Investigating New Polymers for a Chlorine Tolerant RO Membrane

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Abstract

Purification of water has increasingly become an issue during the past decade as the available supply of drinkable water continues to be depleted. Scientists are continuously struggling to create a new membrane that is both reliable and chlorine tolerant. The discovery of such a polymer could potentially enable our utilization of additional water sources, thereby increasing the global supply of water. The purpose of our experiment was to investigate new polymers for a more chlorine tolerant membrane. We tested Acrylonitrile Butadiene Styrene, Polyethylene, Polytetrafluoroethylene, Polyvinylidene Fluoride, and Polyphenylene Sulfide to determine which had the most robust physical and chemical properties. The polymers were soaked in solutions of varying pH and ppm, and after a certain number of days they were removed. We analyzed the chlorine attacks using Atomic Force Microscopy, Fourier Transform Infrared Spectroscopy, and tensile strength tests. We found that PTFE was the most chlorine tolerant polymer, while ABS overwhelmingly had the greatest tensile strength. This data may prove to be very valuable in the future, since the major problem today for water purification is the elimination of chlorine. It may help scientists develop a RO membrane that is more efficient and cost-friendly for both industrial and home RO systems.

Question

With the current issues of chlorine and other contaminants in water, what polymers have the highest chlorine tolerance and the most robust physical structures?

Introduction and Literature

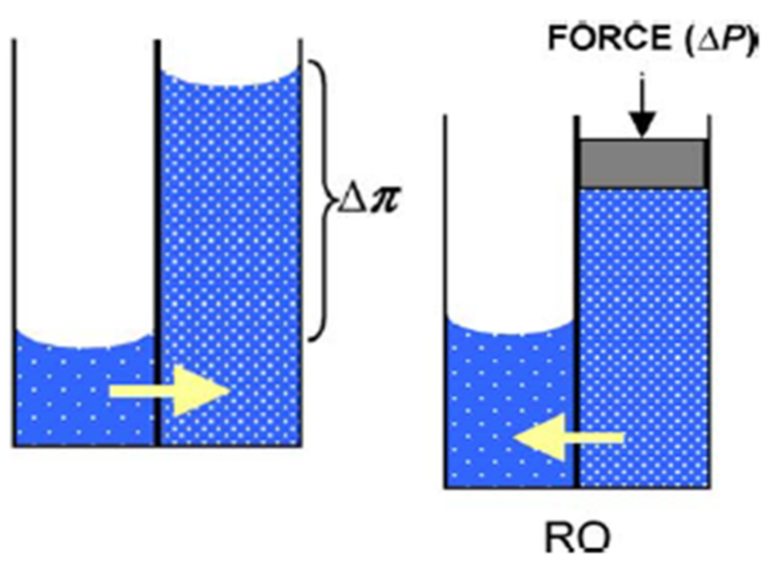


Figure 1: Osmotic pressure and applied reverse osmosis

What is reverse osmosis (RO)? Reverse osmosis is a method of water purification that applies a hydraulic pressure in order to overcome the osmotic pressure of an aqueous feed solution. RO is currently the most cost-efficient method and the finest form of water filtration available today. The membrane is semi-permeable, meaning that water is able to pass through while contaminants are sifted out.

Why a new polymer? The polyamide layer has the smallest holes and is therefore the most important. This is the polymer that makes up the rejection layer of a Thin Film Composite (TFC) RO membrane. Since chlorine the most widely used disinfectant for water, the polyamide must have a high chlorine tolerance.

Desirable characteristics of a RO membrane:
- High contaminant rejection rate
- High selectivity to water, chemically resistant
- High flux (flow per unit area; decreases filter time)

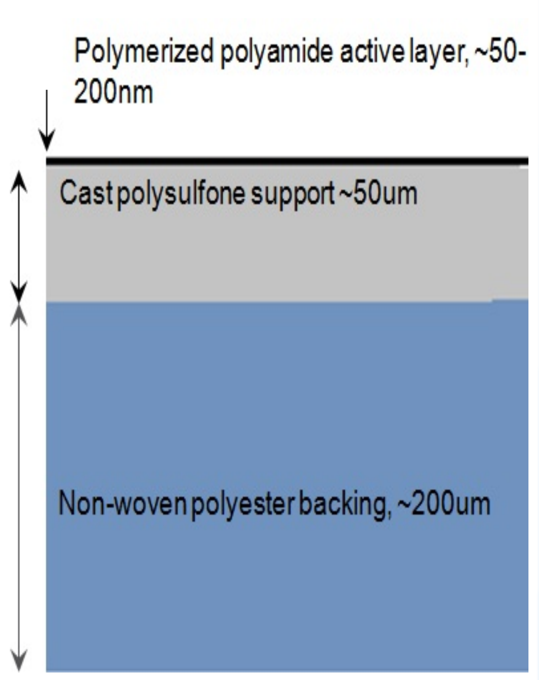


Figure 2: Layers of a membrane

Hypothesis

Polytetrafluoroethylene/Teflon (PTFE) will be the strongest chemically, exhibiting the highest chlorine tolerance due to its stable structure and characteristics. Acrylonitrile Butadiene Styrene (ABS) will show the most chance due to its nitrogen bond, which is susceptible to attack from chlorine. However, it will be the strongest polymer physically, exhibiting the highest tensile strength due to its strength and rigidity.

Five Polymers

Acrylonitrile Butadiene Styrene (ABS): Strong and rigid, resistant to many acids and bases, susceptible to damage by chlorinated hydrocarbons
Polyethylene (PE): Flexible, used for pressurized water systems (ie. sprinklers), NOT for high temperatures
Polyvinylidene Fluoride (PVDF): Strong, very tough, resistant to abrasion, acids, bases, etc.
Polytetrafluoroethylene/Teflon (PTFE): Maximum chemical and pH resistance, highly porous, tough, hot water resistant, difficult to bond
Polyphenylene Sulfide (PPS): Resistant to heat, acids, and bases, absorbs small amounts of solvents

Characterization Techniques

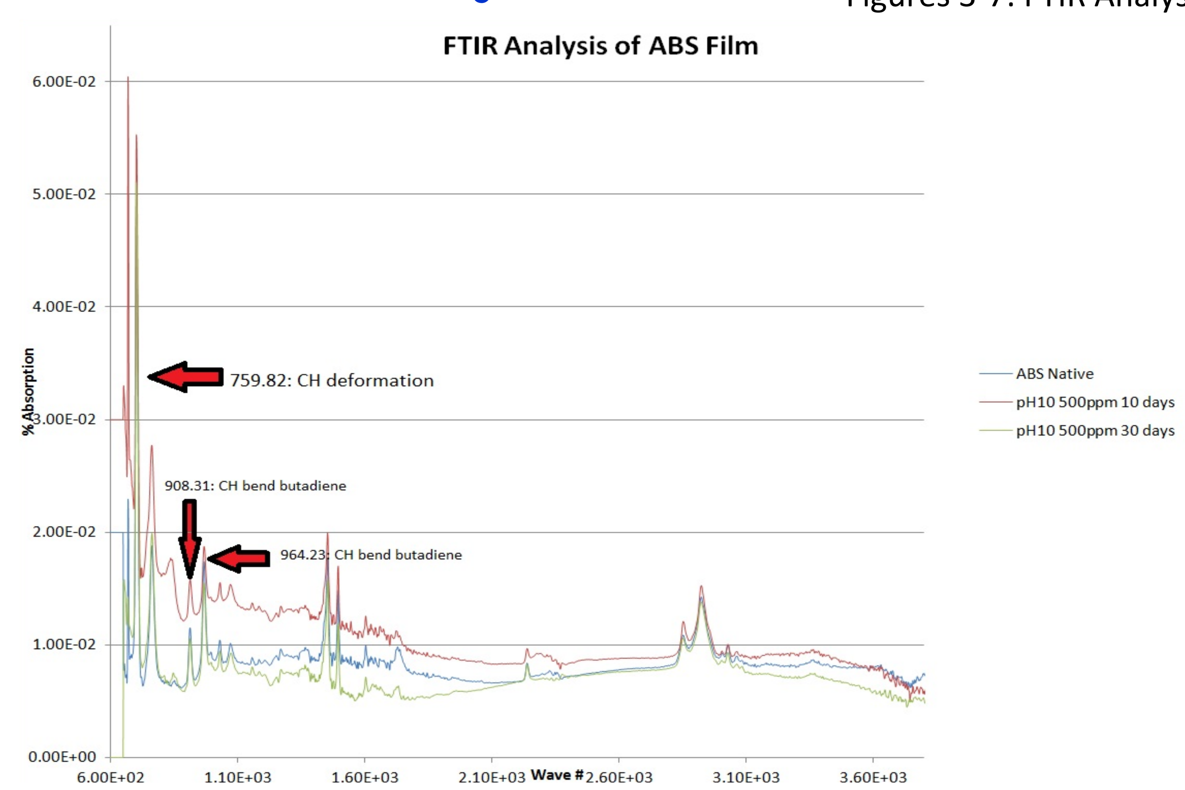
Fourier Transform Infrared (FTIR) Spectroscopy: Infrared radiation passed through a sample; some waves are absorbed, others passed through (transmitted). This creates a spectrum of molecular absorption and transmission, creating a molecular fingerprint of the sample.
Tensile strength: Represents the maximum stress a membrane may withstand as a force is applied; demonstrates overall physical strength
Atomic Force Microscopy (AFM): Heat mapping; provides a surface view of the polymer. Utilizes a needle, which bounces up and down across a membrane. A laser detects the movement to create a 3D map.

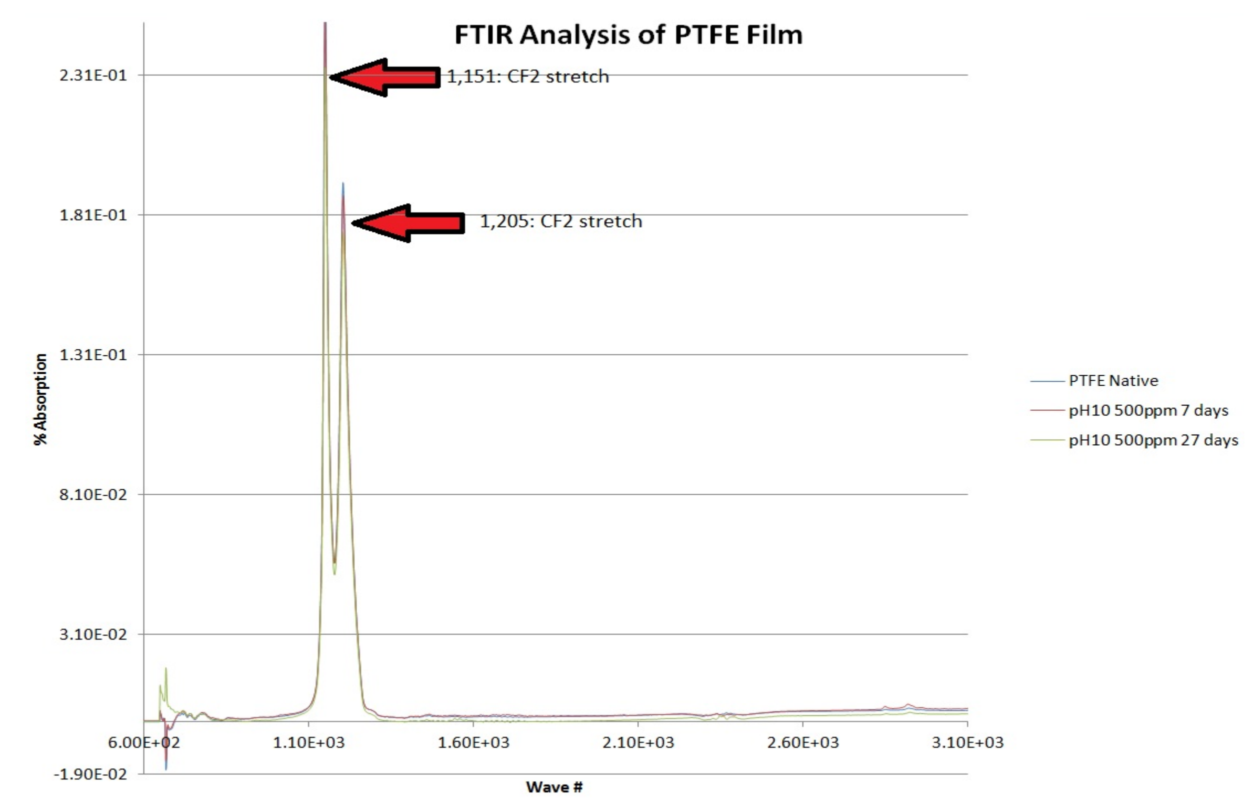
Procedure

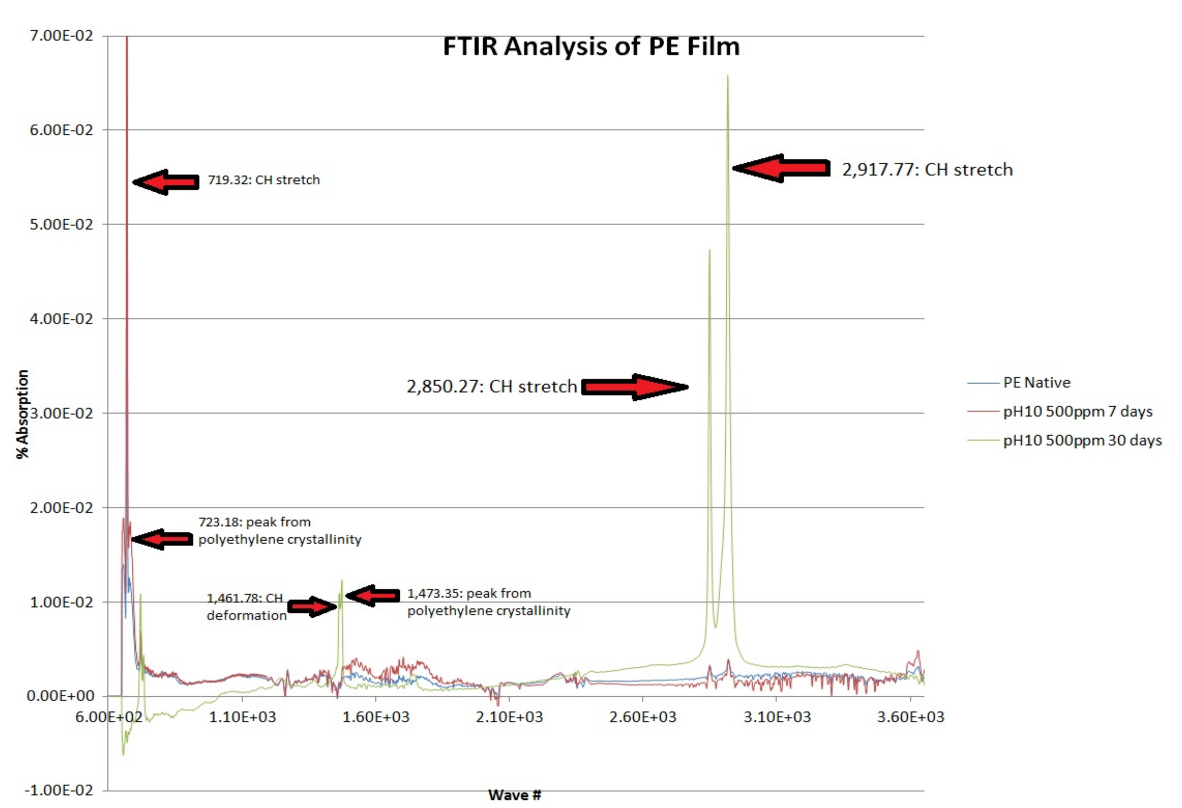
1. Prepare chlorinated solutions of varying pH (7 and 10) and concentration in parts per million (ppm).
2. Cut out strips 2 x 7 cm, six for each of five polymers.
3. Using one of each polymer, perform a FTIR, AFM, and tensile strength test. This will become the native (or control) data sample.
4. Soak the membranes in the solutions for a designated time period (7, 10, and 30 days for accuracy).
5. After each given number of days, remove one strip from each solution and clean with deionized water.
6. Analyze the strips using FTIR, tensile strength, and AFM.

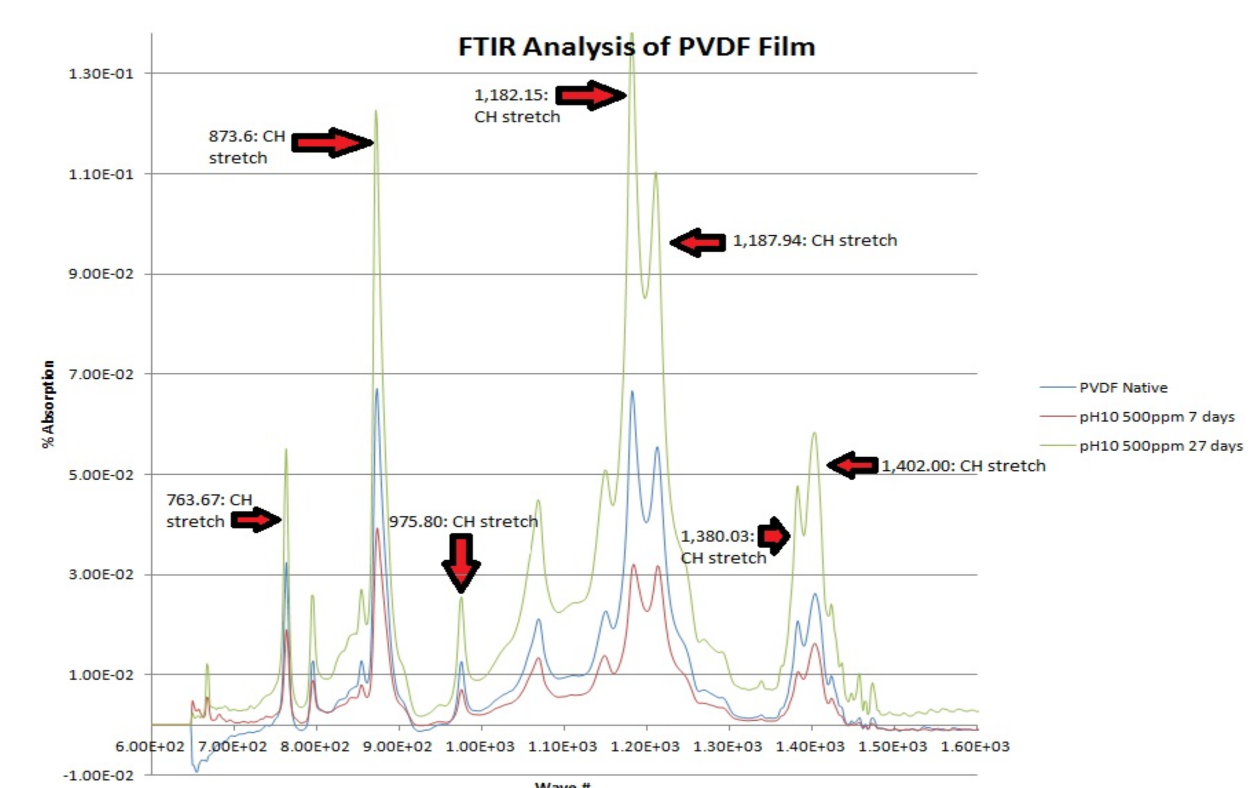
Data and Analysis

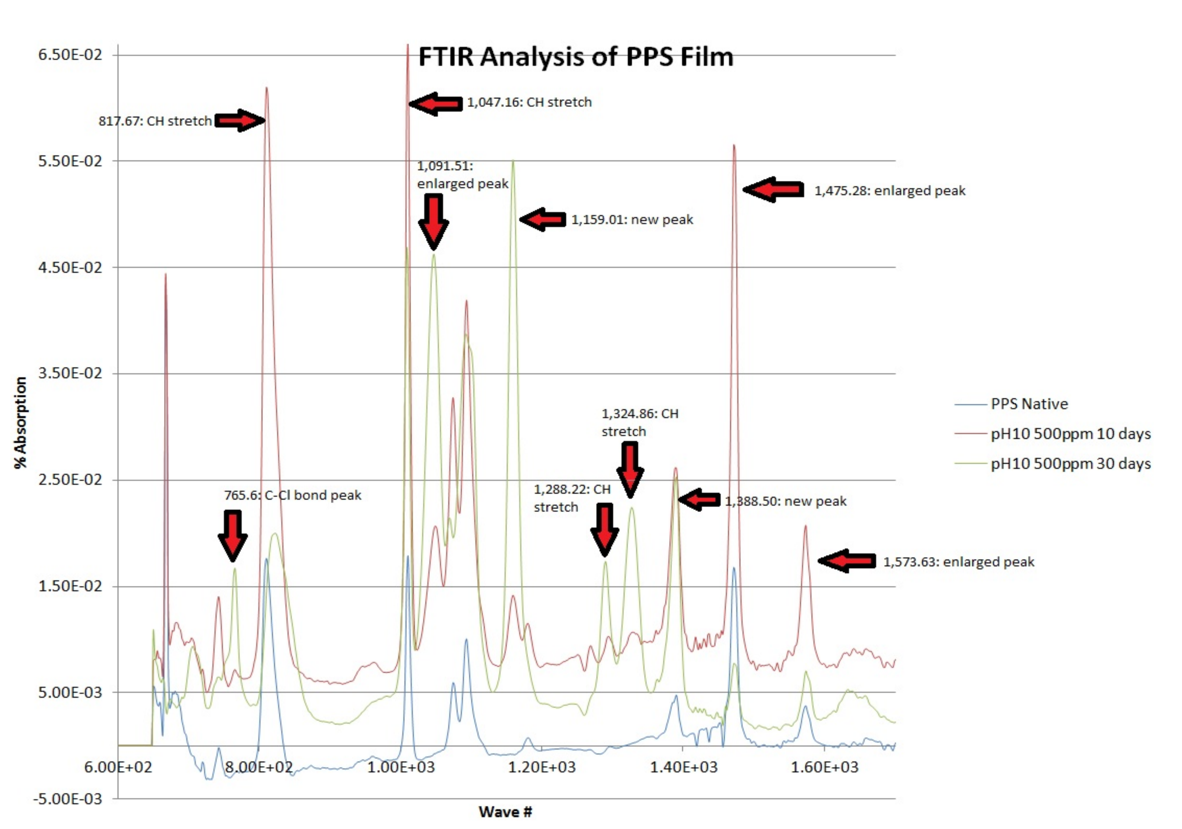
Figures 3-7: FTIR Analysis











Stretches (peaks, deformations) = absorption of wavelengths and infrared
New stretches = significant changes due to chlorine attack

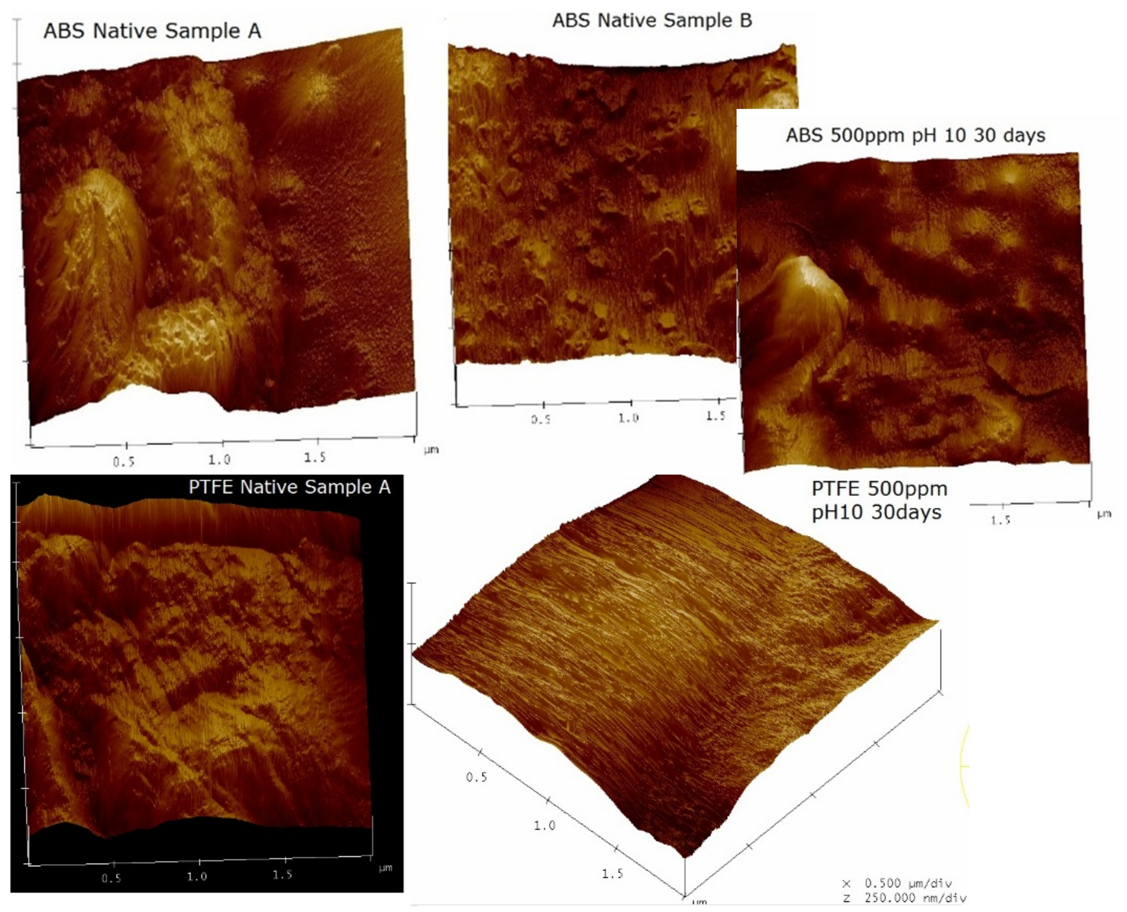
The chlorine slowly affects the membranes, altering their chemical structures slightly and stretching out bonds. When the infrared is passed through the sample, the CH bonds are excited. They then absorb the energy, stretching or deforming as shown in the FTIR results.

Future Research

A possible future study might involve testing RO membranes made with the polymers (ABS, PTFE, PE, PPS, PVDF) to see how efficient they are when put into action. The membranes should also be tested with additional characterization techniques to further support our findings. These supplementary methods include:
X-ray Photoelectron Spectroscopy (XPS): Similar to FTIR, but takes data only from the top layer of nanometers. This would produce results of even higher accuracy, since chlorine does not penetrate too deeply into the polyamide layer.
Instron Test: Similar to the tensile strength, but with even higher accuracy and finer results.
Differential Scanning Calorimetry (DSC): Shows the effects of heat on a polymer. This method may eliminate certain polymers that are unable to withstand high levels of heat.

Atomic Force Microscopy (AFM)

Darker areas = less absorption of heat
Lighter areas = more absorption of heat



Figures 8-9: AFM Analysis

Tensile Strength

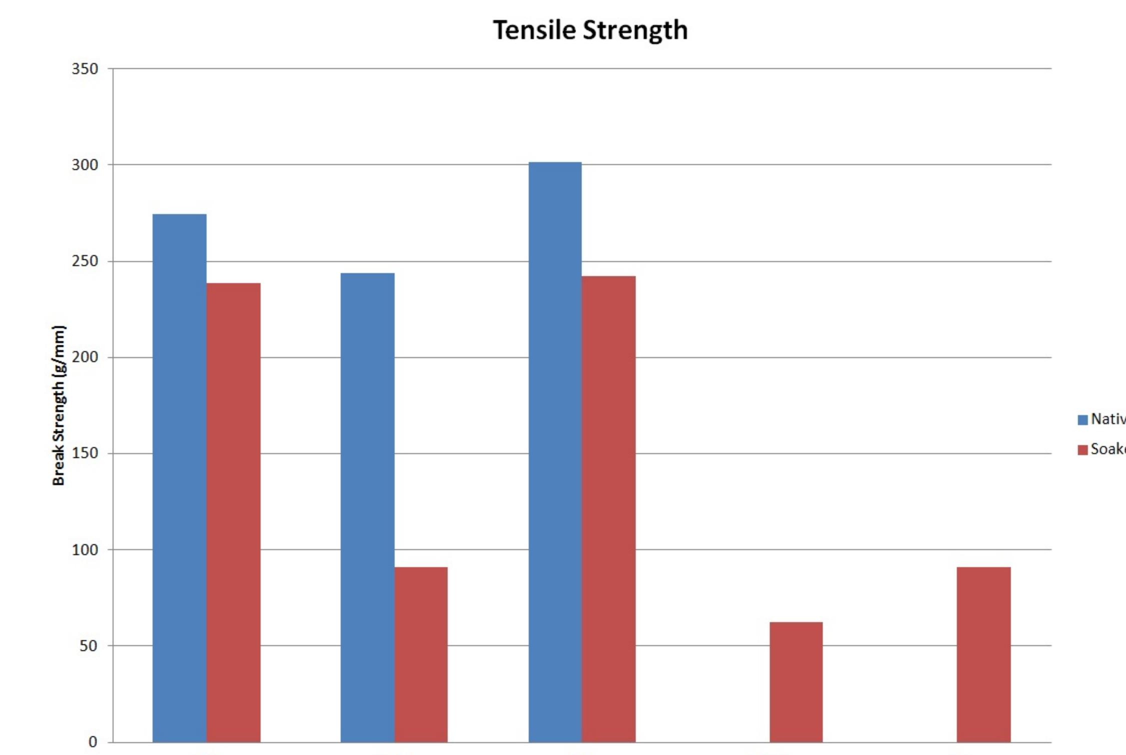


Figure 10: Tensile Strength Analysis

The tensile strengths of native membranes were only taken for PPS, PVDF, and ABS, since these were the three polymers most susceptible to change. Each soaked polymer shows considerable decrease in strength (measured in g/mm) as compared to their native samples.

Conclusions

Overall, PTFE was the most chlorine tolerant, as indicated by the FTIR graphs. It showed the least change over time, demonstrating its low susceptibility to chlorine attack. This may have been due to its low bonding rates and maximum chemical and pH resistance. PPS was clearly the least chlorine tolerant, as indicated by the multitude of additional peaks, stretches, and deformations from the infrared. As for physical strength, PTFE demonstrates the lowest tensile strength, while ABS clearly is the strongest. For each of the three polymers that had native tensile data, the graph indicates that chlorine did have an impact on the physical robustness. Each showed a significant decrease in g/mm strength. Since PTFE was the strongest chemically and ABS was the strongest physically, the AFM graphs for the two are shown above. Whereas ABS shows multiple areas of high heat absorption, PTFE seems smooth and remains fairly unchanged between the native and soaked samples. This supports the notion that ABS was affected by chlorine attack while PTFE resisted.

Bibliography

"Introduction to Fourier Transform Infrared Spectrometry." *Thermo Nicolet*. Thermo Nicolet Corporation, 2001. Web. 15 Mar. 2012.
O'Keefe, Jerome F. "Identification of Polymers by IR Spectroscopy." *The Free Library*. Gale Group, 1 June 2004. Web. 15 Mar. 2012.
"Polytetrafluoroethylene." *PAR*. PAR Group, 2006. Web. 15 Mar. 2012.
"RO Membrane Functionality." *Crobal Water*. Crobal, 2011. Web. 16 Mar. 2012.
Robertson, Grant. "Reverse Osmosis (RO) Water Filters." *Home Water Purifiers and Filters*. MediaWave Communications Corp., 2008. Web. 15 Mar. 2012.
S. Sourirajan, Reverse Osmosis, Academic Press, Inc., New York, NY, 1970.
"Thermoplastics - Physical Properties." *Engineering ToolBox*. The Engineering Toolbox, 2006. Web. 14 Mar. 2012.