Exploration of Reverse Osmosis-based Potable Reuse Trains

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Introduction:

Population growth and climate change have led to a decrease in potable water in the arid western United States, which has prompted a push for water reuse trains to increase the amount of water available to communities.[1] Facilities that seek to produce water for direct and indirect potable reuse applications typically employ conventional wastewater treatment, followed by microfiltration, reverse osmosis (RO), and advanced oxidative processes to meet state regulations.[2] While this reuse train produces water that meets potable standards, both the activated sludge step in conventional wastewater treatment and the RO process use large amounts of energy, and the RO system creates a highly concentrated waste stream that is difficult and requires expensive disposal.[3,4]

Because most of the energy consumption of the conventional potable reuse train lies in the aeration of the activated sludge process that maintains aerobic microbial communities, novel substitutions of secondary treatment have been developed. One such treatment alternative, though not novel, is the membrane bioreactor (MBR). This process still requires aeration which necessitates a large energy input, but many of the processes of conventional wastewater treatment are combined into a single MBR system.[5] Conversely the anaerobic baffled reactor (ABR) uses anaerobic sludge to treat wastewater, which significantly decreases the energy input needed to run the reactor and even has potential to generate energy by producing methane.[6] While the removal of many water quality constituents in ABR systems are comparable to aerobic treatment, nitrogen and phosphorus are not treated, leading to potential violations of standard wastewater discharge regulations.[2,]

Replacing aerobic conventional wastewater treatment with anaerobic baffled reactors in a reuse train could significantly reduce the total energy input, decrease overall energy costs, and in the case of anaerobic wastewater effluent, create the potential for nutrient reclamation through the RO concentrate. The purpose of this project was to compare the impact of aerobically and anaerobically treated wastewater on a high-pressure RO system's performance and operation, and to address common problems associated with RO-based reuse trains. These goals were further split into four sections: (1) Compare membrane performance of ABR and MBR pretreated water in the proposed reuse train, (2) compare dissolved organic carbon (DOC) and total nitrogen composition removal in the reuse train, (3) evaluate the remediation of CMF fouling during ABR treatment, and (4) evaluate RO brine reuse. The reuse trains are displayed in Figure 1.

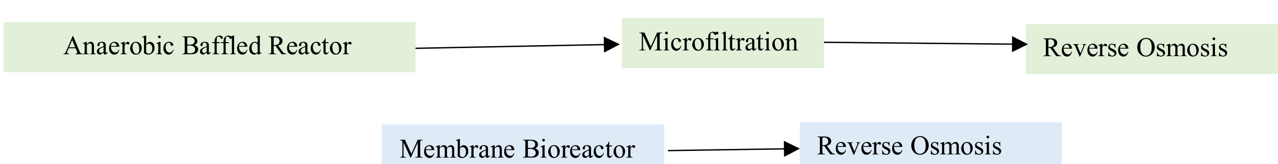

Figure 1: Aerobic and anaerobic reuse trains. The MBR pretreated water does not need additional filtration due to the ultrafiltration membrane in the reactor. The microfiltration step also provides aeration and mitigates dissolved biogas still in the water.

Materials and Methods:

Aerobic (MBR) and anaerobic (ABR) wastewater samples for these experiments were collected from Mines Park Wastewater Treatment Plant, a pilot scale wastewater treatment plant in Golden, CO that houses a sequencing batch reactor-membrane bioreactor (SBR-MBR) hybrid system (referred to MBR in this abstract) to treat 7200 gallons of wastewater per day from a 250-unit apartment complex.[7] In addition, Mines Park houses a four-cell pilot-scale anaerobic baffled reactor that treats 264 gallons per day.[6] Prior to every RO experiment, the anaerobic wastewater was microfiltered to remove large particles. The bench-scale ceramic microfiltration membrane (CMF) (METAWATER Co., Ltd., Rutherford, NJ) with 55 channels had a nominal pore size of 0.1

μm and filtration area of 0.04 m^2, and was operated at 4 L/min for these experiments[2].[9] The bench-scale stainless steel high pressure system for RO experiments contained a SEPA membrane cell with an active area of 139 cm^2, as well as cross-sectional flow area of 0.82 cm^2 with a 34-mil spacer on the feed side and a tricot spacer on the permeate side.[8] The system was run at a flux of 20 LMH for all experiments with a virgin reverse osmosis ESPA2 membrane (Hydranautics, Oceanside, CA).

For the fouling indices, 3 trials of aerobic and anaerobic wastewater were processed in the high pressure reverse osmosis system at low recovery and the decline of the relative specific flux was monitored over 40 hours, then averaged hourly and compared. In addition, samples were taken throughout the MBR-RO and ABR-MF-RO process to assess the changes in chemical oxygen demand (COD), dissolved organic carbon (DOC), nitrate, nitrite, phosphate, ammonia, total nitrogen, turbidity, and 3-D fluorescence EEMS. COD and ammonia were analyzed with Hach testing kits on the Hach DR 5000 (Hach, Loveland, CO); DOC and total nitrogen were analyzed on a Shimadzu TOC-LCSH/TNM-L (Shimadzu, Kyoto, Japan); nitrate, nitrite, and phosphate were additionally analyzed on a Dionex ICS-900 (Dionex, Sunnyvale, CA); turbidity was analyzed on a Hach 2100N Turbidimeter (Hach, Loveland, CO); and the 3-D fluorescence graphs were produced on a Horiba Scientific Aqualog (Horiba, Kyoto, Japan). For the high recovery experiments, 10 L of aerobic and anaerobic wastewater were run through the high pressure system at 20 LMH using the RO membrane, with the initial influent and RO permeate being collected and sampled in 1 L increments until 8L had permeated through the system. These samples were analyzed for DOC, total nitrogen, nitrate, nitrite, and phosphate using the same methods listed above.

<u>Results and Discussion:</u>

Assessing Novel Reuse Trains:

After running the high pressure RO system at low recovery, the averaged fouling of aerobic and anaerobic wastewater is summarized in Figure 2. The fouling propensities of the microfiltered anaerobic wastewater effluent and aerobic MBR effluent were statistically similar, and the fouling overall was less severe than expected.

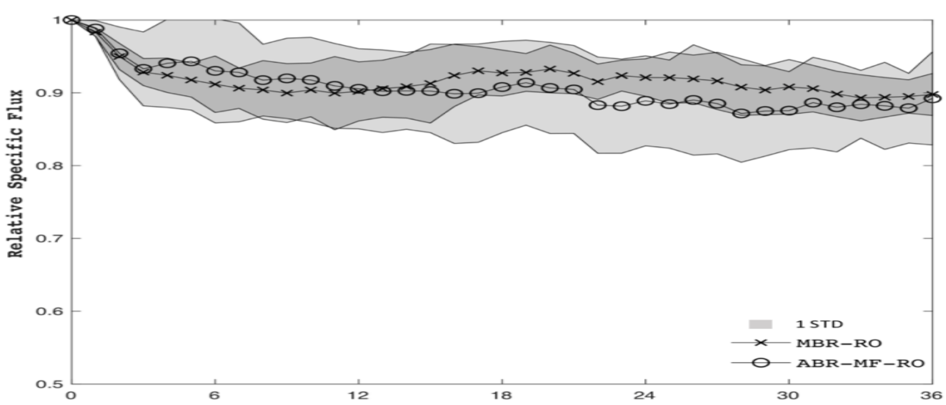

Figure 2: Fouling indices of wastewater from an anaerobic baffled reactor and membrane bioreactor. The decrease of relative specific flux over time indicates fouling of the RO membrane. The dark grey shaded area represents the standard deviation overlap, which denote no statistically significant deviations.

Since the RO membrane performance was satisfactory, the rejection of DOC, phosphate, and nitrogenous compounds could be evaluated in high recovery (Figure 3). As expected, there is high removal of phosphate and the nitrogenous constituents, but DOC removal is surprisingly low for expected membrane rejection for the 10%, 20%, and 80% recovery values. More trials need to be run in this experimental setup to determine if these values are erroneous or artifacts of this membrane rejection performance. In addition, it was found that with ABR pretreatment, nitrite was generated. This could be attributed to nitrifying bacteria that are small enough to pass through the microfiltration system and then are concentrated in the feed tank during the RO filtration stage.

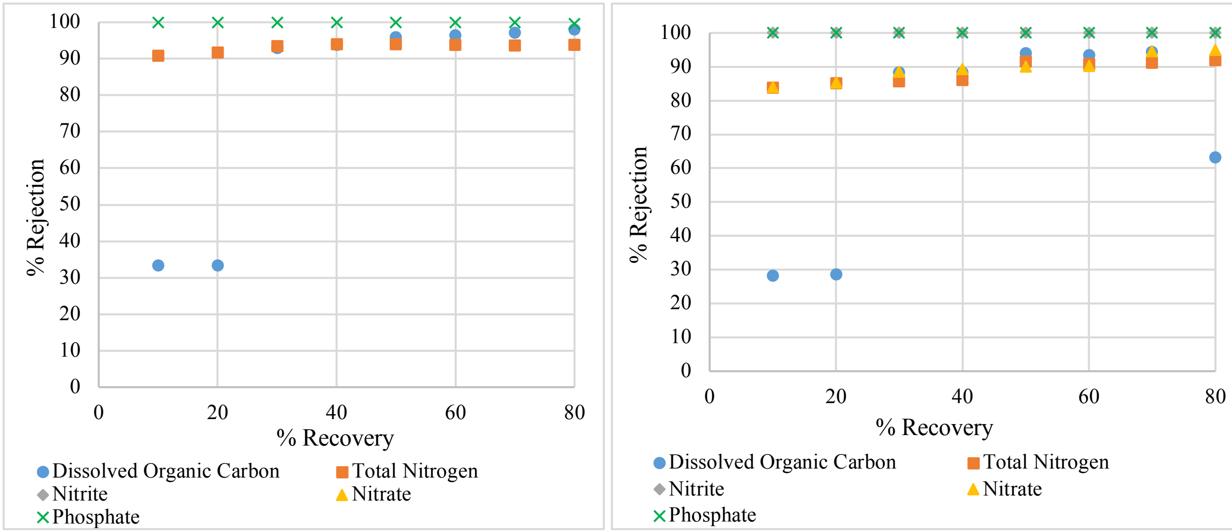

Figure 3: Rejection of DOC, phosphate, and nitrogenous compounds. The ABR pretreated water (pictured left) has the same trends as the MBR pretreated water (pictured right) where good removal is seen for all compounds in the middle recoveries, but the lower than expected DOC in both systems requires further investigation.

Solving Common Reverse Osmosis Reuse Train Problems:

In order to assess the feasibility of the CMF in the reuse train, fouling experiments were done to determine the effectiveness of the microfiltration step to process large amounts of ABR pretreated water. Figure 4 shows the return of the initial specific flux to the same point by using an acid-base wash cycle on the CMF. These changes in pH followed by a DI water flush has proven an effective way to mitigate fouling in this step.

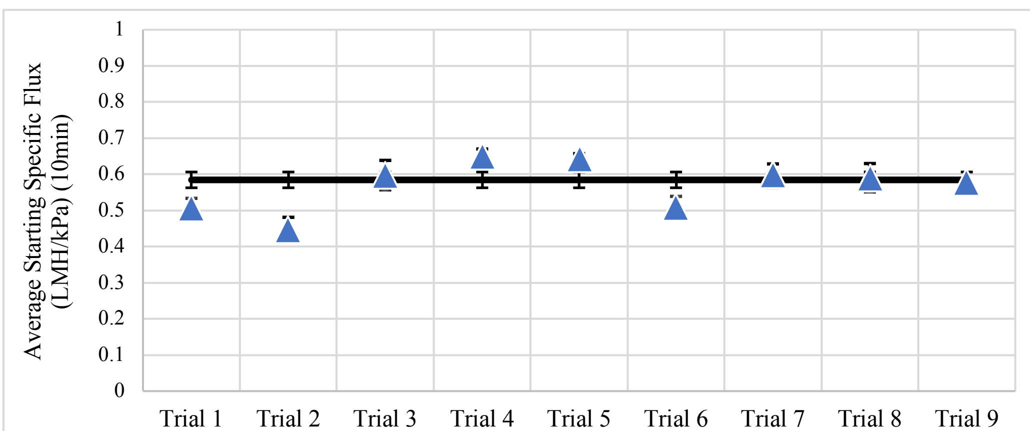

Figure 4: Starting specific flux of CMF after an acid-base wash cycle. The black line indicates the mean of the initial fluxes, and each point represents an initial flux of ABR pretreated water. The blue points indicate trials with the same batch of influent. While all points do not stray far from the mean value, the trials done with the same batch of water tend to be the most similar, which suggests that the contents of the influent vary greatly and can contribute to inconsistent fouling.

The RO concentrate was also evaluated for potential compound recovery after being run in high recovery (summarized in Figure 5). While both types of pretreatment yielded concentration of nitrogenous compounds, they were different in both compound and concentration. The anaerobic pretreatment highly concentrated nitrite and ammonia, whereas the aerobic pretreatment modestly concentrated nitrate. These concentration ratios of ammonia and nitrite are ideal as a feed stream for the anammox process, which is an advanced wastewater treatment system. Nitrate, on the other hand, is essential for agriculture. Both of these potential recovery uses need to be explored further through experiments testing their effectiveness.

	Anaerobic Pretreatment (mg/L)	Reject Concentration (mg/L)	Aerobic Pretreatment (mg/L)	Reject Concentration (mg/L)
Ammonia	37.8	81.8	7.07	ND
Nitrite	ND	183.47	ND	0.22
Nitrate	ND	24.36	7.2	27.97
Phosphate	15.683	23.75	ND	1.29

Figure 5: Contents of RO concentrate. As discussed above, anaerobic concentrate shows promise as a feed stream for the anammox process and the aerobic concentrate could be recovered for agricultural use. It is interesting to note that both nitrite and nitrate are being created within anaerobic the reuse train, which needs to be further explored.

Conclusions and Further Work:

Direct potable reuse is essential for providing enough water to arid communities. This research focused on evaluating effluent from an anaerobic baffled reactor and a membrane bioreactor in place of conventional wastewater treatment in a direct reuse train, while addressing main issues associated with direct potable reuse trains. Anaerobic and aerobic pretreatment had similar membrane fouling performance and compound rejection, while an acid-base wash cycle demonstrated the reversibility of microfiltration membrane fouling and RO concentrate has promise for recovery. Future work will be focused on understanding the nitrogenous compounds throughout the anaerobic pretreatment reuse train to determine the source of partial nitrification being quantified. Also, varying points of the reuse train will be analyzed using LC-MS to evaluate emerging contaminants of concern removal.

References:

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