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

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1 Introduction

To meet dwindling supply of fresh water sources and potable quality water in growingly arid regions of the southwest, wastewater treatment has grown to become more compliant with water quality regulations. In recent years, development of treatment technology by an extremophile found in algae, *Galdieria sulphuraria*, has proven to be successful in removing BOD and nutrients and producing potable quality water and nutrient rich biomass without the reliance on aeration or concern about other bacteria surfacing.

Despite the many benefits, the algae harvesting has difficulty dewatering after the separation process by traditional methods. This research tests the feasibility of the use of forward and reverse osmosis (FO & RO) to separate product water from algae biomass. The process is outlined in [figure 1], which depicts the general process by which primary effluent wastewater is treated by algae photobioreactor and then separated from the biomass using the coupled algal osmosis system. The FO-RO system poses 4 main benefits. First is that it has proven successful in separating water from the algae without problems in the bench scale phase. It also minimizes waste within the process, where the algae can be recycled, and the salt solution can be reused within the system. Also, the FO coupled with the RO protects the reverse osmosis membrane from scaling and fouling in the future, where the hydrophilic FO system operates under low pressure and therefore becomes less of a problem for scaling and fouling in the future. It is also hypothesized that the system will be energy efficient in the long run, saving from maintenance problems in the future and conserving energy that otherwise would have been expended with only the reverse osmosis membrane.

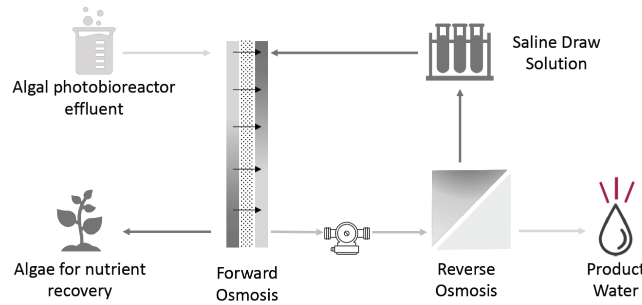

Figure 1. Coupled algal-osmosis system overview

This research was performed in the pilot scale facility located in the Las Cruces Wastewater Treatment Plant and follows successful research in the bench scale. Analysis focused on the relative performance of the membrane system. For the purpose of time, the system was ultimately tested with stimulant algae photobioreactor effluent, but also with other solutions that indicate how the system functions under extreme conductivity and pH.

2 Methods & Procedures

2.1 Materials & Apparatus

The majority of the time in this research project was spent fabricating the pilot size FO and RO system. This system contains seven lines represented by the seven arrows in [figure 1]. Each runs through an analysis line before the remainder of the system to monitor temperature, pH, conductivity for saline content, flowrates, and pressure. The forward osmosis membrane used is a *Porifera PFO-20 Sample Element*, 1 m^2 and within the pH limits that allow the very low pH of the algae bioreactor effluent. The reverse osmosis unit is *Dow FILMTEC™ SW30-2540 [figure 2].*

Figure 2. Pilot scale system

2.2 Process

2.2.1 Batch Testing

During batch testing, the goal is to allow the system to run in piecewise operations in order to better see each part of the process function and observe the performance individually. Therefore, instead of running the process continuously with both the forward and reverse osmosis functioning and feeding or drawing from the same influent supply, the forward osmosis was run to a drain a certain volume of water from the feed solution and then reverse osmosis until the water supply was restored.

2.2.1.1 Forward-Osmosis Performance

Once the system was operational and the membranes proved to be functional, testing could be done with DI water to develop a standard system curve. This was done by carefully adjusting the flow rate through the forward osmosis membrane and correlating with flux through the membrane and headloss calculated by pressure difference across the FO membrane.

2.2.1.2 DI and NaCl Cycles

Once the system was configured for testing, the draw tank was filled with DI water and 58.9 g/L NaCl (s). This is twice the normal salt content of seawater, which we intended on using as the general draw solution. The feed solution was only distilled water. The forward osmosis pump was turned on and manually adjusted to avoid a significant pressure difference between the membrane, and the system was run

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at a continuous flow rate of nearly 1.0 gallon per minute. Once the forward osmosis system drained nearly 25 L of water from the feed solution, reverse osmosis could be run to restore the volume in the draw tank.

2.2.1.3 pH Cycles

Because the wastewater treatment algae maintains a very low pH to function, the system must be able to run at a pH around 4. Therefore, the feed solution was filled with nearly 60 L of distilled water and concentrated HCl (l) to generate a solution of pH 3.98. The draw solution was distilled water and 30 g/L NaCl. Forward osmosis was run at a rate of nearly 1.0 gpm, and pH readings were taken every 5 seconds during the test.

2.2.1.4 Secondary Effluent Cycle

During the time that the system was prepared for testing, the algae was not yet ready to be tested. In lieu of the algae effluent, secondary effluent was gathered from the Las Cruces Wastewater Treatment Plant and used as the feed solution in the system. The draw solution again was 30 g/L NaCl. The flowrate again was near 1.0 gallons per minute and samples were taken before and after testing to analyze the content of the water.

3 Results & Discussions

3.1 FO Performance

Using data regarding flow rate, flux, and headloss, a segment of the standard curve for operation was developed [figure 3]. A trouble we came across in this research was the limitation of the pressure in the forward osmosis system. The inlet and outlet could not exceed 15 psi, which seems to be a value about 3.0 gallons per minute. In the future, adjustments to the membrane must be made if it is required to flow at this speed or higher.

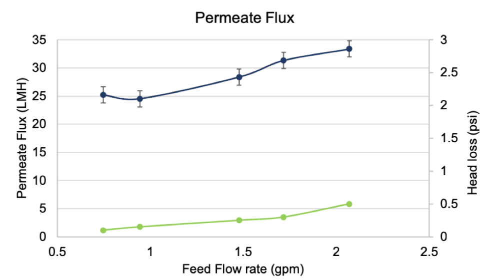

Figure 3.

3.3 High Conductivity Cycles

Converting conductivity to salt mass in grams, the salt content in both the feed and draw solutions was monitored over experiment time. The rise in salt in the feed solution demonstrates back diffusion through the membrane [figure 4], but only 0.6% of the draw solution salt content transferred in nearly 2 hours.

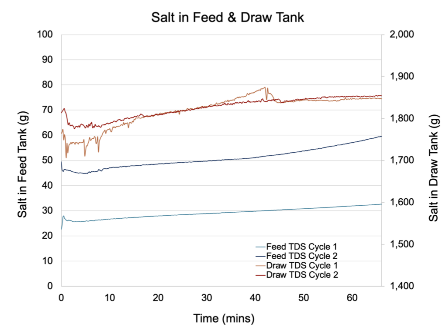

Figure 4.

3.4 Low pH Cycles

Two full batch tests were run at a pH of nearly 4. During the first cycle, the pH increased by nearly 2 [figure 5], which is very dramatic. But, in the second cycle, the pH only increased by close to 0.2 [figure 6]. This disparity will be tested further to determine if the first cycle is an outlier.

3.5 Secondary Effluent Cycle

The results from secondary effluent demonstrated consistent transport rate, pH, and sensible conductivity readings. [Figure 7] 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.

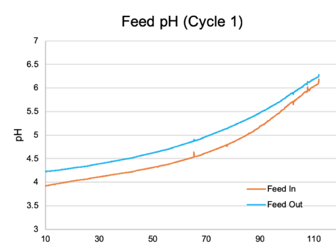

Figure 5.

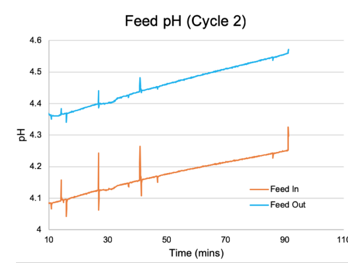

Figure 6.

3.6 Further Steps

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. In the future, there should be more testing of the energy consumption of the system to prove that the coupled-membrane aids in energy conservation, more testing of low pH solutions to determine if an increase in pH is common among FO, testing with algae effluent for application of this technology, and, lastly, a membrane autopsy to determine the limitations of fouling and scaling on the system.

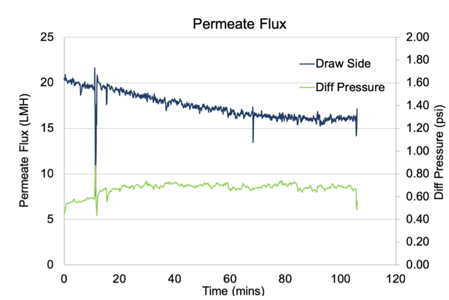

Figure 7.