

Recent Advances for Cost-Effective Membrane Systems

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Introduction

The use of low-pressure membrane systems to produce potable water has become increasingly more common over the last 15 years. Low-pressure membrane filtration consistently provides high quality water regardless of raw water quality. Low-pressure membrane filtration is very effective to remove microbial pathogens such as protozoa, bacteria, and virus. When coupling with traditional pretreatment processes such as coagulation, it is also able to remove a significant amount of disinfection-by-product (DBP) precursors. These technological advantages make low-pressure membrane filtration an excellent treatment option to meet the increasingly stringent drinking water regulations. As a result, the pace of adopting low-pressure membrane filtration in the drinking water industry has been exponential in last decade.

One recent advance in low-pressure membrane filtration is the adoption of the Enhanced Flux Maintenance (EFM) cycle. This is an automatic procedure that is built into the membrane system that can be enabled upon either pre-determined schedule (time, volume of production water, or trans-membrane pressure setting point), or operator's command. By adopting EFM, membrane flux can be increased significantly. As a result, EFM would have significant impact on the capital and O & M costs.

This paper presents three case studies where pretreatment was used to remove DBP precursors. In those studies, the effectiveness of EFM was demonstrated in obtaining higher design fluxes, therefore, lowering project costs. All three case studies were conducted in the Southwest where the reduction of DBP precursors is required for compliance of drinking water standards.

Case Studies

Case A

A utility currently operates a conventional surface water treatment plant and plans to construct a new plant utilizing the same pretreatment followed by a membrane filtration system. A pilot study was conducted to develop design and operating parameters for the membrane system.

The pretreatment system consisted of flocculation followed by settling and preformed well while dosing 150 mg/L of alum on average. The high dose of alum was required due to high Total Organic Carbon (TOC) and alkalinity of the source water. The coagulation was very effective to reduce both turbidity and TOC. As shown in Table 1, raw water turbidity was reduced from over 100 NTU to less than 3 NTU and TOC was decreased from over 20 mg/L to about 2 mg/L.

Table 1. Comparison of Water Quality of Raw and Settled Water

Parameter	Raw Water	Settled Water
Turbidity (NTU)	85 – 320	1.9 – 3.0
pH (Units)		7.0 – 7.4
Total Alkalinity (mg/L as CaCO ₃)	120 – 180	120 – 180
Total Hardness (mg/L as CaCO ₃)	220 – 300	220 – 300
TOC (mg/L)	7 – 20	0.3 – 3.1
Temperature (°C)	16 – 32	16 – 32

The effective pretreatment, coupled with warm water temperatures and the EFM process, allowed high membrane flux rates as shown in Figure 1.

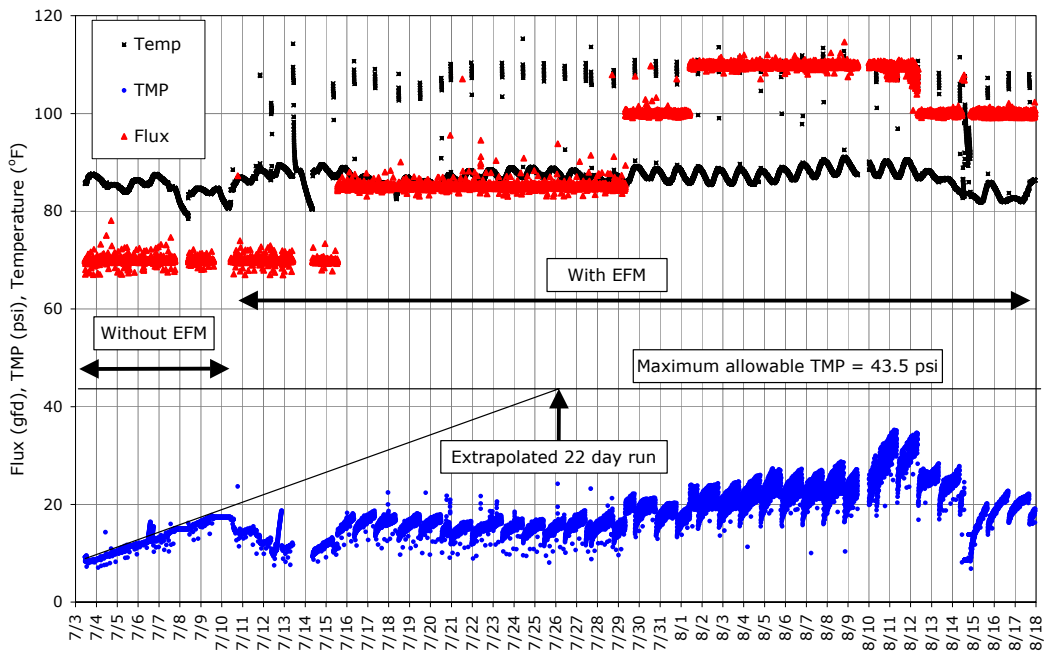


Figure 1. Effect of EFM on Membrane Performance

The pilot was initially operated at a flux of 70 gallons/ft²-day (GFD) without using EFM for 6 days. By extrapolating the slope one can estimate a run time greater than 20 days at these conditions before reaching the maximum allowable TMP of 43.5 psi. At a flux rate of 85 GFD using the EFM process, the overall TMP trend was flat for a period of 14 days, suggesting a run time greater than 30 days was possible. A flux rate of 110 GFD was sustained for a period of 10 days until the maximum capacity of the feed pump was reached. Additional piloting (data not shown) confirmed a cycle greater than 30 days was possible at a flux rate of 87 GFD temperature corrected to 20°C. This represents an increase of 24% in flux with an extended Clean-in-Place (CIP) interval of about 50% more.

Case B

The pilot was conducted with coagulated, settled water from a lake characterized with high alkalinity and moderate to high TOC. The water quality of the source water is presented in Table 2.

Table 2. Water Quality

Parameter (Unit)	Concentration
Turbidity (NTU)	5 – 60
pH (pH Units)	7.3 – 8.4
Total Alkalinity (mg/L as CaCO ₃)	120 - 160
Total Hardness (mg/L as CaCO ₃)	177
TOC (mg/L)	4 - 8
Temperature (°C)	10 - 30

The coagulant dose was optimized based on TOC removal. At the initial stages, 20 mg/L of ferric chloride (FeCl₃) was used for coagulation without pH adjustment of the feed water. In order to get better TOC removals three alternatives were evaluated via a jar test:

1. 20 mg/L of ferric without pH adjustment
2. 20 mg/L of ferric with pH adjustment to 6.5 using hydrochloric acid
3. 50 mg/L of alum with pH adjustment to 6.5 using hydrochloric acid

Based on the jar test, the best TOC removal (40%) and filter performance occurred using 50 mg/L of alum at a pH of 6.5. The result of DOC and TOC removal of three samples under those conditions are presented in Table 3.

Table 3. TOC and DOC Removal at 50 mg/L Alum and pH 6.5 in Case Study B

Raw Water		Settled Water		MF Filtrate		Percent Removal	
DOC	TOC	DOC	TOC	DOC	TOC	DOC	TOC
3.99	4.06	2.62	3.27	2.37	2.45	41%	40%
4.07	3.96	2.54	2.90	2.40	2.32	41%	41%
3.90	3.95	2.72	2.95	2.40	2.42	38%	39%

It is interesting to note that 20% to 29% of TOC was removed by coagulation and settling alone, while an additional 10 to 20% of TOC in the settled water was removed by the membranes.

The membrane performance under various coagulants and pH conditions were evaluated during the pilot test, as illustrated in Figure 2. During the pilot test, EFM was performed daily.

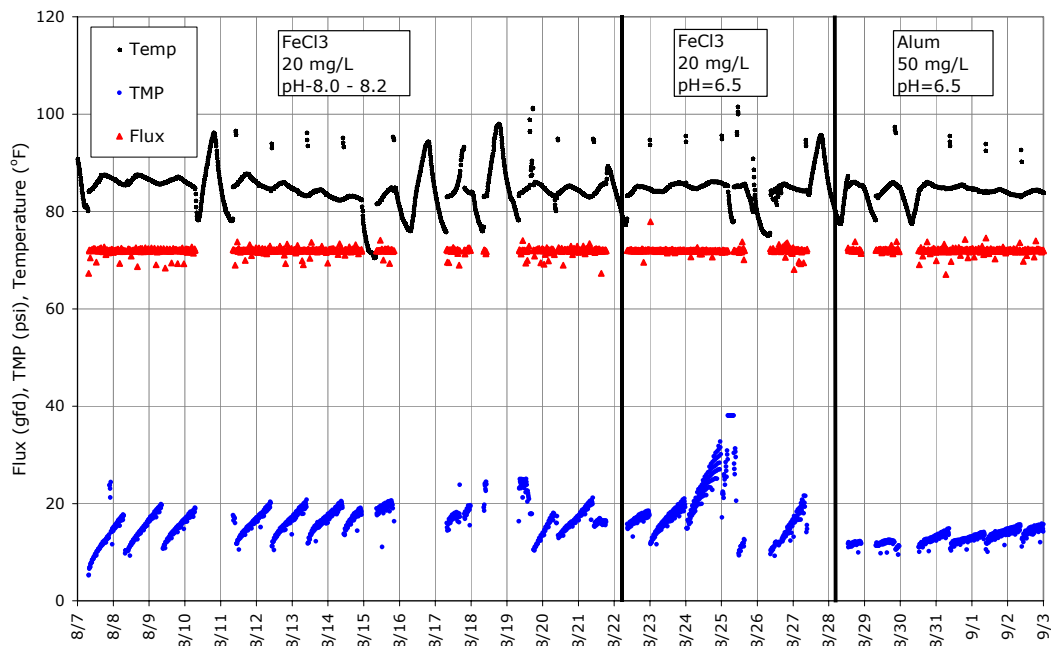


Figure 2. Membrane Performance under different coagulant and pH conditions

Figure 2 indicated that TMP increased rapidly when 20 mg/L of FeCl₃ was used. Reducing pH with acid enhanced the TOC removal, but did not improve membrane performance regarding the rate of TMP increase. Membrane performance was the best when 50 mg/L alum at pH 6.5 was used as coagulation conditions. Based on this pilot study, a design flux of 72 GFD is recommended for lake settled water sources to achieve a 30-day or more clean-in-place (CIP) interval using 50 mg/L of alum as a coagulating agent adjusted to pH 6.5 with hydrochloric acid.

Case C

In Case C, raw water from a lake has moderate to high alkalinity, pH, and hardness, and relatively low turbidity, TOC, and UV absorbency. The water quality of this source water is presented in Table 4.

Table 4. Raw Water Quality in Case Study C

Parameter (Unit)	Concentration
Turbidity (NTU)	0.5 – 6.0
pH (pH Units)	8.0 – 8.4
Total Alkalinity (mg/L as CaCO ₃)	150 – 200
Total Hardness (mg/L as CaCO ₃)	155 – 200
TOC (mg/L)	2.0 – 3.0
UV (cm ⁻¹)	0.031 – 0.059
SUVA (L/mg-m)	1.55 – 2.95
Silica (mg/L as SiO ₂)	9 – 13
TDS (mg/L)	188 – 255
Temperature (°C)	11 – 29

The raw water was continuously dosed with 60 mg/L of ferric sulfate and directly applied to the membrane without settling after a 10-minute retention time in a flocculation tank. The objective was to optimize operating conditions to meet a goal of a 30-day CIP interval without exceeding a terminal TMP of 35 psi.

Two pilot cycles were conducted. The first cycle was run at a flux of 34.8 GFD without EFM. This run reached a terminal TMP of 38 psi on the 30th day of the cycle. A second cycle was conducted with a weekly EFM interval at a flux rate of 34.3 GFD. The TMP after 30 days of run time for the second cycle was only 25 psi. The TMP trend of those two runs are superimposed on Figure 3 in which all TMP values are corrected to the design temperature of 11°C.

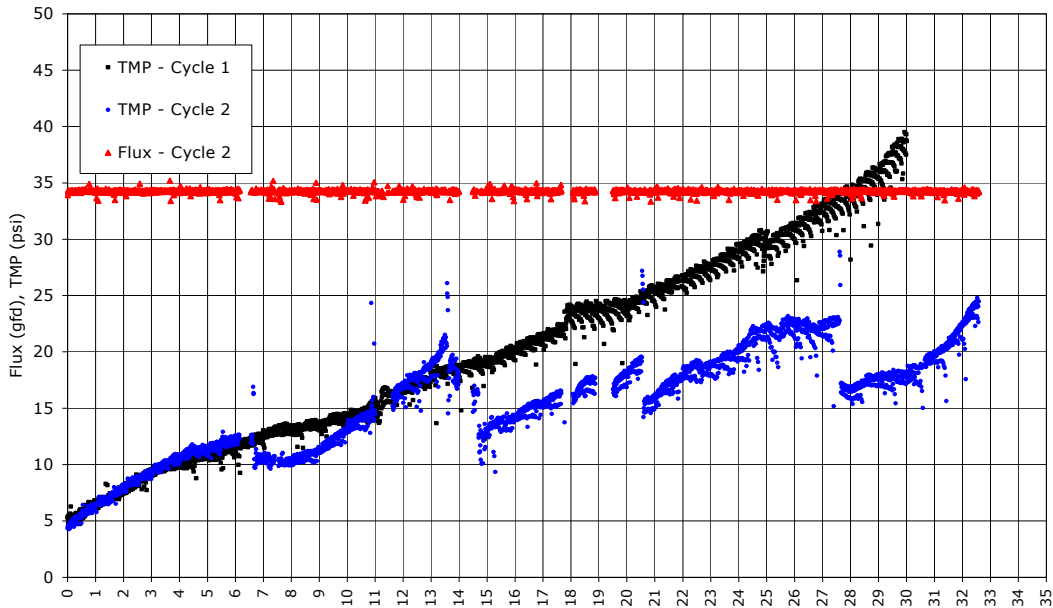


Figure 3. Comparison of the Performance of Runs with and without EFM

Figure 3 shows that the TMP trends in both runs were quite parallel. EFM lowered the TMP after one week from the starting of the second run, and continued each week to lower the TMP. Due to the schedule for the piloting, the second run did not continue after 30 days. However, it is plausible to expect that EFM at a weekly interval can extend CIP interval to well beyond 30 days of design CIP interval. It is also plausible to expect that a considerably higher flux could be achieved if more frequent EFM had been applied.

From the above case studies, EFM greatly enhances process flexibility for both design engineers and operation staff. From the perspective of a design engineer, EFM can increase CIP interval considerably without sacrificing the flux. In addition costs are reduced at higher design flux by decreasing membrane area and plant footprint. From the perspective of plant operating personnel, EFM can be used to handle spikes in raw water quality and manage peak demand, while continuing to supply excellent drinking water quality.

Conclusions

The following conclusions can be drawn based upon the results of these case studies:

1. Low-pressure membrane filtration in conjunction with proper coagulation can effectively remove TOC to the level meeting or exceeding requirements specified in the Enhanced Coagulation Rule.
2. EFM has been a proven technique to increase flux and reduce the capital and O&M costs of low-pressure membrane systems.
3. EFM provides flexibility for both design and operation of low-pressure membrane systems.

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