däschlein, O. Prymak, and M. Ulbricht, “The influence of anion-exchange membrane nanostructure onto ion transport: Adjusting membrane performance through fabrication conditions,” Journal of Membrane Science, vol. 669, p. 121306, Mar. 2023, doi: 10.1016/j.memsci.2022.121306.

Summary: We fabricated dense anion-exchange membranes from the same polymer with variations in the self-assembled hydrophilic and hydrophobic domains. We show how the nanostructure forms during membrane formation and how it can be tuned by rationally designing fabrication conditions.

Highlights:

- Altering polymeric anion-exchange membrane nanostructure solely through fabrication conditions.
- New insights into the mechanism of nanophase segregation during membrane formation.
- Three different ion transport mechanisms found depending on ion species.
- Ion transport rates selectively tuned through fabrication conditions.
- Increases of ionic conductivity by 500% and of acid diffusion rates by 300% for same polymer at same thickness.



Research output

RESEARCH PAPERS - OTHER

- **A new relevant membrane application: CO2 direct air capture (DAC)**

R. Castro-Muñoz, M. Zamidi Ahmad, M. Malankowska, and J. Coronas, “A new relevant membrane application: CO2 direct air capture (DAC),” Chemical Engineering Journal, vol. 446, p. 137047, Oct. 2022, doi: 10.1016/j.cej.2022.137047.

Highlights:

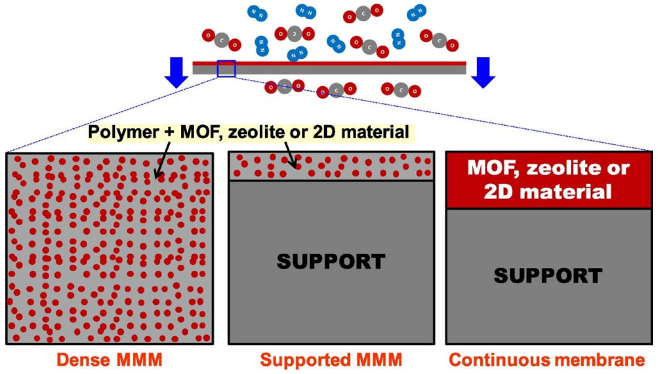
- Membranes as a promising tool for CO2 capture.
- A perspective on direct air capture (DAC) from atmosphere is given.
- Process considerations to make DAC feasible are addressed.
- Advantages and drawbacks of membranes over other DAC technologies are provided.
- An outlook of DAC using membranes is elucidated.

- **Towards large-scale application of nanoporous materials in membranes for separation of energy-relevant gas mixtures**

R. Castro-Muñoz, K. V. Agrawal, Z. Lai, and J. Coronas, “Towards large-scale application of nanoporous materials in membranes for separation of energy-relevant gas mixtures,” 2023, doi: 10.13039/501100004961.

Highlights:

- A review on membranes for separation of energy-relevant gas mixtures is timely reported.
- The opportunities and challenges in applying porous materials in membranes are declared.
- A discussion on limitations and possible improvements of the current membrane systems is addressed.
- Key aspects in highly intensified membrane modules is provided



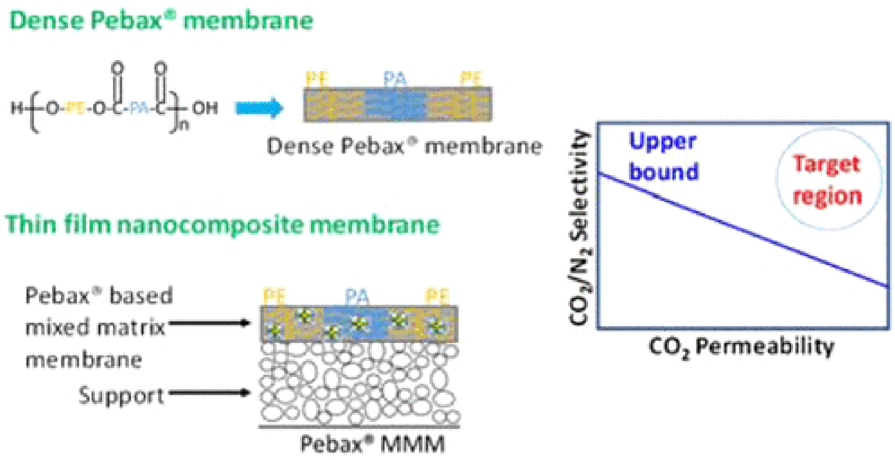
Research output

RESEARCH PAPERS - OTHER

- **Poly(ether-block-amide) Copolymer M embranes in CO2 Separation Applications**

A. S. Embaye, L. Martínez-Izquierdo, M. Malankowska, C. Téllez, and J. Coronas, “Poly(ether-block-amide) Copolymer Membranes in CO2 Separation Applications,” Energy Fuels, vol. 35, no. 21, pp. 17085–17102, Nov. 2021, doi: 10.1021/acs.energyfuels.1c01638.

Summary: Poly(ether-block-amide) (PEBA, commercialized as Pebax) copolymer membranes show a highly promising platform for preparing high-performance membranes for CO2 capture from process streams containing CH4 and N2. Pebax combines high CO2 affinity with the desired mechanical strength for polymeric membranes thanks to its flexible polyether segment and hard polyamide block, respectively. Furthermore, researchers have been improving the performance of these membranes by preparing a thin Pebax selective layer on top of porous supports and by incorporating inorganic and organic nanofillers into the Pebax matrix to overcome the permeance-selectivity limit. The chemical and structural characteristics of Pebax membranes according to the different fabrication techniques and parameters are discussed first. Then, the recent developments in terms of both Pebax-based thin film composite and mixed matrix membranes are summarized. Finally, thermal and water stabilities of these membranes are addressed.



Research output

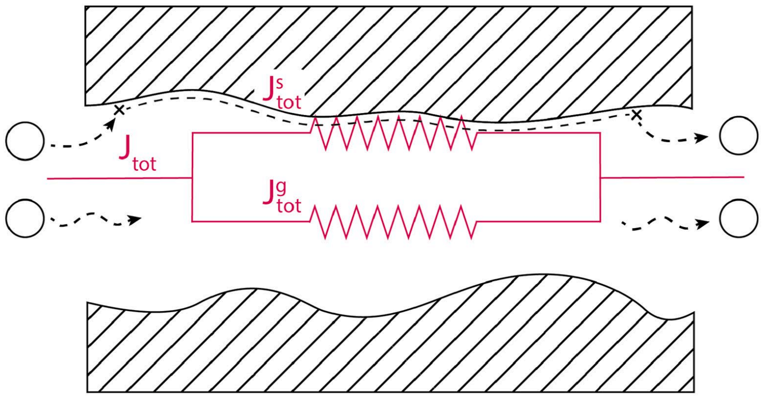
RESEARCH PAPERS - OTHER

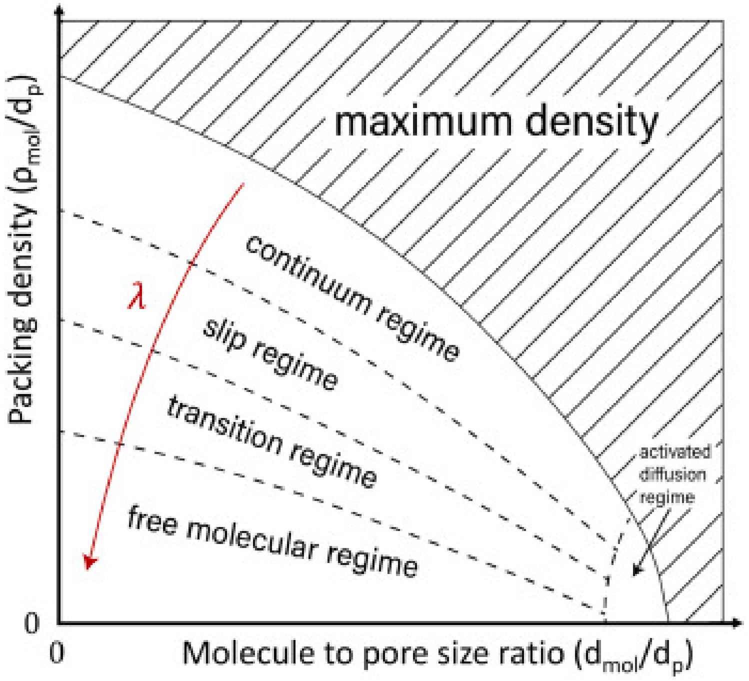
- **Gas permeation through carbon membranes: Model development and experimental validation**

Z. E. Sahin, A. Rahimalimamaghani, M. Gazzani, and F. Gallucci, "Gas permeation through carbon membranes: Model development and experimental validation," International Journal of Hydrogen Energy, Sep. 2023, doi: 10.1016/j.ijhydene.2023.08.272..

Highlights:

- Modelling of permeation through carbon membranes with a global optimization routine.
- Decreased gas permeation due to water is described with a pore-blocking model.
- Pore-size distribution used as a weight factor to sum mass transport phenomena.
- Mixture of transport phenomena for different carbon membranes predicted by model.
- Model validation with pure- and mixed gas measurements for H2, N2, and CO2.





Research output

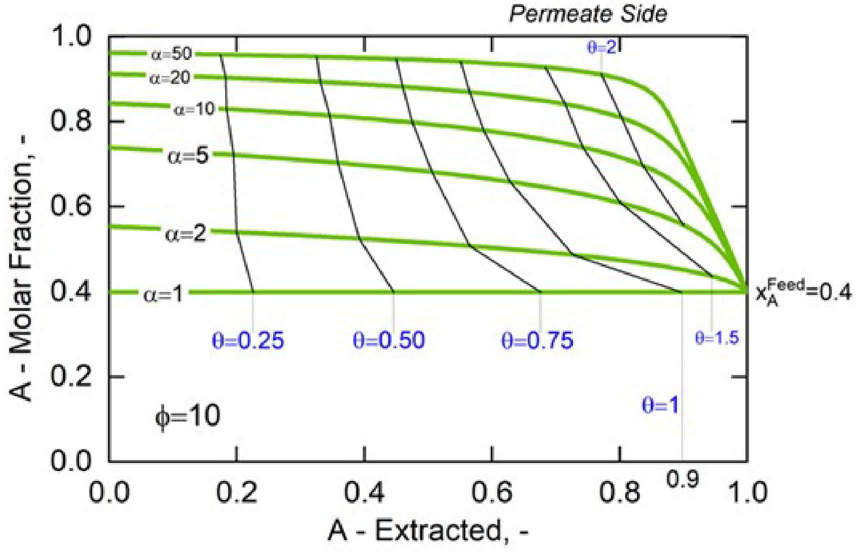
RESEARCH OUTPUT

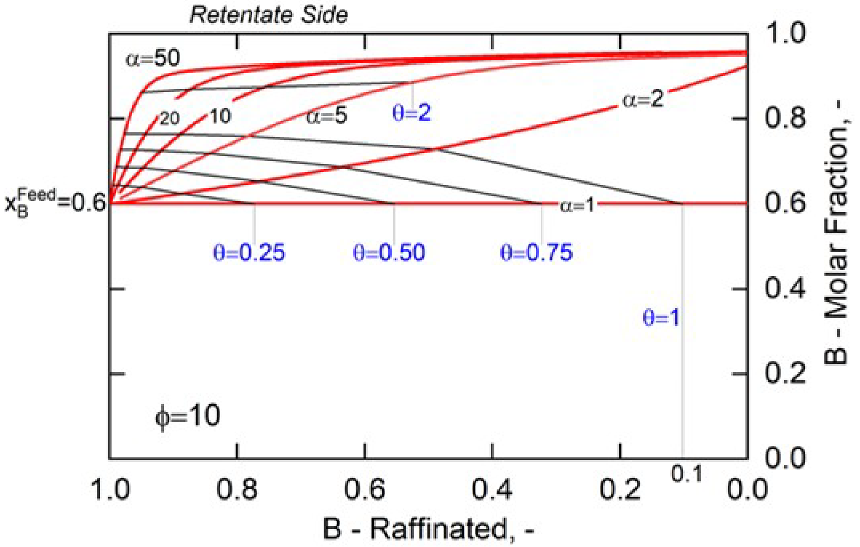
- **Performance Maps**

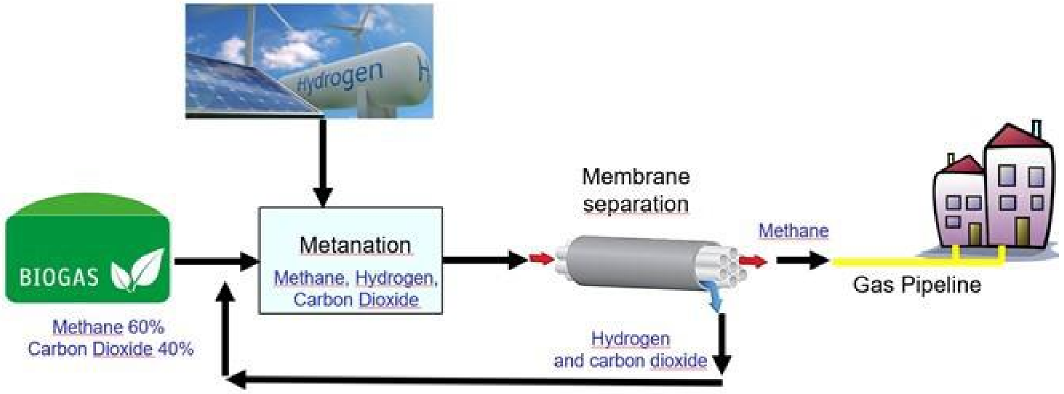
The investigation of the whole range of operating conditions (feed pressure and flow rate) produces global maps showing all the possible solutions for the considered gas separation membrane system, expressed as parametric curves for a fixed selectivity and pressure ratio. Each point in the maps, associated with a specific value of permeation number, corresponds to the total membrane module performance for a given set of operating conditions.

With the maps, it is possible to:

- enhance the CO_2 conversion efficiency processes, for instance, by enabling a greater valorization of CO_2 into methane.
- H_2 upgrading and purification
- Membrane condenser
- Water vapour recovery





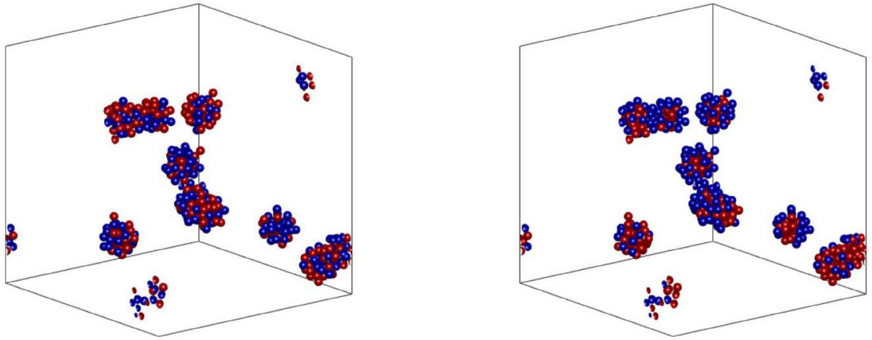


Research output

RESEARCH PAPERS - OTHER

- **Thermal Conduction in Hybrid Nanofluids and Aggregates**

E. D. Skouras, N. P. Karagiannakis, and V. N. Burganos, “Thermal Conduction in Hybrid Nanofluids and Aggregates,” Nanomaterials, vol. 14, no. 3, Art. no. 3, Jan. 2024, doi: 10.3390/nano14030282.



<u>Highlights:</u>

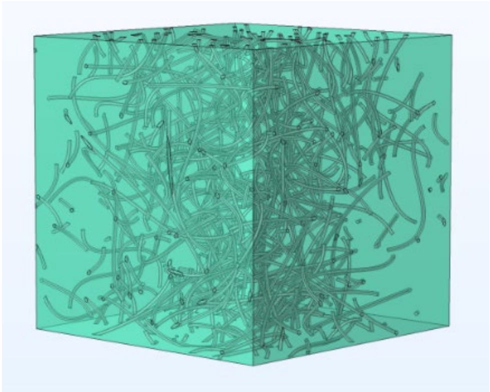
- Simulations show nanoparticle additives to bulk phases favor the transport properties of the material
- The role of a second nanoparticle phase added to a nanomaterial is elucidated through simulations
- An algorithm to simulate the addition of a 2^{nd} nanoparticle phase in a nanofluid or composite

material is presented

- Agglomeration effects on thermal conductivity are evaluated
- Application to membrane separation can be straightforward both at the level of nanofluids and the membrane material itself

- **Nanoparticle shape and agglomeration effects on thermal conductivity of nanofluids: A 3D simulation approach**

P. Polydoropoulou and V. N. Burganos, “Nanoparticle shape and agglomeration effects on thermal conductivity of nanofluids: A 3D simulation approach,” presented at the 14th Panhellenic Scientific Conference of Chemical Engineering, May 2024.

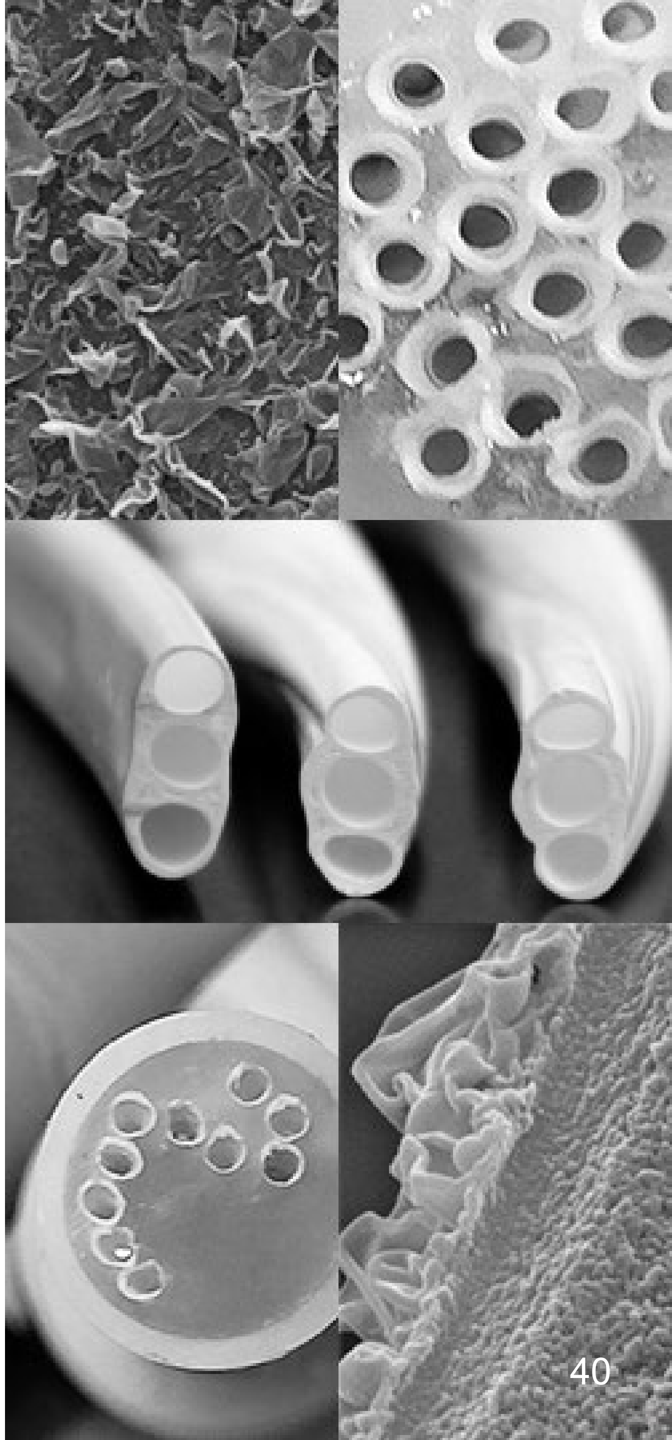


<u>Highlights</u>:

- The structure of nanofluids and nanocomposite membranes is simulated in 3D using in-house and commercial software
- The transport properties of mixed matrix membranes are shown to improve significantly upon addition of carbon nanotubes
- The effects of the carbon nanotube shape and aspect ratio on transport are thoroughly investigated
- Intersection and overlapping of carbon nanotubes are shown to favor transport via networking

Acronyms and the organisations they represent

ACRONYM	ORGANISATION
AU	Aston University
CNR-ITM	Consiglio Nazionale delle Ricerche
EMI TWENTE	European Membrane Institute Twente
EVONIK	Evonik Operations GmbH
FORTH	Forth Institute of Chemical Engineering Sciences
HEREON	Helmholtz-Zentrum Hereon
ICL	Imperial College of Science Technology and Medicine
LIQTECH	Liqtech Ceramics
NXF	NX Filtration
POLYMEM	POLYMEM
RWTH	Rheinisch-westfaelische Technische Hochschule Aachen
TEC	Fundación Tecnalia Research & Innovation
TUE	Technische Universiteit Eindhoven
UDE	Universitaet Duisburg-Essen
UM	Université de Montpellier
UNIZAR	Universidad de Zaragoza
VITO	Vlaamse Instelling voor Technologisch Onderzoek N.V.



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