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Treatment of Highly Organic, Brackish Surface Water by Integrated Membrane Systems

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INTRODUCTION

In recent years, membranes have become fully or partially integrated into all facilities that produce drinking water since membrane processes can resolve technically complex and, at times, conflicting requirements related to compliance with multi-contaminant regulations. However, NF or RO technologies are hydraulically limited by the feed water quality that causes the fouling in a membrane system. In particular, NF or RO systems involved in surface water treatment generally require extensive pretreatment for controlling membrane fouling. The primary objective of this study is to investigate the feasibility of using the integrated membrane systems (IMS) to produce drinking water from sources having high organic and dissolved solids content, in order to supplement the water supply for Central Florida in USA. The integrated membrane system consisted of two advanced pretreatments by ferric sulfate coagulation, which were primarily designed to remove particulate matter, natural organic matter (NOM), and pathogens. Low pressure RO membranes followed by pretreatment were utilized to remove dissolved salts and to further achieve higher levels of NOM removal.

EXPERIMENTAL METHODS

The source water used in this research was obtained from Lake Monroe in Sanford, Florida. This surface water is characterized as highly organic water with high concentrations of dissolved salts (brackish). Specifically, during the rainy season in Florida (May-September), the organics increase significantly due to rainwater runoff, and the total dissolved solids (TDS) decrease due to dilution of the lake water. In the dry season (October-April) the organics decrease and the TDS increase, accordingly.

For the membrane selection of the IMS pilot study, twenty commercial membranes were evaluated based on flat-sheet test and surface characterization. The surfaces of these membranes were thoroughly characterized in terms of roughness, charge and hydrophobicity, using Atomic Force Microscopy (AFM), Streaming Potential Analysis (SPA), and contact angle measurements by Goniometer, respectively. Four membranes selected for pilot study were commercial fouling resistant low pressure membranes from different manufacturers. They were LFC-1 (Hydranautics), X20 (Trisep), BW30FR1 (FilmTec), and SG (Osmonics).

The pilot system in this study utilized two different types of advanced pretreatment processes: Super-pulsator (SP) blanket clarifier followed by dual media gravity filtration, and Zenon (ZN) immersed ultra-filter with in-line coagulation. In addition, monochloramine was used to prevent biofouling, while antiscalants were added to feed water for scaling control. Raw water quality was affected by the seasonal change but pretreated water quality was kept in an acceptable range as feed water for RO membranes. The single membrane elements were operated at a flux of 12 gfd and recovery of 70 %. The pretreatment water qualities were then correlated to membrane productivity through mass loading regression modeling.

RESULTS AND DISCUSSION

Membrane Surface Characteristics

Four commercial fouling resistant membranes were selected for pilot study based on surface characterization and bench-scale membrane performance evaluation. The surface characteristics of selected RO membranes are presented in Table 1. Interestingly the results of surface characterization revealed that each of these membranes had unique surface characteristics to minimize the adherence of the fouling materials to the membrane.

Table 1: Summary of Membrane Surface Characteristics.

Membrane	Roughness, RMS(nm)	Zeta Potential at pH 6.5 (mv)	Contact Angle (°)
BW30FR1	65.01	-6.7	43.8
X20	41.64	-13.2	52.3
LFC-1	67.40	-3.9	51.8
SG	13.09	-7.0	60.9

Specifically, the LFC1 membrane features a low negative surface charge, which minimizes electrostatic interactions with charged foulants. The X20, on the other hand, shows a highly negatively charged surface, and thus, is expected to perform well with feed waters containing negatively charged organics and colloids. The BW30FR exhibits a relatively neutral and hydrophilic surface, which could be beneficial for lessening organic and/or biofouling. The SG membrane has a smooth surface that makes it quite resistant to fouling, particularly for colloidal deposition

Pretreatment Water Qualities

The qualities of feed waters pretreated by two advanced coagulation processes (i.e., SP and ZN) are summarized in Table 2. As shown, these pretreatment processes were able to reduce average turbidity below 0.1 NTU. Organic removal, however, varied from one treatment to another. SP were capable of producing water with NPDOC less than 4 mg/L, while the average NPDOC of ZN processed water was 7.3 mg/L. ZN did not remove organics as effectively as SP because of the relatively higher coagulation pH (5.5) as compared to SP (pH 4.2-4.5). The measurements of UV-254 and color also showed higher values compared to those of SP process. Iron concentration following filtration was less than 0.1 mg/L in all processes. Average SDI values of the pretreated waters ranged from 3.10 to 3.25, which are higher than SDI values recommended for RO and NF membranes (i.e., < 3).

Table 2: Pretreatment Water Qualities.

System	pH	Turbidity (NTU)	Particles (#/mL)	SDI	NPDOC (mg/L)	UV-254 (cm^{-1})	Color (CPU)
SP	6.77	0.083	162	3.25	3.6	0.066	2
ZN	6.21	0.100	NSD	3.10	7.3	0.183	10

Integrated Membrane System Performance

A summary of the initial and final observation of the operating characteristics of all membranes and pretreatments is shown in Table 3. The feed pressure dropped for all membranes regardless of pretreatment during the period of operation. However, the decrease of feed stream pressure over time was more for SP pretreatment than for the ZN pretreatment in all cases. The gradual increase in water MTC (Kw) over time was observed for all of the fouling resistant membranes, suggesting that the membranes might be degraded by monochloramine oxidation and/or no fouling was experienced during operation. MTC change was slightly higher for the SP pretreatment than the ZN pretreatment.

Table 3: Membrane Operating Characteristics (April 10 to August 9, 2002)

Membrane	Feed Pressure (psi)		Pressure Drop (psi)		Productivity (gsfd/psi)	
	SP	ZN	SP	ZN	SP	ZN
LFC1	75-67	108-88	25-35	28-35	0.20-0.22	0.16-0.18
X20	115-70	115-80	21-28	25-32	0.16-0.22	0.16-0.19
SG	140-80	150-125	40-50	40-50	0.12-0.19	0.11-0.11
BW30FR1	120-70	120-100	20-20	20-20	0.13-0.22	0.12-0.12

Productivity Regression Analysis

In order to determine the critical factors affecting membrane performance, the variations of membrane productivity over time were statistically correlated to pilot feed water quality data through a variety of linear and nonlinear regression analyses. The primary water qualities investigated were particle (*e.g.*, turbidity), organic (*e.g.*, UV_{254}) and monochloramine. The temperature was also included in the regression models. The example of the regression models tested in this study was originated from the basic idea that membrane productivity varies according to cumulative loading of foulants such as particle, organic, and monochloramine:

$$K_w = \theta^{T-25}\left(K_{w25} + X_1F_wt + X_2F_wC_{UVA}t + X_3F_wC_{Turbidity}t + X_4F_wC_{NH_2Cl}t\right)$$

where Xi is appropriate regression coefficients. The linear and nonlinear regression models developed accurately described membrane productivity. The representative result is shown in Figure 1. Temperature was the significant factor for all models and all membranes. All of the models predicted that monochloramine was statistically related to increased membrane productivity over time, indicating oxidative degradation of the membranes.

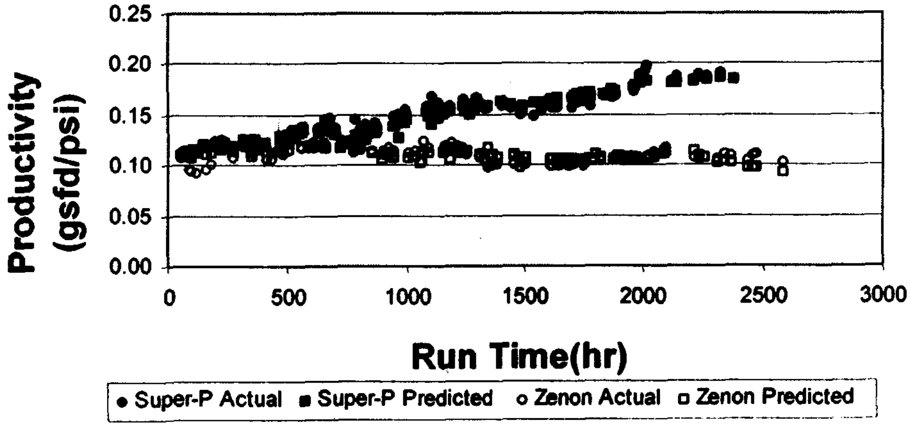

Figure 1: Representative Regression Membrane Productivity Modeling (SG Membrane)

CONCLUSIONS

In this study, commercially available fouling resistant low-pressure RO membranes were investigated for the treatment of seasonally brackish surface water with high organic contents. The results of surface characterization revealed that each of commercial fouling-resistant membranes exhibited one or two unique surface features, which are favorable for minimizing membrane fouling. In the pilot study, all of the four membranes experienced a gradual increase in MTC (water mass transfer coefficient or specific flux) over time, indicating no fouling occurred during the pilot study. The deterioration of permeate water quality such as TDS was also observed over time, suggesting that the integrity of the membranes was compromised by the monochloramine used for biofouling control. The various linear and nonlinear regression analyses utilizing pilot experimental data showed statistically the significance of feed monochloramination on membrane productivity.

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