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Hydrogenated and Sulfonated Triblock Copolymer for Clean Water

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ABSTRACT

Recent studies have explored the use of sulfonated co-block polymers for desalination applications. Use of these types of films would make the sensitivity issues of current films used commercially for desalination trivial. The objectives of this thesis were to 1) begin exploring polystyrene-block-polybutadiene-block-polystyrene (SBS) as an option for desalination applications while pursuing ways to optimize SBS via hydrogenation and sulfonation reactions and 2) compare the performance of similar sulfonated membranes via their ion exchange capacity and water uptake values. This thesis contains some of the first kinetic data for the hydrogenation of SBS and a discussion on decoupling ion exchange capacity and water uptake values by independently controlling the degree of sulfonation and degree of crosslinking in the styrene-blocks and butadiene block of SBS, respectively.

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Chapter 1

Introduction

Fresh water is a vital resource for the modern world. It has abundant industrial, agricultural, and domestic uses. For industrial purposes, fresh water is needed for dilution, steam generation, washing, and cooling of equipment and product. In agriculture, fresh water is essential for irrigation and domestically it is used for drinking, cleaning, and cooking. Fresh water is essential for multiple facets of modern life, and this is further reflected by a four-fold increase in global fresh water consumption over the past 100 years.[1] To keep up with this increased demand, the number of fresh water desalination plants has been increasing fairly rapidly to over 15,000 operational plants in 2020. Over half of these plants can be found in the Middle East and Northern Africa where fresh water can be scarce, but sea water is abundant. The majority of these desalination facilities employ membrane technologies and reverse osmosis (RO) to achieve the required separation.[2]

Chemical separations account for approximately 10-15% of the world's energy consumption.[3] Proper care must be taken when performing a separation method to ensure that the most efficient process is being utilized for the task. A 2015 study by the US Department of Energy estimated that developing and employing more efficient separation methods could reduce CO_2 emissions by 100 million tons per year and reduce energy costs by $4 billion annually.[4] A thermodynamic minimum energy requirement for converting sea water into potable water has been estimated to be approximately 1 kWhr-m^3. Comparing the energy requirements of two different common separation methods to this minimum shows a clear winner for desalination. An

optimized distillation process will require approximately 50 times more energy than the minimum, but membrane desalination uses only approximately 25% more energy than the thermodynamic minimum.[5] This reasoning supports why the majority of desalination plants utilize membrane technology.

Despite their clear energy advantage, membrane technologies still experience their own problems that need to be addressed. Current commercial membranes have difficulty dealing with pollutants commonly found in water which can lead to corrosion, scaling, or biofilm formation on the surface of the membrane.[6] Also, a permeability/selectivity tradeoff has been observed. A membrane with a larger permeability, i.e. the amount of water that can be filtered in a given amount of time, tends to produce a less pure product and membranes that are highly selective and produce ultra-pure water tend to do so at extremely slow rates.[7,8] It is for this reason that desalination plants tend to be large and costly.

Currently, there are two main options for commercially available membranes for RO purposes, cellulose acetate (CA) and aromatic polyamides (PA). Of the two, PA's are more robust. CA's are much more susceptible to microbial attacks, becoming compacted at high pressures and temperatures, and are only viable for a fairly narrow pH range. PA's on the other hand have better transport properties at high pressures and can function over a wider pH range. The downside to PA's are that they are highly susceptible to oxidizing agents, including aqueous chlorine. If a PA membrane is being used for RO, sea water must be treated with chlorine to prevent the formation of biofilms on the membrane surface, then the water must be dechlorinated before coming into contact with the PA membrane, then after the sea water has been desalinated it is treated with chlorine again before being distributed.[9]

A viable choice for the next generation of RO membranes are polysulfones (PS). PS films offer similar resistances to PA's, but with an added resistance to aqueous chlorine. PS membranes and sulfonated membranes in general have been shown to be capable of selective ion transport. Xie et. al. demonstrated selective ion transport using disulfonated poly (arylene ether sulfone) random copolymers (BPS) and Geise et. al. showed similar results using a sulfonated pentablock polymer.[10,11]

The objectives of this work was to: 1) begin exploring Polystyrene-*block*-polybutadiene-*block*-polystyrene (SBS) as an option for desalination applications while pursuing ways to optimize SBS for this purpose via controlled hydrogenation and sulfonation reactions and 2) compare the performance of SBS to other sulfonated membranes via their ion exchange capacity and water uptake values.

Chapter 2

Materials and Methods

2.1 Polymers

Polystyrene-*block*-polybutadiene-*block*-polystyrene (SBS) was acquired from *Sigma-Aldrich* with 30 wt.% styrene and an average molecular weight of 140,000 grams per mole (determined by GPC) and containing less than 0.5 wt.% antioxidant to prevent the oxidation of the double bonds found within the butadiene-block. Sulfonated Polyether Sulfone Resin (BPS) was acquired from Akron Polymer Systems (Akron, OH). Sulfonated pentablock copolymer membranes were acquired from Kraton Performance Polymers, Inc (Houston, TX).

2.2 Hydrogenation Reaction of SBS

SBS was partially hydrogenated to control the amount of double bonds present in the butadiene-block of the polymer. The remaining double bonds will result crosslinking of the membrane in the sulfonation step later on, so control over the number of these bonds also allows for control over the degree of crosslinking. 20 grams of SBS and 1 gram of butylated hydroxytoluene (99%, BHT) were dissolved in 700 mL of o-xylene and stirred overnight to ensure the polymer was fully dissolved. The BHT acts as an inhibitor to prevent oxidation in ambient air. The solution was then purged with nitrogen and heated to 123 ℃ in an oil bath with a circulated water condenser at 16 ℃ connected to the reaction vessel. A well-mixed slurry of 99.38 g p-toluenesulfonyl hydrazide (p-TSH), 300 mL o-xylene, and 100.2 mL tri-propylamine (TPA) was heated to 90 ℃ and quickly added to the reaction vessel. The oil bath temperature

was immediately reduced to 120 ℃ and the reaction was allowed to proceed for a specified amount of time depending on the targeted degree of hydrogenation. The contents of the reaction vessel were then quenched in 4 L of chilled methanol and stirred for 5 hours. A proposed mechanism for the hydrogenation reaction is shown in Figure 1.

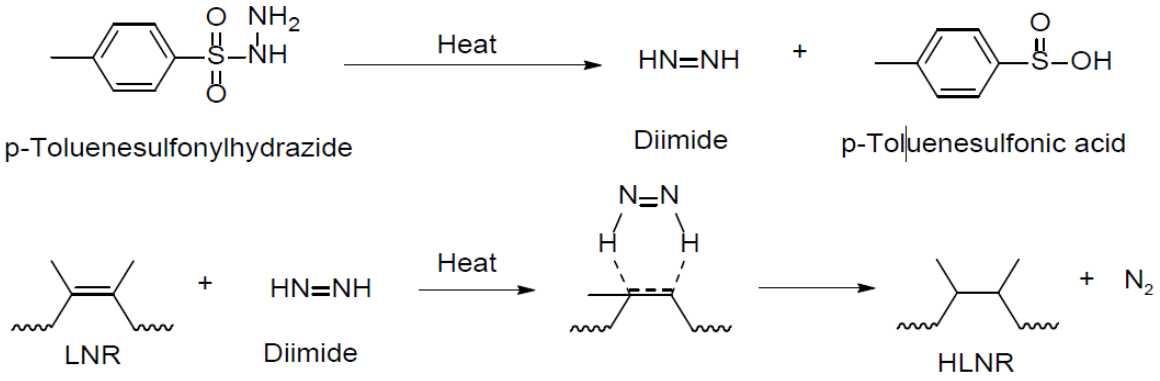


Figure 1. Proposed mechanism for the hydrogenation of SBS.

The resulting polymer was then vacuum filtered and dissolved in 500 mL of o-xylene at 70 ℃ until the solution was homogenous to redistribute any unreacted reagents before being chilled in methanol again. This washing step was conducted twice before the hydrogenated SBS sample was dried under hard vacuum at 90 ℃ for 12 hours. Hydrogenated SBS samples were then stored in air-tight jars below 0 ℃.

2.3 ^{1}H NMR Characterization of Hydrogenated SBS

^{1}H NMR spectra were collected on a NANO-2 400MHz instrument. 1,1,2,2-tetrachloroethane-d_2 ($C_2D_2Cl_4$) was used as NMR solvent and tetramethylsilane (TMS) as the internal standard chemical shift reference. A similar method described by Xicohtencatl-Serrano et. al. and Guan et. al. was used to determine the degree of hydrogenation of SBS samples after

the hydrogenation reaction.[12,13] The chemical shifts δ (ppm) from 6.3-7.4 (aromatic, benzene), 5.1-5.9 (olefinic, 1,2 and 1,4 butadiene), 4.9-5.1 (olefinic, 1,2 butadiene), and 0.5-2.5 (aliphatic) were used in these calculations.

2.4 Glass Plate Preparation for SBS Film Casting

A surface that minimizes interactions with the polymer being cast and that allows for easy removal of the newly-cast membrane from the surface is essential. To achieve both of these criteria for SBS casting, the following procedure was adapted from the work of Szkop, et. al.[14] Large glass plates acquired from Chem-glass were soaked in an acid bath for 30 minutes followed by a base bath for another 30 minutes to remove any residual oils from the glass processing. The base bath also converts end groups on the surface of the glass to hydroxyl groups, which is required for the silane reaction described later. The plates were rinsed with ultra-pure water and methanol before being dried. The large glass plate was set on Teflon supports and submerged in 1 liter of acrylonitrile. 36.76 grams of imidazole powder was stirred into the solution to act as a catalyst.[15] Trimethylchlorosilane (TMCS) was then dispersed into the solution and the temperature was raised to 45 ℃ and stirred for 1 hour, after which the Teflon supports were removed and the solution was stirred for an additional 2 hours. The glass plate was then removed from the solution and rinsed with ultra-pure water and methanol before being dried in an oven. Once dry, the edges of the plate were taped with Digi-key RF tape to form a barrier higher than the desired membrane thickness. The described procedure was necessary only for SBS casting, BPS was cast after the plate was dried from the base bath.

2.5 Film Casting

Casting of SBS and BPS films follow the same procedure with the exception of solvent choice and plate preparation. For BPS casting, dimethylacetamide was chosen as the solvent and o-xylene was the solvent used for SBS casting. A 10 wt% solution was prepared since this concentration tends to provide a low enough viscosity for the solution to evenly spread over the casting plate. The solution was stirred for 24 hours or until the polymer was completely dissolved. While stirring, the previously prepared casting plate was placed on a stand in a vacuum oven and leveled to ensure a consistent film thickness. When the polymer solution was completely dissolved and all gas bubbles were removed, the solution was gently poured and spread evenly onto the casting plate. The oven was then heated to 80 ℃ for 24 hours to remove any temperature history in the polymer. The temperature in the oven was then increased to 110 ℃ and once the temperature was stable a soft vacuum was pulled. After all condensation in the oven cleared, hard vacuum was pulled for 48 hours. The oven was then returned to ambient temperatures. The edges of the membrane were cut free and the casting plate was submerged in ultra-pure water until the film detached from the plate. The ultra-pure water was replaced twice daily to ensure any residual solvent was removed from the membrane.

2.6 Sulfonation Reaction of SBS Film

The ion-exchange capacity of the hydrogenated SBS film can be controlled via the sulfonation reaction by adding a sulfone functional group onto the benzene rings located in the polystyrene block. The hydrogenated SBS film is clamped between two Teflon rings so that it remains uniform and unwrinkled throughout the reaction. The clamped film was then submerged

in 250 mL of 1,2-dichloroethane (DCE) and the solution was stirred at 40 ℃ with a nitrogen purge to remove any oxygen from the system. Oxygen in the reaction vessel would cause chain scission through a side reaction, so any other materials added to the reaction vessel at any point were purged with nitrogen for at least 20 minutes before addition. The sulfonation agent was prepared, as described by Navarro et. al., with 13.3 mL of acetic anhydride, 40 mL DCE, and 4.4 mL sulfuric acid.[16] The sulfonation agent was then added to the reaction vessel via addition funnel. The reaction mechanism is shown below:

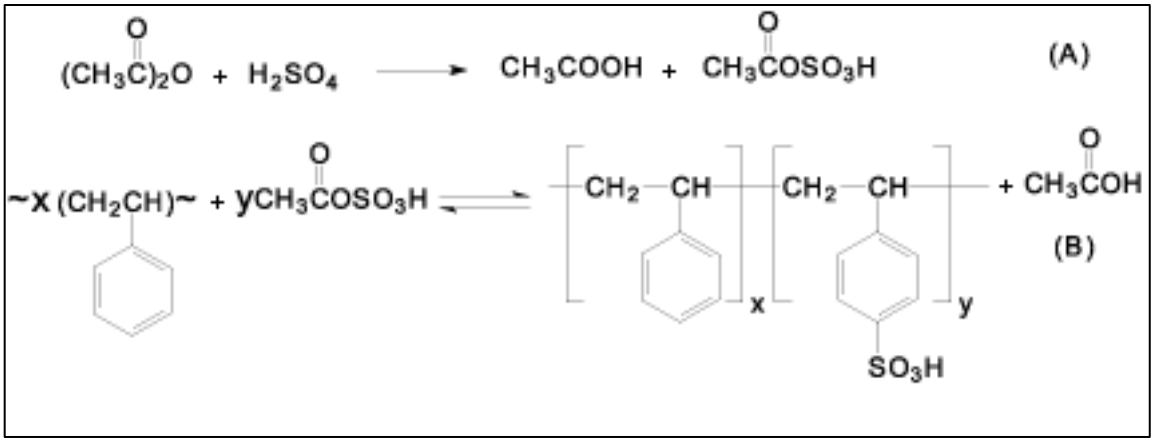


Figure 2.[17] Proposed mechanism for the sulfonation reaction described.

After the desired reaction duration, 20 mL of methanol was used to terminate the reaction. The reaction time can be adjusted to result in a higher or lower ion-exchange capacity. After the reaction was quenched, the film was submerged in ultra-pure water to remove any excess reagent. The water was changed several times until the pH after soaking fell in the range of 5.8 to 6.2, the normal pH of ultra-pure water.

2.7 Water Uptake Measurement

Water uptake is a measure of the maximum amount of water that a film can hold. To determine the water uptake of a polymer film, 7/8-inch diameter circular coupons of a given film were punched out using a die. The coupons were submerged in ultra-pure water for at least 2 hours to ensure the membrane was saturated for wet mass measurements. For films with known diffusivity data, the required time to soak is equal to fifty times the characteristic time, t_c. The characteristic time can be calculated as $t_c = l^2/D_w$ where l is the film thickness and D_w is the water diffusivity of the membrane. Since diffusivity data is not readily available for the custom membranes prepared for this study, the wet mass was compared when films were soaked for 2 hours versus 12 hours and any difference was found to be negligible if not the same value altogether.

After soaking for sufficient time, films were taken from solution and had excess water on the surface dabbed off before a mass was taken. This was done in less than 30 seconds to prevent water evaporating from the film before the mass was taken. After a measurement, the film was re-submerged and two more wet masses were recorded to verify the actual mass. After these measurements, the films were placed under hard vacuum at 50 ℃ to obtain the dry mass of the film. The time in the vacuum oven to completely dry the film was arbitrarily chosen as 2 hours. This time was again compared to 12 hours of drying and negligible to no difference was found. Once sufficiently dry, the film was removed from the oven and weighed in less than 30 seconds to prevent moisture from the ambient air from influencing the measurement. Once the sample was weighed, it was placed back into the vacuum oven and this measurement was repeated two more times to verify the dry mass. Both the dry and wet mass measurements were repeated twice

for verification. The average masses can then be used to calculate the water uptake, w_u, using the equation below:

Equation 1

$$w_u = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

2.8 Ion Exchange Capacity Measurement

Ion exchange capacity (IEC) is used to quantify the number of charged functional groups in a polymer film in units of mmol per gram of dry polymer. For accurate IEC measurements, the films being characterized must be in their acid form, meaning that all counter ions for the sulfone functional group must be hydrogen ions as opposed to another cation. These hydrogen counter-ions will be used to quantify the number of functional groups via the pH change once desorbed into a water.

The acid form film was cut into 7/8-inch diameter circular coupons and dried in a vacuum oven to obtain their dry mass. The coupons were then submerged into ultra-pure water until they were saturated. The same considerations were taken from the water uptake measurements for determining when the coupons were completely dry or saturated in water. Once saturated, the membranes were removed from the ultra-pure water, had any excess water on their surface dabbed off and submerged in 80 mL of 1M sodium chloride solution. The coupons were submerged for at least 24 hours to ensure that all hydrogen counter-ions in the film were replaced with sodium counter-ions. After 24 hours, the coupons were removed from the salt solution and the resulting solution was titrated back to a pH of 6.5-7.0 using a 0.1 M sodium hydroxide solution. pH readings were taken with a Mettler Toledo SD50. The hydroxide reacts

with the hydrogen anions 1-1 to form water, so the amount of hydroxide ions required to neutralize the solution is equivalent to the amount of hydrogen cations desorbed from the film. Using this relation, the IEC can be calculated using the equation below:

Equation 2

$$IEC = \frac{V_{NaOH} \times C_{NaOH}}{m_{dry}}$$

where C_{NaOH} is the concentration of the titrant, V_{NaOH} is the volume of titrant required to neutralize the salt solution, and m_{dry} is the dry mass of the film in its acid form.

Chapter 3

Results and Discussion

3.1 Hydrogenated SBS

Thirteen samples with varying reaction times were prepared to characterize the hydrogenation reaction previously described. The reaction time was recorded as the average of when the quench was started and when the quench was finished. The difference between these two times was typically less than thirty seconds. Table 1 shows a summary of each sample with their corresponding reaction time.

Table 1. Hydrogenated SBS samples named with their corresponding reaction time.

Sample	Reaction time (min)
HSBS0	0
HSBS5	5
HSBS10	10
HSBS15	15
HSBS20	20
HSBS25	25
HSBS30	30
HSBS35	35
HSBS50	50
HSBS80	80

HSBS120	120
HSBS180	180
HSBS240	240

3.2 ^{1}H NMR Characterization of HSBS Samples

Each HSBS sample prepared was characterized via ^{1}H NMR as previously described in the methods section. The spectra for HSBS50 and HSBS30 are shown in Figure 3, below:

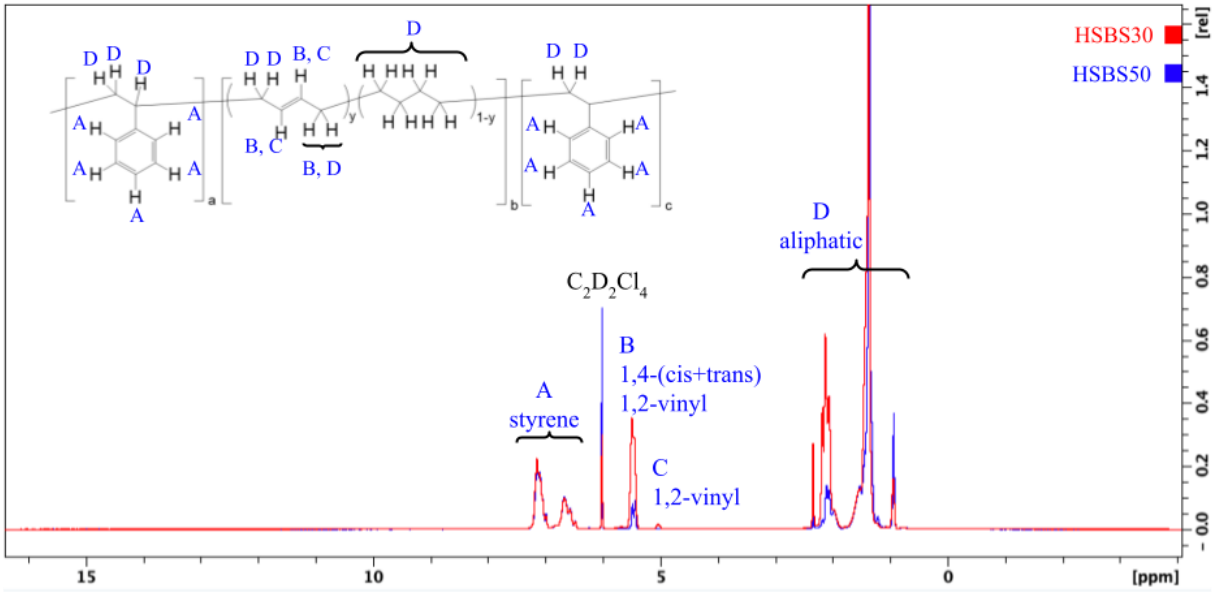


Figure 3. H NMR spectra of HSBS50 and HSBS30

At increased reaction times, the olefinic peaks, B and C, decrease and the aliphatic peaks, D, increase. The peak at 1.4 ppm corresponding to HSBS50 is much larger than the same peak corresponding to HSBS30, resulting in a larger integration value in the aliphatic region for the sample with the longer reaction time. This is attributed to the saturation of the double-bonds

found in the butadiene-block of SBS. A summary of how many protons each microstructure found in HSBS contributes to each region of the spectra is summarized in Table 2.

Table 2. Number of protons each microstructure contributes to each region identified on the NMR spectra.

Microstructure	A (6.3-7.4 ppm)	C (4.9-5.1 ppm)	B (5.1-5.7 ppm)	D (0.5-2.5 ppm)
Styrene	5	--	--	3
1,2-vinyl	--	2	1	3
1,4-butadiene	--	--	2	4
Hydrogenated butadiene	--	--	--	8

The total number of protons contributing to the area under the curve of each specified region can be determined using the values shown in Table 2 with the total number of each repeating unit corresponding to a specific microstructure.

Equation 3

$$A = 5\,M_S$$

Equation 4

$$B = 2\,M_{1,4} + M_{1,2}$$

Equation 5

$$C = 2\,M_{1,2}$$

Equation 6

$$D = 3\,M_{1,2} + 4\,M_{1,4} + 8\,M_h + 3\,M_S$$

where M_s is the total number of polystyrene units, $M_{1,4}$ is the total number of units of both cis and trans 1,4-butadiene units, $M_{1,2}$ is the total number of units of 1,2-vinyl found in the butadiene block, and M_h is the total number of hydrogenated units from the butadiene block. The number of each repeating unit was determined using the molecular weight and weight percent styrene reported by Sigma Aldrich using the equation shown below:

Equation 7

$$M_S = \frac{MW_{SBS} \times wt\%_S}{100 \times MW_S}$$

where MW_{SBS} is the molecular weight of SBS, 140,000 g/mol, $wt\%_S$ is the weight percent styrene in SBS, 30%, and MW_S is the molecular weight of one styrene unit, 104.15 g/mol. The M_S value from Equation 7 can be used to determine the number of units of 1,2-polyvinyl, M_{V12}, and 1,4-polybutadiene, M_{B14}:

Equation 8

$$M_{V12} = \frac{(8 \times M_S) \times C}{A}\left(\frac{1}{3}\right)$$

Equation 9

$$M_{B14} = \left(\frac{B - C}{2}\right)\left(\frac{8 \times M_S}{A}\right)\left(\frac{1}{8}\right)$$

where A is the integral from 6.3-7.4 ppm, C is the integral from 4.9-5.1 ppm, and B is the integral from 5.1-5.7 ppm from the corresponding ^{1}H NMR spectra. These equations use the known M_s value to establish the amount that a single proton adds to the resulting integral value. Using the integral values determined from running NMR and the number of protons that each microstructure contributes to each region of the NMR shown in Table (2), the number of

repeating units present was calculated. Equations 8 and 9 can be used to determine the number of units that were hydrogenated, M_h:

Equation 10

$$M_h = \frac{\left(D \times \frac{8 \times M_S}{A}\right) - (3 \times M_S + 3 \times M_{V12} + 4 \times M_{B14})}{8}$$

Using the values determined from equations 8, 9, and 10 the degree of hydrogenation, DoH, was calculated:

Equation 11

$$DoH = \left(1 - \frac{M_{V12} + M_{B14}}{M_{V12} + M_{B14} + M_h}\right) \times 100$$

The DoH was determined for every HSBS sample and the results are summarized in Figure 4:

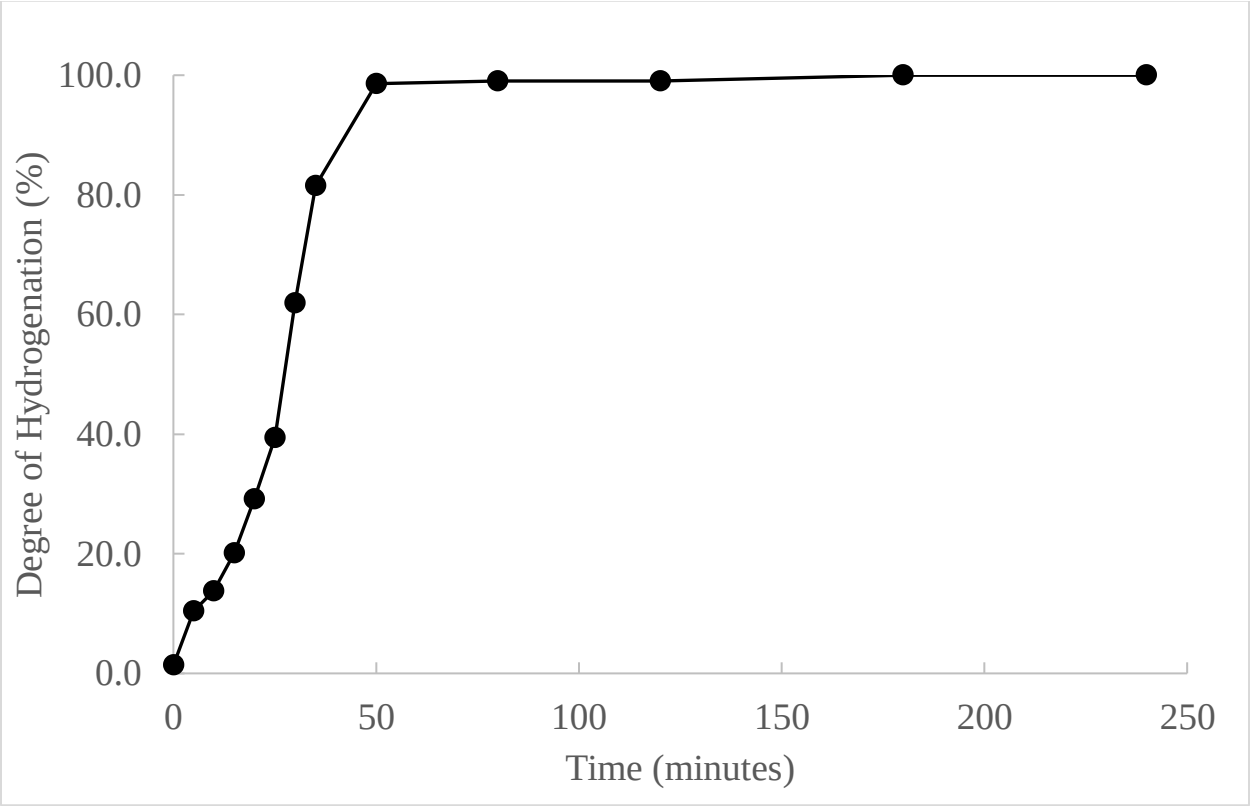


Figure 4. Degree of Hydrogenation versus reaction time

Figure 4 shows that that hydrogenation reaction approached 100% conversion of the double bond found in the butadiene block after approximately 50 minutes. Figure 4 can be referenced to determine the required reaction time to achieve a target DoH of SBS. This will allow for control over the degree of crosslinking in later steps as a higher DoH results in a lower degree of crosslinking. Control over the degree of crosslinking allows for control over the rigidity and flexibility of the of the film and can affect its ion transport properties.

3.3 Sulfonation Reaction of 100% Hydrogenated SBS

Four samples were prepared with varying reaction times to characterize the sulfonation reaction previously described. All four samples were 100% hydrogenated before being cast and sulfonated. Table 3 shows a summary of each sample with their corresponding reaction time.

Table 3. Summary of sulfonated 100% hydrogenated SBS samples prepared with corresponding reaction time.

Sample name	Reaction time (min)
S-SBS0	0
S-SBS30	30
S-SBS60	60
S-SBS240	240

100% hydrogenated samples experience the lowest possible degree of crosslinking for an SBS film sample. It is reasonable to assume that different degrees of crosslinking in the butadiene block will affect the rate that styrene in the styrene-block will be sulfonated, since the increased crosslinking will restrict the film network and decrease the amount of reagent that can sorb into the film initially. Similar studies at the same sulfonation reaction times but at varying degrees of hydrogenation should be conducted for reliable characterization over range of hydrogenation levels.

3.4 IEC Characterization of Sulfonated Films

Using the procedure previously outlined, IEC characterization of the sulfonated film samples was carried out and is summarized in Figure 5.

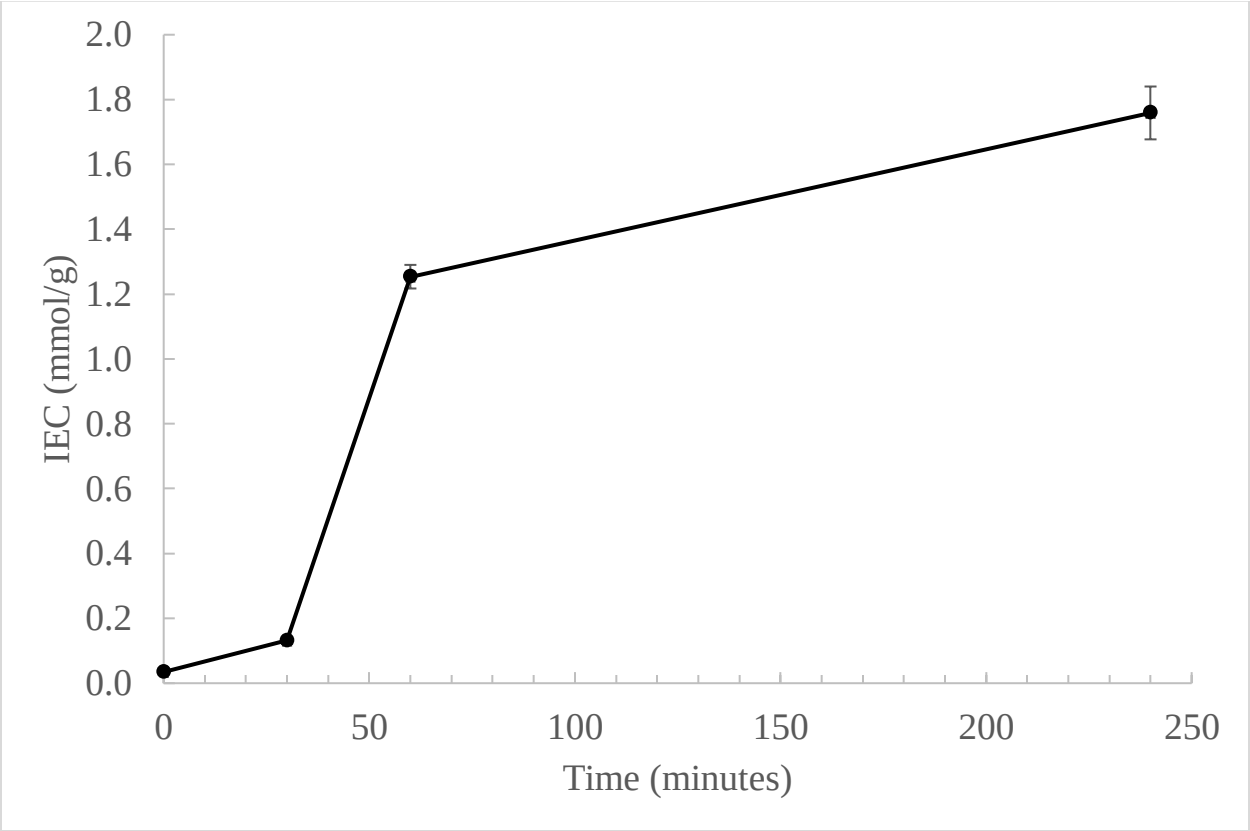


Figure 5. IEC versus sulfonation reaction time.

As the reaction time increases, more sulfone groups are able to attach to styrene in the styrene block of the polymer, increasing the number of functional groups in the film and increases the number of protons that could be released into solution during IEC characterization. The highest recorded IEC is approximately 1.8 ± 0.08 mmol per gram of dry film. A typical maximum IEC for films used in aqueous solutions is approximately 2 mmol per gram of dry film. This is typically the point where a film will become hydrophilic enough that it will dissolve in water. The maximum IEC recorded for this experiment is below this desired upper limit.

3.5 Water Uptake of S-SBS Films

Per the previously described procedure, the water uptake was characterized for each of the four sulfonated membrane samples; a representative sample of each of these measurements is shown in Figure 6.

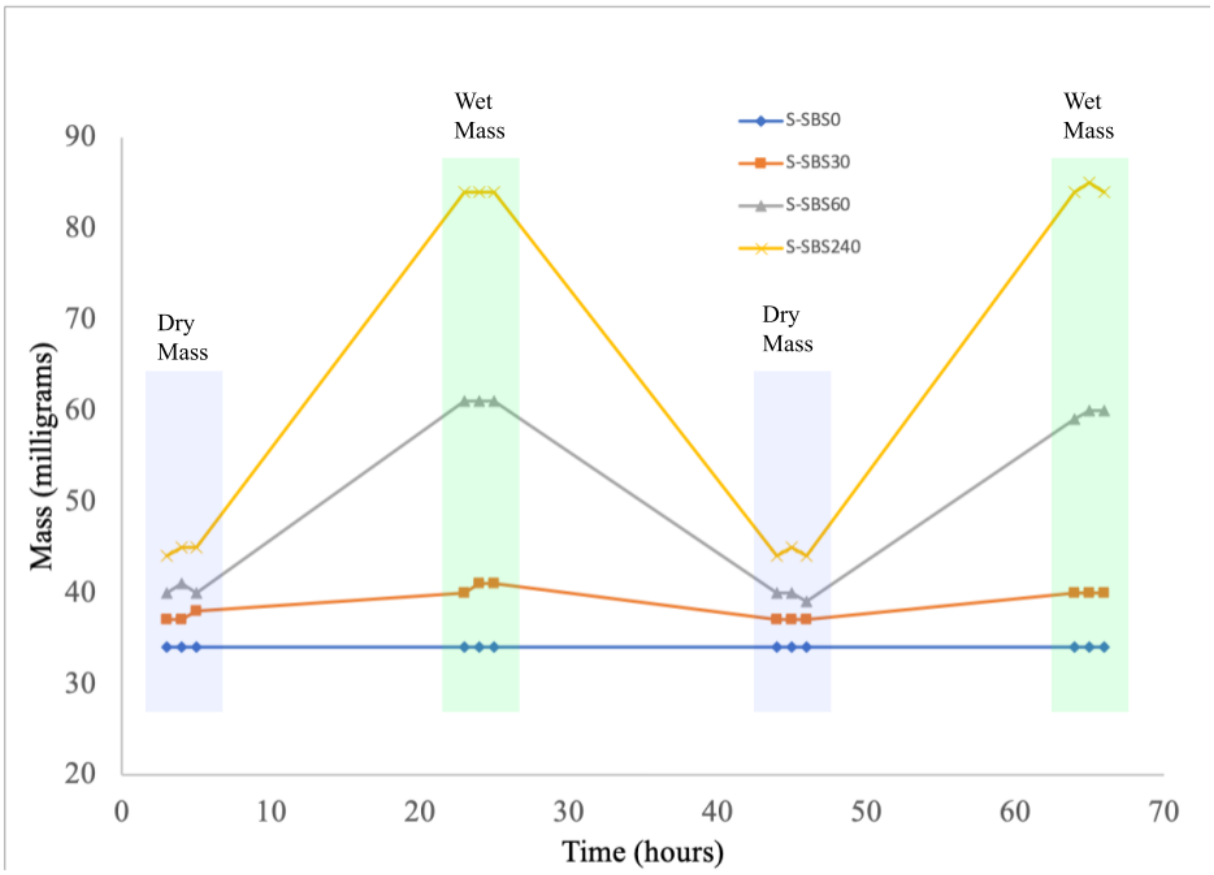


Figure 6. Sample of wet and dry mass measurements versus time.

The difference in dry mass between the four samples can be explained by a combination of difference in film thickness and the mass added via the sulfone functional groups during sulfonation. The dry film thickness of each sample shown in Figure 6 is 104.2 μm, 111.6 μm,

118.4 μm, and 113.2 μm for samples S-SBS0, S-SBS30, S-SBS60, and S-SBS240, respectively. The three samples with the smaller ion-exchange capacities have dry mass magnitudes ordered in correspondence to their dry thickness, however, the film with the highest IEC, S-SBS240, has a larger dry thickness than S-SBS60, which has a larger film thickness. The increases number of sulfone groups in S-SBS240 is likely the cause of this upset.

The water uptake values of each film were plotted over their IEC as seen in Figure 7, below:

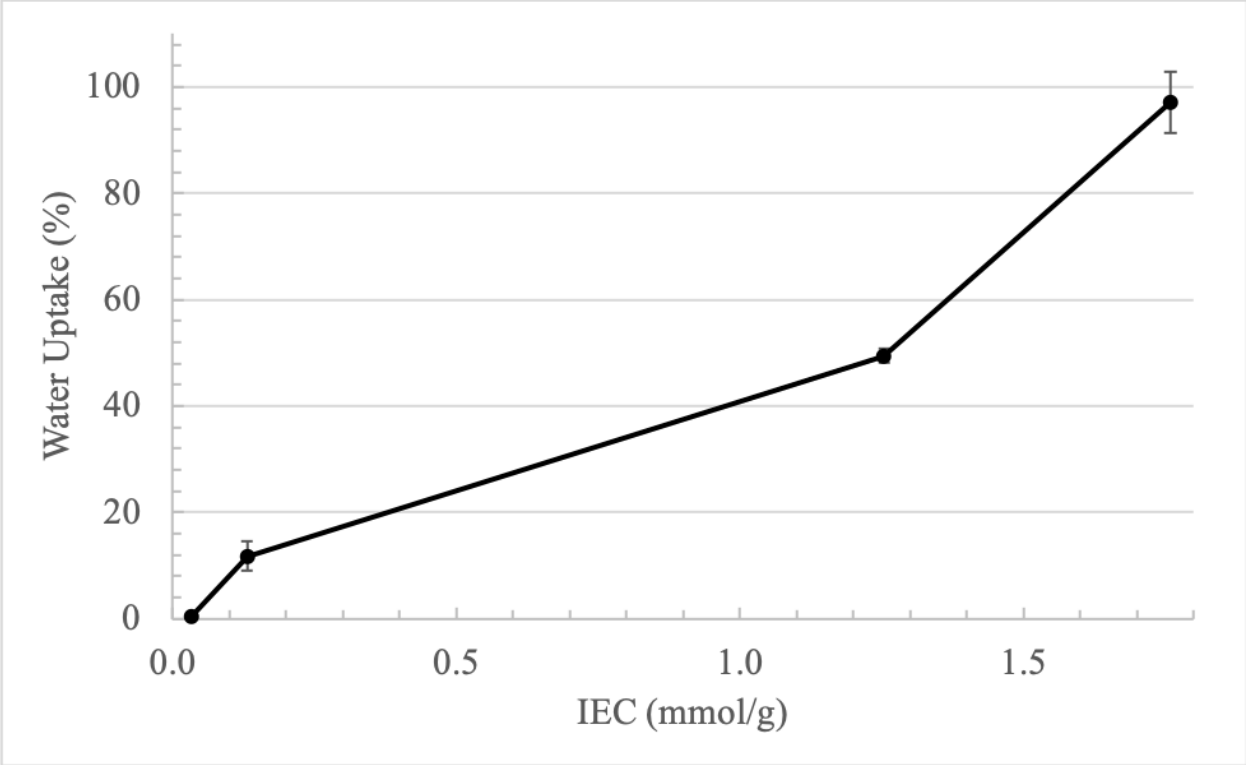


Figure 7. Water uptake versus IEC for 100% hydrogenated SBS films.

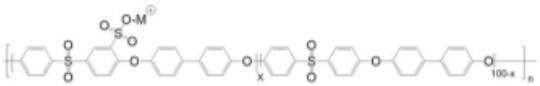
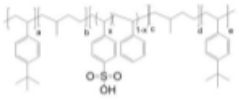
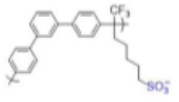
At the lowest IEC, no water is sorbed into the fully hydrogenated SBS film. This suggests that both the styrene-block and hydrogenated butadiene-block are very hydrophobic as all water is rejected from the film. As IEC increases, so does water uptake. The addition of the charged

functional groups into the styrene block of the film increases the hydrophilicity of the block which creates a driving force for water to sorb into the film. Since only the styrene-block participates in sulfonation, it is reasonable to assume that no water is sorbed into the hydrogenated butadiene-block and the any permeation through the film would occur through the sulfonated styrene-block.

3.6 Other Films Characterized

A variety of other films with sulfone functional groups were characterized to determine if the procedures followed would align with literature values for previously characterized films. BPS films and penta-block copolymer films characterized for this thesis were comparable to

Table 4. Name, structure, water uptake, and IEC values of other sulfonated films that were studied.

	Structure	Membrane	Wu [g water/g dry polymer]	IEC [mmol/g dry polymer
Polysulfones		BPS-20H	0.175	1.002
		BPS-20K	0.085	
		BPS-35H	0.241	1.44
		BPS-35	0.2317	
Penta-block copolymer		MD-9151	1.011	2.01
		MD-9210	1.778	2.59
Triblock copolymer (SBS)		B-74	0.0048	0.028
Polyphenylene		mTPSA	0.38	2.04

literature values.[10,11] The name, structure, and characterized IEC and water uptake values of other sulfonated films are summarized in Table 4.

The H and K seen on BPS samples correspond to the counter-ion present on the sulfone functional group at the time of water uptake measurements. BPS-35 with no H or K was characterized as received and was determined to have a combination of H and K counter-ions. It was found that having larger counter-ions reduced the water uptake of the film. B-74 in Table 4 is a 0% hydrogenated, 0% sulfonated, 100% crosslinked SBS film and shows similar properties to S-SBS0. Generally, as IEC increases between the different films, the water uptake also increases, despite the difference in polymer structure. However, the comparison of MD-9151 and mTPSA is of note and shown in Figure 8, below:

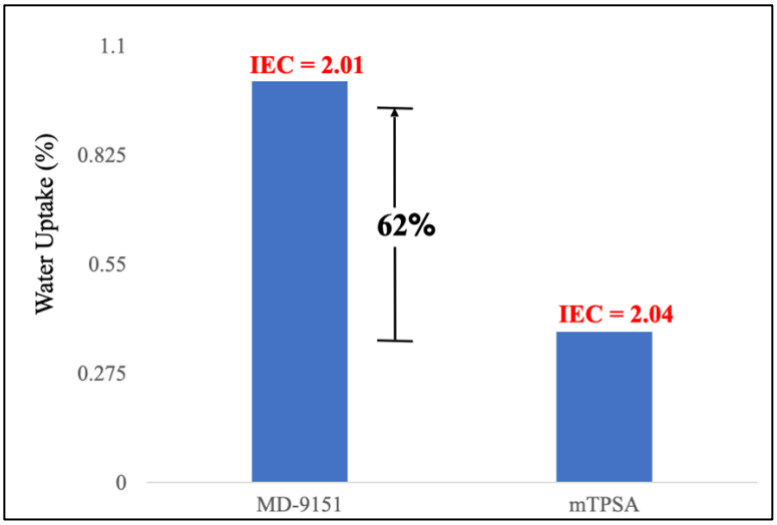


Figure 8. MD-9151 and mTPSA water uptake comparison.

As seen in Figure 8, MD-9151 and mTPSA have very similar IEC values but there is a substantial difference between their water uptake values. A hypothesis of why this occurs is related to the rigidity of their backbone structures. The backbone of mTPSA consists of three

phenol rings which is much more restrictive than the backbone of MD-9151. This increased rigidity increases the elastic resisting force for water sorption into the film.

Chapter 4

Conclusion

This thesis provides the first set of kinetic data for the hydrolysis and sulfonation of SBS along with a seemingly reliable method for determining the DoH for a polymer with a known MW and known initial composition. IEC and water uptake characterization values for previously studied sulfonated films was reproduced and the same methods were used for the characterization of 100% hydrogenated SBS samples at four different degrees of sulfonation.[10,13] The four H-SBS samples showed how increasing the number of charged functional groups in a film has a direct effect on water uptake of said film. The H-SBS0 sample also demonstrated that essentially no water will sorb into either block of an SBS film without the addition of some charged functional group. Since the charged functional group only exists in the styrene-block of the film, it can be assumed that only the styrene-block contains water and that the hydrophobic butadiene-block remains water-free. Comparison of MD-9151 and mTPSA shows how films with a similar amount of charged functional groups can have varying water uptakes due to increased rigidity in the film structure.

For future work, kinetics of the sulfonation reaction could be determined at different degrees of hydrogenation. The kinetics may be different due to increased rigidity in the film from a higher level of crosslinking in the butadiene-block. Using the degree of crosslinking in the butadiene block, the water uptake could be varied for the same IEC value. This would essentially decouple these variables and allow for the study of IEC or water uptake on the transport properties of a film independently from one another.

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EDUCATION

Bachelor of Science in Chemical Engineering Graduation: December 2022
Minor in Engineering Leadership Development
The Pennsylvania State University, University Park, PA
Schreyer Honors Scholar

PROFESSIONAL EXPERIENCE

Process Engineer COOP, **Kimberly-Clark**…… Aug. – Dec. 2021

- Operated filament and resin 3D printers to push forward the development of rapid prototyping methods which led to a first of a kind tissue making trial
- Awarded a "People of the Year Award" for my efforts toward continuous learning and creative solutions
- Restored 78 Course Based Trainings (CBTs) by working independently with a contractor after an introductory meeting

Leadership Development Intern, **RippleMatch**……. Jan. – March 2021

- Strategically assessed growth and performance metrics to improve, change and/or help design new growth strategies
- Selected from a pool of thousands of candidates to work closely with leaders of RippleMatch's Leadership Team

Carpenter's Assistant, **Scott's Home Improvement**……..... Summers 2016 - 2020

- Installed windows and doors in customer homes and built additions to homes under the instruction of a carpenter/contractor

Pathway to Success Summer Start Employee, **Center for Career Education and Development**.....…… June – Dec. 2019

- Prepared reports to keep my employer informed on issues pertaining to her meetings involving education pathways and career opportunities pertaining to students while also cataloging local resources for student use

LEADERSHIP EXPERIENCE

Engineering Leadership Society……. VP of Consulting

- Train and connect members to technical teams within Penn State to apply leadership and project management skills
- Review feedback to provide monthly performance reviews as well as scoring towards an internal Consultant Competition
- Oversee the mentor program to connect lower and upper classmen within ELS and the ELD minor

Rotaract and Entrepreneurship Club…… Vice President

- Collaborated with local businesses at the Mon Valley Launch Box to promote products and organize community events such as Turkey Drives, Angel Trees, and charity runs

Puerto Rico Hurricane Relief ……... Volunteer

- Transcended translational barriers to work with locals to efficiently clean up abandoned schools for reopening and tutoring students at a Boys and Girls Club
- Provided a positive attitude towards work which attributed to more productive days for my team

PROJECT EXPERIENCE

Chemical Engineering Thermodynamics I & II (ChE 220/320) Honors Option.....……Fall/Spring 2020

- Optimized a flash separation process utilizing Mathematica to calculate properties of a mixture
- Communicated findings to professor weekly as well as in a formal final report summarizing the project
- Utilized Mathematica to create a notebook to calculate the properties of various fluids with given conditions and used it to perform an energy balance on a refrigeration cycle

Leadership Principles (ENGR 408) ..…... Spring 2019

- Lead my team through the creativity portion of the design process by brainstorming and researching solutions to decrease the environmental impact of deicing procedures for the Airport Cooperative Research Program Design Competition

Technology-Based Entrepreneurship (ENGR 407)…… Fall 2020

- Created value propositions for entrepreneurial products and services while on diverse teams in low structure environments

Organic Chemistry I (CHEM 210) Honors Option.....…… Fall 2019

- Awarded second place at the PSUGA Honors Poster Conference for presenting on the production and consequences of plastics in modern day

RESEARCH EXPERIENCE

Biofellowship and REM program, Penn State – Dr. Oh's group……May 2021 – Aug. 2022

- Explored the use of crown ethers for selective adsorption of cesium ions in solution and designed experiments for this study
- Produced data for controlling hydrogenation level in polymer membranes and determined membrane transport properties

iPad Spectrometer, CURE Lab, Honors Poster Conference, with Dr. Megan Lee Nagel.…… Fall and Spring 2019

- Communicated findings to professional staff in a formal setting and answered questions/ discussed future applications

References available upon request