Investigating the Structural Basis for the Performance of Electrodialysis Membranes for Water Desalination

UG student, mechanical engineering

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CHRES CONSORTIUM OF HYBRID RESILIENT ENERGY SYSTEMS

DE-NA0003982

NANOMATERIALS, INTERFACES, AND CONFINEMENT FOR ENERGY & THE ENVIRONMENT LABORATORY

Agenda

01 Objectives

02 Background

03 How do ionic exchange membranes work?

04 Approach

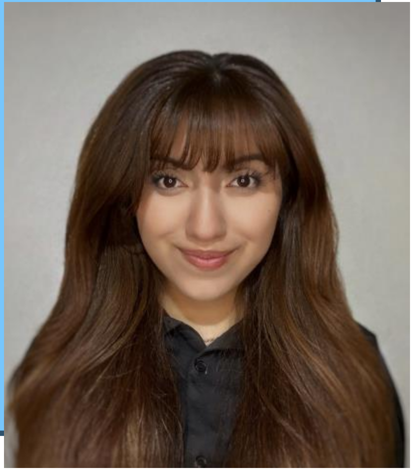
05 Method

06 Data/Results

07 Conclusion

08 Acknowledgments

About me



School: The University of Texas At El Paso

Major : BS in Mechanical Engineering

Minor : Electrical engineering and Mathematics

Time in UTEP :

CHRES Program

Investigating the Structural Basis for the Performance of Electrodialysis Membranes for Water Desalination

21st-century ACE tutor

sharing knowledge in engineering while coaching the drone team and tutoring kids before and after school and during summer for 6-12 students in Title I schools.

Associations :

PI TAU SIGMA (International Honor Society for Mechanical Engineers)
President
WOAA (Women of Aeronautics and Astronautics)
Vice President
AIAA (American Institute of Aeronautics and Astronautics)
Member
ASME (American Society of Mechanical Engineers)
Member
Sun City Rocket Team (Sub team: propulsion)
Member

As a mechanical engineer, my career goals are centered around exploring the aerospace and automotive industries, where I can apply my expertise in problem-solving, design, and analysis to contribute to cutting-edge technologies and advancements in these sectors. I am particularly passionate about the environment, and I aspire to integrate sustainable practices and eco-friendly solutions into my work within these industries. My **ultimate** aim is to be part of projects that not only push the boundaries of engineering but also prioritize environmental consciousness, creating a positive impact on our planet's future.

objectives

- Investigating the impact of various electrolytes on structural properties of functionalized membranes using small-angle X-ray scattering experiments.
- Target energy efficiency
- Precise control over ion selectivity
- Explore innovative material extraction possibilities from desalinated water using functionalized membranes.

Outcomes:

- Drive advancements in membrane technology and industrial processes.
- Contribute to a more sustainable and resource-conscious future through cutting-edge research on membrane behavior and interactions.

Background

Significance

Water scarcity

- Population Growth
- Depletion of Surface Water Sources

Water quality

- Water Pollution
- Groundwater Contamination

Vulnerable populations

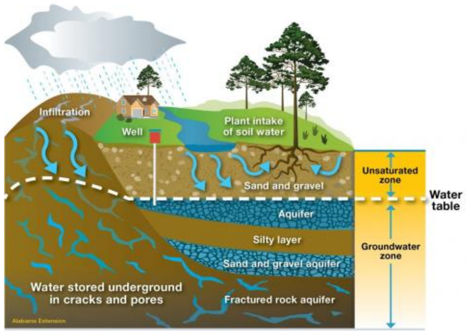
- Limited Access to Safe Drinking Water
- Health Impacts
- Climate change displacements

Why should we care ?

01 Remove high mineral content

- Arid regions

relies on subsurface aquifers

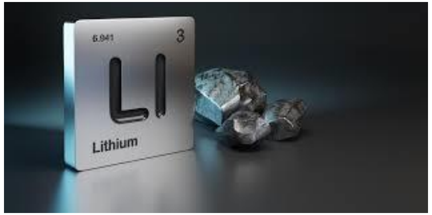


02 Clean waste water

- Potential to clean polluted water in several applications

03 Liquid separations

- Precious or rare earth element extractions
  Ex) lithium



Revolution of EDM technology

Electrodialysis has been gaining popularity over the years due to its unique capabilities and advantages in various applications. Some of the key areas where electrodialysis is experiencing growth in popularity include:

1. Desalination
2. Wastewater Treatment
3. Recovery of Valuable Compounds
4. Resource Recovery from Brine Solutions
5. Agriculture and Aquaculture

Limitations :

We do not understand the relation between performance of these membranes and structure.

Problem: doesn't allow us to advance the science.

If we understand structure then that means we can make better membrane designs.

How do Ionic exchange membranes work?

Ionic Exchange Membranes

Anion

(AEMs) are polymeric membranes that selectively transport negatively charged ions.

They are used in various electrochemical devices and processes like fuel cells, water electrolysis, and desalination.

Cation

(CEMs) are polymeric membranes that selectively transport positively charged ions.

Their selective ion transport properties make them valuable tools in various fields, facilitating the advancement of cleaner and more resource-efficient solutions.

(IEMs) are a type of selectively semi permeable membrane that allows the passage of dissolved ions in a liquid while restricting/blocking other ions. Depending on the membranes electric charge , they allow certain ions to pass while blocking the others.

METHOD: ELECTRO DIALYSIS METATHESIS (EDM)

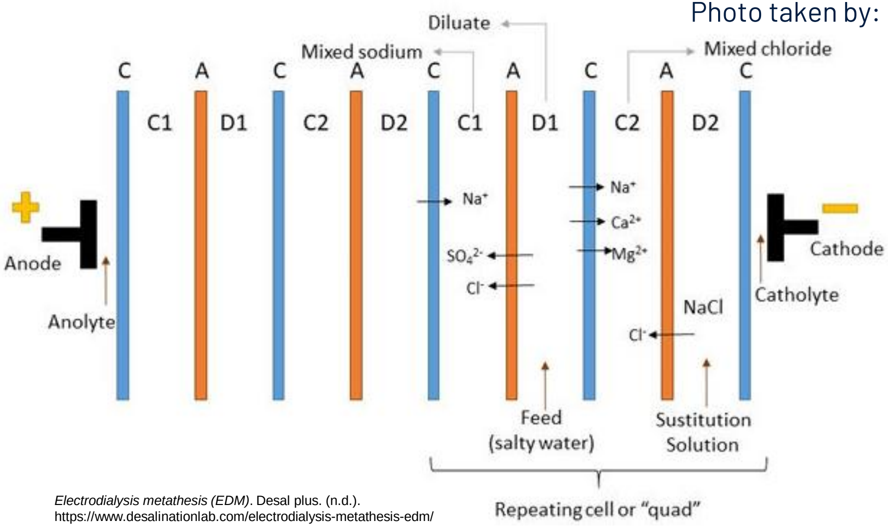
Electrodialysis Metathesis (EDM) is a variation of reversal electrodialysis in which a metathesis (exchange) reaction occurs.

A conventional electrodialysis (ED) system is composed of repeating cells of two alternating cation- and anion-exchange membranes.

A feed solution compartment and a concentrate solution compartment are both present in every cell.
There's an electric potential between the cathode and anode that causes the charged ions to move toward the appropriate electrode .

In the EDM system, a substitution solution is introduced to give the exchangeable ions for the metathesis reaction, and four alternating ion-exchange membranes form a repeating quad of four compartments.

Photo taken by: Eva Deemer



Electrodialysis metathesis (EDM). Desal plus. (n.d.). https://www.desalinationlab.com/electrodialysis-metathesis-edm/

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Approach

Xeuss 2.0

What is it :

Xeuss is a versatile system that measures material structure on a sub nanometer to micron scale. It is a modular platform supporting various applications with units for SAXS and WAXS.

SAXS

Small Angle X-Ray Scattering

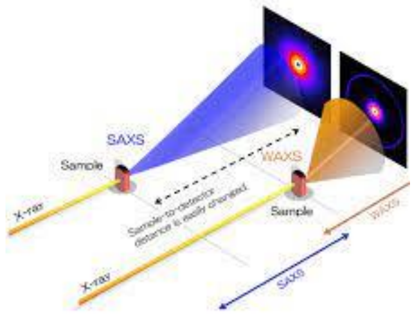
It enables the determination of nanoparticle size distributions, and shape of macromolecules, pore sizes, and characteristic distances in partially ordered materials. This is achieved by analyzing the scattering behavior of X-rays as they pass through the material, recording the scattering at small angles. provides valuable insights into the nanoscale properties and structures of various materials.

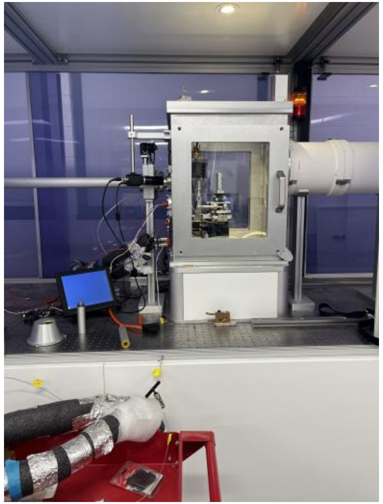
How can we apply x-Ray scattering to our membranes?

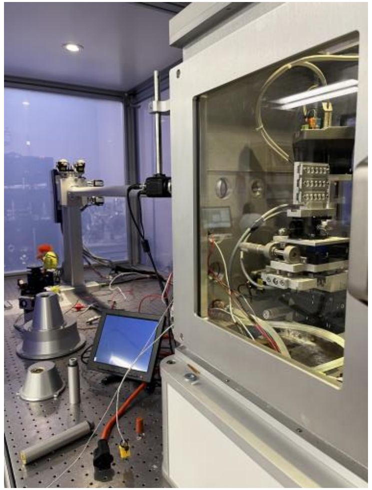
We can study:
Structural characteristics of functionalization and Interactions w/ electrolytes

Provides valuable information on :

- Polymer chains
- Intermolecular distances
- Membranes microstructure







NANOMATERIALS, INTERFACES, AND CONFINEMENT
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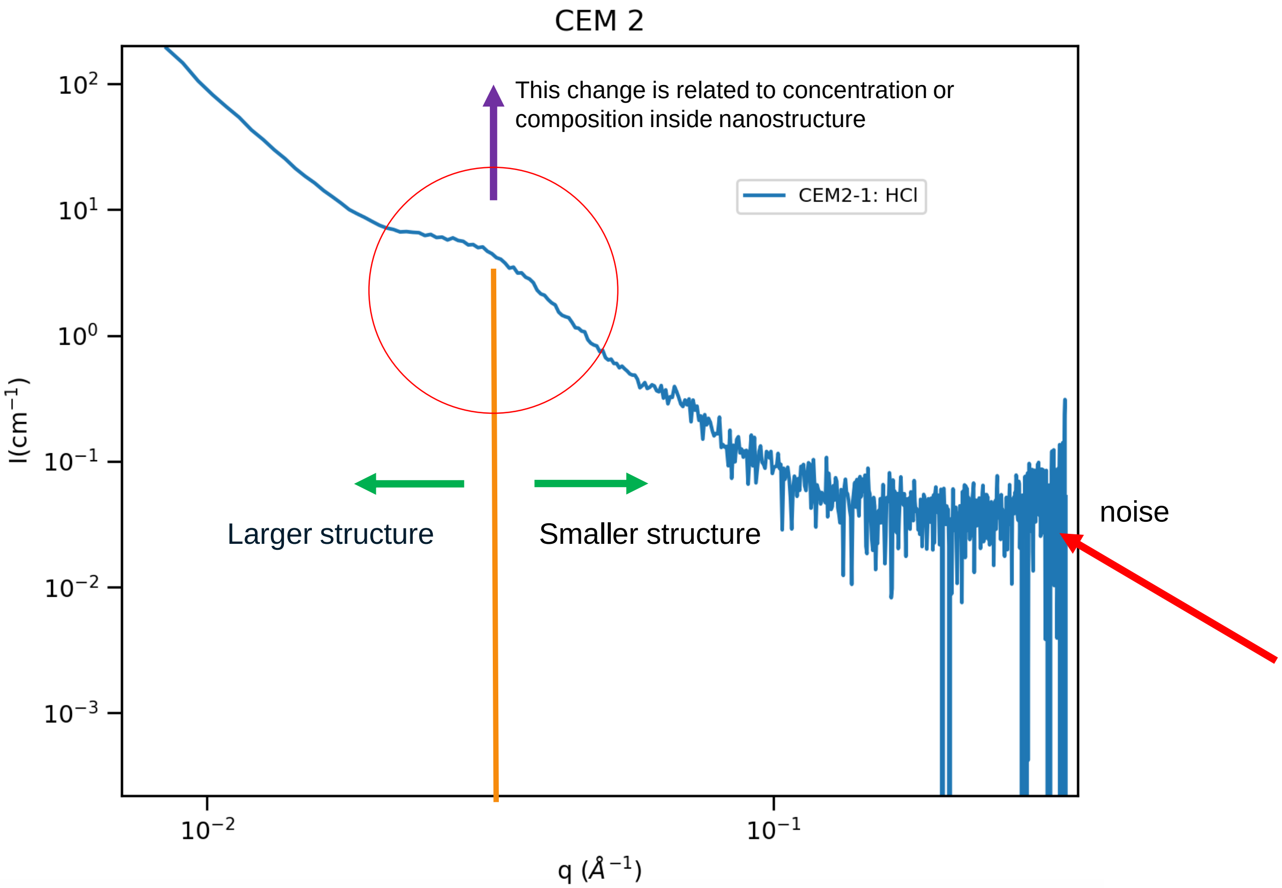
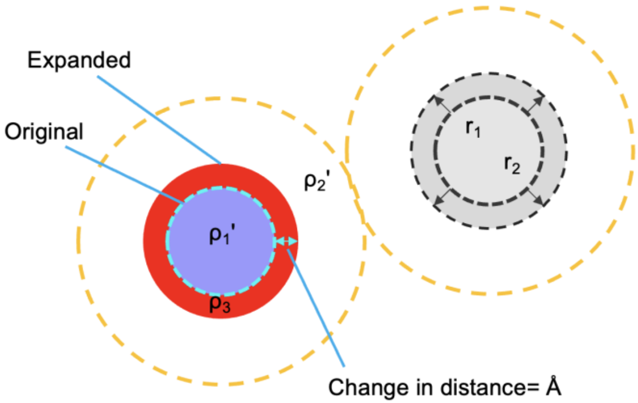
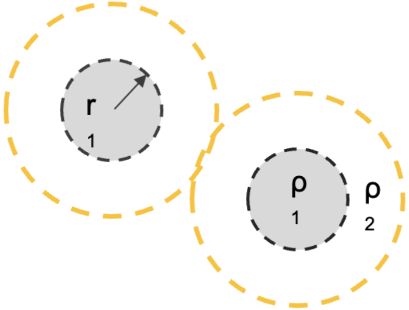
READING GRAPH: MANTID



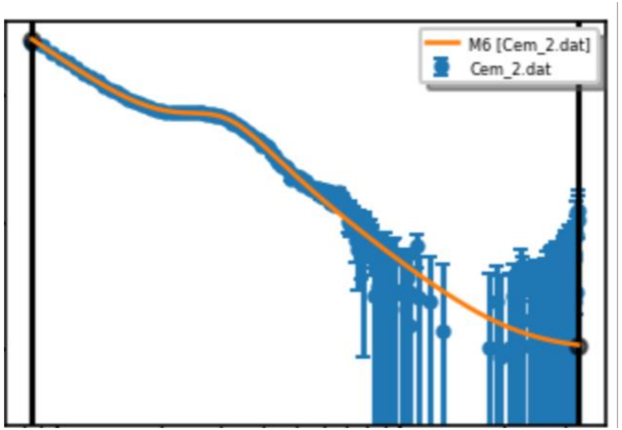


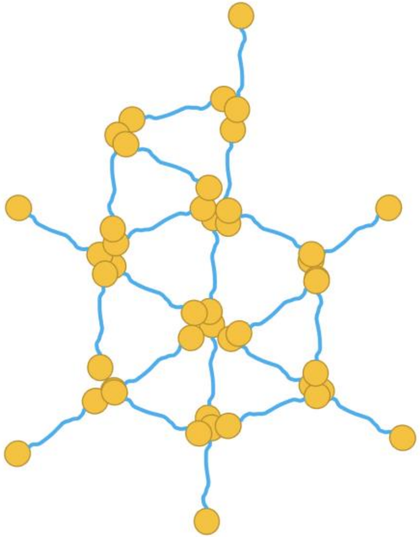


Non-Expanded Phase

Expanded Phase

scale = 1.0 (fixed)
background = 0.001 (fixed) cm^{-1}
powertsmata = (fixed)
A_scale = 1.1446e-06 ± 1.1404e-07
A_power = 3.7746 ± 0.021842
B_scale = 0.0077369 ± 1.4513e+06
B_volfraction_a = 0.30219 ± 9.9989e+07
B_sld_a = 0.3 (fixed) $10^{-6}/Å^2$
B_sld_b = 6.3 (fixed) $10^{-6}/Å^2$
B_d = 213.78 ± 0.47463 Å
B_xi = 100.72 ± 1.0947 Å



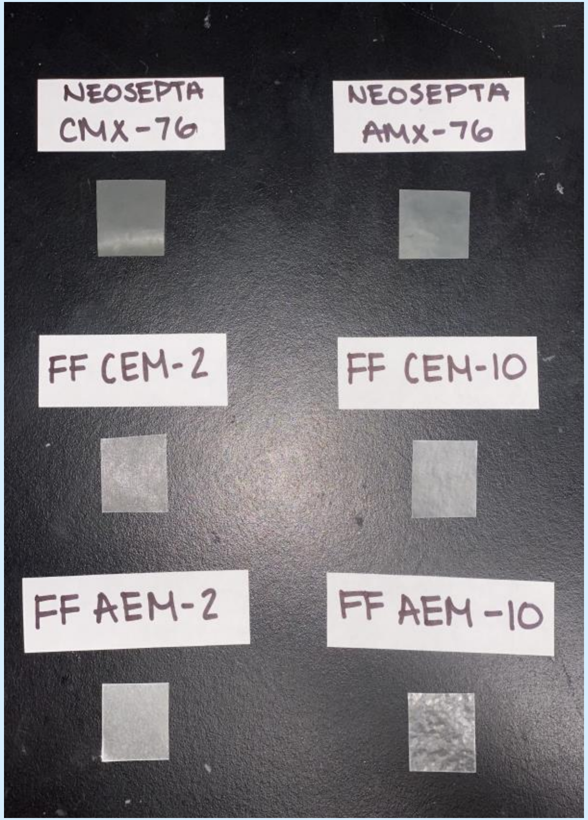


Collection of
Polystyrene polymers

Connecting SAXS to structural analysis

Method

Membranes



NEO SEPTA:

CMX-76
AMX-76

FUJI FILMS:

CEM 2
CEM 10

AEM 2
AEM 10

CONDITIONING PROCESS

Three conditioning solutions:

HCl

1M

NaCl

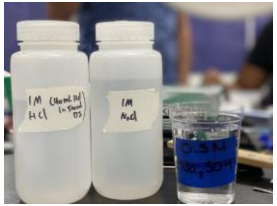
1M

Na2SO4

0.5 M

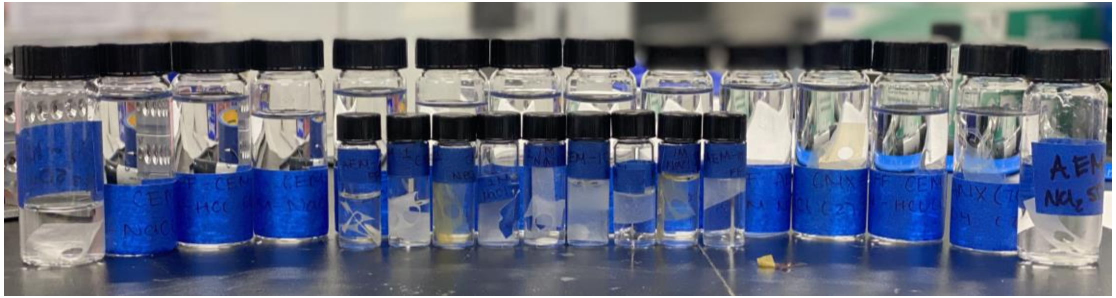
Cation Membranes:

The membrane is soaked in 1M HCl and soaked for 24 hrs. followed by washing w/deionized water to remove the H+ contained on the surface , & then immersing the membrane in 1M NaCl for 24hrs.



Anion membranes:

The membrane is soaked in 1M NaCl and soaked for 24 hrs. followed by washing w/deionized water to remove the Cl- contained on the surface , & then immersing the membrane in 0.5M Na2SO4 for 48hrs.



About the Conditioning

1.Ion Selectivity: Conditioning with specific electrolytes can enhance the membrane's selectivity towards certain ions.

2.Membrane Stability: Conditioning can improve the membrane's stability and resistance to fouling.

3.Ion Mobility: Conditioning can affect the mobility of ions within the membrane.

For this project :

For example, we conditioned for the ion exchange.
So we did acid conditioning and salt for CEM. It converts the functional groups to an acidic form (sulfonic acid group) and the NaCl converts that sulfonic acid to having H+.

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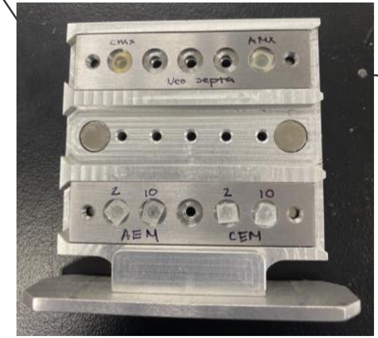
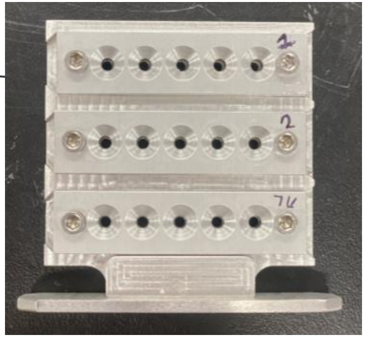
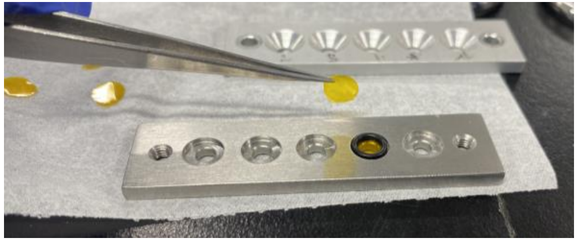
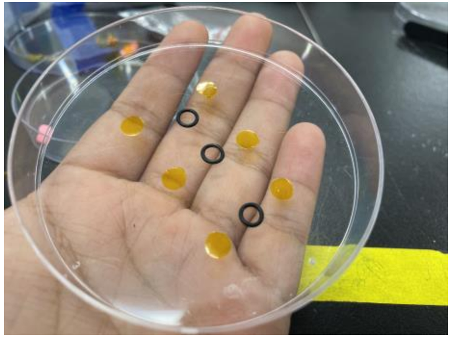
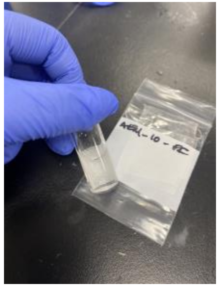


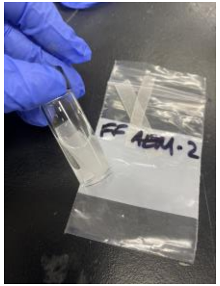


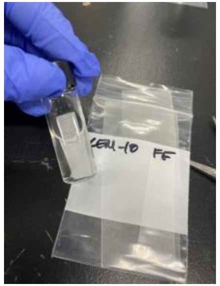


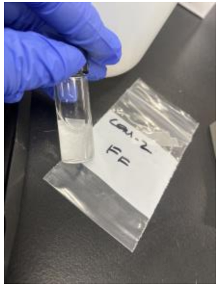


SETTING UP SAMPLES ON THE EMPTY HOLDER









SCANS :

1. UNCONDITIONED

Dry samples
SAXS

2. CONDITIONED

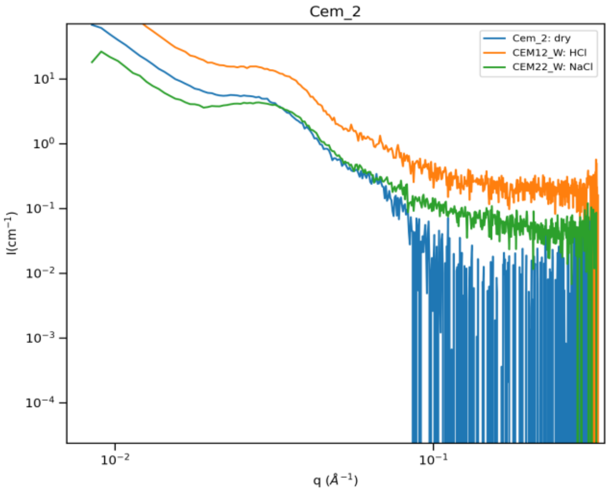
Wet samples
SAXS

3. DRY POST EXPOSURE

In oven at 50 C for 24hrs.
SAXS

DATA/RESULTS

FF CEM –2

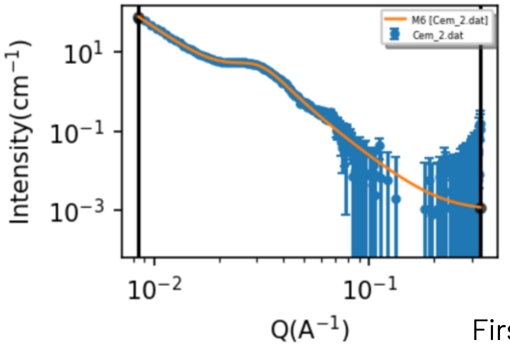


dry vs. wet

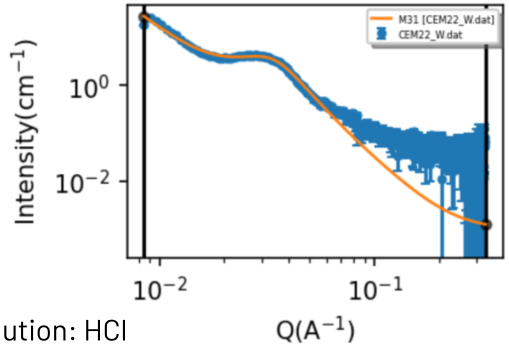
CEM 2: DRY		CEM2-1: WET		CEM2-2: WET	
scale	1	scale	1	scale	1
background	0.001	background	0.001	background	0.001
A_scale	1.14E-06	A_scale	0.00040394	A_scale	1.95E-06
B_scale	0.0077369	B_scale	0.024078	B_scale	0.0081029
B_d	213.78	B_d	190.51	B_d	197.62
B_xi	100.72	B_xi	144.63	B_xi	82.042

SAS view fitted

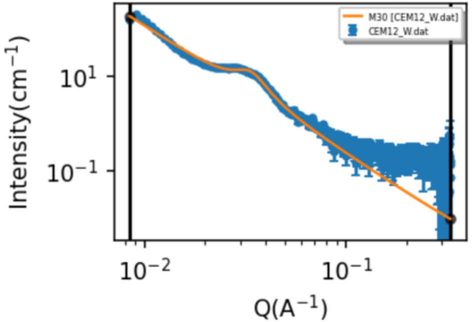
Dry: Unconditioned

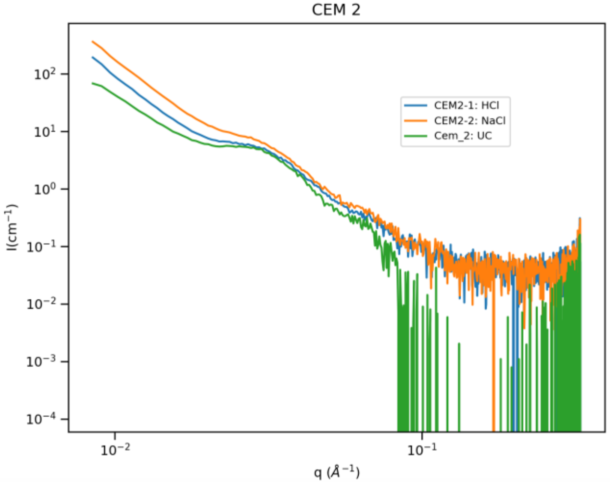


Second solution: NaCl



First solution: HCl

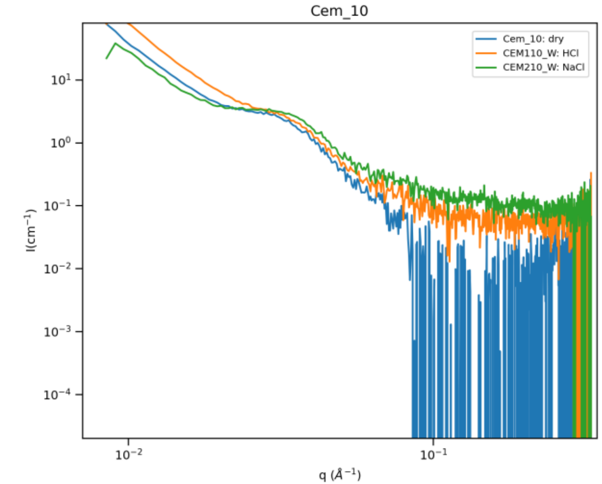




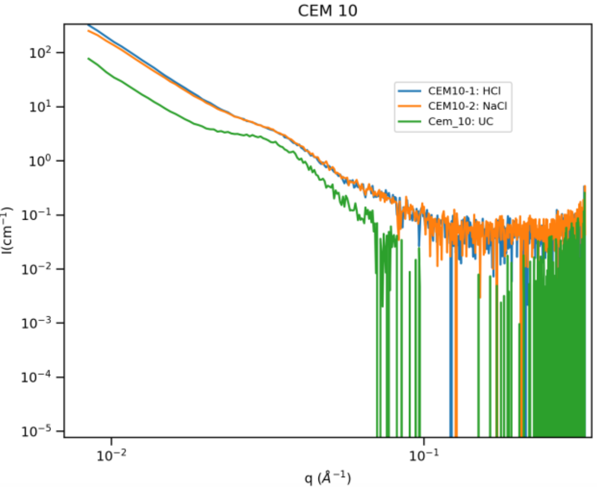
dry after exposure vs. original dry

FF CEM –10

CEM 10:DRY		CEM10-1: WET		CEM10-2: WET	
scale	1	scale	1	scale	1
background	0.001	background	0.001	background	0.001
A_scale	5.28E-07	A_scale	1.09E-05	A_scale	0.00023371
B_scale	0.0037864	B_scale	0.0043382	B_scale	0.0085282
B_d	207.41	B_d	184.98	B_d	183.36
B_xi	96.656	B_xi	115.56	B_xi	124.96



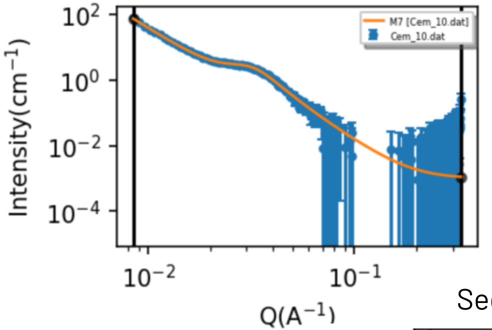
dry vs. wet



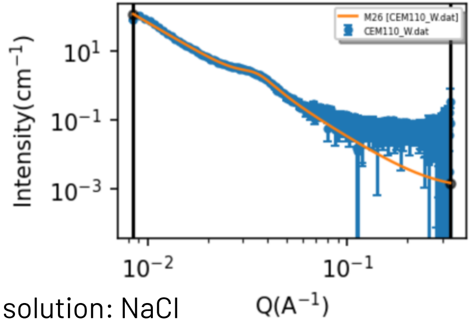
dry after exposure vs. original dry

SAS view fitted

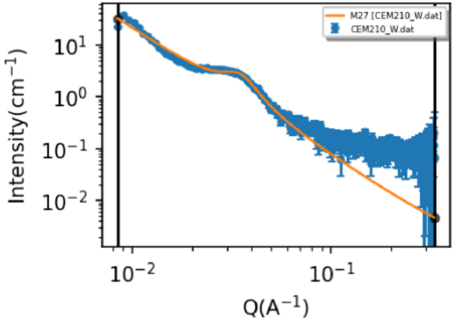
Dry: Unconditioned



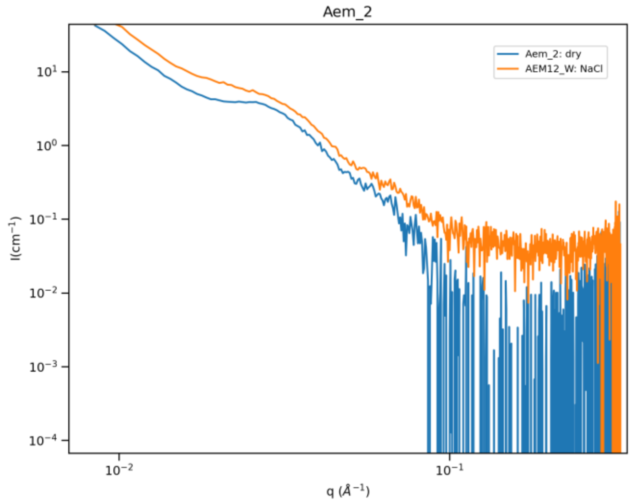
First solution: HCl



Second solution: NaCl

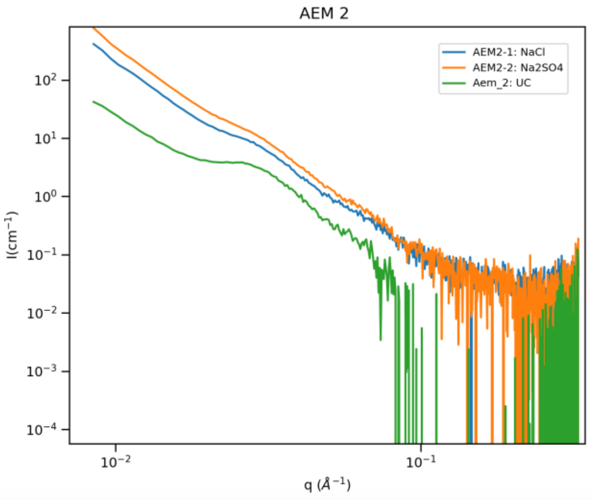


FF AEM –2



dry vs. wet

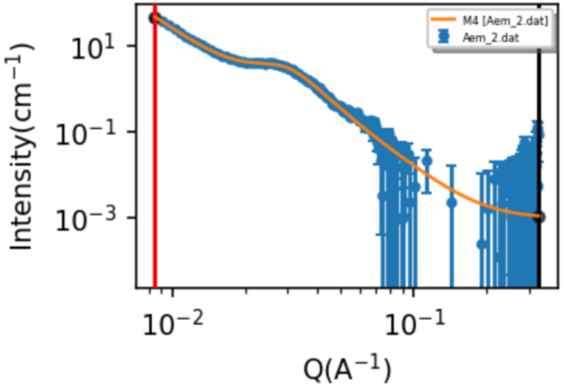
AEM 2: DRY		AEM2-1: WET	
scale	1	scale	1
background	0.001	background	0.001
A_scale	5.38E-07	A_scale	2.54E-05
B_scale	0.0044265	B_scale	0.83475
B_d	223.85	B_d	223.47
B_xi	95.267	B_xi	81.737



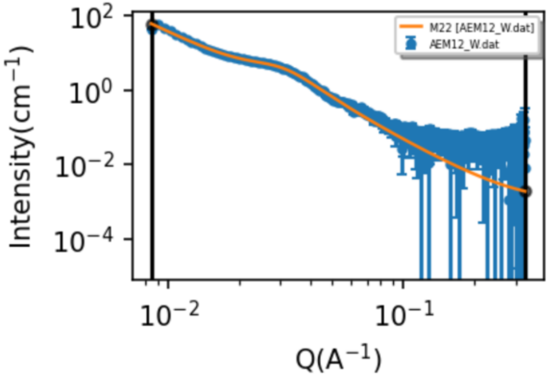
dry after exposure vs. original dry

SAS view fitted

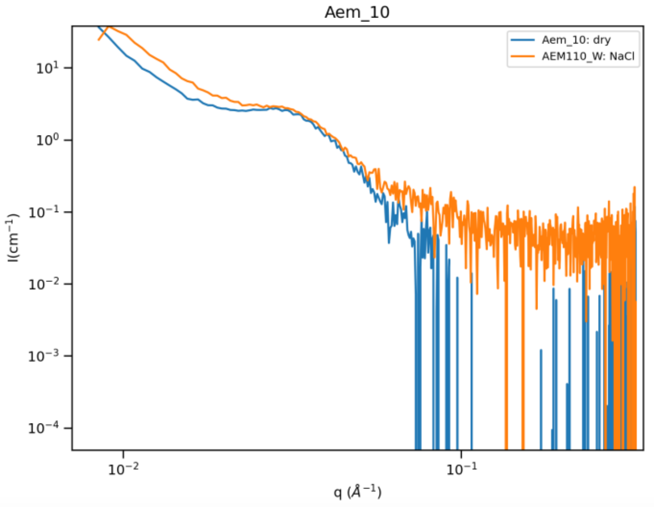
Dry: Unconditioned



First solution: NaCl

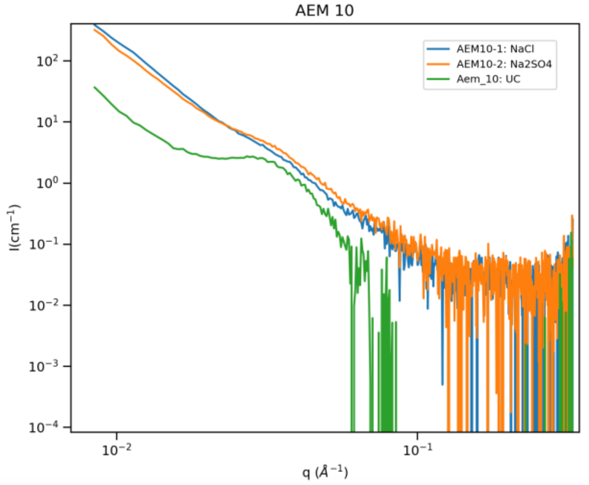


FF AEM -10



dry vs. wet

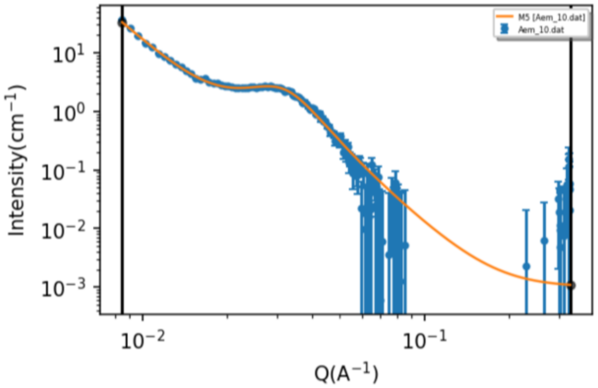
AEM 10: DRY		AEM10-1: WET	
scale	1	scale	1
background	0.001	background	0.001
A_scale	7.11E-08	A_scale	0.00012163
B_scale	0.0041244	B_scale	0.0020491
B_d	206.52	B_d	190.38
B_xi	97.722	B_xi	145.57



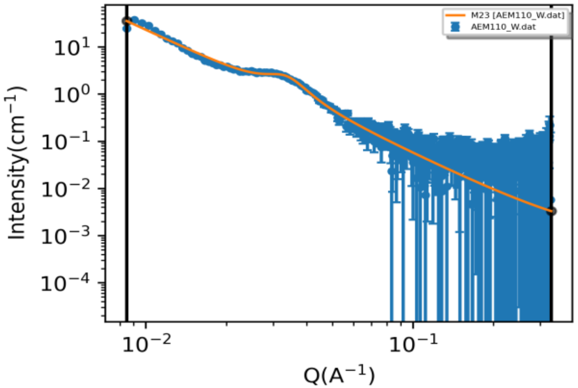
dry after exposure vs. original dry

SAS view fitted

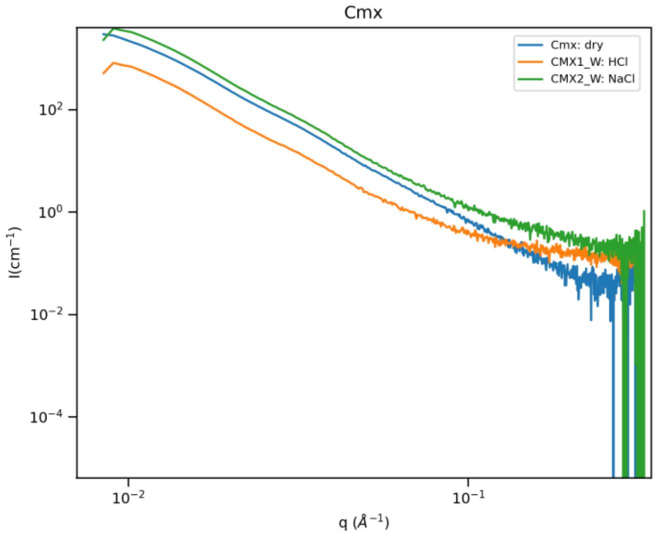
Dry: Unconditioned



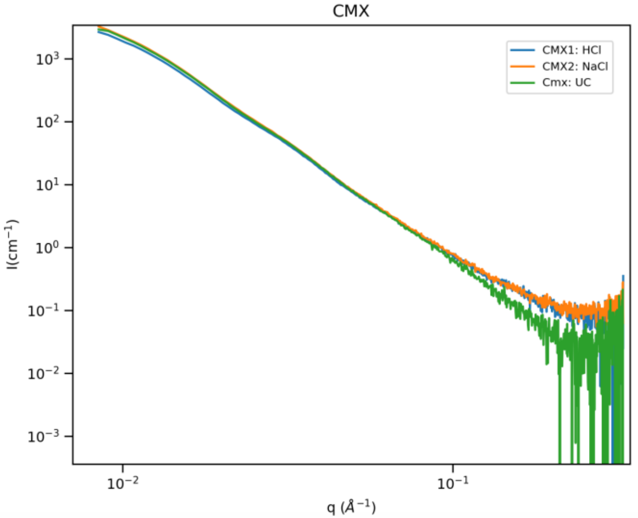
First solution: NaCl



NEOSEPTA CMX -76



dry vs. wet

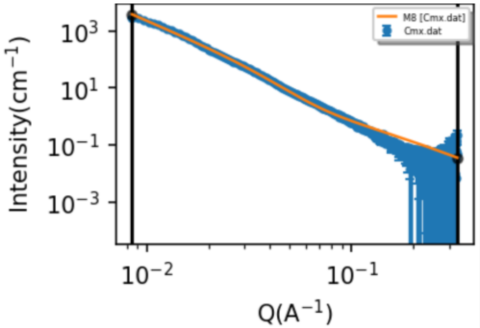


dry after exposure vs. original dry

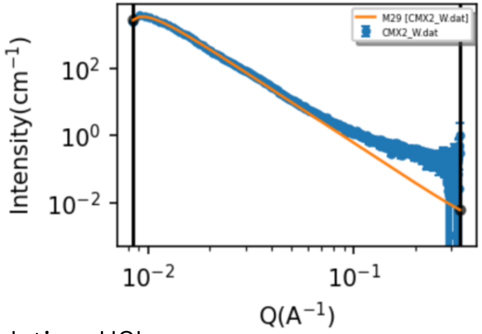
CMX76:DRY		CMX1: WET		CMX2 : WET	
scale	1	scale	1	scale	1
background	0.001	background	0.001	background	0.001
A_scale	0.0016006	A_scale	0.00020837	A_scale	-0.0002191
B_scale	-0.17638	B_scale	0.99993	B_scale	3.1821
B_d	1.05E+06	B_d	200	B_d	1.71E+03
B_xi	22.833	B_xi	80	B_xi	257.56

SAS view fitted

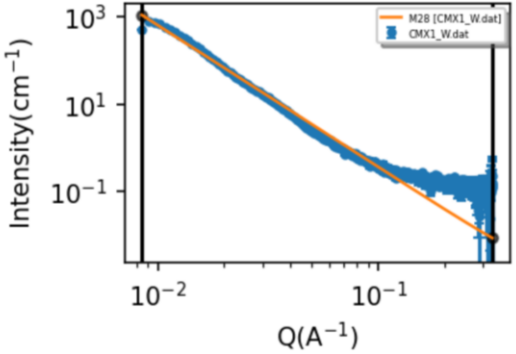
Dry: Unconditioned



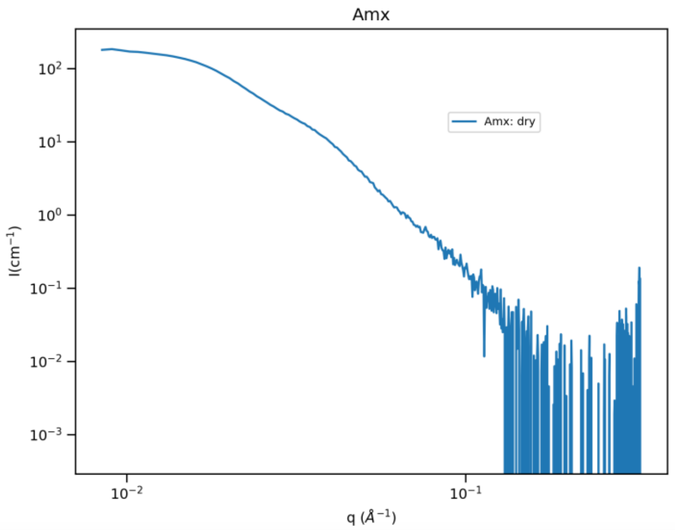
Second solution: NaCl



First solution: HCl



NEOSEPTA AMX –76

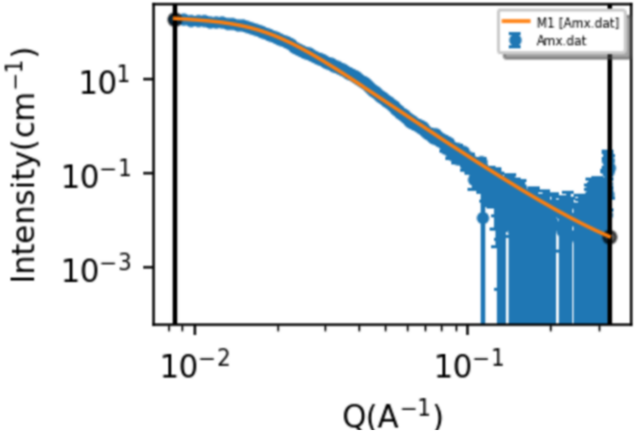


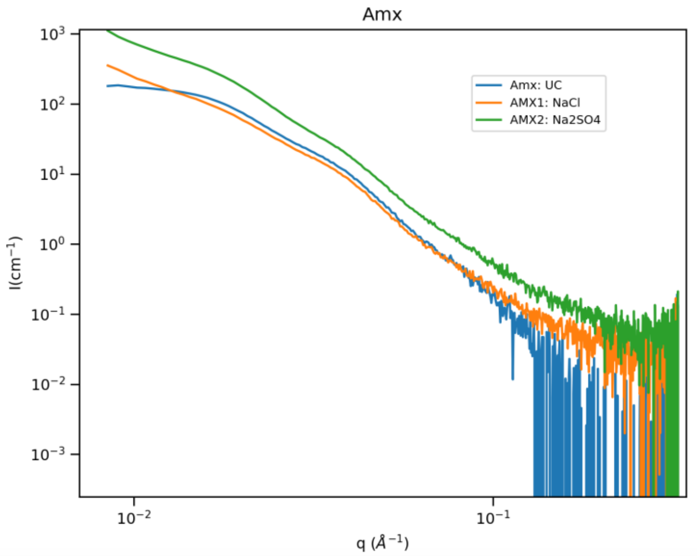
dry

AMX dry	
scale	1
background	0.001
A_scale	0.00011956
B_scale	0.48563
B_d	473.02
B_xi	80

SAS view fitted

Dry: Unconditioned





dry after exposure
vs. original dry

CONCLUSION

MOVING FORWARD

1. doing experiments to test micro selectivity
2. Placing membranes under applied voltage
3. Using different electrolyte solutions
4. Testing membranes after going through an actual real life application over periods of time

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Thanks!

Do you have any questions?

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FUJIFILM MEMBRANES

	TYPE 2		TYPE 10		TYPE 12	
Homogeneous	AEM	CEM	AEM	CEM	AEM	CEM
	Anion permselective	Cation permselective	Anion permselective	Cation permselective	Anion permselective	Cation permselective
Reinforcement	polyolefin		polyolefin		polyolefin	
Thickness dry (µm)	160	160	125	135	110	110
Electrical Resistance (1)	5.0	8.0	1.7	2.0	6.0	6.0
Perm selectivity (2)	95	96	95	99	95	99
IE Capacity (3)	0.9	1.1	1.8	1.5	1.1	1.0
Water permeation (4)	3.0	3.5	6.5	6.5	2.0	2.5
Burst strength (5)	5.0	4.7	2.8	2.8	3.8	3.8
pH stability	pH 2-10	pH 4-12	pH 1-13		pH 1-13	
Temp stability (6)	40		60		60	
Typical applications	purifying process water concentrating waste water brackish to potable water		purifying process water concentrating waste water sea & brackish to potable water food desalination		purifying process water concentrating waste water	