Effects of Hydrophilic Membrane Modifications and Natural Organic Matter Fouling on Reverse Osmosis Membrane Performance

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Abstract:

Reverse osmosis diffusion processes offer an effective method for filtering brackish and sea waters. Thin-film composite (TFC) membranes function as the filter in these systems. However, the main drawback to using the TFC membranes is their susceptibility to fouling by hydrophobic natural organic matter (NOM) and various inorganic salts commonly found in brackish waters. One proposed method of mitigating this problem is to modify the polyamide active layer of the TFC membrane to be more hydrophilic using polyethylene glycol (PEG). The focus of the project is to determine the effect of hydrophilic PEG grafting on membrane performance in the presence of NOM and model brackish water constituents. Using a tabletop reverse osmosis setup, feed stream conditions containing NOM and/or aqueous salts were tested for both grafted and unmodified membranes. Analysis of the permeate stream indicated that PEG-grafted membranes reduced permeate flux but also increased the ion rejection in most systems.

Introduction:

The desalination of brackish water and seawater is employed to provide fresh water to people around the world. A common method of desalinating water is reverse osmosis (RO), where an applied pressure is used to overcome the osmotic pressure through a semipermeable membrane. A feed stream often containing inorganic salts and NOM (which are generally hydrophobic) is fed to the system, with permeate, or filtered, and concentrate streams leaving the system [1]. However, the TFC membranes, shown in Figure 1, used during the process are often fouled by the deposition and clogging of pores caused by the NOM and salts present in the feed stream. This reduction in efficiency leads to less effective filtration and more frequent membrane cleaning/replacement [2].

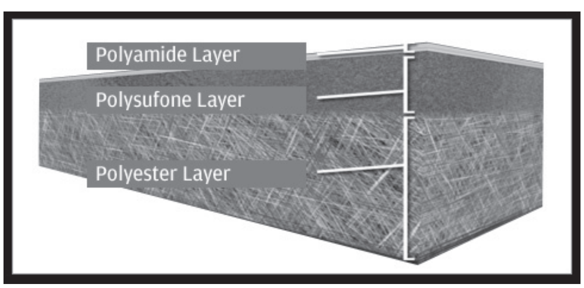

Figure 1: TFC membrane displaying the three layers including the top polyamide active layer [2].

One proposed method of mitigating this problem is to modify the top polyamide layer of the TFC membrane to be more hydrophilic and resistant to fouling. PEG has been determined to be a suitable candidate for this process because it is a flexible, water-soluble polymer with a hydrophilic head [3].

Experimental Procedure:

Membranes were tested using a reverse osmosis benchtop setup to determine their fouling characteristics in different feed solutions. Half of these membranes were grafted with PEG using a cross-linker solution of ethylene glycol dimethacrylate and potassium disulfate and potassium persulfate initiators. The membranes were placed in the system depicted in Figure 2. The various feed solutions were placed in the plastic tub and

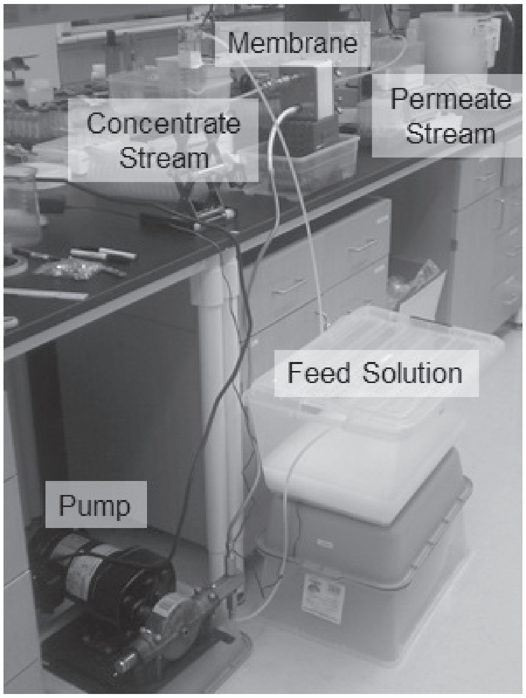

Figure 2: Reverse osmosis benchtop setup used for testing.

each system was left to run for four hours. The feed streams all contained one molar sodium chloride and at least one added potential fouling agent. For our potential foulants we used humic acid as the NOM and calcite ($CaCO_3$) and gypsum ($CaSO_4$) as our salts, two common foulants found in brackish waters. An autosampler collected a sample of the permeate stream every three minutes during the experiment. After each system finished running, we measured the calcium and chlorine ion concentrations in the permeate stream using ion selective electrodes. Permeate flux was also calculated using the collected volume in each test tube. The NOM concentration was measured using a Total Organic Carbon Analyzer. We then took a sample from each used membrane and analyzed the fouling morphology using scanning electron microscopy (SEM).

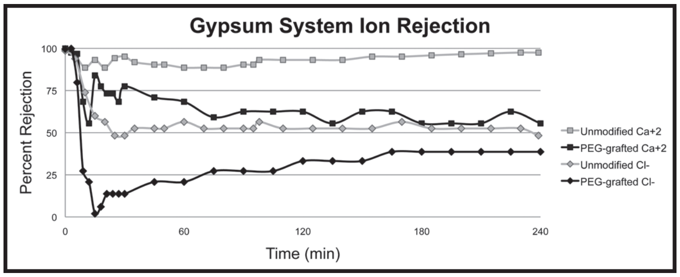

Figure 3: Graph modeling gypsum system ion rejection.

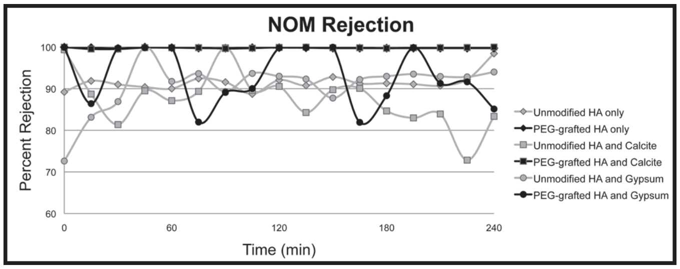

Figure 4: Graph modeling NOM rejection.

Results and Conclusions:

From the SEM images gathered, the calcite was found to form a consistent rhombohedra aggregate on the surface of the membrane. The gypsum formed more irregular rod and sheet-like structures. From the ion concentration data, we found that PEG-grafted membranes had an increased ion rejection (calcium and chloride) in calcite forming systems, but a decreased ion rejection in gypsum forming systems, as shown in Figure 3. When systems containing just the calcium salt and systems containing both a calcium salt and humic acid were tested, the PEG-grafted membranes in the gypsum (Ca^{2+} - SO_4^{2-}) systems also showed more overall fouling than the unmodified systems, even at a lower saturation index. In addition, PEG-grafted membranes did also reject more NOM than their unmodified counterparts as you can see in Figure 4. Interestingly, the PEG-grafted gypsum system did not reject the humic acid as well as the PEG-grafted calcite system or the PEG-grafted system with only humic acid, but it did perform better than the unmodified gypsum system. However, PEG-grafted membranes also resulted in a lower permeate flux amounting at about a 65% decrease in systems not containing NOM and roughly a 33% decrease in systems containing NOM. Cost analysis would have to be performed to determine if the PEG modification to the TFC membranes would be economically beneficial because the decrease in flux could potentially outweigh the benefit of increased NOM and ion rejection (except in gypsum systems).

Future Work:

The next step would be to replicate the reverse osmosis test. Ideally, more systems would also be tested using other inorganic salts and NOM commonly found in brackish waters, such as $MgSO_4$ and $MgCO_3$. Another important aspect to further investigate is the driving force of the inverse effects of fouling in Gypsum systems.

Acknowledgments:

I would like to thank Dr. Young-Shin Jun, Ms. Jessica Ray, and everyone at the Environmental Nanochemistry Lab for their guidance and support. I would also like to acknowledge the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Progam and the National Science Foundation for giving me this exceptional opportunity and experience.

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