Hydration Analysis of Carbon Nanotubes/Polyamide Nanocomposite Thin Films

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With the ever growing population and scarcity of clean, drinkable water, filtration and desalination have become essential in daily life. Polyamide (PA) reverses osmosis (RO) membranes have become the industry standard for water desalination because of their high salt rejection, high water flux and robustness, but they have limited lifespans due to low oxidant tolerance and high fouling rate. Carbon nanotube/PA nanocomposite RO membranes have shown improved flow rate, oxidant tolerance, and lower fouling rates without compromising salt rejection. Computational and theoretical findings [1] have suggested that the carbon nanotubes act as a support structure for the PA membrane, increasing the density of the active layer. This suggests there are fewer water pockets within the membrane, which act as ion transport channels, resulting in a higher salt rejection. However, this proposed mechanism has yet to be confirmed due to a lack of experimental measurements. In this work, we examine the changes in hydration of PA membranes prepared with the addition of carbon nanotubes. Our measurements indicate the membranes containing carbon nanotubes have a lower relative water absorption, suggesting an increase in membrane density. These results are in agreement with the numerical simulations, and provide additional insight into the much needed advancements in water filtration technologies.

[1] S. Inukai, R. Cruz-Silva, J. Ortiz-Medina, A. Morelos-Gomez, K. Takeuchi, T. Hayashi, A. Tanioka, T. Araki, S. Tejima, T. Noguchi, M. Terrones & M. Endo. High-performance multi-functional reverse osmosis membranes obtained by carbon nanotube/polyamide nanocomposite Scientific Reports 5, Article number: 13562 (2015) DOI:10.1038/srep13562

[2] T. Araki, R. Cruz–Silva, S. Tejima, K. Takeuchi, T. Hayashi, S. Inukai, T. Noguchi, A. Tanioka, T. Kawaguchi, M. Terrones, and M. Endo. Molecular Dynamics Study of Carbon Nanotubes/Polyamide Reverse Osmosis Membranes: Polymerization, Structure, and Hydration *ACS Applied Materials & Interfaces* 2015, *7* (44), 24566-24575 DOI:10.1021/acsami.5b06248

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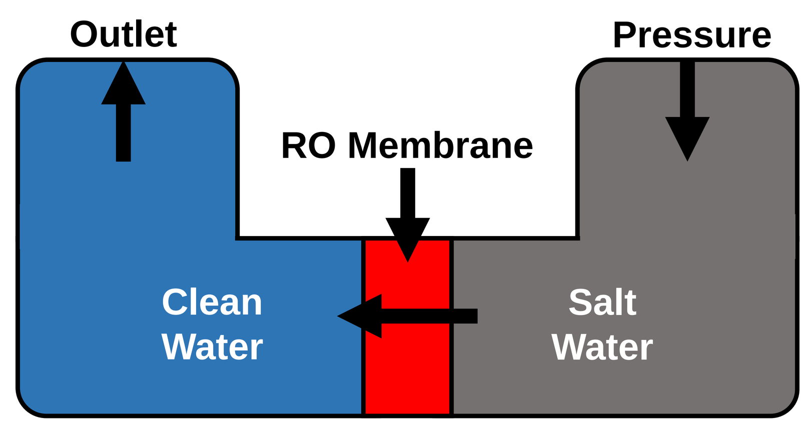
Background

According to the World Health Organization (WHO), 663 million people still do not have access to a safe and reliable source of clean, drinkable water [1].

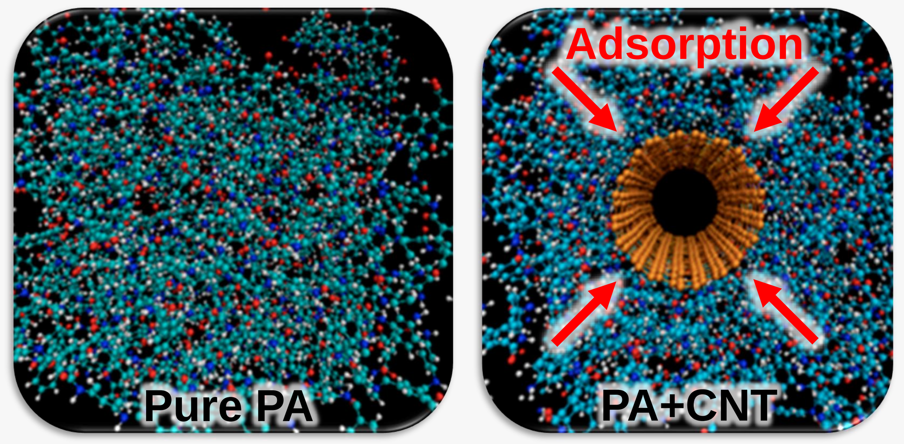
Reverse Osmosis (RO) Desalination



Polyamide RO Filters:
- Industry standard for desalination
- High salt rejection, high water flux, and relative robustness
- Limited life-span due to low oxidant tolerance and high fouling rate increasing cost of water filtration

Introduction

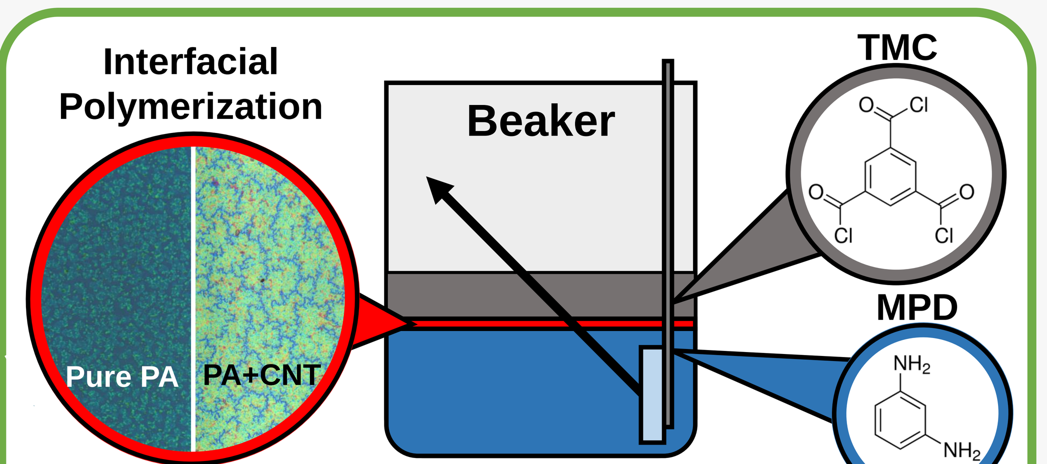
Why add Carbon Nanotube (CNT):
- Improves water flux, oxidant tolerance, anti-fouling properties, and increase salt rejection [2]
- Theoretical analysis [3]:
  - CNT act as a support structure
  - Creates more dense membrane



Images modified from Inukai et al [3]

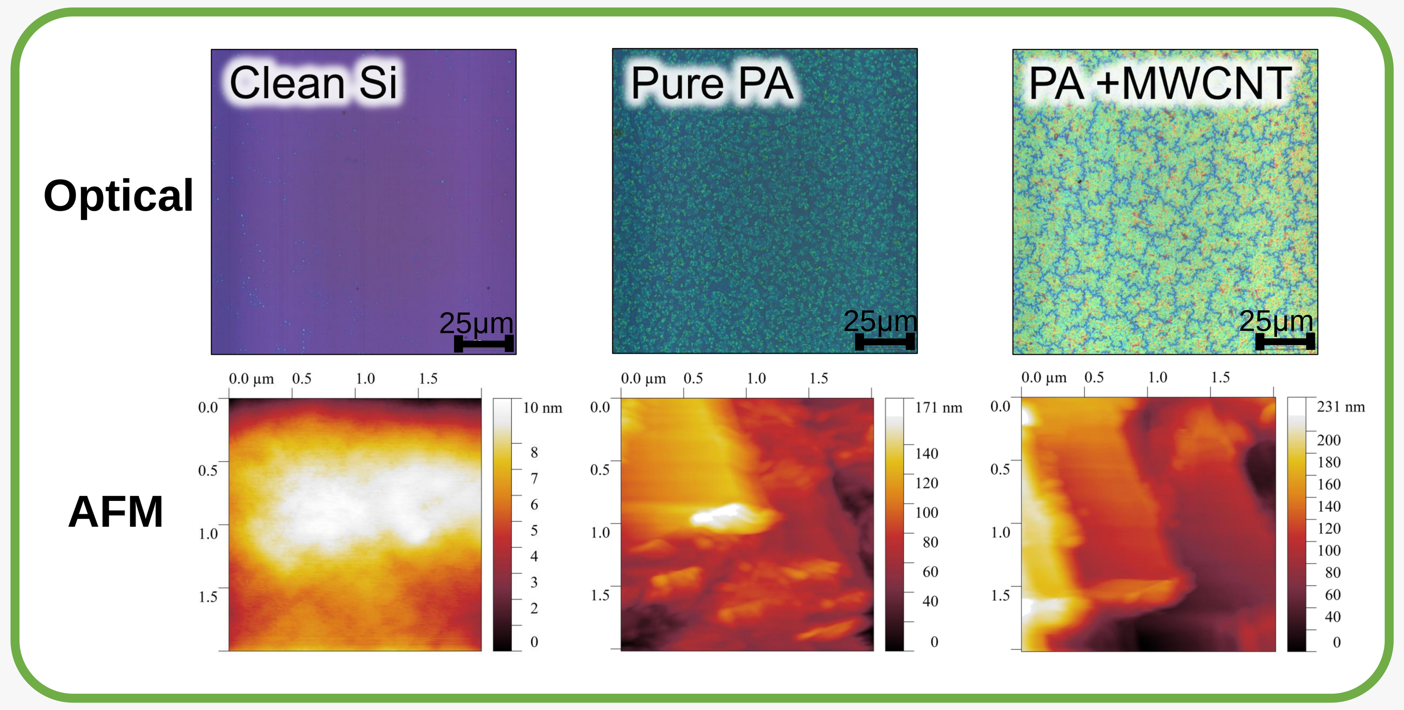
Purpose of this work:
- To study how the addition of multi-walled carbon nanotubes (MWCNT) affect the hydration of polyamide reverse osmosis thin films
- Develop a method of lab-scale dip coating of PA membrane on substrates
- Compare these results to computational and theoretical findings

Film Synthesis and Collection

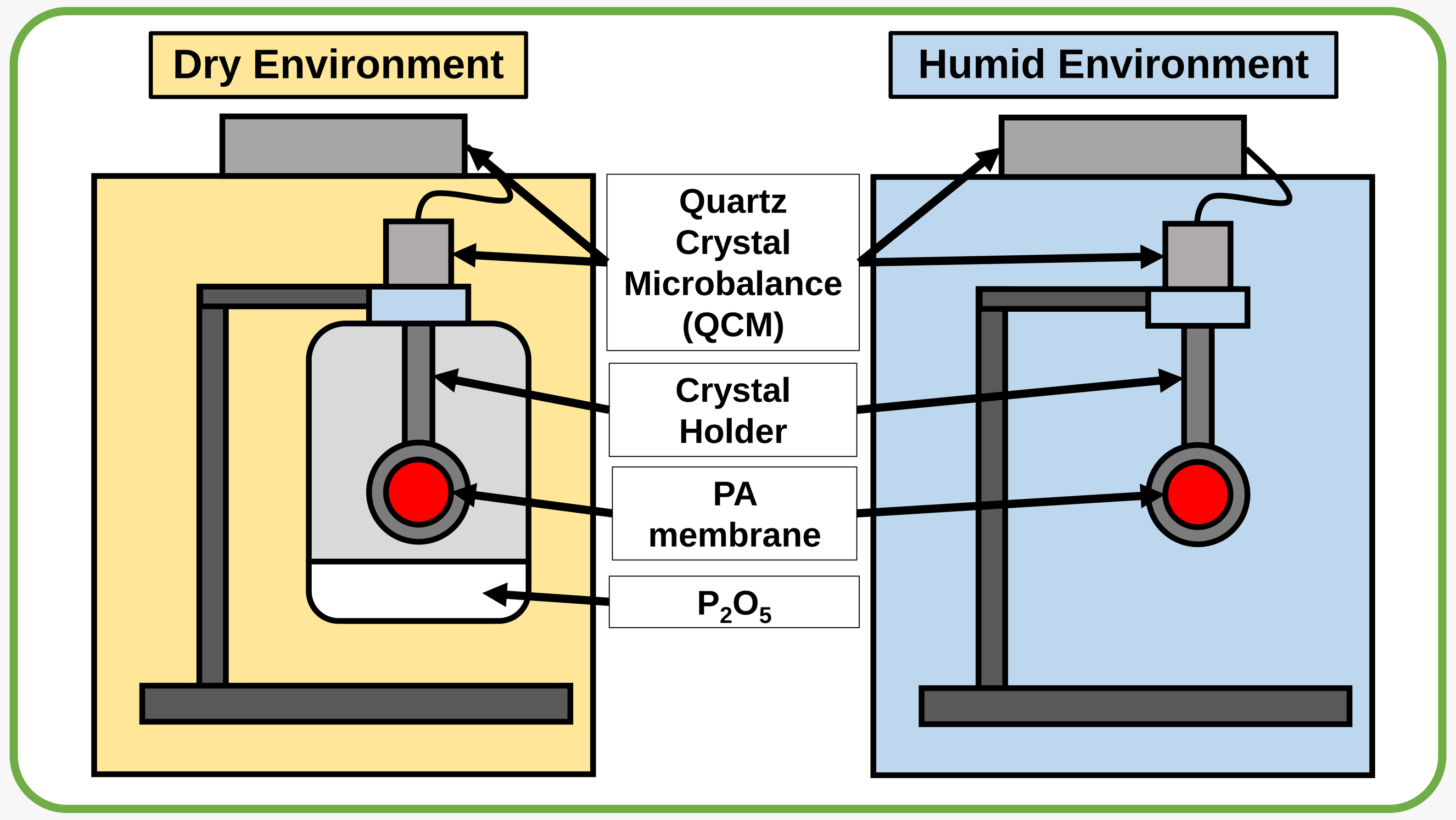


- m-Phenylenediamine (MPD) in water (Aqueous Phase)
- Benzenetricarbonyl trichloride (TMC) in hexane (Organic Phase)

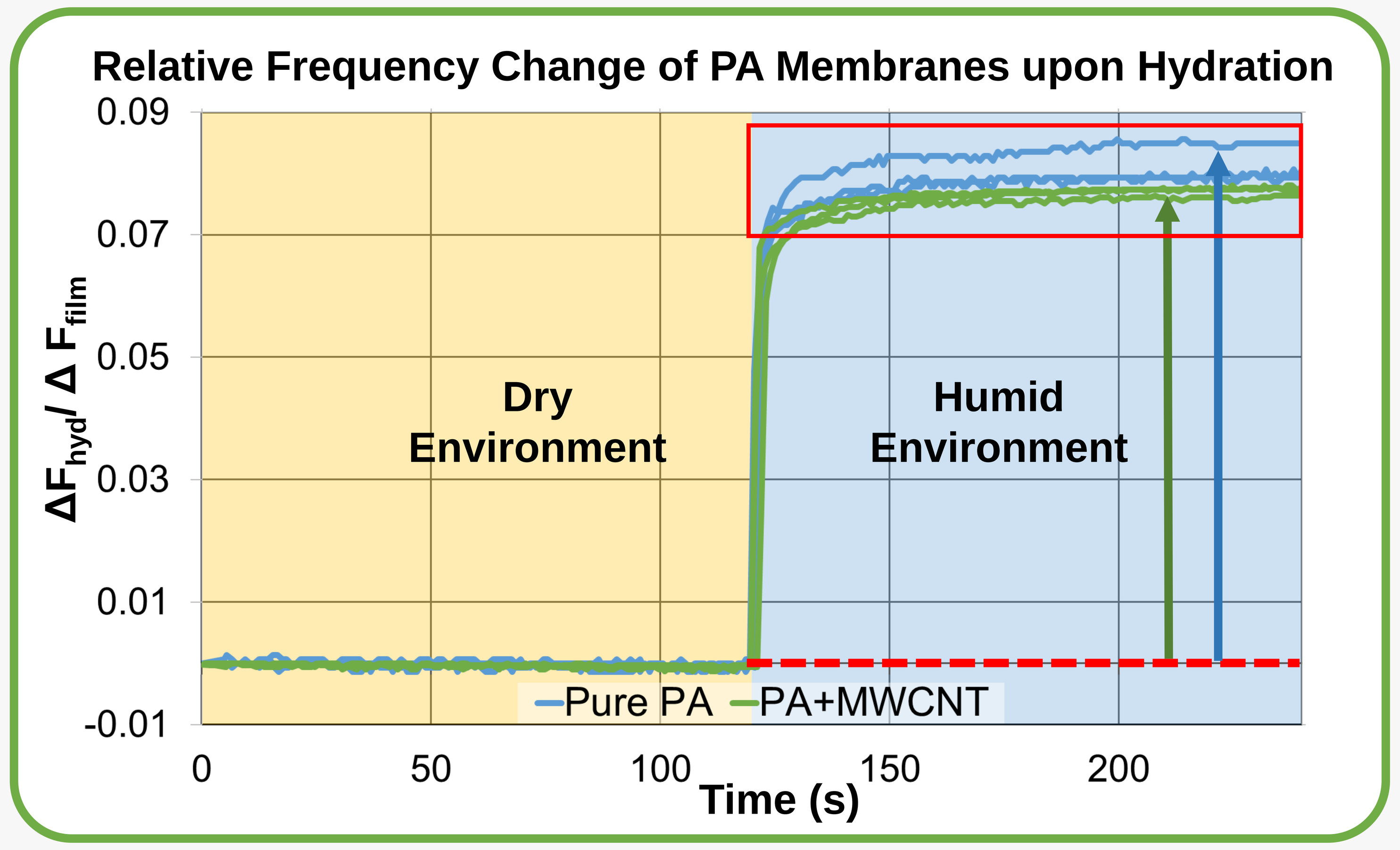
Film Characterization



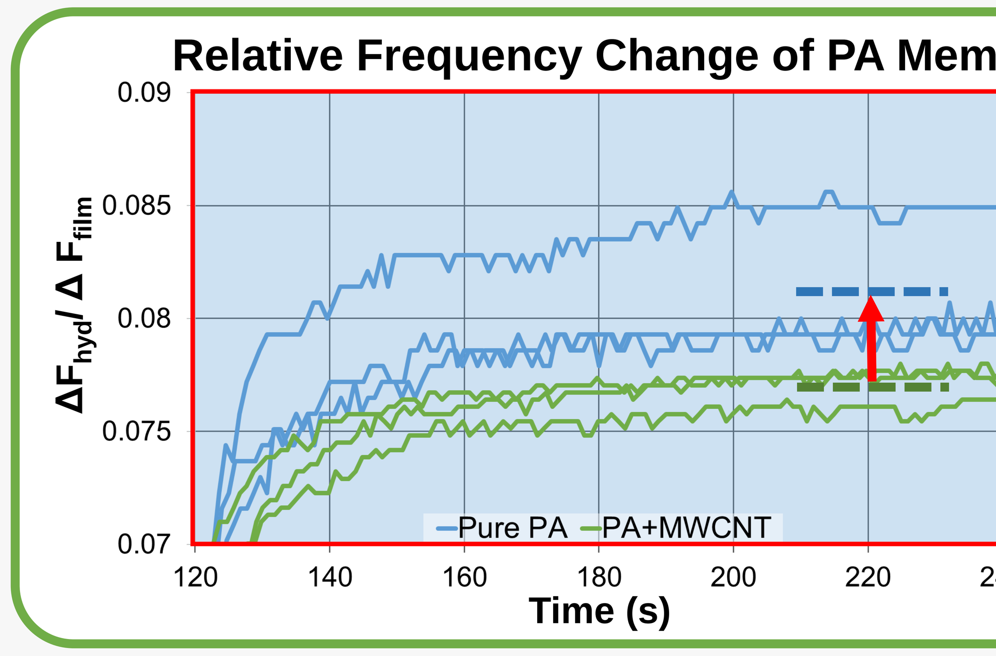
Film Hydration Setup



Results



Analysis and Discussion



- Slight difference in relative water absorption
- Suggests PA+MWCNT film is slightly more dense than pure PA

Material	Δf_{film} (Hz)	Ave. Δf_{hyd} (Hz)	$\Delta F_{hyd} / \Delta F_{film}$	% Change
Pure PA	-142.5	-11.6	81.4×10^{-3}	4.96± 0.005
PA+MWCNT	-314.1	-24.3	77.1×10^{-3}	

Conclusion

- Observed the PA+MWCNT films to have ~5.0% decrease in absorption when compared to Pure PA
- Potential evidence for computational/theoretical findings which suggest ~9.6% reduction in absorption
- Developed a automated apparatus for lab scale dip coating of PA membranes on substrates

Next Steps:
- Use other carbon nanostructures such as single and double walled CNT
- Create a more controlled humid and dry environments to help reduce experimental error and improve repeatability
- Use different concentration of MPD for different membrane thicknesses

Acknowledgements

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2. S. Inukai, R. Cruz-Silva, J. Ortiz-Medina, A. Morelos-Gomez, K. Takeuchi, T. Hayashi, A. Tanioka, T. Araki, S. Tejima, T. Noguchi, M. Terrones & M. Endo. High-performance multi-functional reverse osmosis membranes obtained by carbon nanotube/polyamide nanocomposite *Scientific Reports 5*, Article number: 13562 (2015) DOI:10.1038/srep13562
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