Academic Report

Fall 2015 Internship at NASA Ames Research Center

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Mountain View, California. October 4th - December 18th

Index

Introduction

The following report is divided in two parts, the first one contains a list of the different activities that I participated in during my internship at Ames Research Center as part of the program coordinated by the Office of Education, as well as some extracurricular activities that are worth mentioning in this report.

The second part is the technical report of the research conducted during my internship. This report is based on the paper submitted to the 46th International Conference on Environmental Systems (ICES), that will take place in Vienna (Austria) during July 10-14 of 2016, and in which paper I am a co-author.

Picture Index

Extracurricular Activities

1. **Proposal writing workshop.** Speaker: Elizabeth Blaber, who started at Ames as an intern, she gave us tips to write effective request letters to obtain grants for attending meetings or getting accepted in any school program.

2. **SETI (Search for Extraterrestrial Intelligence) Institute.** Speaker: Seth Shostak – Senior astronomer. Seth is an enthusiastic participant at the Institute's SETI observing programs. He also leads the International Academy of Astronautics' SETI Permanent Committee.

3. **Life in the International Space Station**. Speaker: Steve Smith. He is a veteran of four space flights covering 16 million miles and seven space walks totaling 49 hours and 25 minutes. Smith's spacewalk time places him in the top five on the all-time American and World spacewalk duration lists.

Picture 1. *Interns with astronaut Steve Smith*

4. **Centrifuge chamber tour.** We had a tour in the centrifuge chamber, a place where future astronauts experience some of the effects of a space launch.

Picture 3. *Centrifuge chamber*

5. **Artificial Intelligence Building tour.** This is the building that houses **Pleiades**, one of the world's most powerful supercomputers. It represents NASA's state-of-the-art technology for meeting the agency's supercomputing requirements, enabling NASA scientists and engineers to conduct modeling and simulation for NASA missions.

Picture 4. *NASA engineer showing a simulation of world's climate change using Pleiades*

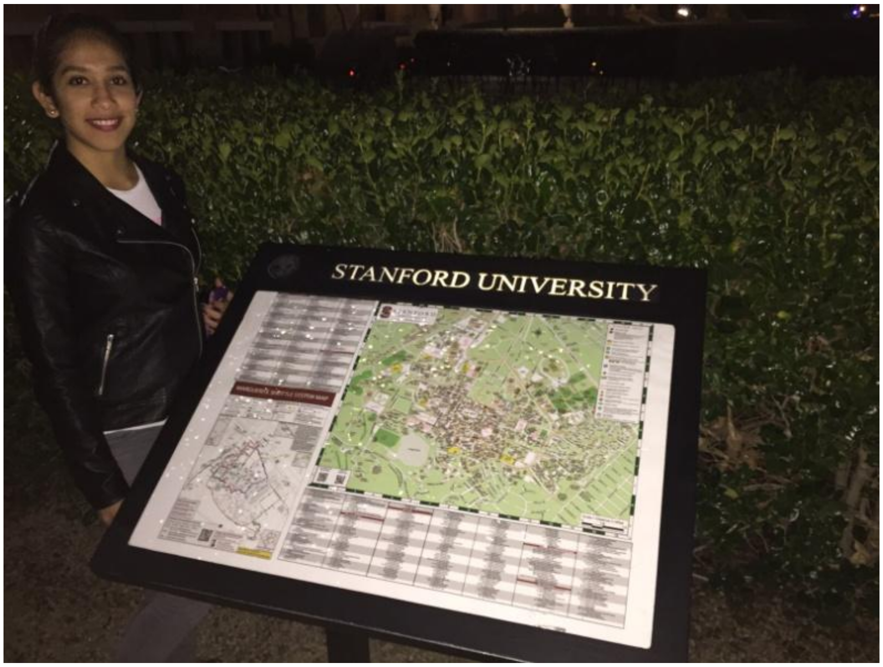
6. **Meeting with Ileana Rossell,** Mexican Consul of education programs and internships in San Jose, California. She met both of the Mexican students doing a fall internship at Ames, Mario Gurrola Morga and myself. We talked to her about our experience and the process to get in the internship, so future Mexican interns will have an easier process.

Picture 5. *Mario Gurrola Morga, Consul Ileana Rossell and Sonia Gamboa Vázquez*

7. **Meeting with Carlos Ponce,** Mexican Consul in San Jose, California. Mexican interns at Ames at the time, Mario Gurrola and I, had breakfast with him, and then we went to the radio station where he introduced us as the week's "Successful Mexicans" section in the consulate's radio program "Discovering Mexico", to tell other Mexicans in California about our internship opportunity.

Picture 6. *Mario Gurrola, Consul Carlos Ponce, Consul Ileana Rossell and Sonia Gamboa Vázquez at radio station*

8. **Visit to Stanford.** My supervisor took me to one of the most recognized universities in the United States, Stanford. It is a very large campus, and I walked around some of the faculties and museums inside.



Picture 7. *Sonia Gamboa next to a Stanford map*

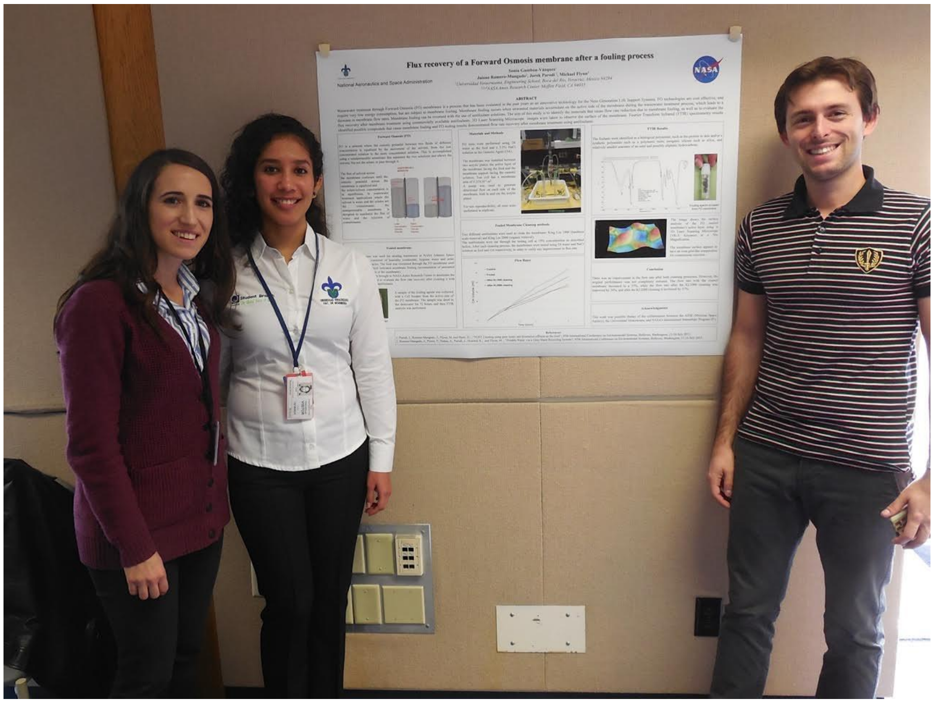
Picture 8. *Stanford Campus*

9. **AGU Fall Meeting. San Francisco, CA, December 15th.** I had the chance to attend the American Geophysics Union Fall Meeting. This is the largest Earth and space science meeting in the world. Fall Meeting brings together the entire Earth and space science community from across the globe for discussions of emerging trends and the latest research. The technical program includes presentations on new and cutting-edge science, much of which has not yet been published. It was a very enriching experience for me, as I could attend the talk by Elon Musk, CEO of SpaceX and Tesla. I also attended different talks around the exhibit hall.

Picture 9. *Sonia Gamboa outside AGU FM at Moscone Center*

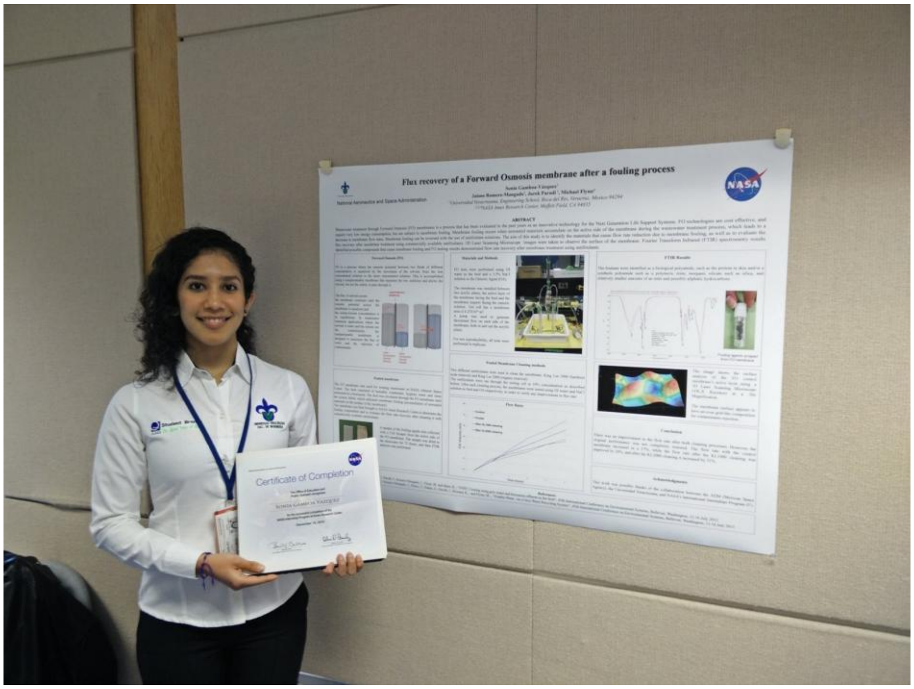
Picture 10. *AGU FM event badge*

10. **Poster session**. During the poster session, all the interns presented the results of the work of our internship. Many people from around Ames went to the session, and our Certificates of Completion were given to us.



Picture 11. *Sonia Gamboa with her technical supervisors Jaione Romero Mangado and Jurek Parodi*

Picture 12. *Some of the Fall 2015 interns at Completion Ceremony*



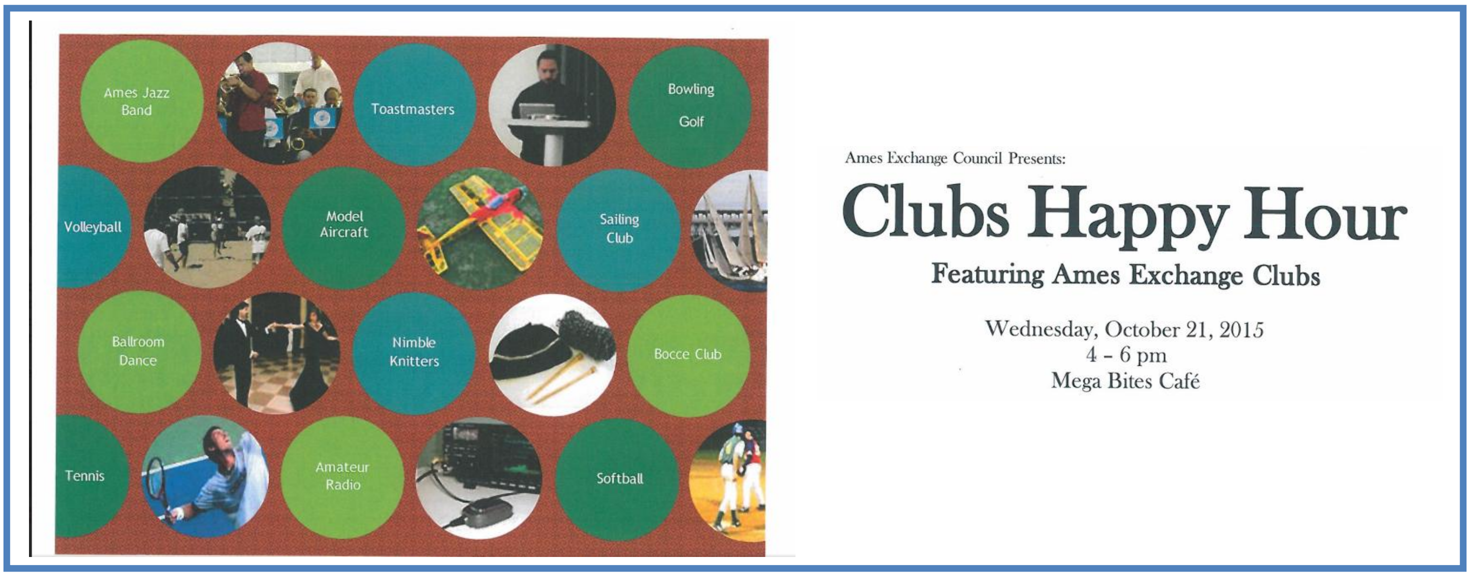
Picture 13. *Sonia Gamboa with her Certificate of Completion, next to her poster*

Personal Experience

The internship experience was amazing. I worked next to people from different places of the world. My mentor Michael Flynn is from San Francisco, California, while my supervisor Jaione Romero is Spanish, and my supervisor Jurek Parodi is Italian.

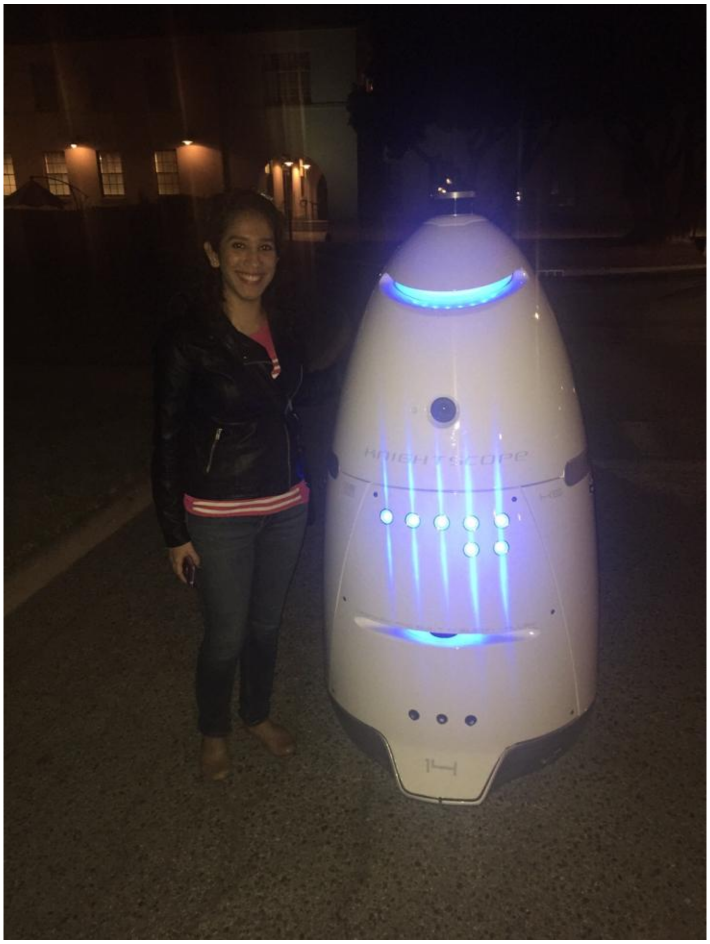
My colleagues also were from all over the world. Some of them from the U.S., some of them were Swedish, Spanish, Lithuanian and Puerto Rican, and Mario Gurrola and I, Mexican. This allowed all of us to share our diverse stories and cultural backgrounds, which made the whole internship very enriching. I learned a lot from each one of my fellow interns, and we ended up being a close group of friends.

I experienced some American traditions, like carving a pumpkin on Halloween, and going to a Thanksgiving dinner at a colleague's house. Thanksgiving is a very big event that is often celebrated all week long with themed Happy Hours and a special lunch at the NASA Ames cafeteria. Once a month, a Happy hour organized by Ames Exchange Clubs took place at NASA's main cafeteria it was a great opportunity to meet people at Ames.



Picture 14. *Happy Hour poster*

Living in Mountain View, California, right in the center of the Silicon Valley, is very different from what I was used to. Everything around that area has very high-end technology, with companies like Apple, Facebook and Google established near Ames, it was very common to see Self Driving Cars in the streets, having WiFi in the light rail, or seeing security robots at night around Ames Park.



Picture 15. *Sonia Gamboa next to a Security Robot at Ames Park*

I traveled around the Bay Area, to cities near Mountain View like Palo Alto, where Stanford is, the city of San Jose, and of course, to San Francisco. This city is very beautiful and big.

Picture 16. *View from the top of the Young Tower, at Golden Gate Park in San Francisco*

I met a lot of people who encouraged and inspired me to keep on looking for diverse opportunities to develop my academic career and to pursue a Graduate degree in Engineering.

Flux recovery of a forward osmosis membrane after a fouling process

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Wastewater treatment through Forward Osmosis (FO) membranes is a process that has been evaluated in the past years as an innovative technology for the Next Generation Life Support Systems. FO technologies are cost effective, and require very low energy consumption, but are subject to membrane fouling. Membrane fouling occurs when unwanted materials accumulate on the active side of the membrane during the wastewater treatment process, which leads to a decrease in membrane flow rates. Membrane fouling can be reversed with the use of antifoulant solutions. The aim of this study is to identify the materials that cause flow rate reduction due to membrane fouling, as well as to evaluate the flux recovery after membrane treatment using commercially available antifoulants. 3D Laser Scanning Microscope images were taken to observe the surface of the membrane. Fourier Transform Infrared (FTIR) spectrometry results identified possible compounds that cause membrane fouling and FO testing results demonstrated flow rate recovery after membrane treatment using antifoulants.

Nomenclature

FO = Forward Osmosis
FTIR = Fourier Transform Infrared
LSS = Life Support Systems
OA = Osmotic Agent
RO = Reverse Osmosis

I. Introduction

FO SYSTEMS are the base for next generation LSS, because it is a reliable and a low-cost technology for its utilization in future space missions.

Since it would be impractical, in terms of volume and cost, to completely stock a spacecraft with oxygen or water for long duration missions, it is indispensable to create a lightweight water recycling system that will provide astronauts with the water supply they need for as long as the mission lasts.

Conventionally, osmosis is defined as the net movement of water across a selectively permeable membrane driven by a difference in osmotic pressure across the membrane. The selectively permeable membrane allows water to pass through it, but it rejects the solutes and contaminants. This approach is used to recycle wastewater, humidity condensate and urine into drinking water to provide astronauts with a reliable water source.

The greatest advantages of FO water treatment systems are the low consumption of energy and the reduction in fouling compared to RO systems. However, fouling is still a major issue in the long-term performance of the system. The aim of this study is to find an efficient cleaning system using commercially available antifoulants that will restore the system's flow rate after fouling occurs, and extend the membrane's lifespan.

II. Background

A. Forward Osmosis (FO)

Forward osmosis is a physical phenomenon that allows the transport of water across a selectively permeable membrane from a region of higher water chemical potential to a region of lower water chemical potential (Fig. 1). It is driven by a difference in solute concentrations across the membrane itself, which causes a difference in osmotic pressure that allows passage of water but rejects most solute molecules or ions. [1].

As the feed water comes through the active side of the membrane, leaving contaminants behind, the membrane tends to catch the contaminants in its active surface, eventually reducing or blocking the water flux. When this occurs, the membrane must be cleaned in order to restore its optimal function. In this work, two different methods have been tested and measured to find the most practical cleaning method for fouled membranes.

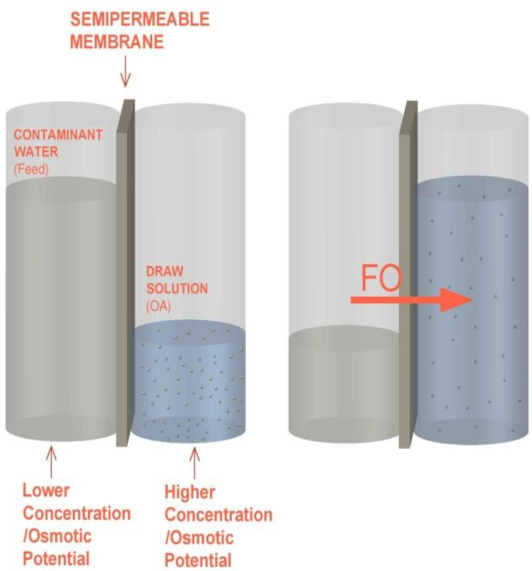

Fig. 1. Forward osmosis

B. Membrane Fouling

The organic fouling of a membrane is caused by a deposition of biopolymers. Previous studies have demonstrated that the major percentage of those polymers are proteins and polysaccharides [2] more specifically polysaccharides and other non-setteable organic matter with a molecular weight larger than 120 000 Da [3]. Biological precipitation can be another contribution to inorganic fouling. The biopolymers contain ionisable groups (COO- , CO32- , SO42- , PO43- and OH-) which are easily capturable by metal ions. Metal ions play a significant role in the formation of fouling layers, which can bridge the deposited cells and biopolymers and then form a dense cake layer. There exists a synergistic interaction among biofouling, organic fouling and inorganic fouling [4].

In the filtration process of wastewater, different fouling mechanisms may occur, expressed by the filtration resistance R (Fig. 2). The retained components can form a cake layer (C) on top of the membrane surface, block the membrane pores (P) or adsorb (A) at the membrane surface or in the membrane pores, depending on their chemical and physical properties. [3]

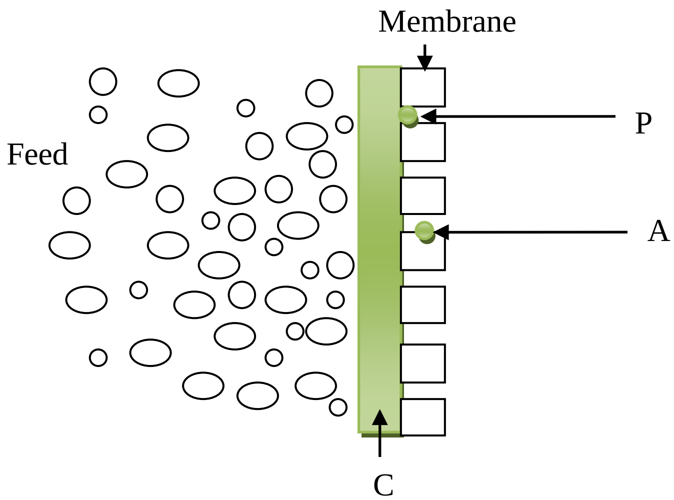

Fig. 2. Schematic drawing of filtration resistances

Antiscalants act as threshold inhibitors of growth scales from supersaturated brine. In smaller concentrations, they complex with the surfaces of seed crystals, preventing them from growth in the super-saturated brine. Some antiscalants also inhibit the precipitation of inorganic gels such as hydroxide/oxides of aluminum, iron, manganese, other heavy metals and silica and silicates. Certain antiscalants also inhibit the polymerization of reactive silica that results in membrane fouling by polymeric hydrated silica and silicates. [5]

C. Fouled membrane

The FO membrane (Fig. 3) was used for treating wastewater at NASA Johnson Space Center. The feed consisted of humidity condensate, hygiene water and urine pretreated in a bioreactor. The feed was circulated through the FO membrane until the system failed, which indicated membrane fouling (accumulation of unwanted materials on the surface of the membrane).

The membrane was then brought to NASA Ames Research Center to determine the fouling composition and to evaluate the flow rate recovery after cleaning it with commercially available antifoulants.

Fig. 3. New FO membrane and fouled FO membrane

III. Materials and Methods

We want to compare the flow rate difference in the fouled membrane before and after the cleaning process, and in the control membrane. We also submitted the fouling composition for FTIR analysis to characterize which fouling agents were present in the membrane.

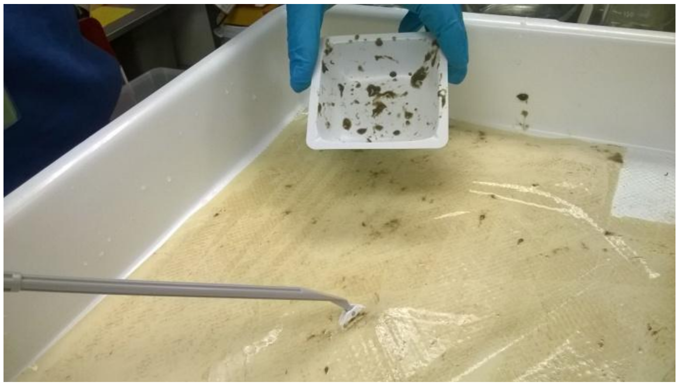

Fig. 4. Fouling agents on the surface of the fouled membrane

First, the flow rate in the fouled membrane was measured. Then, it was cleaned with the King Lee 1000 antiscalant, and after that, another run with distilled (DI) water as feed was performed to see if there was any improvement in the flow rate. Following that, it was cleaned with King Lee 2000, measured and then a final DI water run was performed.

A. Fouling composition

FTIR sample analysis protocol

Membrane fouling agents were subjected to FTIR analysis. Samples of the fouling agents were collected with a Corning® Small Cell Scraper from the fouled Porifera FO membrane. The samples (Fig. 5) were placed in a weight boat, and were dried in the desiccator for 72 hours. Following the drying process, the samples were placed in an Eppendorf tube, and were delivered to Evans Analytical Group, which performed the FTIR analysis.

Fig. 5. Desiccated fouling sample

B. Membrane Performance Testing

The experiment set (Fig. 6) consisted in a set of two graduated cylinders (1 and 2), each connected to a pump (5) (for fluid recirculation purposes) and to the test cell (3) between them The membrane (4) was installed between two acrylic plates; the active layer of the membrane facing the feed (1) and the membrane support facing the osmotic solution (2). Test cell has a membrane area of 4.25X10-4 m2.

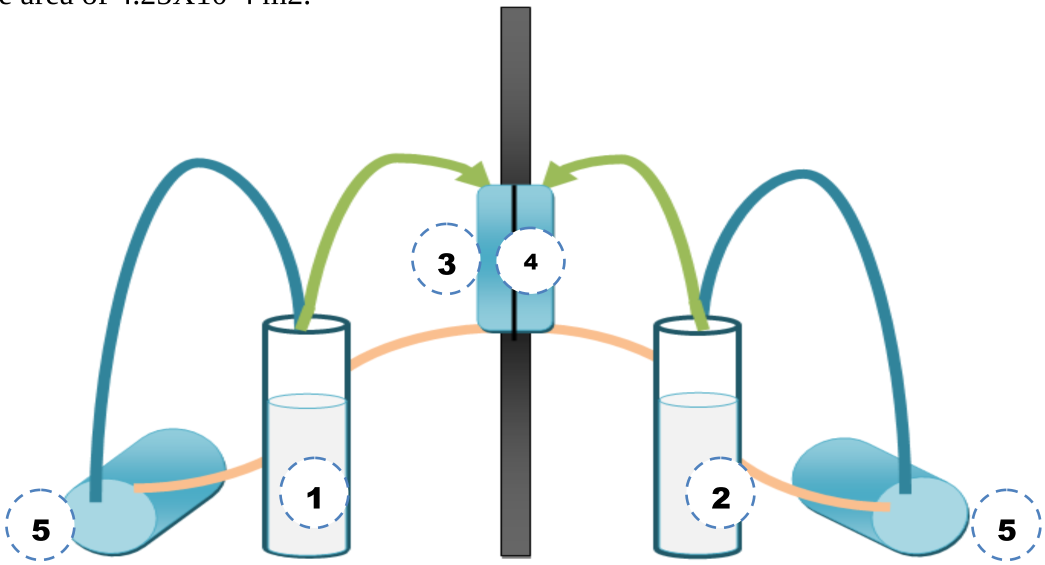

Fig 6. Testing cell diagram

The left beaker was filled with 70ml of DI water (Feed), and the right one was filled with 70ml of an Osmotic Agent (OA), a 3.5% NaCl Solution. Two tubes were set next to a ruler in order to measure and control the pressure of the fluids. The pressure in the Feed side was always higher than in the OA side.

After ten minutes of starting the pumps, and the system was stabilized, the volume of the beakers was adjusted again with 70ml of fluid each, since some of the fluid was inside the tubes.

The system was controlled and volumes of feed and OA solutions were measured every hour for a period of five hours to calculate the flux rate. For test reproducibility, the experiments were conducted in triplicate. First we tested the new Porifera membrane (control) and then the fouled membrane. We compared the flux rate difference afterwards.

C. Cleaning methods

Two different antifoulants were used to clean the membrane: King Lee 1000 (hardness scale removal) and King Lee 2000 (organic removal).

The antifoulants were ran through the testing cell at 10% concentration using the same procedure as the membrane performance testing (Fig. 7). After each cleaning process, the membranes were tested using DI water and NaCl solution as feed and OA respectively, in order to verify an improvement in flux rate.

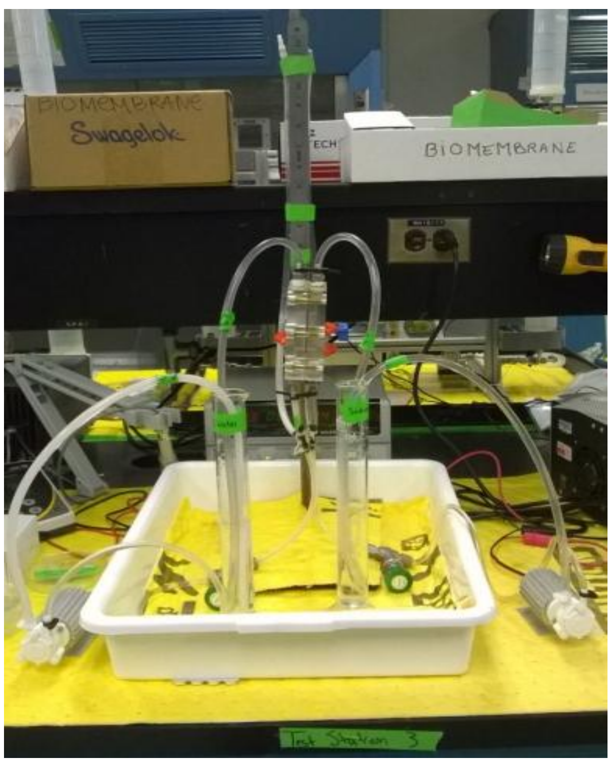

Fig 7. Testing cell

IV. Results

A. FTIR Analysis

The components from the FO membrane were identified as a biological polyamide such as the protein in skin and/or a synthetic polyamide such as a polymeric resin; inorganic silicate such as silica, and relatively smaller amounts of an ester and possibly aliphatic hydrocarbons.

A representative sample of the dried residue was transferred to an infrared transmitting substrate and examined by the Fourier Transform Infrared Spectrometer (FTIR, Thermo Nicolet 6700) with the FTIR Continuum microscope in transmission mode.

Fig. 7 shows FTIR spectrum of two micro-pieces of the components from the osmosis membrane, in an overlay format, demonstrating its homogeneity (i.e., the match of the bands between the two measurements). The components were identified as:

- Biological polyamide such as the protein in skin and/or synthetic polyamide such as a polymeric resin (e.g., bands at ~ 3292, 2921, 2851, 1657, 1544, 1463 and 1381 cm-1);
- Inorganic silicate such as silica (e.g., bands at ~ 1102 and 805 cm-1);
- A small amount of ester (weak band at ~ 1734 cm-1), and
- Possibly aliphatic hydrocarbon (intensity of the bands at ~ 2921 and 2851 cm-1).

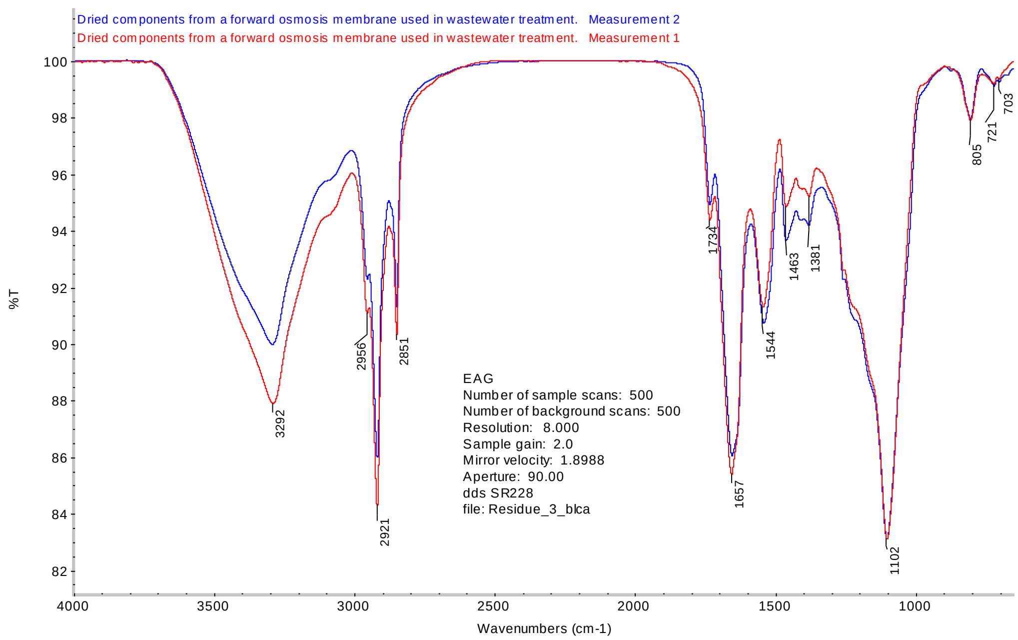

Fig. 8. FTIR spectrum of dried components from a FO membrane used in wastewater treatment

B. Flow rates

Fig. 9 shows the difference between the flow rates of the fouled and the control membrane. The control membrane obtained a flow rate of 96 ml after a five hour run, while the fouled membrane reached a flow rate of 88 ml after a five hour run.

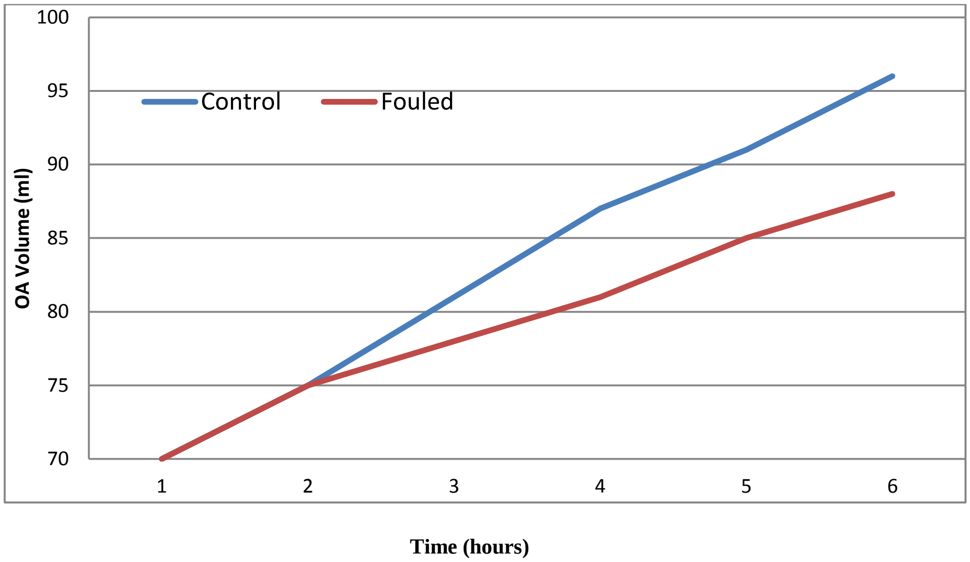

Fig. 9. Flow rate difference between fouled and control FO membrane

Fig. 10 shows the differences between the flow rates of the fouled and control membranes, as well as the flux after each cleaning procedure. The flow rate after the first cleaning remained the same, and after the second cleaning it improved, reaching 92 ml after the run. However, it did not reach the flow rate of the control membrane.

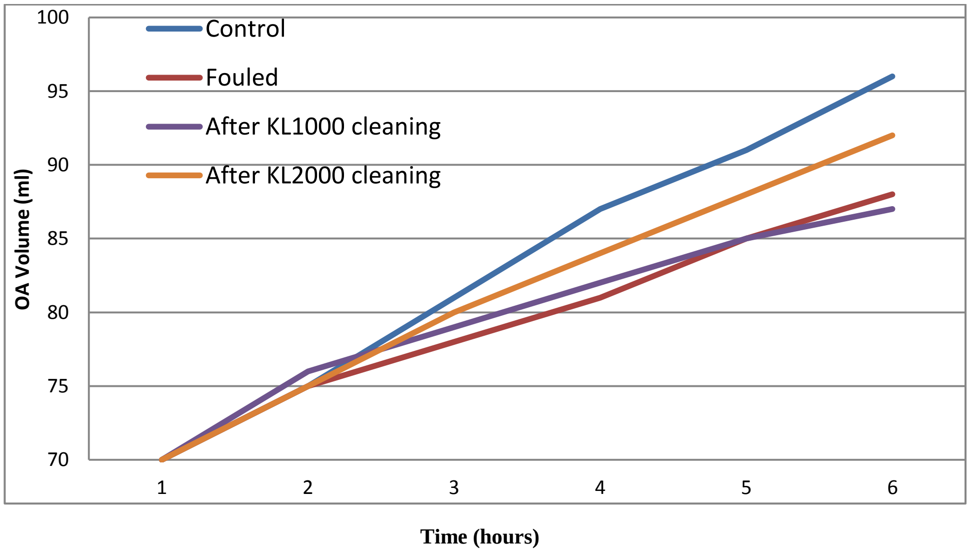

Fig. 10. Flow rate of the Control and fouled FO membranes, and the FO membranes after cleaning procedures.

V. Conclusion

There was an improvement in the flow rate after both cleaning processes. However, the original performance was not completely restored. The flow rate with the control membrane increased in a 37%, while the flow rate after the KL1000 cleaning was improved by 24%, and after the KL2000 cleaning it increased by 31%.

Acknowledgments

The authors thank Universidad Veracruzana for providing the funding for Sonia's internship to perform the experimental section in this testing, and STMD and GCD programs for the funding of the the Synthetic Biological Membrane project in support of this study.

References

[1]Parodi, J., Romero-Mangado, J. Flynn, M. and Shaw, H. , "FOST 2 testing using grey water and bioreactor effluent as the feed", 45th International Conference on Environmental Systems, Bellevue, Washington, 12-16 July 2015.

[2]Jun, Z., YANG, F. L., MENG, F. G., Peng, A. N., & Di, W. A. N. G. (2007). Comparison of membrane fouling during short-term filtration of aerobic granular sludge and activated sludge. Journal of Environmental Sciences, 19(11), 1281-1286.

[3]Rosenberger, S., Evenblij, H., Te Poele, S., Wintgens, T., & Laabs, C. (2005). The importance of liquid phase analyses to understand fouling in membrane assisted activated sludge processes—six case studies of different European research groups. Journal of Membrane Science, 263(1), 113-126.

[4]Meng, F., Chae, S. R., Drews, A., Kraume, M., Shin, H. S., & Yang, F. (2009). Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. Water research, 43(6), 1489-1512.

[5]Ning, R., Troyer T., Tominello, R., "Antiscalants for near complete recovery of water with tandem RO process", Conference on Membranes in Drinking and Industrial Water Production, Toulouse, France, 20–24 October 2008., 92–95.