Efficient PFAS Removal in Hypo/Hyper Saline Waters Via Direct Contact Membrane Distillation

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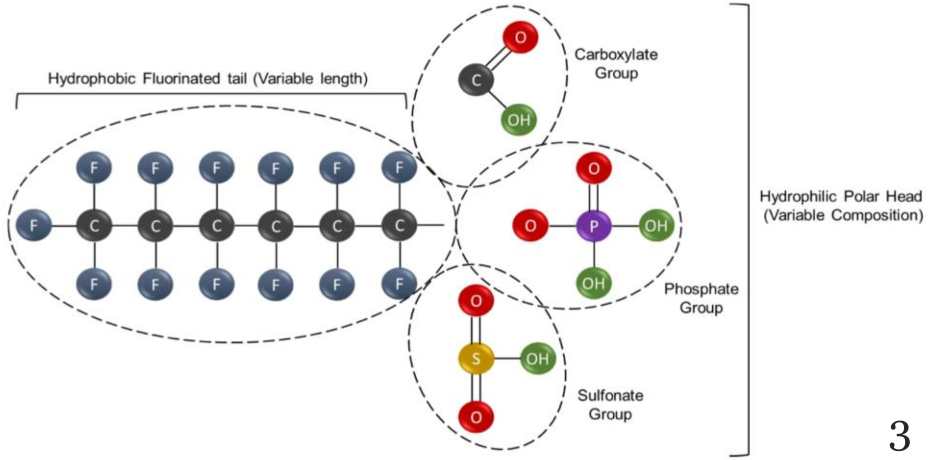
Outline

- What are PFAS?
- Membrane Distillation Process
- Objectives
- Materials and Methods
- Results and Discussion
- Future Directions

What are PFAS?

- Per- and polyfluoroalkyl substances (PFAS) with family of >4,700 chemicals
- Manufactured and used in thousands of processes and products since the 1940s
- Became popular because they repel oil and water, are temperature-resistant, and reduce friction
- They have been widely used in industry due to their thermal stability, lipophilic and hydrophobic properties
- The US Environmental Protection Agency (EPA) lists over 14,000 fluorinated substances that can be potentially classified as PFAS.



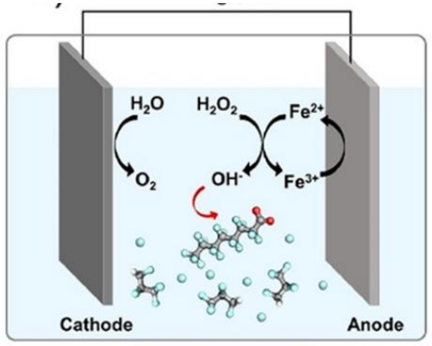
Sources of PFAS

- Household products
- Stain-repellant clothing, carpets
- Metal plating and wire manufacturing
- Firefighting foams (military sites)
- Wastewater treatment plants
- Biosolids and landfill leachate.
- Found in **soil, air, and water**

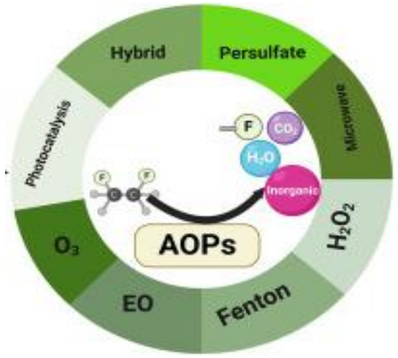
Treatment Technologies

Destructive

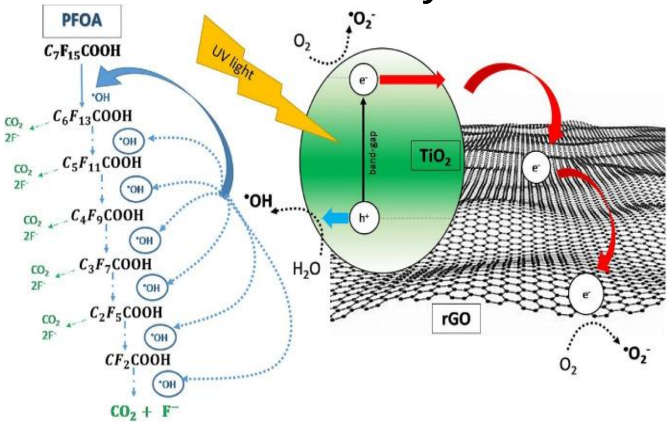
Electro chemical



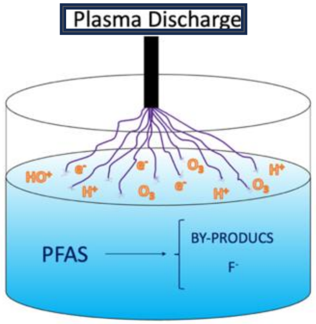
Advance Oxidation Process



Photolysis



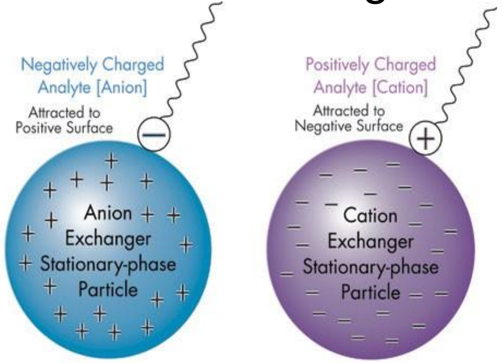
Thermolysis/Plasma



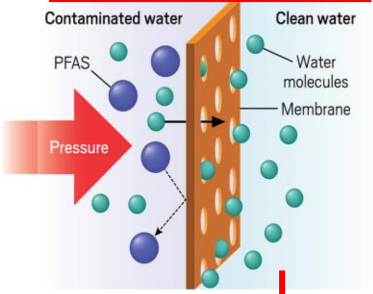
Non-Destructive

Adsorption

Ion - exchange



Membrane Process



Microfiltration
(0.1 µm -10 µm)

Ultrafiltration
(0.01 µm -1 µm)

Nanofiltration
(0.5 nm - 2 nm)

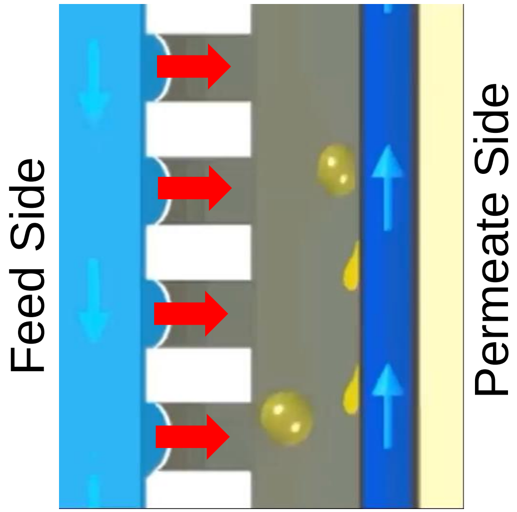
Revers osmosis
(0.001 µm - 0.0001 µm)

Membrane distillation
(0.1 µm - 2 µm)

Why Membrane Distillation (MD)?

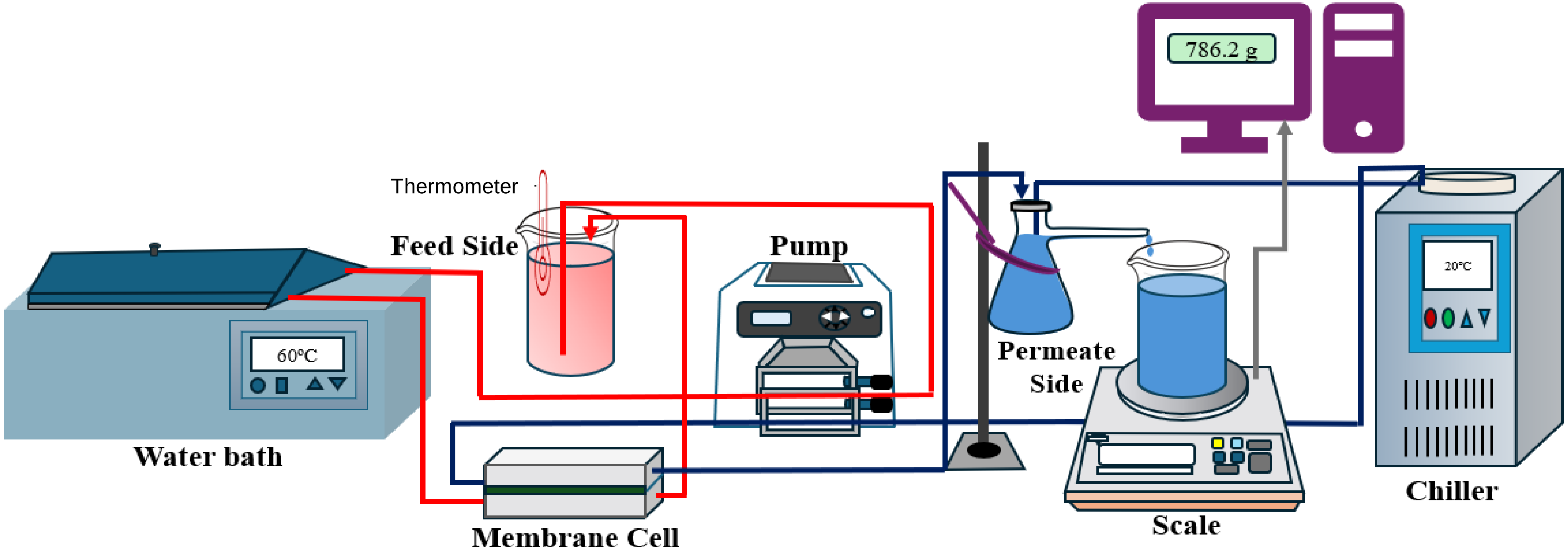
- **Thermally Driven Separation Process at atmospheric pressure:** Utilizes temperature difference across a hydrophobic membrane to drive water vapor (but not liquid) transport.

- **Key Advantages:**
  - Produces distilled water,
  - Operates at lower temperatures (30°C–70°C) compared to conventional thermal desalination technologies (such as Multi-Stage Flash Distillation which requires 110°C–120°C),
  - Tolerant to high salinity and fouling,
  - Operation with waste heat (industry) and solar thermal energy,
  - Reduced electrical cost.



Conventional Applications
- Mining
- Pulp & Paper Industry
- Desalination
- Galvanic Industry
- Hybrid System
- Textile Industry
- Food and Beverage

MD Process Description



Feed Side: Hot feed solution (ΔT: 30-50 ^oC)

Permeate Side: Cold water (T: 20 ^oC)

Membrane: Hydrophobic membrane

Driving Force: Vapor pressure difference created by temperature gradients

Scale and data collection: Data are stored on a computer connected to a scale

Literature Background on MD

Membrane	Surface modification	Background	Used PFAS	Flux (LMH)	Rejection (%)	Reference
PTFE	No	Modeled contaminated water	PFPeA	43	85	Chen et al., 2020
PTFE	MOF and PVA	Landfill leachate	PFBS, PFPeS, PFOA, PFOS, PFHpS,PFHpA PFHxS, PFHxA	16	PFOS, PFHxS-99 PFOA - 0 Other - 54	Zhang et al., 2022
PVDF	Dimethyl acetamide	Natural water	PFOA	Modified16 Commercial 13	Modified 96 Commercial 67	Yousefi et al., 2024
PTFE, PVDF	No	Contaminated groundwater	PFOA	21	51 & 80	Ying Shi et al., 2024
PVDF	MOF	Groundwater	PFHpA	13.2	79.6	Prajapati et al., 2025

Research Gaps

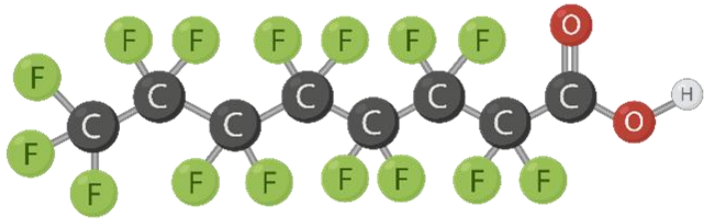
- ❖ Limited studies on varying hydrophobic membranes.
- ❖ Same background was explored in different membrane.
- ❖ Lack of understanding of how membrane characteristics impact on PFAS removal.

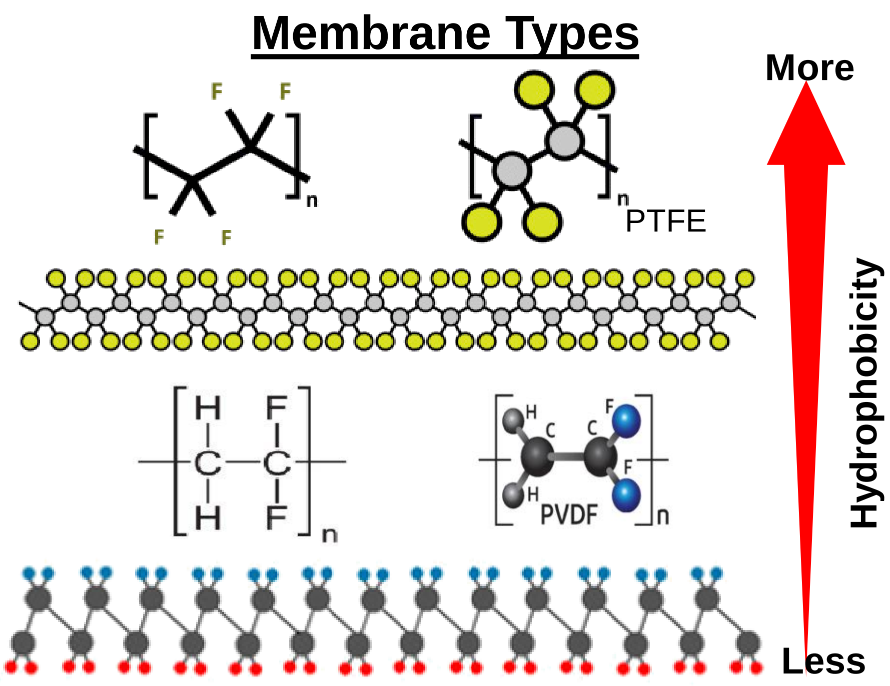
Objectives

The main objectives of this study are to:

1. Evaluate the effectiveness of various hydrophobic membranes including poly-tetrafluoroethylene (PTFE), and polyvinylidene fluoride (PVDF) on PFAS removal,
2. Investigate the influence of pore size variations (0.1 µm, 0.45 µm, 1 µm) in PTFE membranes,
3. Assess the impact of varying salinity (100 mg/L, 1000 mg/L, and 5000 mg/L as NaCl) on PFAS removal,
4. Examine the operational factors (pH [4 - 10], feed temperature gradient [30 -50^{o}C]) to optimize the system for efficient PFAS removal.

Materials and Method





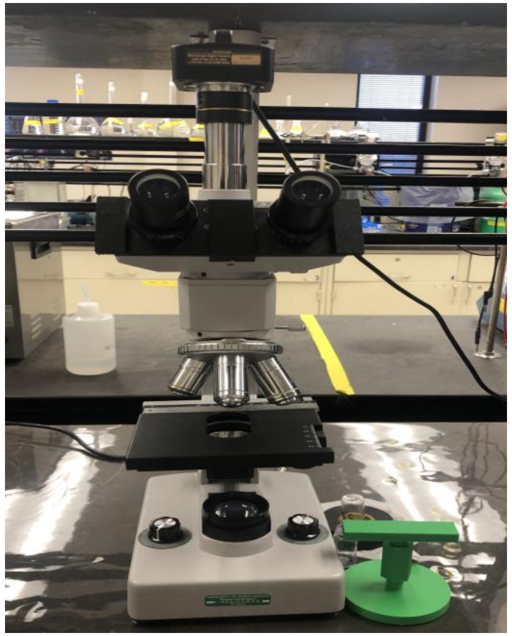
- **PFAS compound**: Perfluorooctanoic acid (PFOA at100 ppm)
- **Membrane type**: Poly-tetrafluoroethylene (PTFE) membranes, and Polyvinylidene fluoride (PVDF)
- **Pore sizes:** 0.1 µm, 0.45 µm, 1 µm
- **Variation in salinity**: DI Water with 100 mg/L, 1000 mg/L, and 5000 mg/L of NaCl
- Operational condition: T_{feed}: 60^{0}C and $T_{permeate}$: 20^{0}C, pH = 4

Characterization Techniques

Fourier-Transform Infrared Spectroscopy (FTIR) : Chemical composition and surface chemistry analysis

Scanning Electron Microscopy (SEM): Morphology and surface roughness evaluation

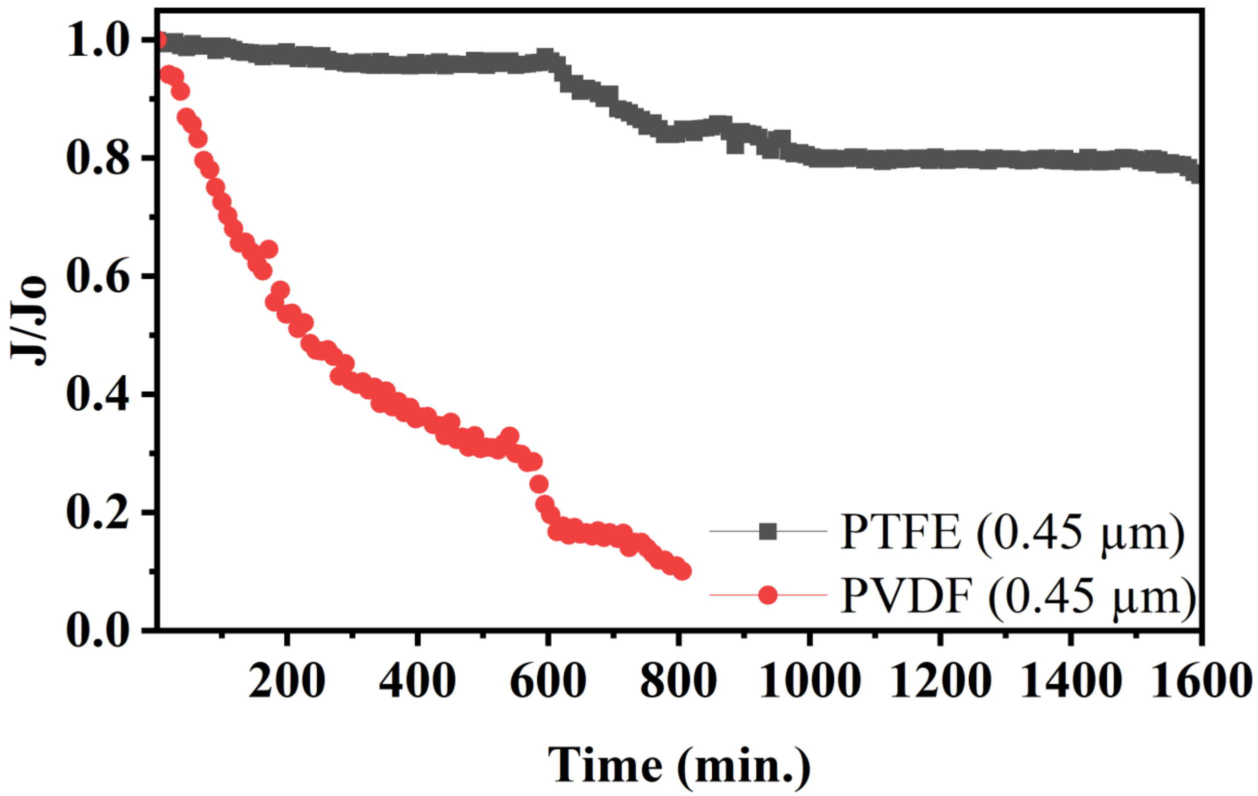
Contact Angle Measurement: Hydrophobicity assessment with Microscope

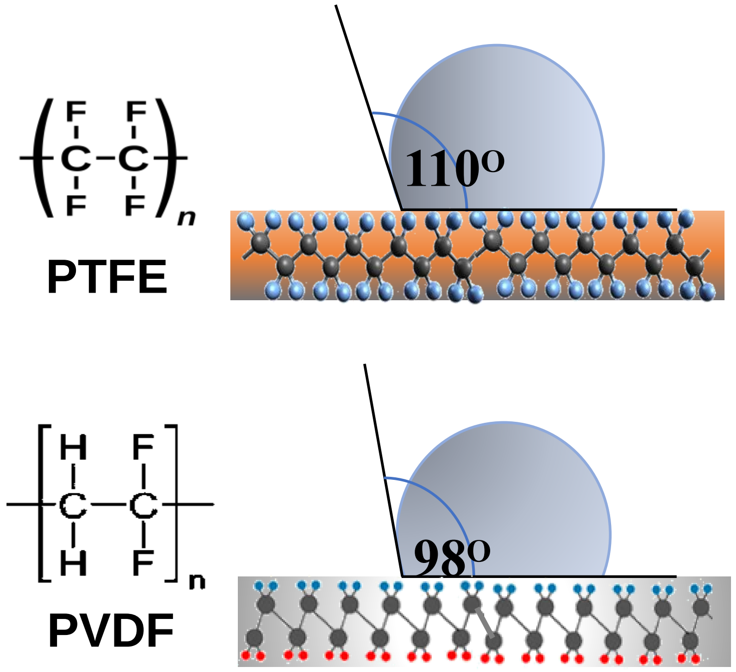


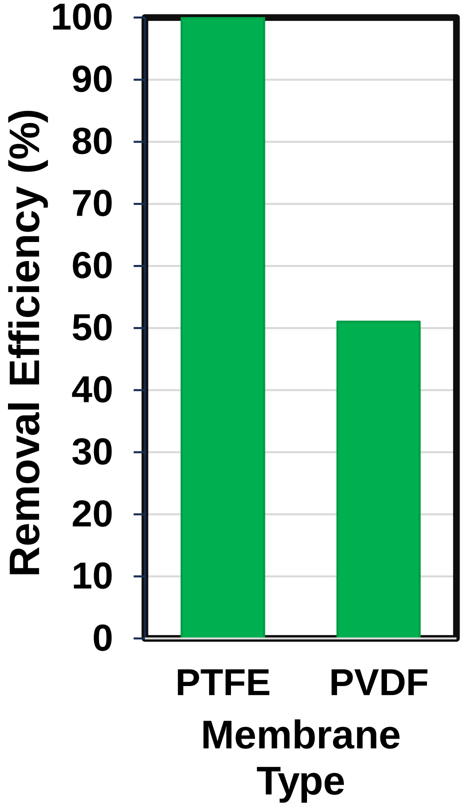
High Performance Liquid Chromatography (HPLC): PFAS concentration

Results and Discussion

<u>Objective # 1:</u> Effectiveness of various hydrophobic membranes (PTFE versus PVDF)







Water flux, $J = \frac{V}{At}$

V = Volume of distillate water (L)

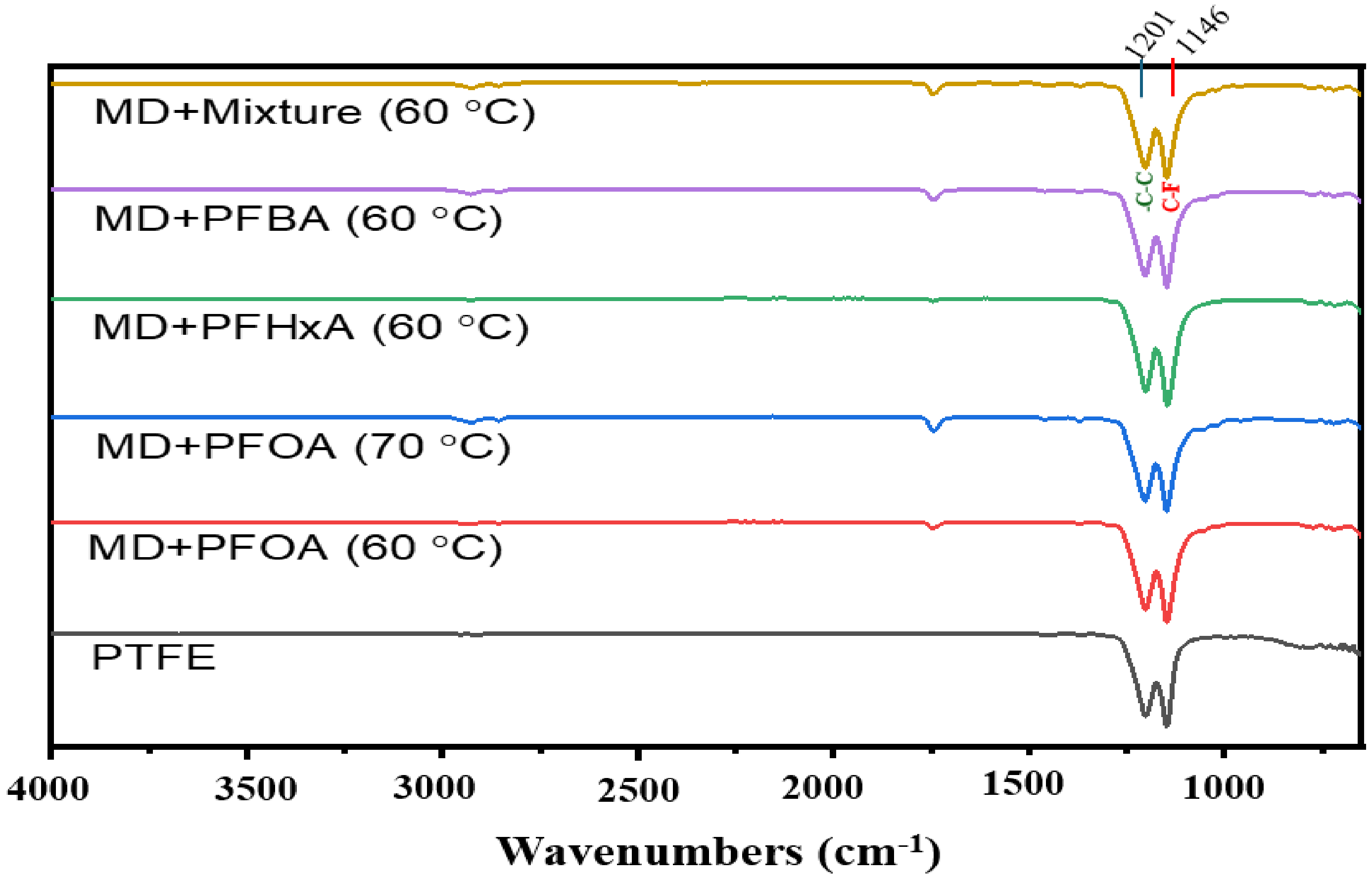
A = Membrane surface area (m^2)

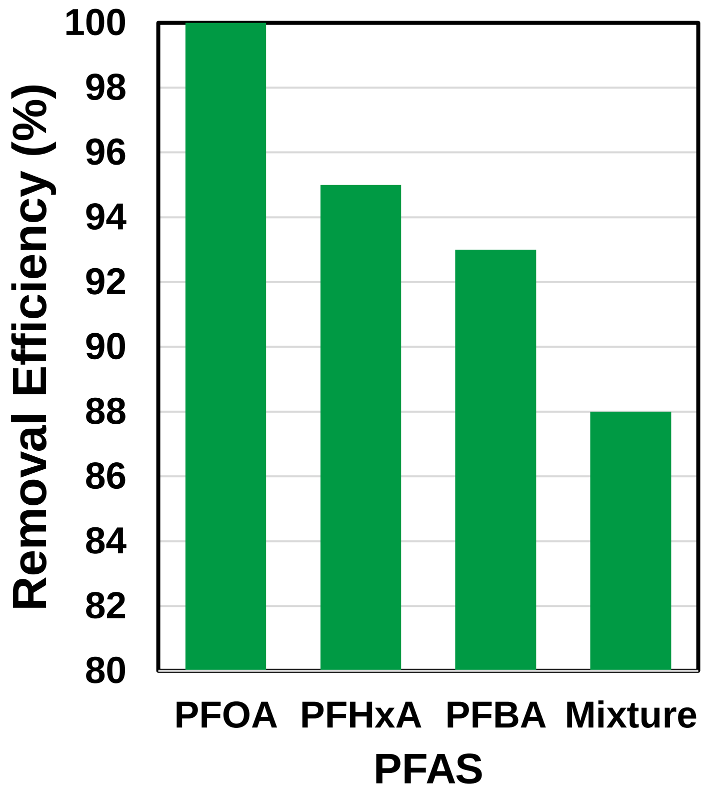
t = time (min)

- PTFE maintains a higher and more stable water flux, and complete removal of PFOA compared to PVDF due to its higher hydrophobicity

Results and Discussion

Objective # 1: PFAS removal efficiencies on PTFE membrane

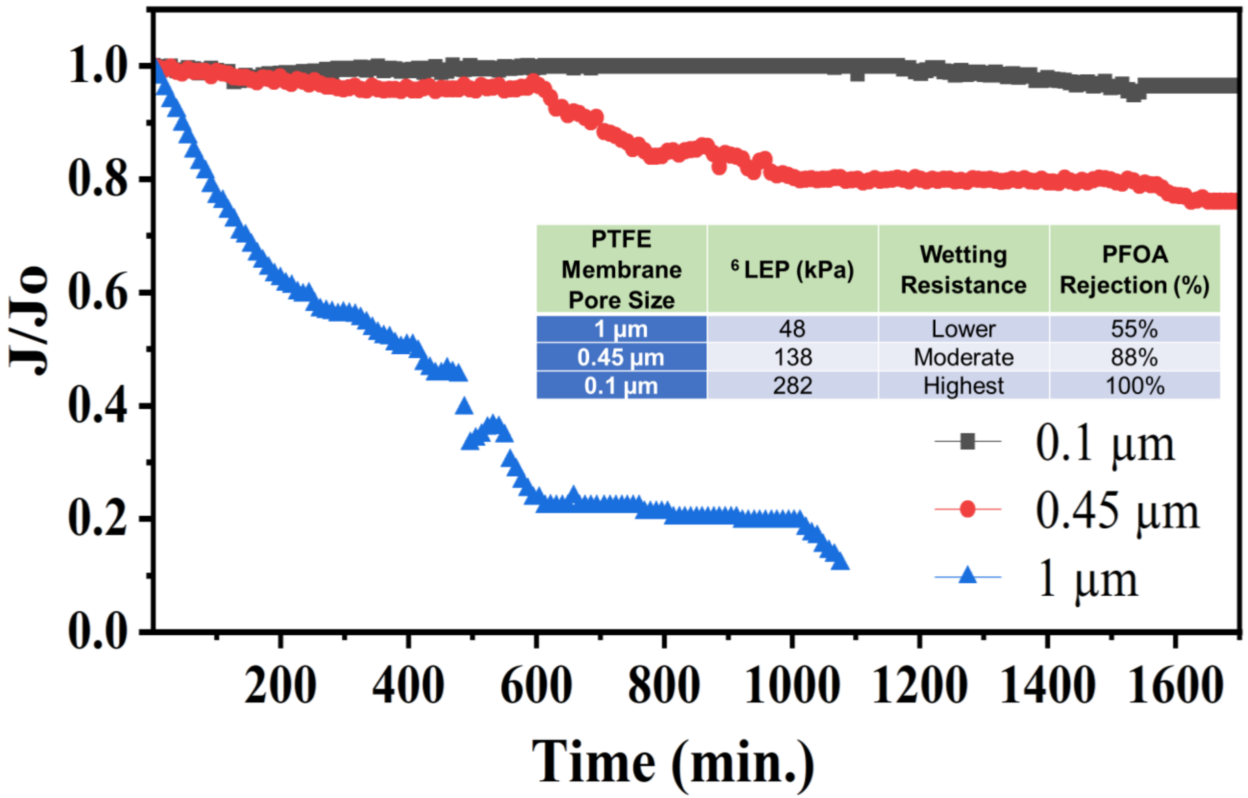




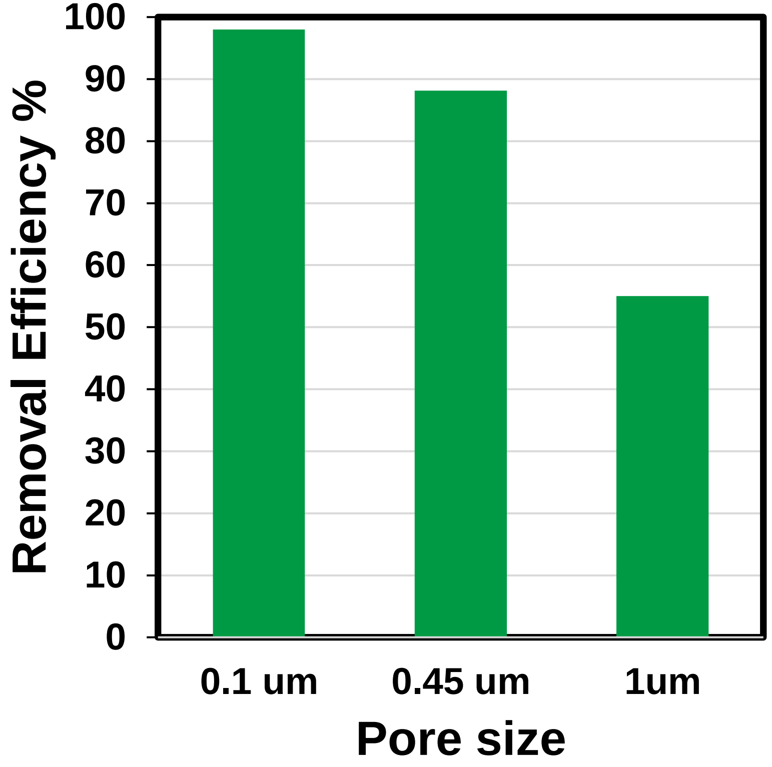
- Longer-chain PFAS compounds achieve higher rejection rates due to their greater hydrophobicity and lower vapor pressure

Results and Discussion

Objective # 2: Impact of different pore sizes



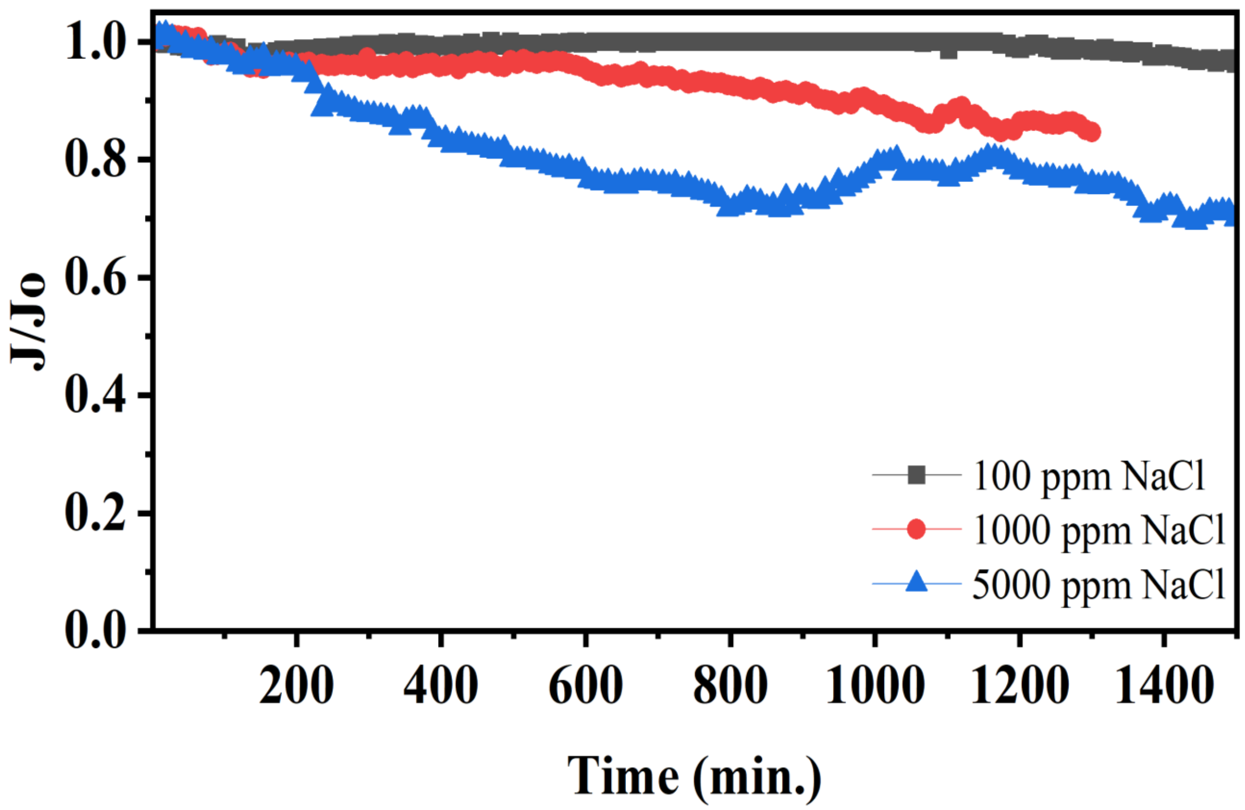
PTFE Membrane Pore Size	[6] LEP (kPa)	Wetting Resistance	PFOA Rejection (%)
1 µm	48	Lower	55%
0.45 µm	138	Moderate	88%
0.1 µm	282	Highest	100%

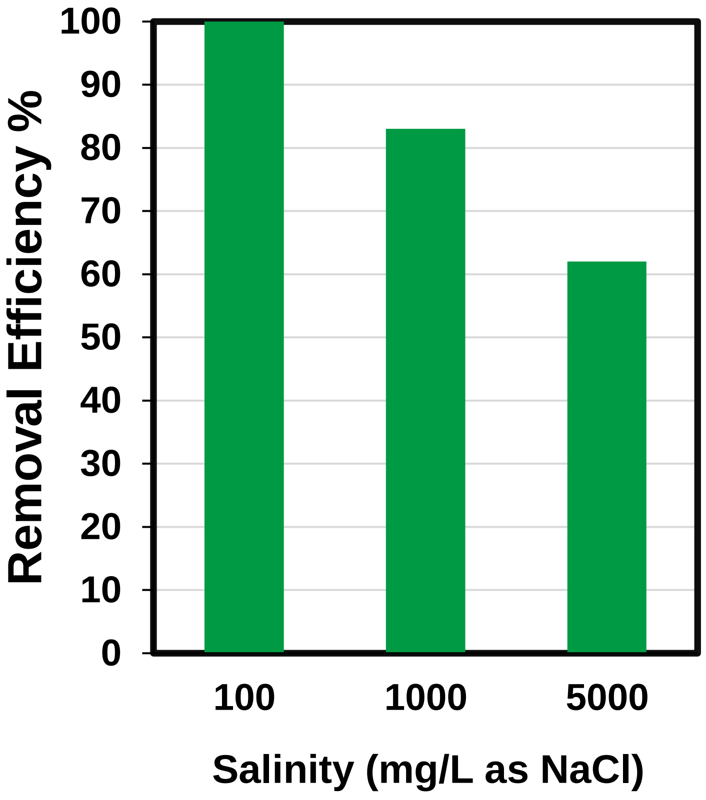


- ➢ PFOA removal efficiency decreased with increasing PTFE membrane pore size due to lower liquid entry pressures (LEPs) and reduced wetting resistance, leading to higher susceptibility to pore wetting and solute penetration

Results and Discussion

Objective # 3: Impact of varying salinity

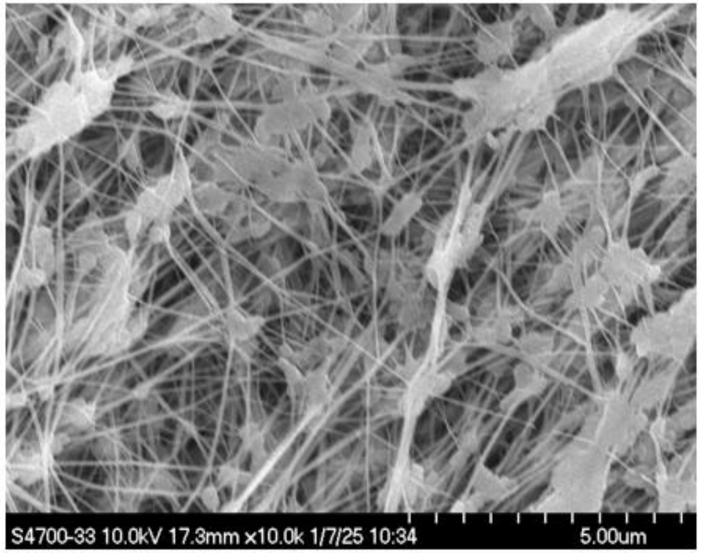




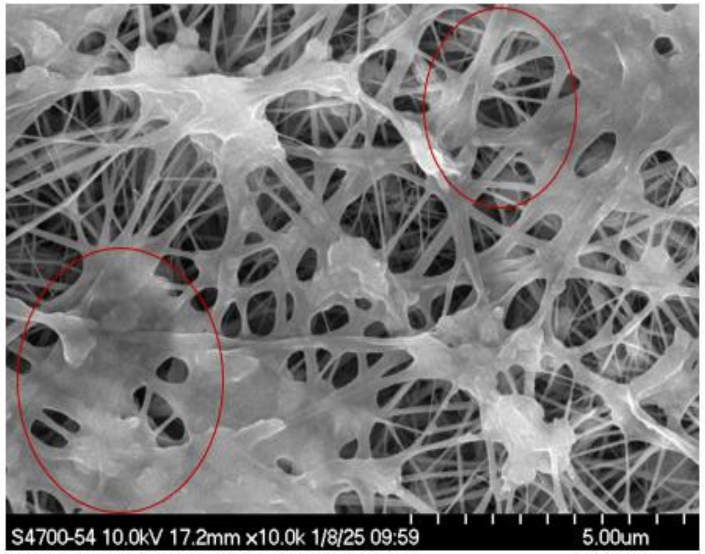
- PFOA rejection efficiency decreased with increasing salinity due to the lower surface tension of water, which facilitates PFOA penetration into membrane pores

Results and Discussion

<u>Objective # 4:</u> Impact of temperature gradient on PTFE

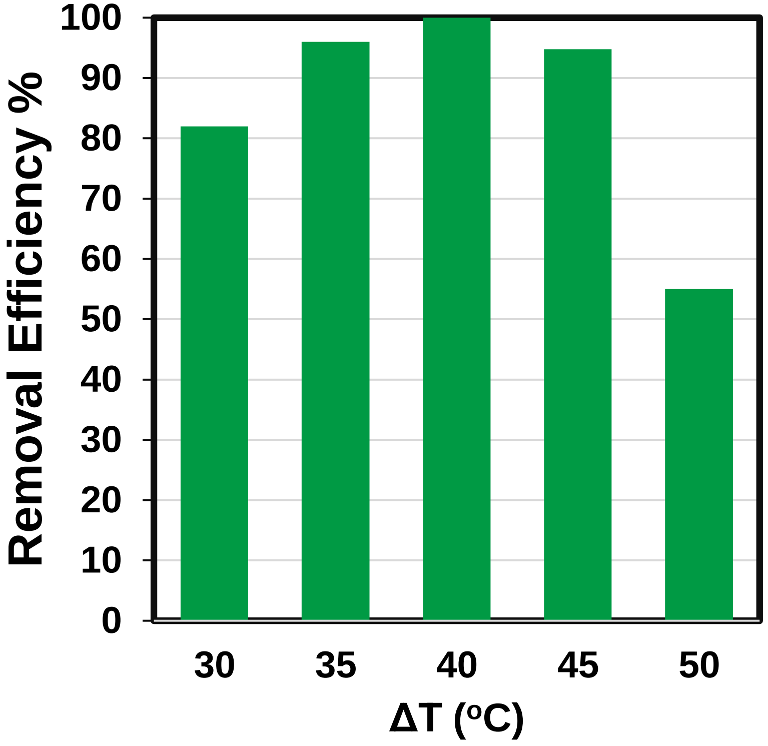


Before



After

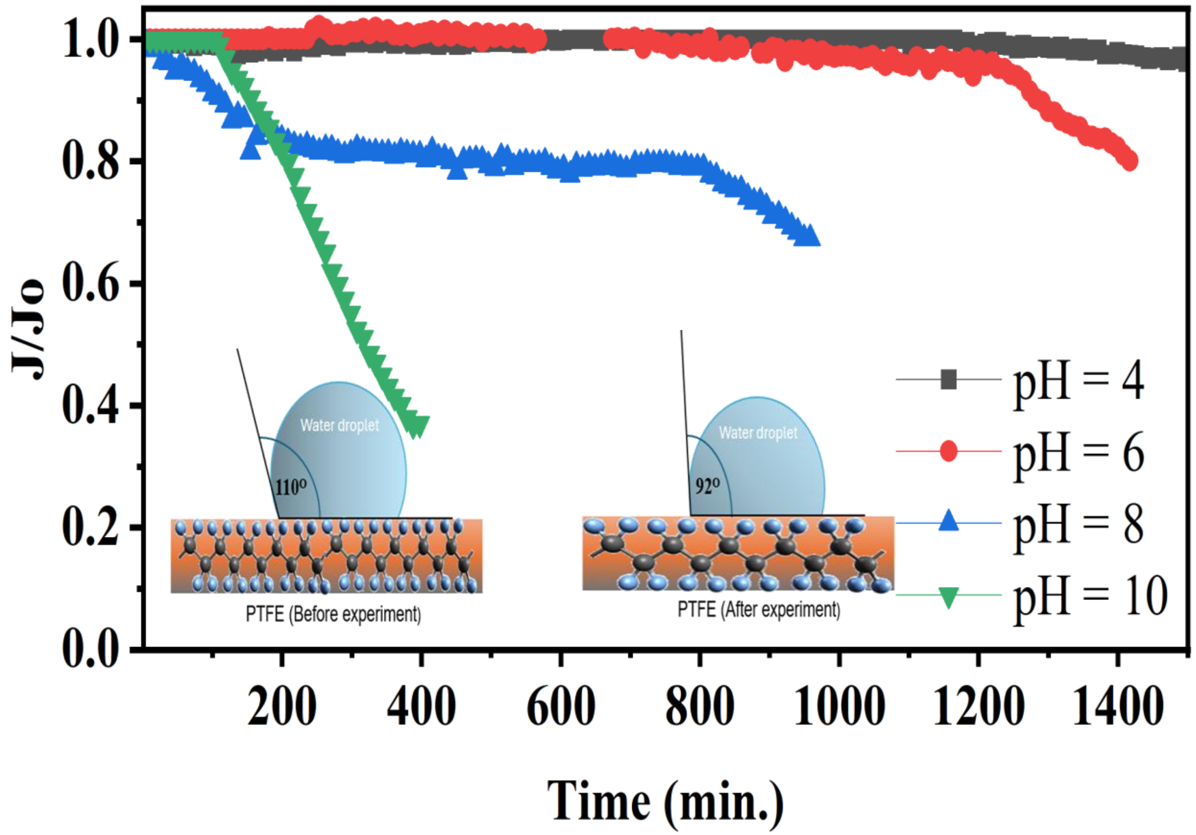
Scanning Electron Microscope (SEM) images of the membrane surface in the membrane distillation process

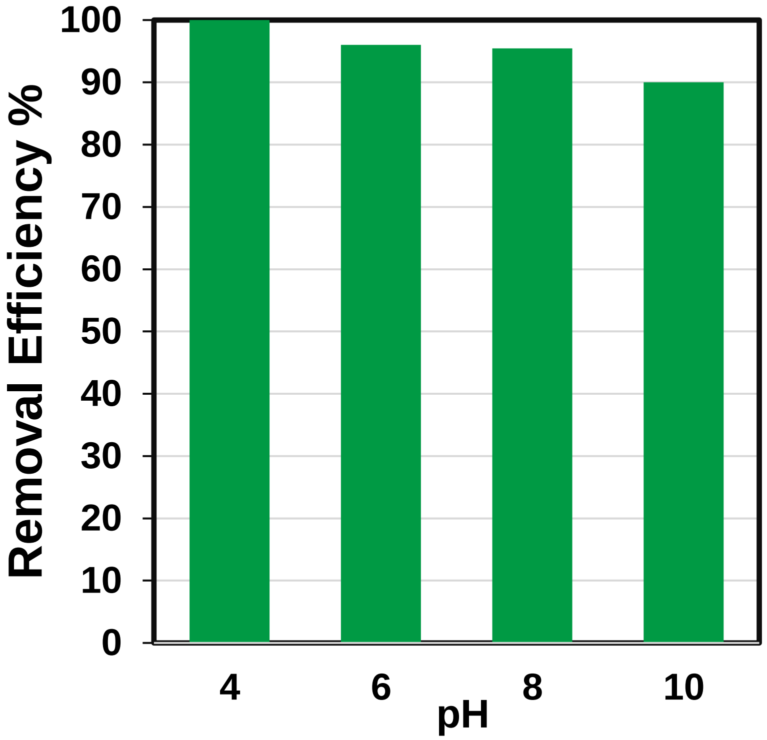


- A temperature gradient of 40°C reflects the optimal temperature for removing PFOA

Results and Discussion

Objective # 4: Impact of pH on PTFE





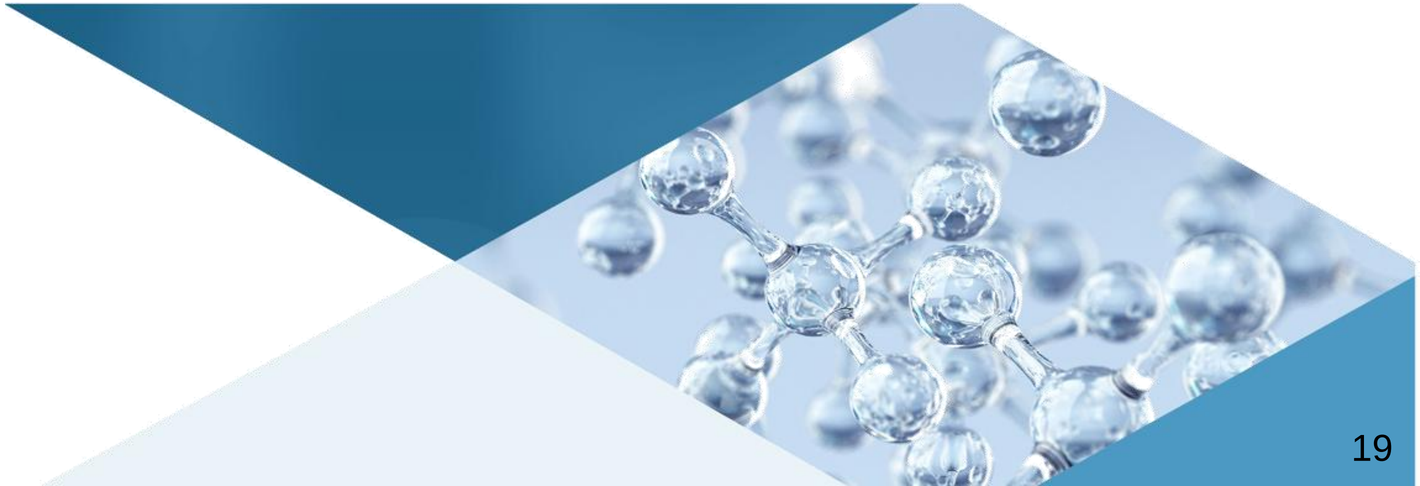
- A significant flux decline was observed with increasing pH due to increased pore wettability, which led to a slight decrease in PFOA removal

Key Findings

- **PTFE** membranes exhibited 100% PFOA removal efficiency while PDVF achieved 51% removal efficiency. Longer-chain compounds showed higher rejection, attributed to lower volatility and stronger membrane interactions on PTFE membrane.
- The **0.1 µm pore size of PTFE** demonstrates the best PFOA rejection due to its superior hydrophobicity with higher LEP and enhanced molecular sieving effect, achieving ~100% rejection efficiency.
- PFAS rejection efficiency **decreased** with increasing salinity, achieving 100% rejection at 100 ppm, 83% at 1000 ppm, and 62% at 5000 ppm.
- At **pH 4**, PFOA is in its neutral form, leading to stronger hydrophobic interactions with the PTFE membrane and maximum removal efficiency, whereas at pH 10, PFOA is anionic, causing electrostatic repulsion and reduced rejection.
- A **temperature gradient of 40°C** (Feed: 60°C, Permeate: 20°C) was the most effective, resulting in **100% PFOA rejection**.

Future Directions

- To investigate with a variety of PFAS (**with sulfonate vs carboxylate group and short-long chain PFAS**)
- To operate with real **Hydraulic Fraction** water
- To coat the membrane with **different absorbent** materials to increase the efficiency.



Acknowledgment

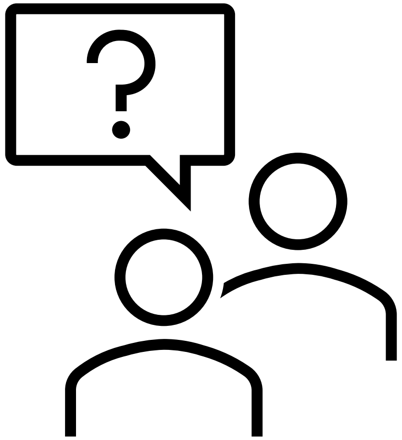
Ersan Research Lab

References

For more information

Scanning electron microscope imaging was performed at the UND Imaging Core Facility, supported by NIH grant P20GM113123, DaCCoTA CTR NIH grant U54GM128729, and UNDSMHS funds.

Thank You!



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