NDnano
Center for Nano Science and Technology

NDnano Summer Undergraduate Research
2019 Project Summary

1. Student name & home university: Thomas Kasl, University of Notre Dame

2. ND faculty name & department: Professor William Phillip, CBE and Professor Jennifer Schaefer, CBE

3. Summer project title: *Spin-assisted fabrication of biomimetic membranes with artificial water channels for next generation water purification*

4. Briefly describe new skills you acquired during your summer research:
The first and most important skills I gained during this fellowship were not lab skills, but intellectual research skills. During the process of familiarizing myself with my specific field (water purification membranes), I honed my abilities to survey literature, assimilate relevant progress, synthesize new ideas, and then realize those ideas in the lab. Not only did these skills aid my research on this project, but the foundation they have built will solidly support any further research I pursue. In addition to an informed intellect, to undertake efficient research I needed to develop regimens for organizing my thoughts, lab progress, and lab items. These regimens may have been as simple as writing detailed notes both in and outside of the lab, keeping a chemical inventory, and putting in the effort to make engaging presentations, but they are crucial to successful research. I would never say that the technical lab skills I gained are not valuable—they are, but without intellectual, organizational, presentational skills, and a lot of patience their value would be greatly diminished. The technical lab and analysis skills I acquired this summer are numerous and diverse. Lab skills include organic synthesis techniques, proper glove box use, membrane permeability testing, lab plumbing, custom part design and fabrication, 3D printing heuristics, and automated tool programming (GUI and a strongly typed C-based language). Validation and analysis techniques include NMR, mass spectroscopy, LCMS, FTIR, and AFM.

5. Briefly share a practical application/end use of your research:
The number of people living in water-distressed areas is on the rise; water purity and availability issues continue to worsen as a result of freshwater source depletion, contamination, and salinization. If sea levels continue to rise, brackish spillover into aquifers could salinize the drinking water of millions of people. Development of new membrane technologies to increase selectivity, durability, and energetic performance could lead to monetary savings in desalination and other water purification processes that will increase the availability of clean, drinkable water to all people. Biomimetic membranes have the potential to increase selectivity of desalination processes and reduce the need for or eliminate costly post-treatment stages in desalination plants.

6. 50- to 75-word abstract of your project:
Naturally-occurring aquaporin protein channels exhibit a combination of high permeability and selectivity that state-of-the-art desalination membranes do not possess. Fragile aquaporins are not feasibly integrated into a functional and scalable reverse osmosis (RO) membrane. Bio-inspired pillar[5]arene artificial water channels have been synthesized as integrable aquaporin alternatives, and via a “click” synthesis approach can be designed with finely-tuned pore characteristics. Automated spin coating, inherently scalable and repeatable, allows for a simple and straightforward incorporation of these channels into biomimetic membranes.

7. References for papers, posters, or presentations of your research:

Kasl, T. (2019). *Spin-assisted fabrication of biomimetic membranes with artificial water channels for next generation water purification*. Project presented at meeting of NDnano Undergraduate Researchers, Notre Dame, IN

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One-page project summary that describes problem, project goal and your activities / results:

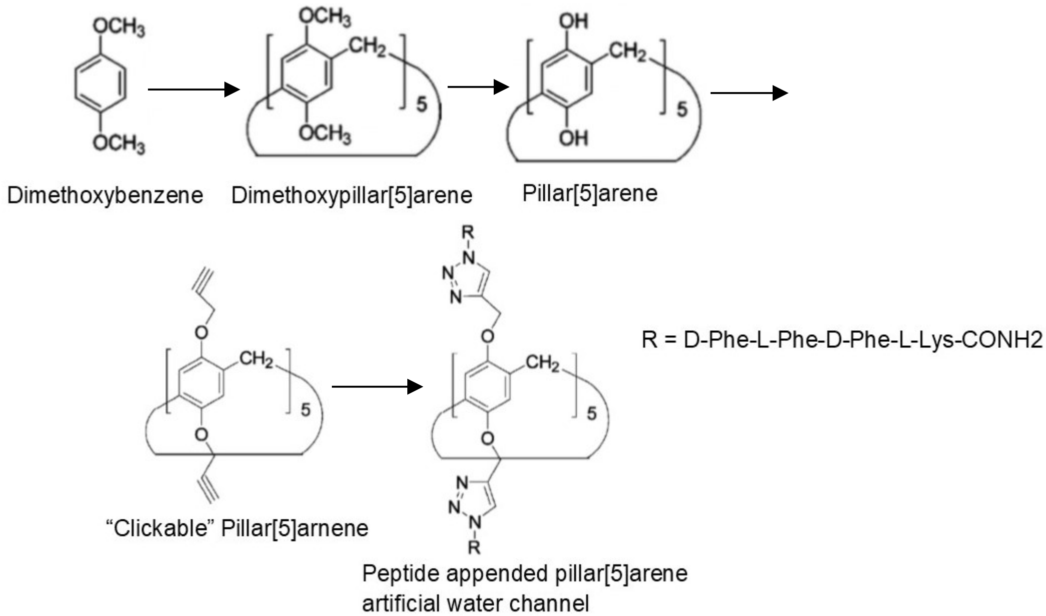
The most efficient water purification membrane with the highest permeability and selectivity can only be found in nature. Aquaporin is a transmembrane protein channel that filters out ions and large molecules with a combination of steric impedance and electrostatic repulsion. A biological membrane uses aquaporins embedded in a phospholipid bilayer to allow the passage of water with high specificity; a biomimetic membrane ideally attempts to replicate that functionality as a durable and scalable material. Since a phospholipid bilayer is fragile and difficult to embed in a commercial membrane, alternative fabrication approaches are desired.

Some would say that an ideal biomimetic membrane might consist of aquaporins in a polymer-based membrane, however these types of membranes are difficult to fabricate and prone to defects. Considering these difficulties, an alternative to aquaporin may be artificial water channels. Synthetic peptide appended pillar[5]arene water channels have the possibility to replicate aquaporin's high permeability and selectivity while remaining stable enough to be fabricated into a membrane via a spin coating process.

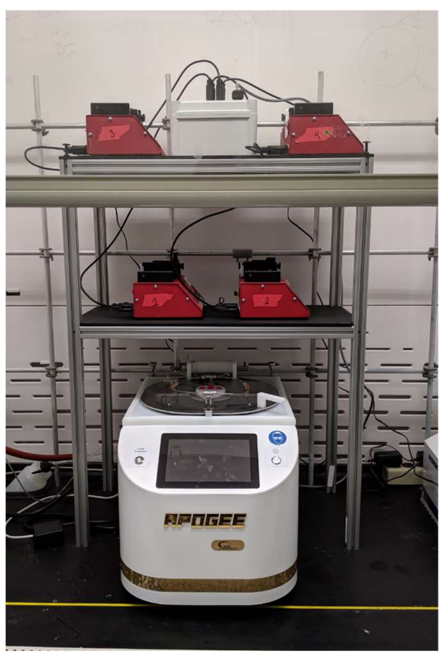
The main focus of this research is to develop a new fabrication approach for biomimetic membranes. By establishing an automated spin coating system in our lab, we now have access to that new approach. Spin coating is a repeatable and efficient process that has the potential to create defect free water purification membranes. Polyamide (the traditional RO membrane material) membranes can be fabricated via a spin coating process to create a membrane with minimal surface roughness (~2 nm). These ultra-smooth polyamide supports can be used to fabricate biomimetic membranes with alternating layers of polyamide and water channels.

Peptide appended pillar[5]arene channels with terminal lysine residues will be spin-coated onto a 25 nm thick polyamide layer where the amine (NH3) groups present in lysine can react with the acyl chloride (COCl) groups on the surface of the polyamide. Once the channel layer has been spin coated onto the polyamide support, atomic force microscopy (AFM) will be employed to verify the fabrication of a densely-packed 2D layer of channels. These two layers of polyamide and channels will be deposited an additional 1-2 times to minimize the effects of possible defects in the layers. The membranes will be characterized by permeability and rejection tests. Once this fabrication approach is successfully completed, modified channels can be used in the process in order to create membranes with finely-tuned pore chemistry to alter the overall selectivity.

The following scheme outlines the synthesis for the peptide appended pillar[5]arene water channels:



At the conclusion of this fellowship, both pillar[5]arene and the tetrapeptide had been synthesized and verified by NMR, mass spectroscopy, or LCMS. The automated spin coating system consists of a CEE Apogee Spin Coater and four NE-1000 syringe pumps:



My work on this project will continue into the school year. Once the channels are fully synthesized and the polyamide roughness is verified by AFM, biomimetic membranes will be fabricated and tested as described above.