Potable-quality water recovery from primary effluent through a coupled algal-osmosis membrane system

Sam Hertle[1] with Dr. Xuesong Xu[2] and Dr. Pei Xu[3]

Introduction

Partnering with another lab at NMSU under Dr. Khandan, the coupled algal-osmosis membrane system was developed to separate algae that treats primary effluent wastewater from the water for potable reuse. The system contains both forward and reverse osmosis, essentially taking the water from algae to a saline solution using forward osmosis and retrieving water using a reverse osmosis of the salt solution created during forward osmosis.

This summary demonstrates information about the pilot scale system testing that functions in the Las Cruces Wastewater Treatment Plant. It also follows research that was successful in the bench scale, so it should explore the trial that accompanies the scaling-up process.

Purpose

This system is more complex than the average algae dewatering technology. But, coupled with the efficiency and promise of the algae bioreactor, the system contains the four following benefits.

DEWATERING THE ALGAE

Traditional methods for separating the water from the algae that treats it proved unsuccessful in the past. But, this method works efficiently for the system as proved during bench scale testing.

MINIMIZING WASTE

As shown by the process diagram [See Figure B], much of the system can be recycled within its process and the gentle separation by forward osmosis allows the algae to be harvested for nutrient recovery

PROTECTING REVERSE OSMOSIS

The reverse osmosis (RO) membrane functions at very high pressure. The FO membrane, functioning before the RO, prevents fouling and scaling, which does much more damage on the RO membrane.

ENERGY EFFICIENCY

Although this is only a hypothesis, the protection of the reverse osmosis membrane will prove the system to be energy efficient in the long run, even though the reverse osmosis process consumes a high amount of energy.

B

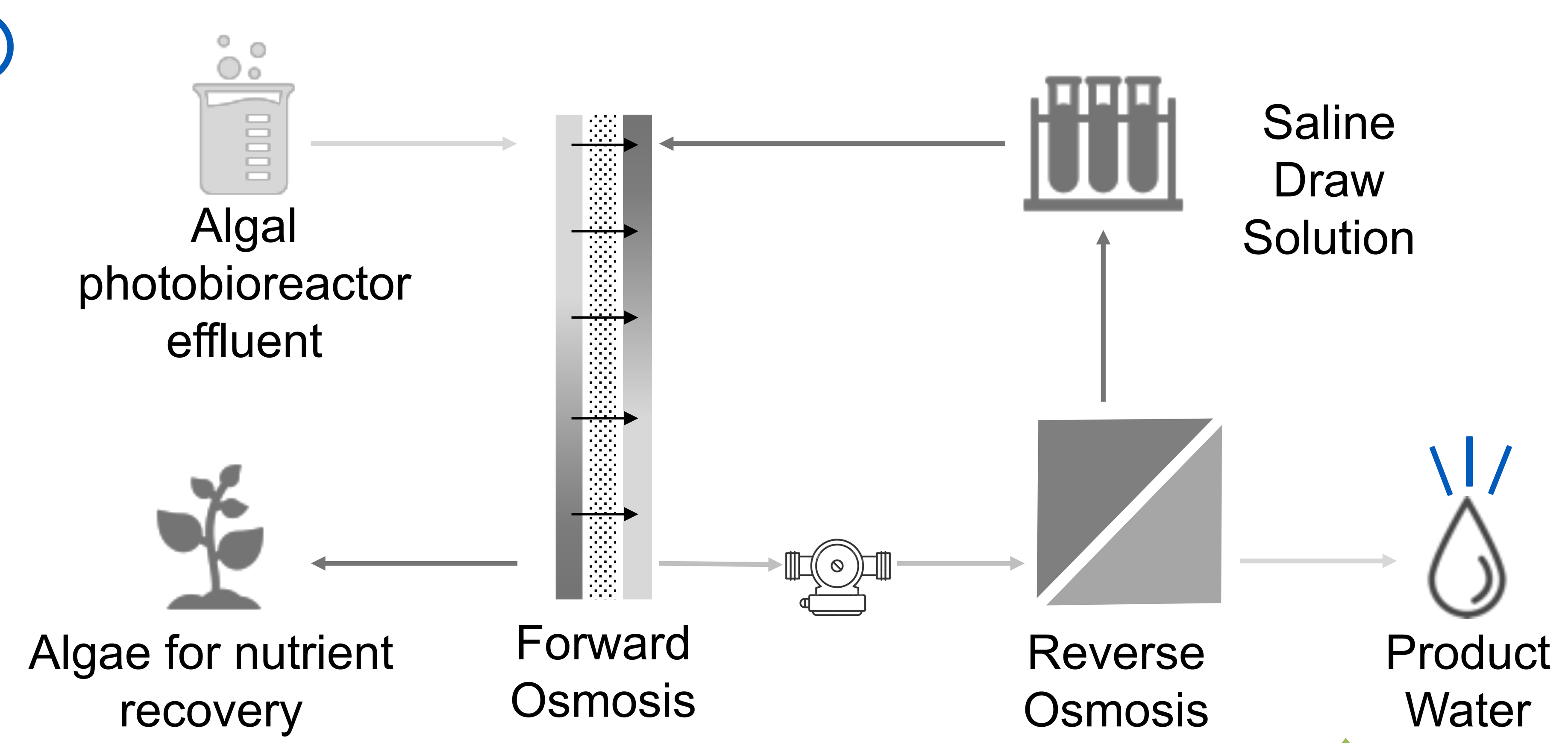


Figure B: The outline of the coupled algal osmosis system separation process.

Methods

In early stages of the experiments, only batch testing was used to run the system. Batch testing proceeded as follows:

SETUP

- The system is cleaned of the last solution and the data is checked for consistency.

SOLUTION PREPARATION

- Solutions are customized to test properties of the limitations of the system.

FORWARD OSMOSIS

- Forward osmosis is run alone and water from the feed solution is drained to the saline draw solution.
- Pressure is closely monitored (<15 psi) to ensure safety of the system

REVERSE OSMOSIS

- Reverse osmosis is run alone and the draw solution is forced by a high pressure pump through a semi-permeable membrane to retrieve water
- Pressure is gradually increased to nearly 300 psi

A

Figure A: The pilot scale system in the Las Cruces Wastewater Treatment plant.

Materials

The materials that were used for this testing included mainly the pilot scale system developed over the summer [See Figure A]. The system contains:

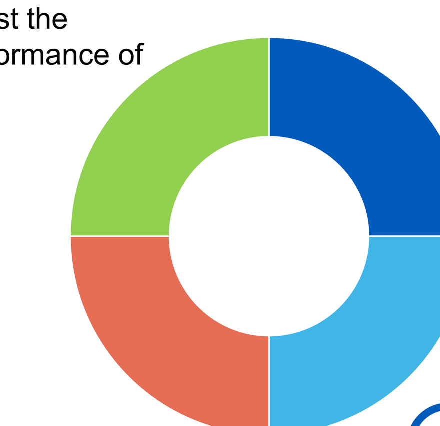
- pH, conductivity, pressure, and flow meters.
- A forward osmosis unit.
- A reverse osmosis unit.
- A PLC and CPU for data monitoring, collecting, and displaying.

Test Solutions

The system was tested under 4 different draw and feed solution conditions to understand about how the system would function under given conditions.

1 **DISTILLED WATER FEED**
The feed solution was DI water to test the standard performance of the system

2 **CONCENTRATED SALT DRAW**
The draw solution was nearly 60 g/L of NaCl to test salt flux.



3 **LOW PH FEED**
The pH of the feed solution was set to 4 in order to test algal-pH conditions.

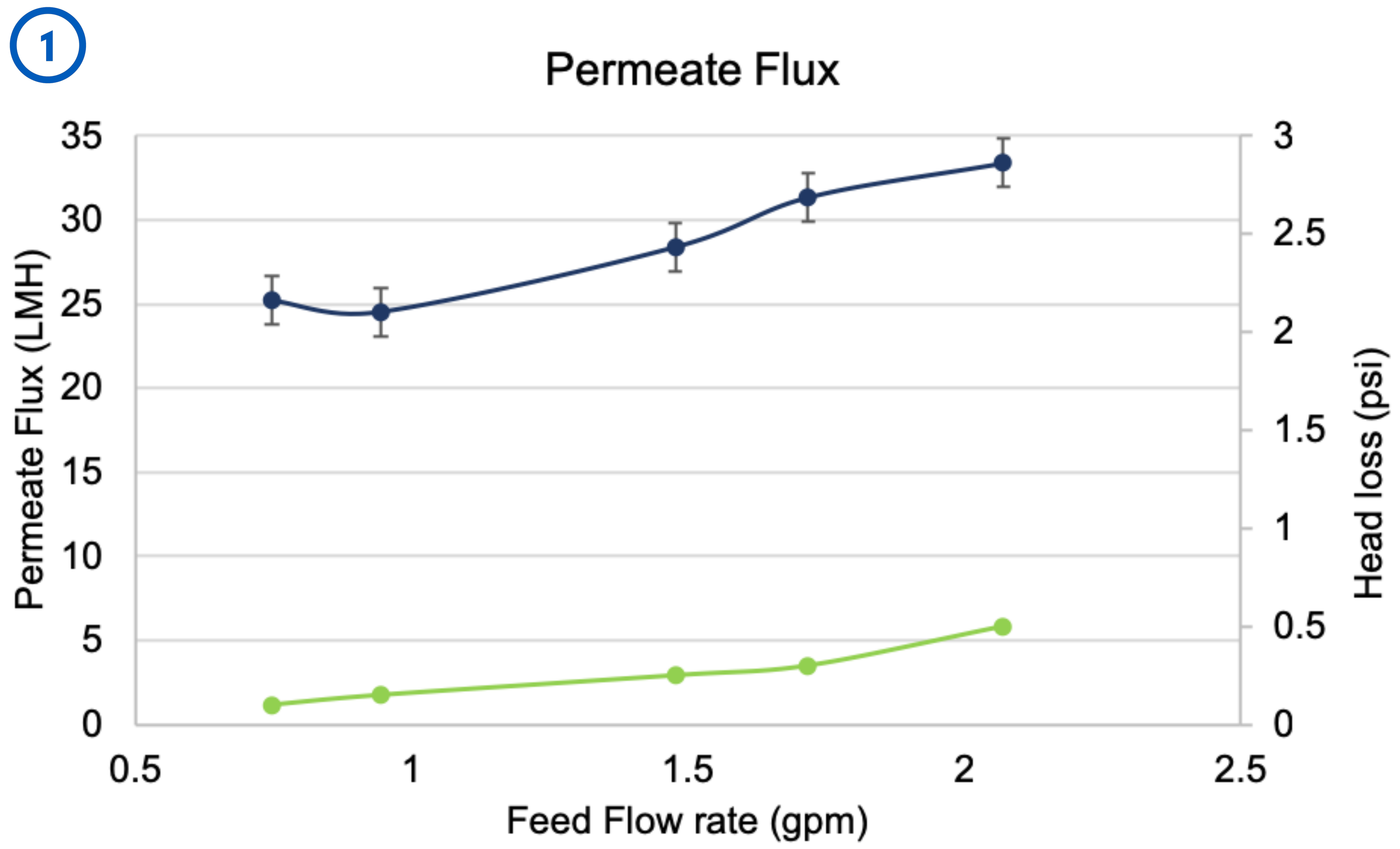
4 **SECONDARY EFFLUENT**
Secondary effluent is very similar to the algae bioreactor effluent that will be tested eventually, but the algae was not yet ready.

Footnotes

1. Cornell University Undergraduate, REU Student
2. Post-Doc Student, NMSU Dept. of Civil Engineering
3. Professor, NMSU Dept. of Civil Engineering

Data & Results

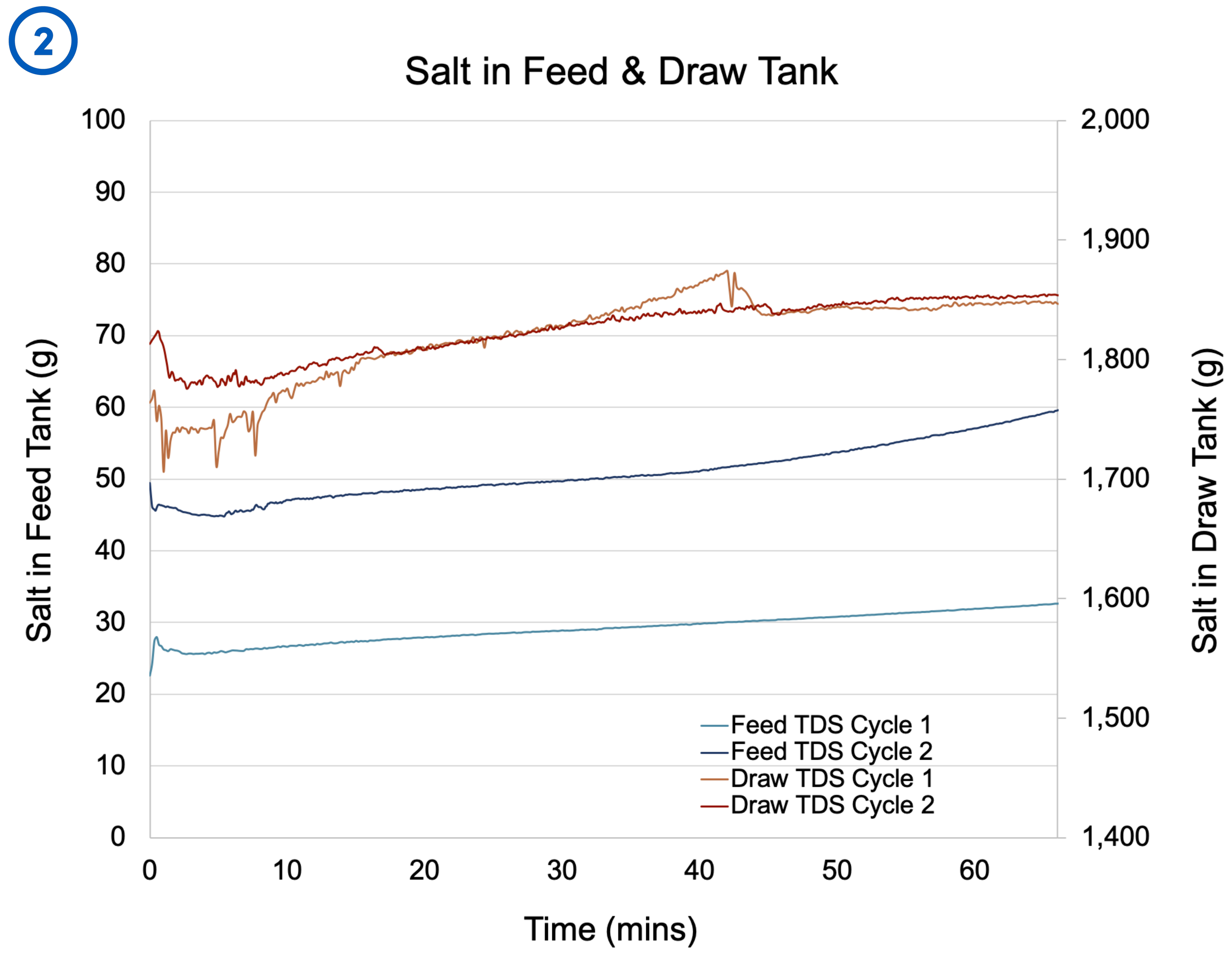
1



DISTILLED WATER TEST SOLUTION

The performance of the forward osmosis system can be evaluated with distilled water and compared to the manual's performance rating to ensure that the system is operating as it is meant to. The results in the figure above demonstrate that the system performs efficiently and as expected. Because of pressure limitations on the square meter of membrane in the pilot scale system, the flow rates possible range from 0.5-2.5 gallons per minute.

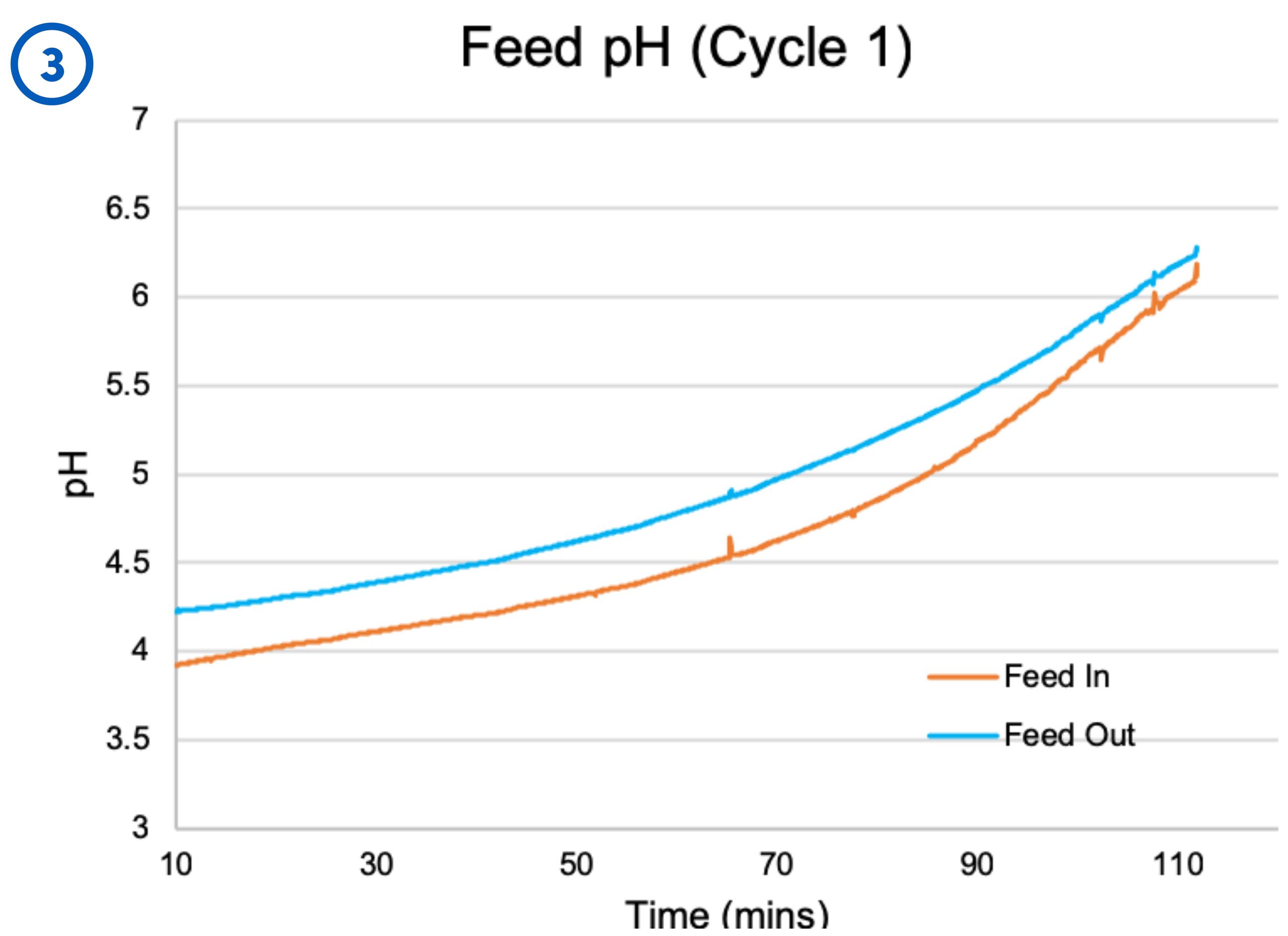
2

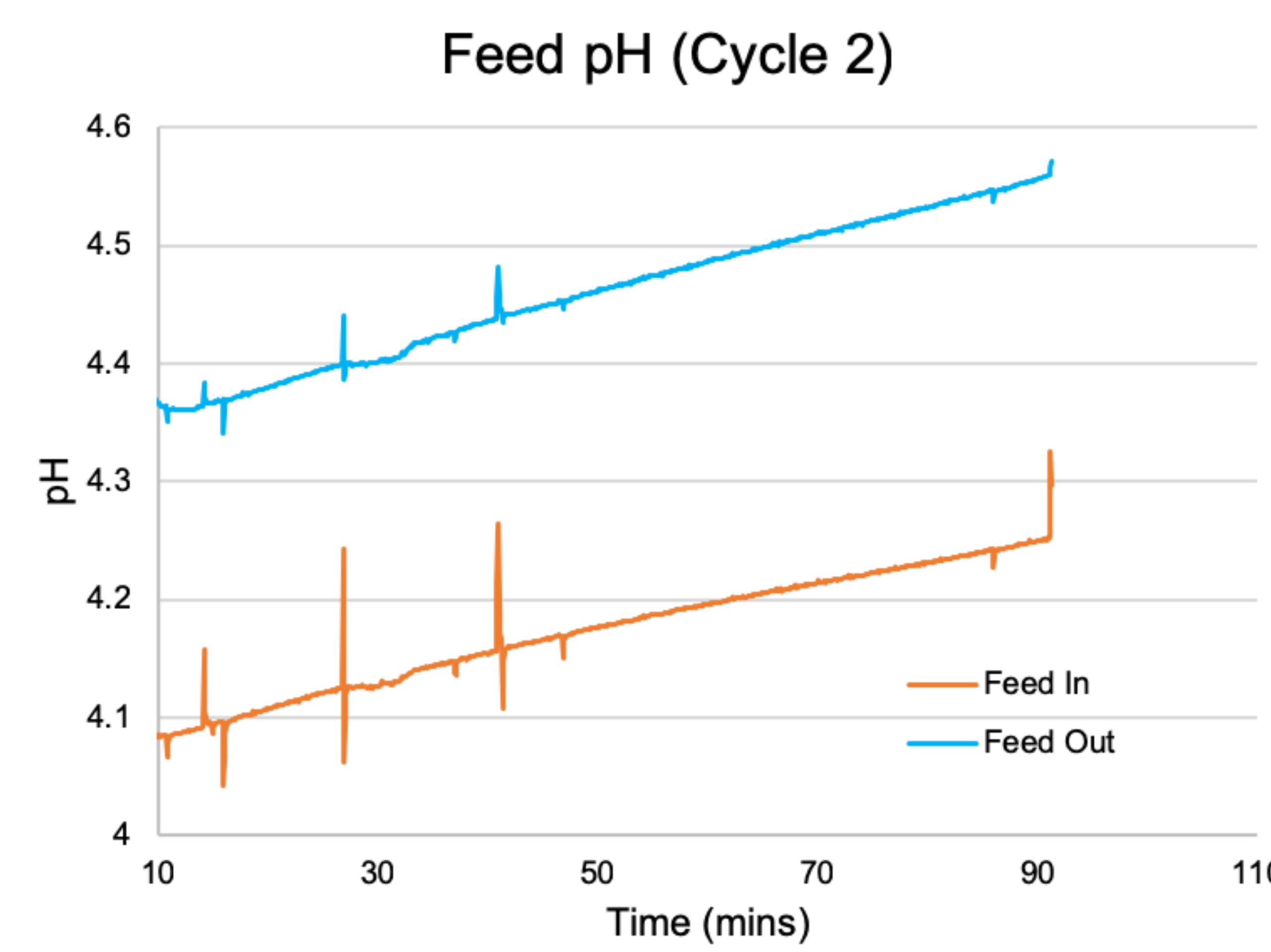


CONCENTRATED NACL DRAW SOLUTION

Normally, the forward osmosis draw solution is intended to be used at a concentration of nearly 30 g/L NaCl. In this trial, the draw solution contained 60 g/L NaCl. The system maintained a transport rate[1] of nearly 8%, very consistent with the capacity of the membrane[2]. The above plot demonstrates the salt mass in each of the solutions over time. This demonstrates a back diffusion through the membrane by the increase in salt in the feed solution over time. But, the overall back diffusion only transferred 0.6% of the salt in the draw solution over nearly 2 hours, so very minimal amount.

3





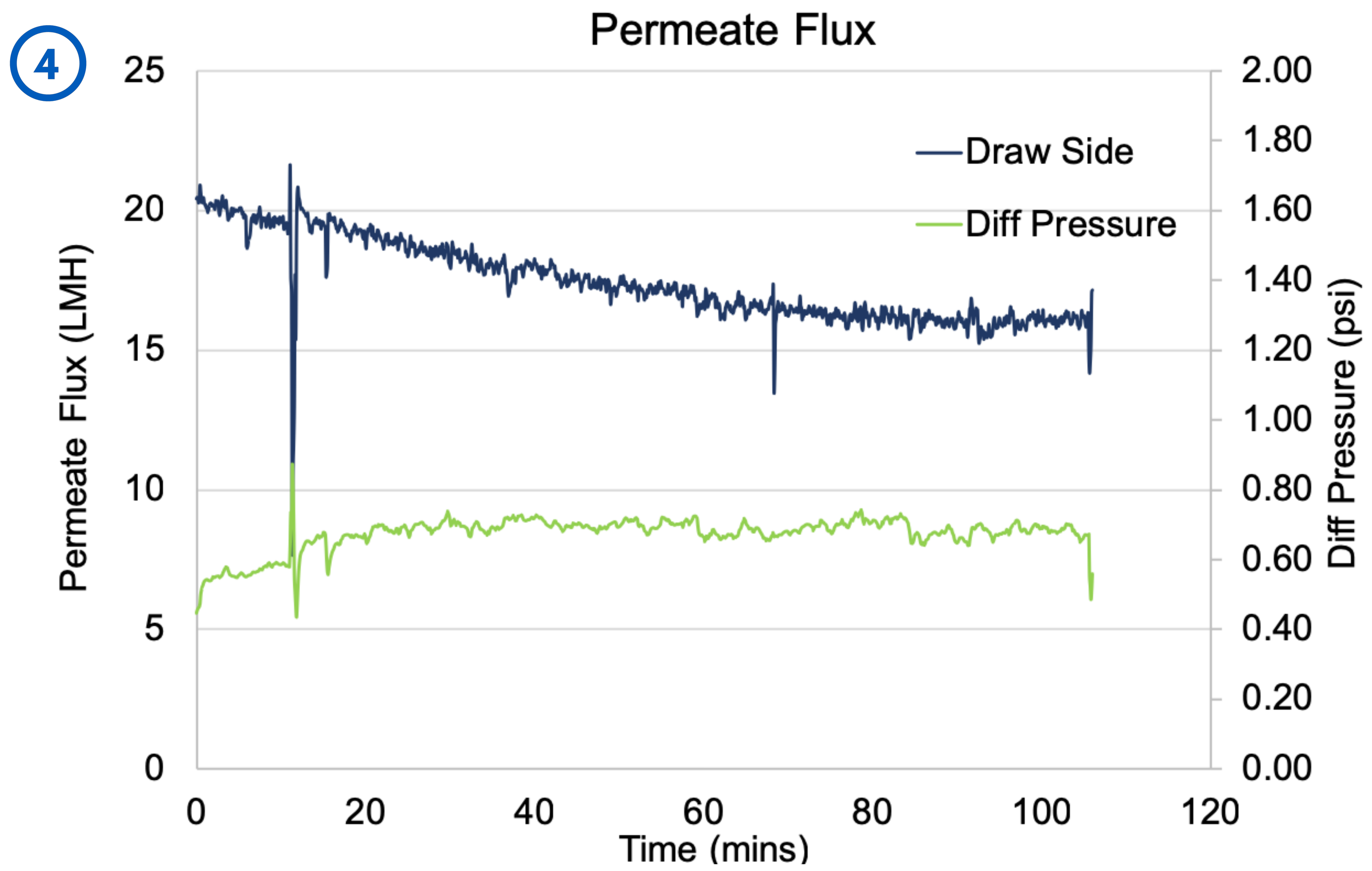
LOW PH TEST SOLUTION

Two full batch tests were run with a feed solution of pH close to 4. The transport rate remained close to 8% which meant the system was functioning as usual. Although the pH did not affect the transport rate, during the first cycle, there was a significant rise in pH over the trial. But in the second cycle, there was minimal rise in pH across the membrane and over time.

References

1. Transport Rate $= \frac{V_{Draw-In} - V_{Draw-Out}}{V_{Feed-In}} \times 100\%$
2. *Porifera PFO-20 Element, 1 m²*

4



SECONDARY EFFLUENT TEST SOLUTION

Secondary effluent is a very close substance to algae effluent, in terms of possible organic content and ability for high fouling and scaling on the membrane. The results demonstrated consistent transport rate, pH, and sensible conductivity readings. The plot above demonstrates the immediate permeate flux across the membrane graphed with the differential pressure corresponding to the flux. The results are logical in that the flux should begin at around 20 and slowly decrease as the draw solution becomes less and less concentrated. This was a higher differential pressure than usual but not too close to the limit of 2.5 psi so the system was functioning correctly.

Conclusions & Future Work

Based on the data and results, the system seems to be functioning according to expectations. The system maintains a transport rate near 8%, a flux near 20 liters/hours/m^2, and no significant back diffusion. The following are some future tasks for this research.

- **Energy Data:** To test whether this system upholds the notion that it will be energy efficient in the long term, it is important to track the energy usage of the system under different conditions.
- **pH Trials:** The data from the third test solution demonstrates two different conclusions, and there will be future testing regarding pH to ensure that the first cycle was an outlier in terms of the large increase in pH.
- **Algae testing:** The system should be tested with the algae-bioreactor effluent soon.
- **Membrane conditions:** After running this system for a significant amount of time, an autopsy can be performed on the forward and reverse osmosis membranes to monitor fouling and scaling and confirm the hypothesis about reverse osmosis membrane protection.