

ICR Treatment Study Summary Report

Evaluation of Membrane Technology Using the Single Element Bench-Scale Test for Compliance with the Information Collection Rule

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Attachments: 3 diskettes containing the Data Collection Spreadsheets



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SECTION I. CONCLUSIONS AND RECOMMENDATIONS

Recent developments have lead to the development of new, low-pressure nanofiltration (NF) membranes that are capable of removing significant amounts of total organic carbon (TOC) and low molecular weight synthetic organic compounds (SOCs). Such membranes show promise for making NF technologies more affordable. However, in many instances these membranes have shown a high fouling potential and require extensive particle control. To implement NF as a polishing treatment for lime softening to remove disinfection by-product (DBP) precursors and SOCs, greater pretreatment should be investigated prior to NF to control particle fouling. The Interim Enhanced Surface Water Treatment Rule would allow lime softening plants to acidify turbidity samples to account for the turbidity resulting from lime carryover though filtration (*Federal Register*). While such a measure is replicated in pretreating NF feed water (acidifying to control inorganic salt precipitation), the issue of lime carryover may be indicative of a larger problem associated with particle transport through filtration media and should be looked at again, especially with respect to particle fouling and NF.

NF has demonstrated superior water quality with respect to DBP and SOC removal. While blending of NF permeate water with conventionally treated plant water may produce a blended water quality that meets regulatory standards, any disinfection gained through NF will be negated. Blending should be conducted in light of all water quality objectives to produce a finished water that best meets each utilities individual needs.

To implement NF as a polishing treatment in an existing lime softening plant of approximately 84.6 MGD in capacity would likely increase current water prices by approximately 40 percent over the current cost. Such an increase in price would have to be weighed with the benefits received from implementing an advanced treatment process like NF. More research than the information collected during this treatment study needs to be conducted on both optimizing advanced treatment processes and risks associated with treatment objectives to make such a cost benefit analysis.

SECTION II. BACKGROUND INFORMATION

As a Public Water System (PWS) serving between 100,000 and 499,999 people with an average annual TOC exceeding 4 mg/L, Water District No. 1 of Johnson County (WDNo1JC), Kansas elected to conduct Single Element Bench Scale Tests (SEBST), evaluating 4 nanofiltration (NF) membranes over two quarters to meet their Information Collection Rule (ICR) treatment study requirement. WDNo1JC utilizes a softening treatment typical to most PWSs along the Missouri River. The Kansas City Missouri Water Services Department (KCMWSD) is a neighboring PWS (within 20 river miles) which employs a similar treatment to that of WDNo1JC. Consequently, KCMWSD agreed to host Johnson County's ICR treatment study as part of a collaborative research effort funded by the Missouri River Public Water Supplies Association (MRPWSA), the Electrical Power Research Institute (EPRI), and the American Water Works Association Research Foundation (AWWARF).

A schematic diagram representing the treatment processes employed at the KCMWSD is presented in Figure 1. There are six separate treatment trains utilized during the treatment of Missouri River water at the KCMWSD. Water utilized during the ICR treatment study came from Train #2b. No chloramines were added to this train prior to granular filtration. The point at which treatment study influent water was drawn is indicated in Figure 1. Design Plant Parameters and Design Plant Chemical Parameters as reported in the *ICR Water Utility Database System* for each unit process in Figure 1 are listed in Appendix A.

As a source water, the Missouri River may be characterized as a high hardness source with periods of high turbidity and high total organic carbon (TOC) concentrations. As a result of the seasonal spikes in turbidity and TOC, the KCMWSD has corresponding difficulties in meeting proposed delivered water turbidity and total trihalomethane (TTHM) concentrations (0.3 for turbidity and 80/40 µg/L for Stage I/II TTHMs respectively). A summary of source and delivered water quality for the KCMWSD is presented in Table 1. Averages and standard deviations are calculated from daily values over 15 months of daily monitoring data (1998 average values monitored under the ICR are reported in the *Treatment Study Summary Report Spreadsheet*).

Figure 1. Kansas City, Missouri Water Services Dept. plant schematic

Kansas City, MO Water Services
PWS ID # MO1010415
Kansas City Water Treatment Plant
ICR Plant No. 430
Design Capacity 240 MGD

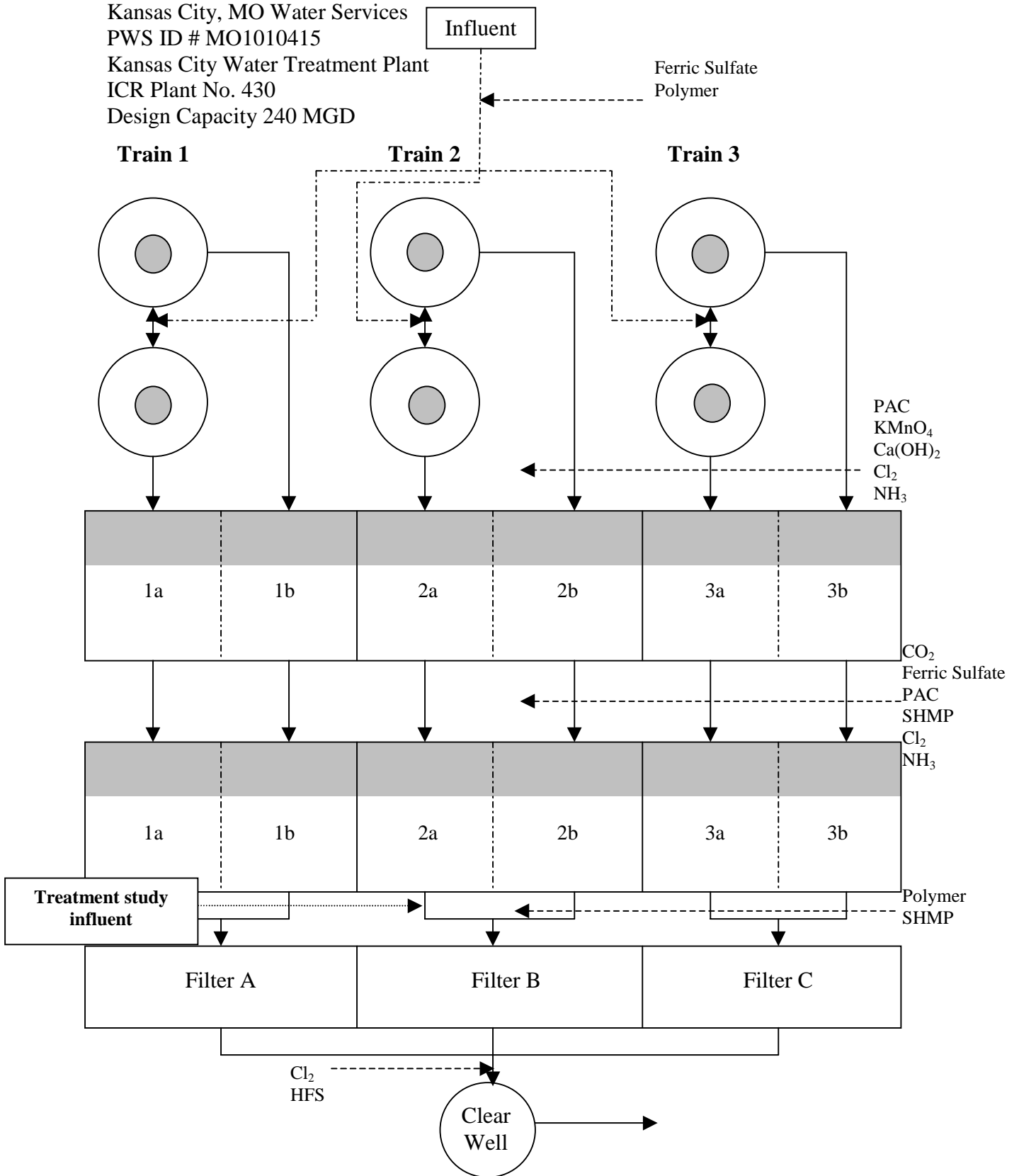


Table 1a. Source water quality

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature (°C)	14.6	9.0	30	-2.1
pH	7.9	0.4	8.8	6.5
Turbidity (ntu)	158.1	360	3950	7
Alkalinity (mg/L as CaCO ₃)	172	22	436	96
Calcium Hardness (mg/L as CaCO ₃)	154	25	255	98
Total Hardness (mg/L as CaCO ₃)	232	27	340	165
TOC (mg/L)	4.4	1.1	11.7	2.5
UV ₂₅₄ (cm ⁻¹)	0.112	0.024	0.200	0.074
Bromide (µg/L)	< 0.1	0.0	0.2	< 0.01

Values taken from 12 months of daily monitoring data (July 1997 – June 1998)

Table 1b. Finished water quality

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature (°C)	15.2	8.4	30	0.6
pH	9.7	0.2	10.5	8.7
Turbidity (ntu)	0.16	0.15	1.23	0.01
Alkalinity (mg/L as CaCO ₃)	50	8	76	26
Calcium Hardness (mg/L as CaCO ₃)	119	22	193	73
Total Hardness (mg/L as CaCO ₃)	142	16	196	103
TOC (mg/L)	2.22	0.23	3.08	1.76
UV ₂₅₄ (cm ⁻¹)	0.008	0.061	0.106	0.038
Bromide (µg/L)	< 0.1	0.0	0.1	< 0.1
Distribution System THM4 (µg/L)	3.3	7.0	25.1	2.5

Values taken from 12 months of daily monitoring data (July 1997 – June 1998)

SECTION III. MATERIALS AND METHODS

The objective of this study was to evaluate four nanofiltration (NF) membranes of varying physical and chemical properties over two quarters (6 months). In accordance with the ICR, these membranes serve as a polishing treatment for an existing lime softening water treatment plant. Membranes were to be judged on their ability to remove disinfection by-product (DBP) precursors as required by the ICR. In addition to ICR requirements, atrazine removal and the ability to operate cost effectively at a low pressure were also evaluated.

PRETREATMENT OF INFLUENT WATER

The purpose of this ICR treatment study was to evaluate the effectiveness of NF as a polishing treatment in an existing water treatment facility for removing DBP precursors and atrazine. To determine the effectiveness of NF as a polishing treatment to an existing process it is important that water treated by NF membranes be subject to the same or a similar pretreatment as that seen in the water utility required to conduct the test.

WDNo1JC and KCMWSD are neighboring PWSs who treat Missouri River water using a lime softening process. With the consent of the Environmental Protection Agency (EPA), Johnson County's ICR testing was conducted on the premises of the KCMWSD water treatment plant. A schematic diagram of all full scale and bench scale processes, including chemical addition points prior to NF is presented in Figure 2. It is important to note that ICR requires no disinfection occur prior to NF to evaluate the ability of NF to remove DBPs. As a result, no chloramines were added to water from treatment train #2b (see Figure 1). Water from treatment trains #2a and #2b are mixed during final (granular) filtration. Since water from treatment train #2a has been exposed to chloramines, ICR treatment study influent had to be drawn prior to granular filtration. Filtration was replicated on the bench scale.

Pretreatment design data for all processes prior to NF are listed in Table 2. Cartridge filtration after granular filtration was deemed necessary due to the fact that spiral wound NF membranes are sensitive to particulate fouling. Acid and scale inhibitors were also injected prior to NF to prevent the precipitation of inorganic salts on a membrane's surface.

Figure 2. Pretreatment to nanofiltration

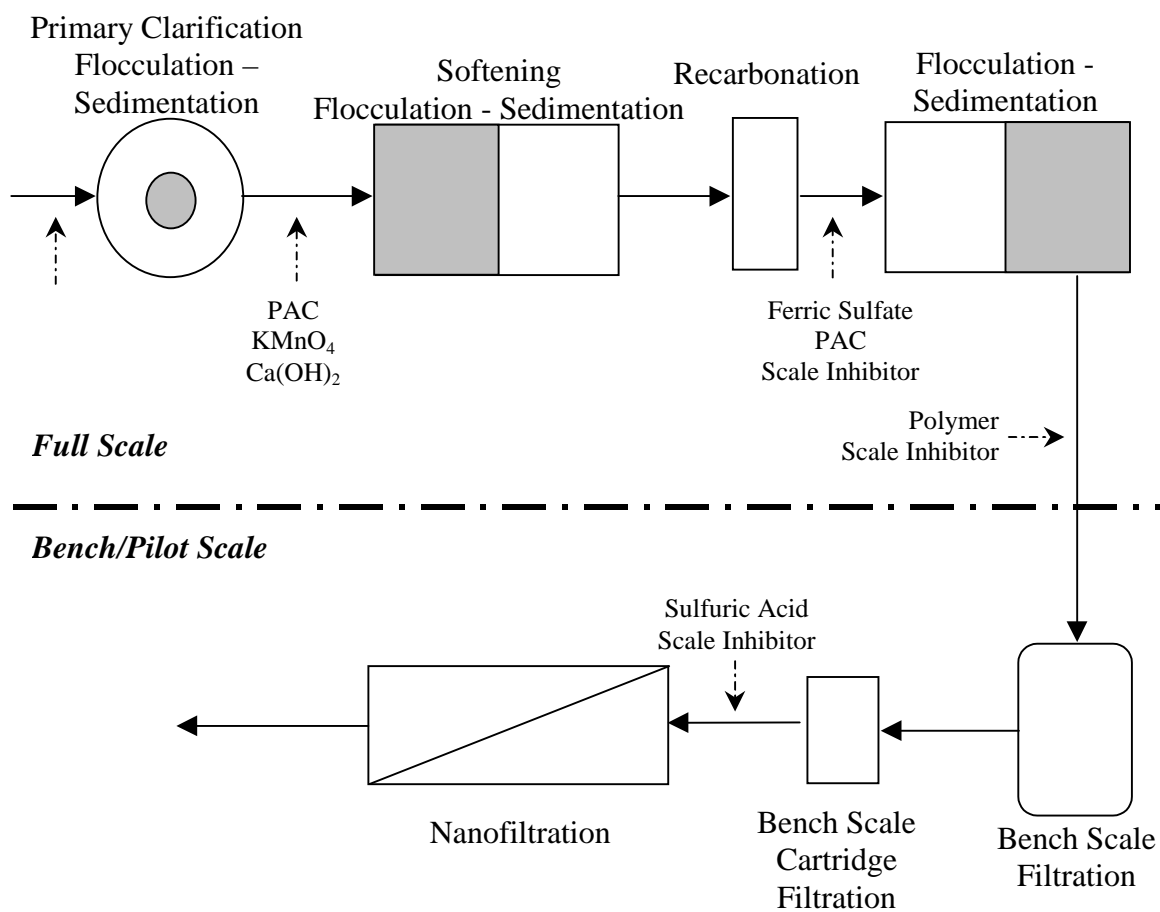


Table 2. Pretreatment design data (Train #2)

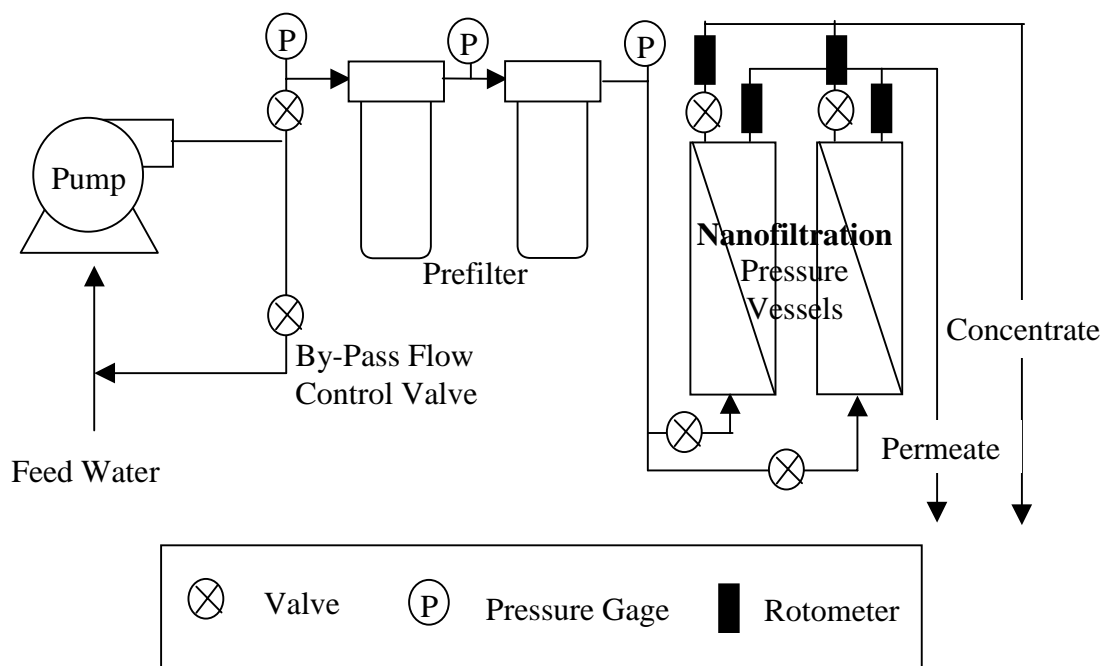
Unit Process	Process Description
Flocculation Basin (Full Scale)	Type of Mixer: Mechanical Liquid Volume (gal): 752,000 Short Circuiting Factor: 0.3 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 28 Stage Liquid Volume (gal): 752,000
Sedimentation (Full Scale)	Surface Area (ft^2): 52,780 Liquid Volume (gal): 9,882,000 Baffling Type: UN Short Circuiting Factor: 0.3
Flocculation Basin (Full Scale)	Type of Mixer: Mechanical Liquid Volume (gal): 1,944,000 Short Circuiting Factor: 0.4 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 71 Stage Liquid Volume (gal): 1,944,000
Sedimentation (Full Scale)	Surface Area (ft^2): 80,600 Liquid Volume (gal): 9,672,000 Baffling Type: UN Short Circuiting Factor: 0.4
Flocculation Basin (Full Scale)	Type of Mixer: Mechanical Liquid Volume (gal): 3,152,000 Short Circuiting Factor: 0.4 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 105 Stage Liquid Volume (gal): 3,152,000
Sedimentation (Full Scale)	Surface Area (ft^2): 30,600 Liquid Volume (gal): 3,777,400 Baffling Type: UN Short Circuiting Factor: 0.4
Filtration (Bench Scale)	Surface Area (ft^2): 1.4 Liquid Volume (gal): 4.6 Total Media Depth (in): 18 Media Type: Sand
Cartridge Filtration (Bench Scale)	Surface Area (ft^2): 0.1 Nominal Pore Size (μm): 5.0 Filter Material: Polypropylene Filter Life (gallons of water processed): 20,000
Single Element Nanofiltration	

PRELIMINARY SELECTION OF CANDIDATE MEMBRANES

Preliminary selection of NF membranes consisted of a literature review followed by rapid bench scale membrane screening tests (RBSMTs). Upon completion of the literature review, nine candidate membranes were identified from four different manufacturers. Table 3 presents a summary of these membranes along with their physical and chemical properties. Membrane manufacturers were then contacted and asked to provide a sample membrane, suitable for RBSMT screening or data that would prove candidacy based on study objectives (i.e. atrazine removal). Eight membrane samples were obtained for RBSMT evaluation, which consisted of monitoring TOC, UV₂₅₄, atrazine, and total dissolved solids (TDS) removal at a normalized flux. Membrane samples used for RBSMT evaluations were 2" x 12" spiral wound modules that fit into pressure vessels rated for 125-psi maximum pressure. Figure 3 presents a schematic of the bench scale apparatus used for RBSMT evaluations.

Table 3. Physical and chemical properties of commercially available NF membranes

Membrane	Average Operating Pressure (psi)	MWCO (Daltons)	Active Layer Composition	Application
<i>Sepa-Osmonics</i>				
ST	400	160-210	Cellulose acetate	Softening
MS	200	100-150	Polyamide	Softening
<i>Purification Products</i>				
B-22-1	100	~ 200	Polyamide	Softening
B-22-9	100	~ 200	Polyamide	Softening
<i>Hydranautics</i>				
NTR-7450	143	10000	Sulfonated polyether sulfone	Organics
NTR-7410	143	6000	Sulfonated polyether sulfone	Organics
PVD1	143	100-300	Polyvinyl alcohol derivative	Softening
ESNA	75	~ 200	Polyamide	Organics-Softening
<i>Dow FilmTec</i>				
NF200B	60	~ 300	Polypiperazine	Micro-pollutants

Figure 3. Rapid bench-scale membrane screening test apparatus

For ICR purposes, the Hydranautics NTR-7450 and NTR-7410 membranes were eliminated from further consideration due to the fact that their molecular weight cut-offs (MWCOs) were greater than 1000 Daltons. However, these membranes were included in the preliminary screening to determine the fractionation of source water NOM and to determine if the membranes' negative surface charge alone was capable of repelling 215.68 Dalton atrazine molecules. In lieu of providing membrane samples, Dow FilmTec provided data which proved candidacy for their membrane. Remaining candidate membranes were either selected or eliminated based on their rejection of TOC and atrazine. To be considered for single element ICR testing, membranes were required to have a minimum of 80% and 60% atrazine and TOC rejection respectively with mass balance errors (Error_{MB}) falling within a range explainable by experimental error. Mass balance error was calculated as follows:

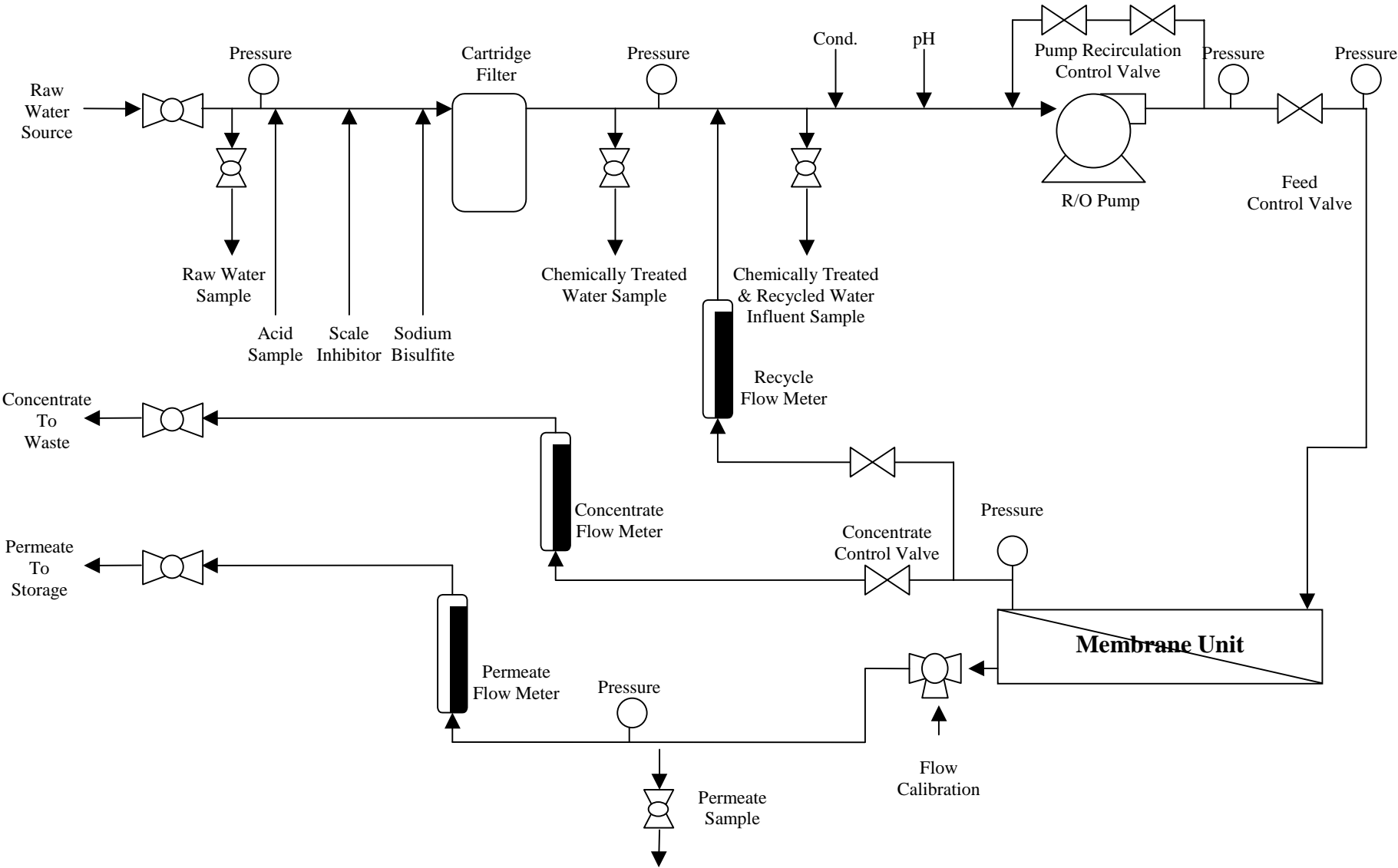
$$C_{\text{C(cal)}} = (C_{\text{F}} - R \times C_{\text{P}}) / (1 - R) \quad \text{Error}_{\text{MB}} = ((C_{\text{C}} - C_{\text{C(cal)}}) / C_{\text{C}}) \times 100\%$$

Where: $C_{\text{C(cal)}}$ is a calculated concentration of a solute based on feed, C_{F} , and permeate, C_{P} , concentrations at the operating recovery, R .

SINGLE ELEMENT BENCH SCALE TESTING

To meet the ICR treatment study requirements for WDN01JC, two single element membrane pilot plants were installed on the premises of the KCMWSD's water treatment facility. Each pilot plant, as illustrated in Figure 4, was capable of housing one 4" x 40" spiral wound membrane element.

Figure 4. Single element bench scale membrane test schematic



SEBST OPERATING PARAMETERS

In variation to the recommended ICR procedure, with the consent of the EPA, four membranes were tested over two quarters. Testing four membranes over two quarters was accepted as an alternative to testing two membranes over four quarters as recommended by the ICR due to the collaboration between WDN01JC and KCMWSD. As part of this joint collaboration, the best performing membrane from two quarters of SEBST evaluation would be chosen for a year long pilot study in fulfillment of KCMWSD's ICR treatment study requirements.

In accordance with the intent of the ICR, each of the four selected membranes were operated for two, thirty-day quarters (60 days per membrane, 240 days total). Daily monitoring of hydraulic parameters, pH and TDS were performed as specified in the *ICR Manual for Bench and Pilot-Scale Treatment Studies*. An overall system recovery of $75\% \pm 5\%$ was also employed. Fluxes were normalized daily to an average temperature representative of the historical average temperature for the testing period. Normalization was achieved by varying the permeate flow based on the following equations:

$$Q_T = Q_{T_{ave}} \times 1.03^{(T - T_{ave})}$$

$$F_{T_{ave}} = Q_{T_{ave}} / A$$

Where: Q_T = permeate flow at ambient temperature T = ambient temperature
 $Q_{T_{ave}}$ = permeate flow at average temperature A = membrane surface area
 T_{ave} = average quarterly temperature $F_{T_{ave}}$ = Flux at average temperature

To design system operating conditions, each selected manufacturer was contacted and asked to provide basic information about their membrane elements. Appendix B lists the physical and chemical properties as reported by the manufacturer for their corresponding membrane elements.

Typically, operating conditions such as flux, recovery, cross flow velocity and pH limit the overall system performance. Membrane manufacturers generally provide a recommendation for standard operating conditions and some computer models, such as *RO DESIGN* by Hydranautics, have been developed to aide in system design. Due to the brevity of this study, most system variables were held constant during both quarters. Fluxes were normalized to 12 gfd at 7°C and 13°C for ICR quarters one and two respectively.

As indicated in Figure 2, NF feed water was subject to bench scale sand and cartridge filtration. In order to control mineral scaling, pH was adjusted to a target value of 6.0 with sulfuric acid. In addition, 4 mg/L of sodium hexametaphosphate (SHMP) or Hypersperse SI 300 (Argo Scientific; San Marcos, California) was added as a scale inhibitor.

Samples were drawn from the SEBST system as prescribed by the ICR. Table 4 provides the sampling matrix for ICR SEBST evaluations. It should be noted that permeate and feed water TDS concentrations were measured online. The TDS feed probe was located improperly by the pilot plant manufacturer for ICR evaluations. As noted in Figure 4, the sample probe has been located within the recirculation loop instead of in the feed stream prior to acid and scale inhibitor addition. Therefore, the TDS concentrations measured were bulk concentrations and not feed concentrations.

Table 4. SEBST sampling matrix

Parameter	Frequency	Location	# of Samples
<i>Hydraulic</i>			
Flow	Daily	P, C, R	124
Pressure	Daily	P, C, I	124
Temperature	Daily	I	124
TDS	Daily	F, P, C	124
pH	Daily	F, P, C	124
<i>Water Quality</i>			
pH	Weekly	F, P, C	20
Total Hardness	Weekly	F, P, C	20
Calcium Hardness	Weekly	F, P, C	20
Alkalinity	Weekly	F, P, C	20
TDS	Weekly	F, P, C	20
Turbidity	Weekly	F, P, C	20
TOC	Weekly	F, P, C	25
UV254	Weekly	F, P, C	25
Bromide	Weekly	F, P	25
SDS-THM4	Weekly	F, P	25
SDS-HAA9	Weekly	F, P	25
SDS-TOX	Weekly	F, P	25
SDS-Chlorine Demand	Weekly	F, P	25
Atrazine	Weekly		

F: Feed
P: Permeate
C: Concentrate
I: Inlet
R: Recycle

The ICR also requires that the effects of seasonal variation on membrane operation be investigated. Since WDN01JC and the KCMWSD are collaborating on this study, the effects of seasonal variation will only be investigated for one membrane chosen for the yearlong pilot study. As the seasons change, run-off conditions to the Missouri River also change, which ultimately impacts the nature of source water natural organic matter (NOM). NOM is a common cause of fouling in membrane operation and the quality of

NOM in surface water at various times of the year may impact system operation and design should fouling be an issue.

MEMBRANE CLEANING

Membranes were considered to require a chemical cleaning when a 15% increase in pressure or productivity (MTC_w) decline was observed or when permeate water quality (TDS rejection) decayed by more than 15%. Typical foulants that hinder membrane production, making cleaning necessary include sparingly soluble materials such as: calcium carbonate scale, calcium sulfate scale, metal oxides, silica and organic or biological deposits.

Cleaning procedures recommended by most manufacturers require either an acid or alkaline cleaning solution based on the nature of fouling and the observed symptoms of said fouling. Appendix C lists a recommended cleaning procedure as provided by Hydranautics for various types of fouling conditions categorized by symptoms and cleaning action(s) required. It is important to note that all the membranes used during this study were considered sensitive to chlorine. Under no circumstances were any of the membranes exposed to chlorine during cleaning conducted as part of this treatment study.

ATRAZINE CHALLENGES

Technical grade atrazine was acquired from Novartis Crop Protection (Greensboro, North Carolina). NF membranes were challenged with atrazine on a quarterly basis. A stock solution of atrazine was prepared and injected into the feed water via a metering pump to produce a feed water concentration of approximately 6-10 $\mu\text{g/L}$.

ANALYTICAL METHODS

Analytical methods employed during this ICR study, listed in Table 7, were performed by the Kansas City Missouri Water Services Laboratory and Carollo Engineers. Analytical protocols required by the *DBP/ICR Analytical Methods Manual* were followed. The Kansas City Missouri Water Services Laboratory is a certified laboratory for ICR analysis.

Minimum reporting levels (MRLs) are also reported in Table 5. The MRL for total organic carbon (TOC) was determined on a weekly basis by the Kansas City Missouri Water Services Laboratory. In the case of TOC, the MRL was equal to twice the minimum detection level. A low level calibration check standard equal to the determined MRL was prepared and analyzed immediately following to instrument calibration. A relative percent difference (RPD) was calculated after two injections of the low-level calibration check standard. TOC analysis would only proceed once an $RPD \leq 10\%$ was achieved.

Table 5. Analytical methods and minimum reporting levels

Analyte	Method	Minimum Reporting Level
Alkalinity	2320 B	5 mg/L as CaCO ₃
Ammonia	EPA 350.1	0.03 mg/L
Bromide	EPA 300.0	10 µg/L
Calcium Hardness	3120 B	0.16 mg/L as CaCO ₃
Chlorine Residual	4500-Cl G	0.5 mg Cl as Cl ₂ /L
DCAA, TCAA, MBAA, DBAA, BCAA, BDCAA*, CDBAA*, TBAA*	6251 B	1 µg/L
MCAA	6251 B	2 µg/L
pH ^{JCE}	4500-H ⁺ B	Not Applicable
TDS ^{JCE}	2510 B	1 mg/L
Temperature ^{JCE}	2550 B	Not Applicable
THM4	EPA 502.2	1 µg/L
Total Hardness	5710 C	0.65 mg/L as CaCO ₃
TOC	5310 B	0.2 mg/L
TOX	5320 B	25 µg Cl ⁻ /L
Turbidity ^{JCE}	2130 B	0.05 ntu
UV ₂₅₄	5910	0.009 cm ⁻¹
Atrazine*	EPA 505	0.05 µg/L

^{JCE} Analyses performed by John Carollo Engineers staff

* Not required by the ICR

SDS testing, DBP and water quality analyses was performed in accordance with ICR procedures and only reagent grade chemicals were used.⁹ To ensure that residual concentrations of free chlorine were met after 48 hours of incubation, multiple samples were chlorinated at varying TOC:Cl₂ ratios. A summary of SDS conditions employed is listed in Table 6.

Table 6. SDS incubation conditions

Incubation Conditions	SEBST Quarter #1	SEBST Quarter #2
Time (hours)	48	48
pH	7.0	7.0
Temperature (°C)	7	13
Free Cl ₂ Residual (mg/L)	0.5 – 1.0	0.5 – 1.0

Optional haloacetic acids (HAAs), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA) and tribromoacetic acid (TBAA) were analyzed in addition to the six required haloacetic acids. The DBP/ICR analytical methods require that the optional HAAs be analyzed using EPA method 552.2 and MRLs be set at 1, 2 and 4 µg/L for DBCAA, CDBAA and TBAA respectively. However, *Standard Method 6251B* was used to analyze these compounds and a single standard of 10 µg/L was used for calibration. Regardless, these compounds have been included in the Treatment Studies Spreadsheets and MRLs have been set at 1 µg/L.

SECTION IV: RESULTS AND DISCUSSION

FEED WATER QUALITY

Table 7 summarizes the feed water used for bench scale and single element membrane evaluations. Average values and standard deviations of water quality constituents monitored during ICR SEBSTs are listed for each quarter of testing. Alkalinity and pH values represent an aggressive water, which is necessary to prevent fouling of inorganic salts on NF membranes. Although PAC was added on the full scale, primarily as a measure for removing SOC's, and taste and odor causing compounds, proposed stage II MCLs for THM4 and HAA5 were exceeded on the average during the second quarter of single element testing. This would indicate the need for an advanced treatment process such as NF.

Feed water used for bench scale and single element scale NF was subject to pilot scale sand and cartridge filtration. Filtered feed water may be characterized as having a turbidity less than 1 ntu and a Silt Density Index (SDI) ranging from 3 to 5. Due to the relatively high SDI, particle fouling was expected to be an issue.

Table 7. ICR Treatment Study Feed Water Quality

Water Quality Parameter	January – April Average (SD)	April – July Average (SD)
Temperature (°C)	10.1 (3.5)	20.5 (4.6)
pH	6.9 (1.0)	6.7 (0.9)
Turbidity (ntu)	1.5 (0.8)	0.8 (0.7)
Alkalinity (mg/L as CaCO ₃)	23.5 (8.4)	28.0 (15.9)
Calcium Hardness (mg/L as CaCO ₃)	149.5 (40.9)	157.3 (27.0)
Total Hardness (mg/L as CaCO ₃)	195.1 (43.7)	172.5 (26.5)
Bromide (µg/L)	74.3 (30.1)	77.8 (14.4)
TOC (mg/L)	2.3 (0.4)	2.6 (0.9)
UV ₂₅₄ (cm ⁻¹)	0.07 (0.1)	0.06 (0.0)
SDS-THM4 (µg/L)	14.8 (11.0)	43.1 (3.9)
SDS-HAA5 (µg/L)	9.6 (6.0)	27.5 (10.8)
SDS-HAA6 (µg/L)	12.0 (7.8)	33.3 (11.9)
SDS-TOX (µg Cl ⁻ /L)	78.1 (29.8)	123.1 (14.0)
SDS-Chlorine Demand (mg/L)	2.0 (0.4)	2.2 (0.2)

Historical Missouri River atrazine concentrations are presented as an exceedance diagram, Figure 5. As indicated, the maximum contaminant level (MCL) for atrazine is exceeded 10% of the time. Typically atrazine concentrations are highest during the spring due to run-off from agricultural lands which surround the Missouri River basin. Atrazine challenges to the SEBST systems were performed to mimic the concentrations seen in the Missouri River with feed water concentrations ranging from 6 – 10 µg/L.

PRELIMINARY MEMBRANE SCREENING

Candidate membranes were screened on the bench-scale to determine which membranes would best meet study objectives. Pre-screening consisted of RBSMT evaluations of eight membranes for TOC, UV₂₅₄, atrazine, and TDS removal. The results of these evaluations and the recoveries employed during prescreening are presented in Table 8. Due to bench-scale system limitations, recoveries were limited to those achievable through single pass operation.

Table 8. Results of RBSMT evaluation on candidate membranes

Membrane	Recovery	TOC Rejection	UV ₂₅₄ Rejection	Atrazine Rejection	TDS Rejection
<i>Sepa</i>					
ST	13%	64%	69%	35%	93%
MS	30%	81%	73%	98%	90%
<i>Purification Products</i>					
B-22-9	80%	45%	14%	47%	4%
B-22-1	70%	77%	70%	81%	81%
<i>Hydranautics</i>					
NTR-7450	33%	17%	67%	4%	32%
NTR-7410	77%	7%	4%	9%	0%
PVD1	32%	57%	96%	92%	82%
ESNA	26%	63%	92%	96%	90%

During prescreening of candidate membranes, mass balance calculations for water quality constituents were conducted to ensure the soundness of experimental data and also to ensure that atrazine removal was the product of rejection and not adsorption to the membrane. Table 9 lists the rejection of atrazine with corresponding errors in mass balance for membranes screened using the RBSMT.

Figure 5

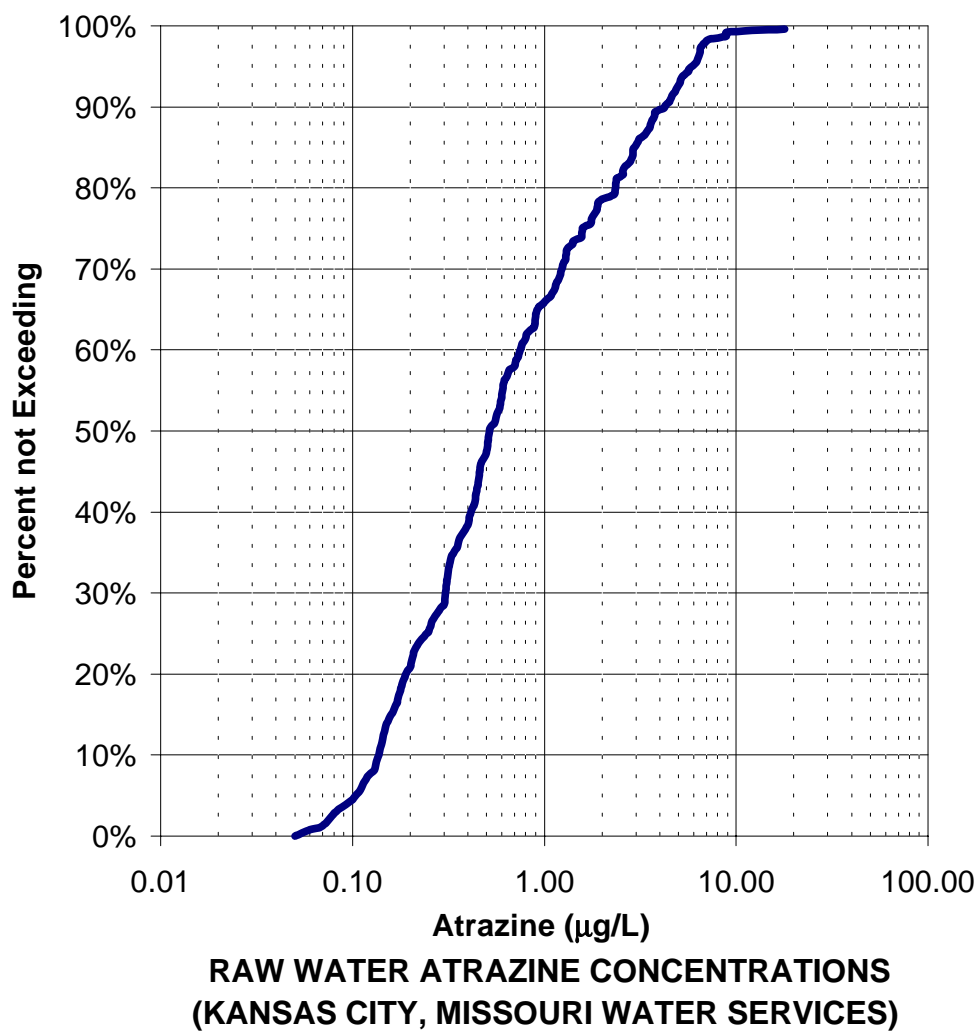


Table 9. Atrazine rejection

Membrane	Scale of Test	Atrazine Observed Rejection	Error _{MB}
Sepa ST	RBSMT	35%	-17 %
Sepa MS	RBSMT	98%	-2 %
B-22-1	RBSMT	81%	8%
B-22-9	RBSMT	47%	- 410%
NTR-7450	RBSMT	4%	- 41%
NTR-7410	RBSMT	9%	-1 %
PVD1	RBSMT	92%	- 43%
ESNA	RBSMT	96%	- 2%

Feed Concentrations 4-6 µg/L

Note: A negative Error_{MB} may indicate adsorption to the membrane

Candidate membranes screened using the RBSMT may be separated into three categories based on the Error_{MB} associated with their respective atrazine rejections. The first category may be described as those membranes having an Error_{MB} $\pm 10\%$, which may be attributed to experimental error. A second category, those membranes with an Error_{MB} between - 10% and - 50% may be characterized as those membranes that may exhibit atrazine removal through adsorption of atrazine on the membrane surface. The third category of membrane, those membranes with an Error_{MB} lower than - 50%, are membranes who adsorb atrazine. Extended operation of category two and three membranes would likely show an increase in atrazine concentrations in the permeate stream over time.

Based on study objectives (80% atrazine and 60% TOC removal respectively), taking the pre-selection Error_{MB} of atrazine for each membrane into account, the Sepa MS, Purification Products B-22-1, and the Hydranautics ESNA membranes were selected for SEBST evaluation. The Dow FilmTec NF200B was also selected based on data that the manufacturer provided which indicated that this membrane would also meet study objectives.

SINGLE ELEMENT PILOT TESTING

Permeate Water Quality

Permeate water from NF membranes may be characterized as high purity water, low in organic carbon, alkalinity and mineral content. A summary of NF permeate water collected as part of ICR SEBST evaluations is presented in Table 10. Values of water quality parameters listed in Table 10 are the average weekly values from 4 weeks of ICR testing. Of the four membranes tested, average permeate TDS concentrations ranged from 4.1 mg/L for the Sepa MS to 195.9 mg/L for the NF200B. Having the highest quarterly average permeate hardness concentrations, the NF200B membrane appears to have the lowest rejection of divalent cations such as calcium and magnesium. The B-221

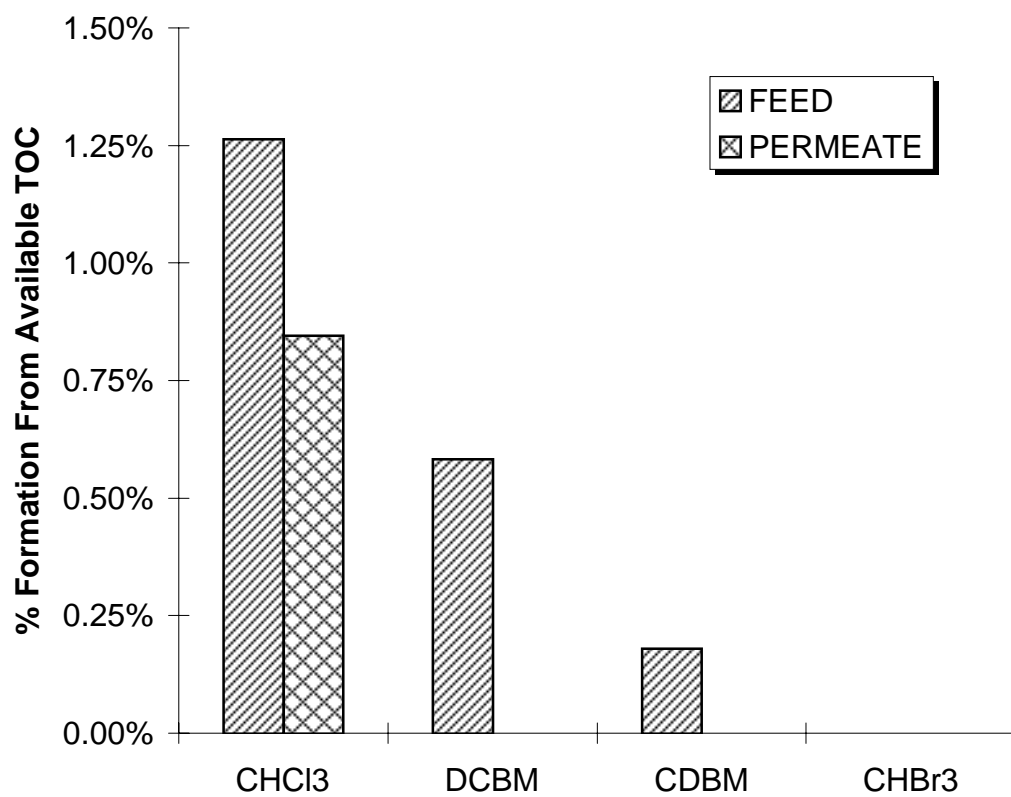
and ESNA had similar concentrations of alkalinity and TDS in their permeate waters. Trends in average permeate alkalinity concentrations mirror TDS concentrations while bromide concentrations were frequently reduced to below detection levels for all membranes tested.

The application of traditional NF and RO membranes has been limited in the past due to high operating pressures and the need for post treatment of permeate water for remineralization and LSI adjustment. Low alkaline, low pH waters have been characteristic of NF permeate waters. The future of NF lies in the development of membranes that may operate at low pressures while rejecting fewer inorganic constituents. This puts membranes like the ESNA and the NF200B on the cutting edge of NF due to the reduced rejection of inorganics while rejecting significant amounts of organics (i.e. TOC).

Observed rejections of atrazine for SEBST evaluations of the B-22-1 and ESNA membranes were relatively lower than the rejections observed during the RBSMT, 64% and 84% respectively. It should be noted that recoveries employed during the RBSMT were lower than the 75% recovery employed during the SEBST due to system limitations. As recovery increases, at a constant feed water concentration of atrazine, the bulk concentration of atrazine would increase likewise. With a greater concentration of atrazine in the bulk stream, the driving force for atrazine mass transfer would be greater, thereby forcing more atrazine to the permeate stream and ultimately producing a lower observed rejection. Rejection of atrazine for the Sepa MS membrane remained superior at close to 100% rejection (permeate concentrations of atrazine were below detection). The NF200B membrane rejected only 50% of feed water atrazine, which is lower than rejections observed by other researchers (Ventresque, 1997). Source water chemistry as well as membrane chemistry has been noted to effect the rejection of atrazine from NF membranes and it is likely that the solution chemistry softened Missouri River water played a role in this discrepancy (Devitt et. Al., 1998).

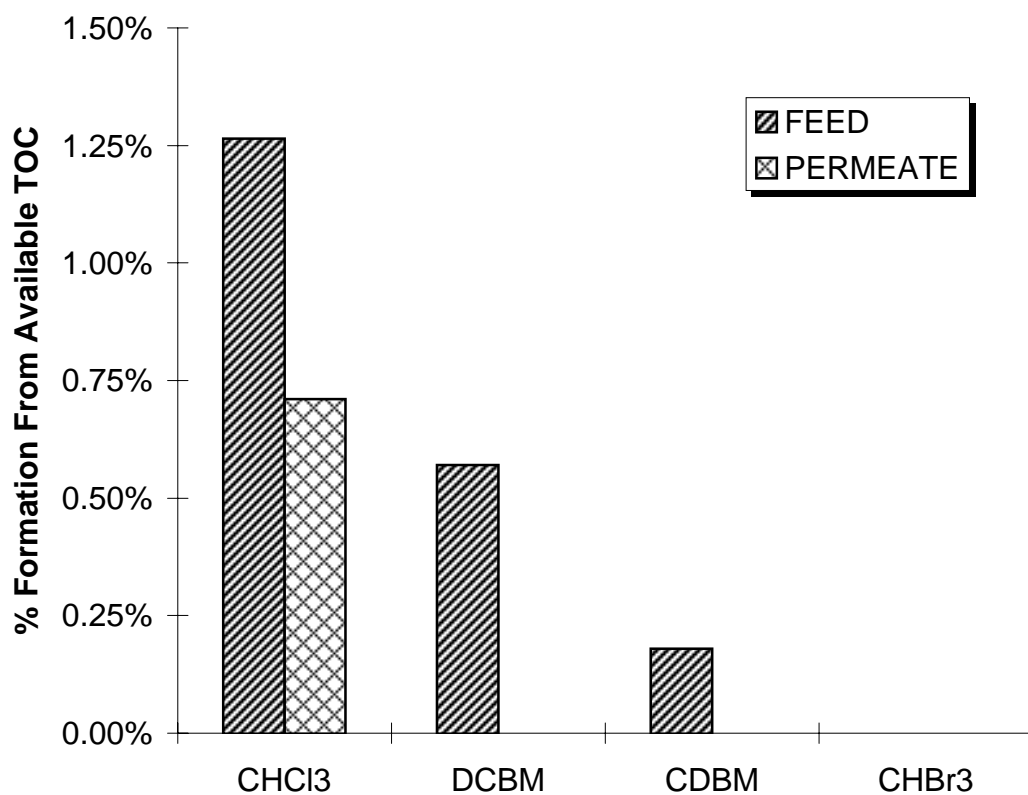
The need for remineralization and treatability of concentrate are limitations to the implementation of NF on the full scale. A membrane that may pass sufficient amount of inorganics while rejecting a maximum amount of organics represents the future of nanofiltration. However, inorganic compounds that may pass such a membrane will likely include bromide. Ultimately, any organics passing which are precursors to DBP formation would subject to form a greater percentage of brominated DBPs since the bromide to TOC ratio would increase and brominated DBP formation is favored kinetically to chlorinated DBP formation. Figures 6 – 9 present the percent DBP yield from available TOC in feed and permeate waters during this study. There is a marked increase in brominated DBP yield in the permeate water from the NF200B (Figure 9) which, as discussed passed the most significant concentration of TDS and hardness during both quarters of SEBST evaluation. Examination of permeate THM yield from other membranes does not indicate this shift toward brominated DBP formation.

Figure 6



**Percent Trihalomethane Formation From
Available TOC
Osmonics Sepa MS
Quarter #2: SDS48_{Hr}, pH = 7.2, 13°C**

Figure 7

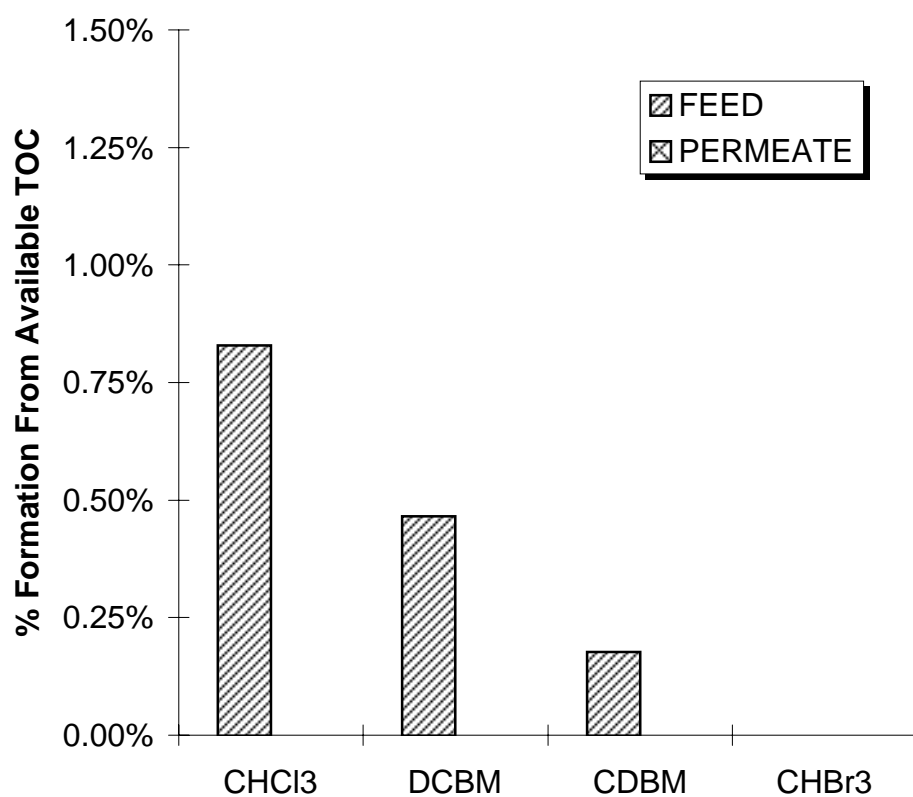


**Percent Trihalomethane Formation From
Available TOC**

Purification Products B-22-1

Quarter #2: SDS48_{Hr}, pH = 7.2, 13°C

Figure 8

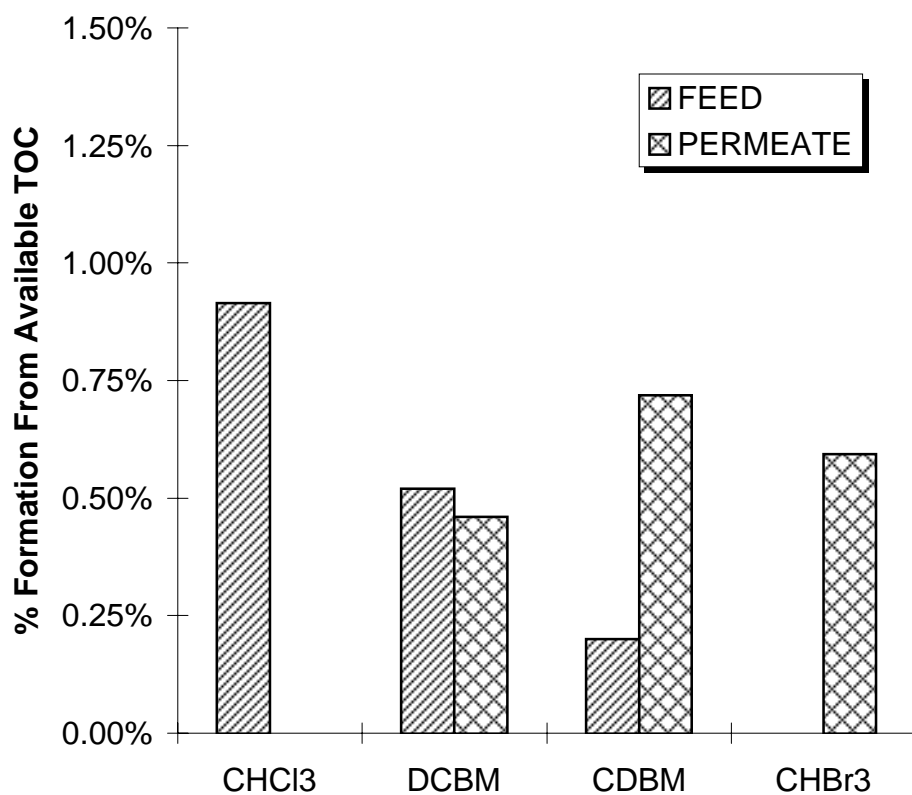


**Percent Trihalomethane Formation From
Available TOC**

Hydranautics ESNA

Quarter #2: SDS48_{Hr}, pH = 7.2, 13°C

Figure 9



**Percent Trihalomethane Formation From
Available TOC**

FilmTec NF200B

Quarter #2: SDS48_{Hr}, pH = 7.2, 13°C

Table 10. ICR Treatment Study Permeate Water Quality

Water Quality Parameter	Sepa MS Quarter 1 Ave (SD)	Sepa MS Quarter 2 Ave (SD)	B-22-1 Quarter 1 Ave (SD)	B-22-1 Quarter 2 Ave (SD)	ESNA Quarter 1 Ave (SD)	ESNA Quarter 2 Ave (SD)	NF200B Quarter 1 Ave (SD)	NF200B Quarter 2 Ave (SD)
TDS (mg/L)	4.1 (1.7)	11.9 (1.4)	95.8 (31.4)	52.1 (15.6)	34.8 (17.3)	70.3 (7.8)	75.0 (53.4)	195.9 (30)
pH	7.3 (1.1)	6.3 (0.4)	6.4 (0.4)	6.6 (0.7)	6.4 (0.2)	7.0 (0.6)	7.7 (1.2)	5.9 (0.7)
Alkalinity (mg/L as CaCO ₃)	5.0*	5.0*	10.0 (1.0)	8.8 (3.0)	8.9 (1.5)	9.0 (1.6)	11.8 (5.9)	34.0 (15.8)
Calcium Hardness (mg/L as CaCO ₃)	4.0*	1.9 (2.1)	12.2 (11.5)	8.0 (4.6)	2.8 (1.1)	3.0 (0.9)	19.8 (12.3)	53.9 (24.9)
Total Hardness (mg/L as CaCO ₃)	6.9*	1.9 (2.1)	15.2 (13.8)	8.6 (5.0)	3.3 (1.7)	3.2 (1.2)	28.5 (17.8)	58.6 (23.5)
Bromide (µg/L)	BMRL	BMRL	85.0 (21.1)	50*	60*	BMRL	78.8 (16.5)	BMRL
TOC (mg/L)	0.4 (0.1)	0.3 (0.1)	0.4 (0.1)	0.4 (0.2)	0.3 (0.2)	0.4 (0.1)	0.5 (0.1)	0.8 (0.2)
UV ₂₅₄ (cm ⁻¹)	0.02 (0)	0.2 (0)	0.02 (0)	0.02 (0)	0.02 (0)	0.02 (0)	0.2 (0)	0.03 (0)
SDS-THM4 (µg/L)	3.4 (6.4)	2.7 (0.5)	18.1 (14.3)	4.8 (1.9)	2.6 (0)	3.2 (0.6)	1.4 (1.6)	15.7 (7.9)
SDS-HAA5 (µg/L)	4.9 (6.3)	5.5 (1.8)	15.3 (8.0)	3.9 (1.1)	2.1 (0.1)	1.7 (0.5)	1.6 (0.2)	4.8 (1.9)
SDS-TOX (µg Cl ⁻ /L)	BMRL	BMRL	32.0*	25.0* (5.9)	BMRL	BMRL	BMRL	25*
SDS-Chlorine Demand (mg/L)	0.3 (0.1)	0.4 (0.1)	0.7 (0.2)	0.6 (0.1)	0.5 (0.3)	0.6 (0.1)	0.5 (0.3)	0.8 (0.1)

* All but one week (which is reported) was below detection

BMRL = Below minimum reporting level

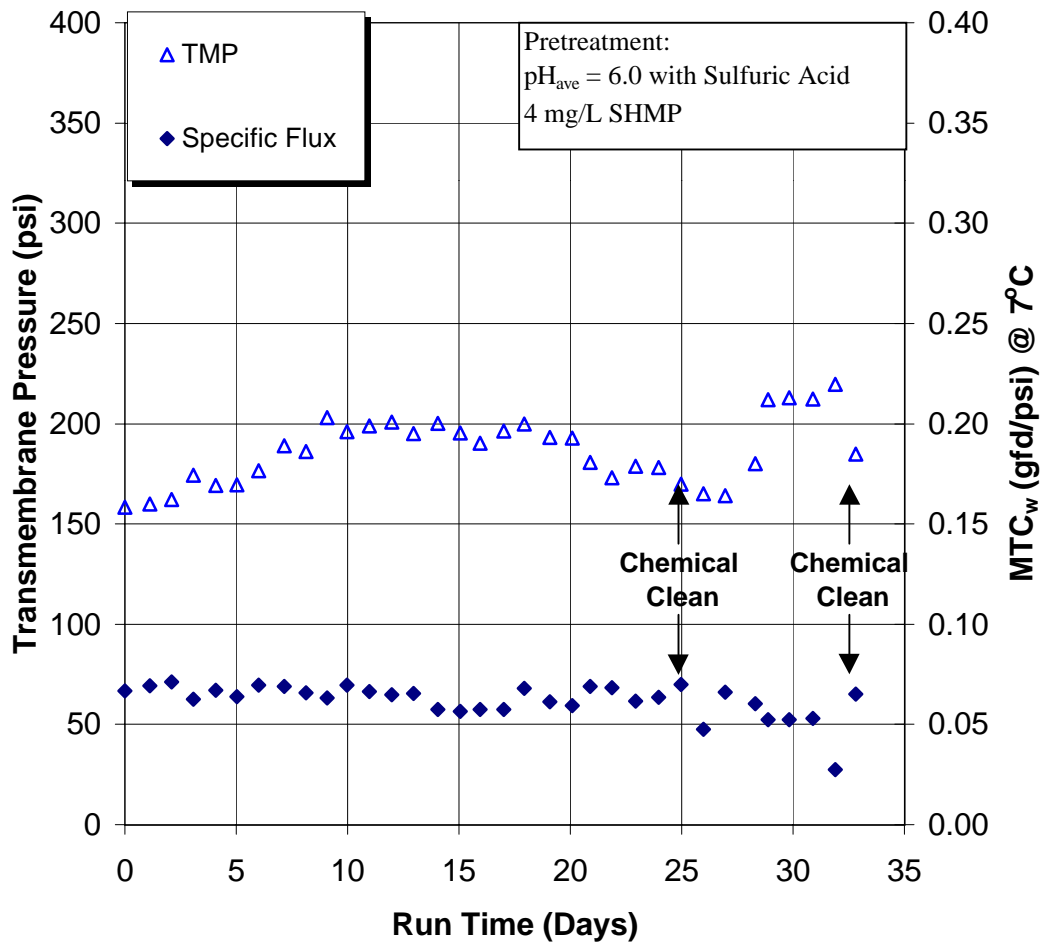
Membrane Productivity

Membrane productivity is referred to as the mass transfer coefficient of water (MTC_w) by the ICR, but is more commonly called specific flux. A membrane's MTC_w is expressed as volume of water produced per unit area of membrane surface per unit time per unit of applied pressure (gfd/psi or L/hr.m².bar). MTC_w is a measure of how productive a membrane may be through the application of pressure. To achieve an equal production, a membrane with a low MTC_w would require either more pressure or more membrane surface area. Either may result in a greater capital or operating cost. Thus, the examination of MTC_w decline (gfd/psi/day) during a pilot study is an important element in cost analyses.

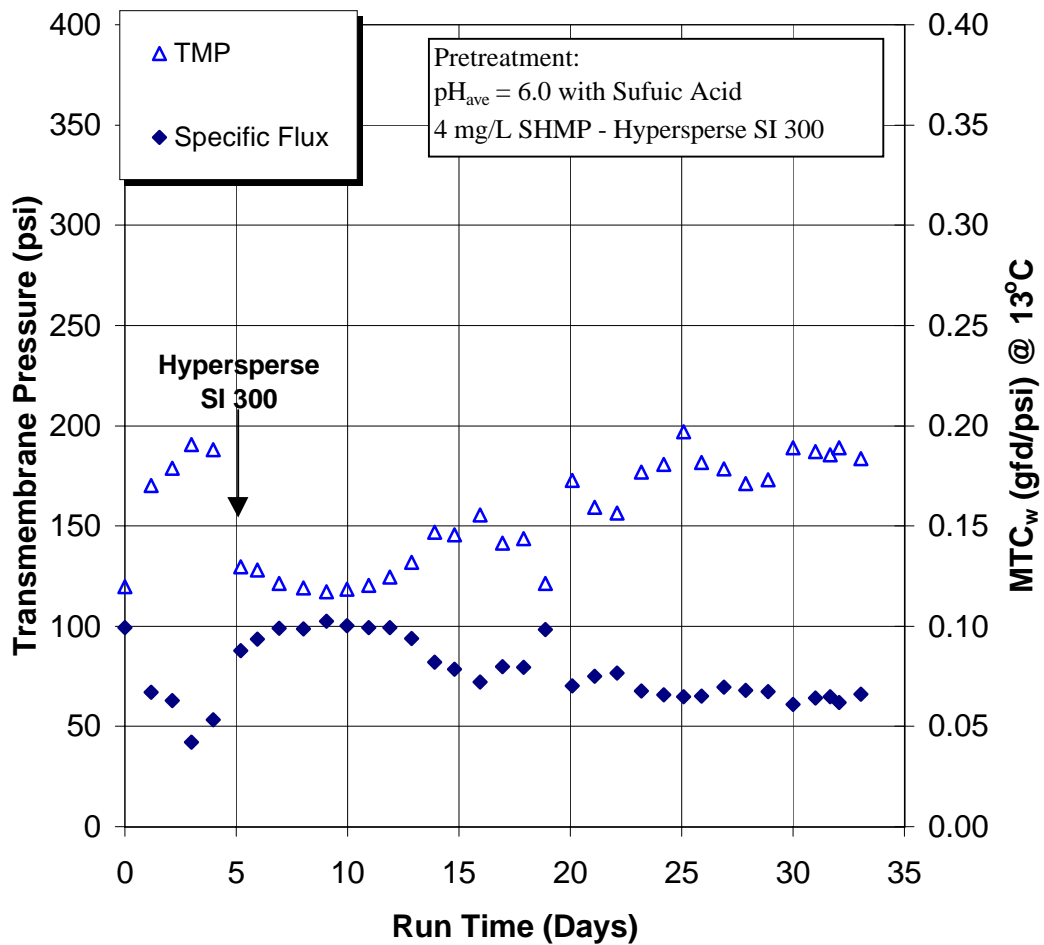
To satisfy the requirements of the ICR, each of the four membranes selected for SEBST evaluation were operated for two, 30-day quarters. Figures 10 – 17 present the results of daily hydraulic monitoring for each quarter of SEBST evaluation. As required by the ICR, each SEBST was operated at a recovery of 75%. Cleaning events are indicated on each graph. A detailed summary of SEBST operation is provided in Appendix D.

Figures 10 and 11 present the results of operating the Sepa MS membrane. This membrane is characterized by a high operating pressure, as noted in Table 3, operating at approximately 150 psi. During the first quarter of evaluation, the transmembrane pressure (TMP) increased steadily over the first ten days of operation to reach 200 psi after which it stabilized for the following ten days. A chemical clean was performed at day 24 due to a breakthrough of PAC from the pilot scale sand and cartridge filters. PAC breakthrough continued plagued operation during the last 7 days of operation as noted with a sharp increase in TMP to 225 psi. During the second quarter of Sepa MS evaluation, the first 5 days of operation saw a steady increase in TMP. This increase was attributed to inorganic deposits on the membrane brought on by the rapid hydrolysis of SHMP to ortho-phosphate. SHMP hydrolysis was enhanced by an increase in seasonal temperatures. As a result, scale inhibitor was switched from SHMP to Hypersperse SI 300 as noted in Figure 5. TMP increased steadily during the second quarter of Sepa MS operation and the test was terminated with a TMP of 190 psi.

Two issues arose during the operation of the B-22-1 membrane that are noteworthy. During the first quarter of testing (Figure 12) the MTC_w rapidly decreased and operation stabilized at an unexpectedly high transmembrane pressure (TMP) upon initial operation. This TMP was much higher than that reported by the manufacturer (Table 3) and that seen during bench-scale pre-screening. This rapid increase in TMP was mistaken for compaction of the membrane's porous matrix and the B-22-1 was operated at this high TMP throughout the first quarter. Due to this high operating pressure, a recovery of 75% could not be maintained and a lower flux (12 L/hr.m²) was required for operation. Prior to storage, this membrane was cleaned (caustic followed by acid wash) and the second quarter of B-22-1 operation (Figure 13) yielded a TMP of 45 psi. Due to recovery in TMP and MTC_w , it is assumed that this membrane experienced some form of rapid fouling which was either biological or inorganic in nature during the first day of operation during quarter number one.

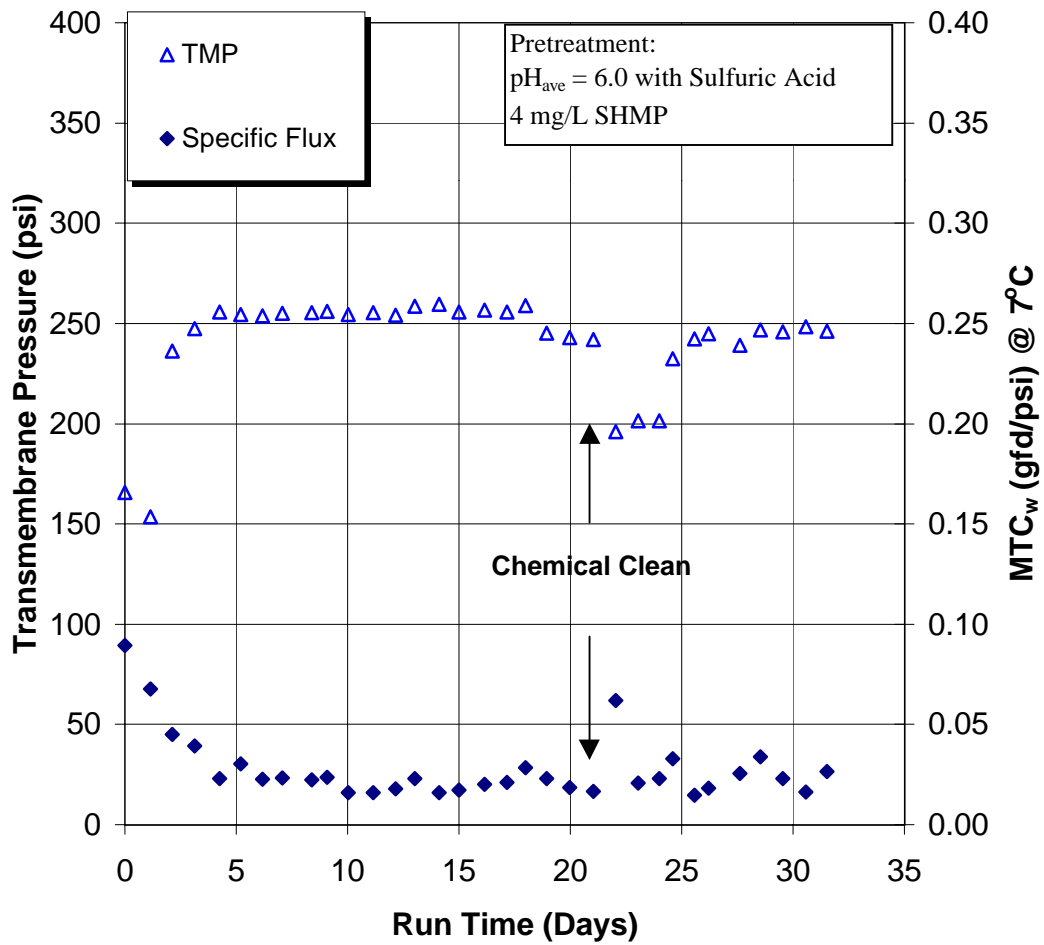


**SEPA MS (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #1
At 12 gfd @ 7 °C, 75% Recovery**



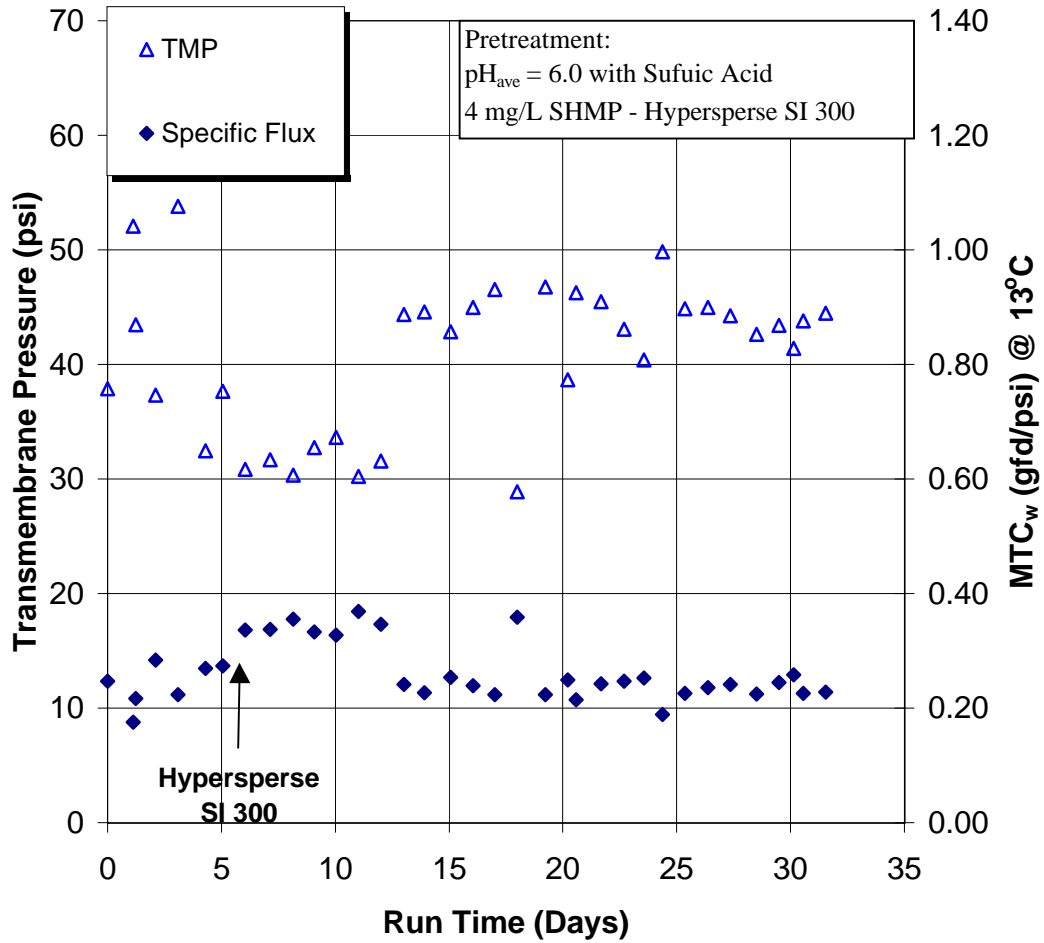
**Sepa MS (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #2
At 13.5 gfd @ 13 °C, 75% Recovery**

Figure 12



**PPC B-22-1 (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #1
At 7 gfd @ 7 °C, 55% Recovery**

Figure 13



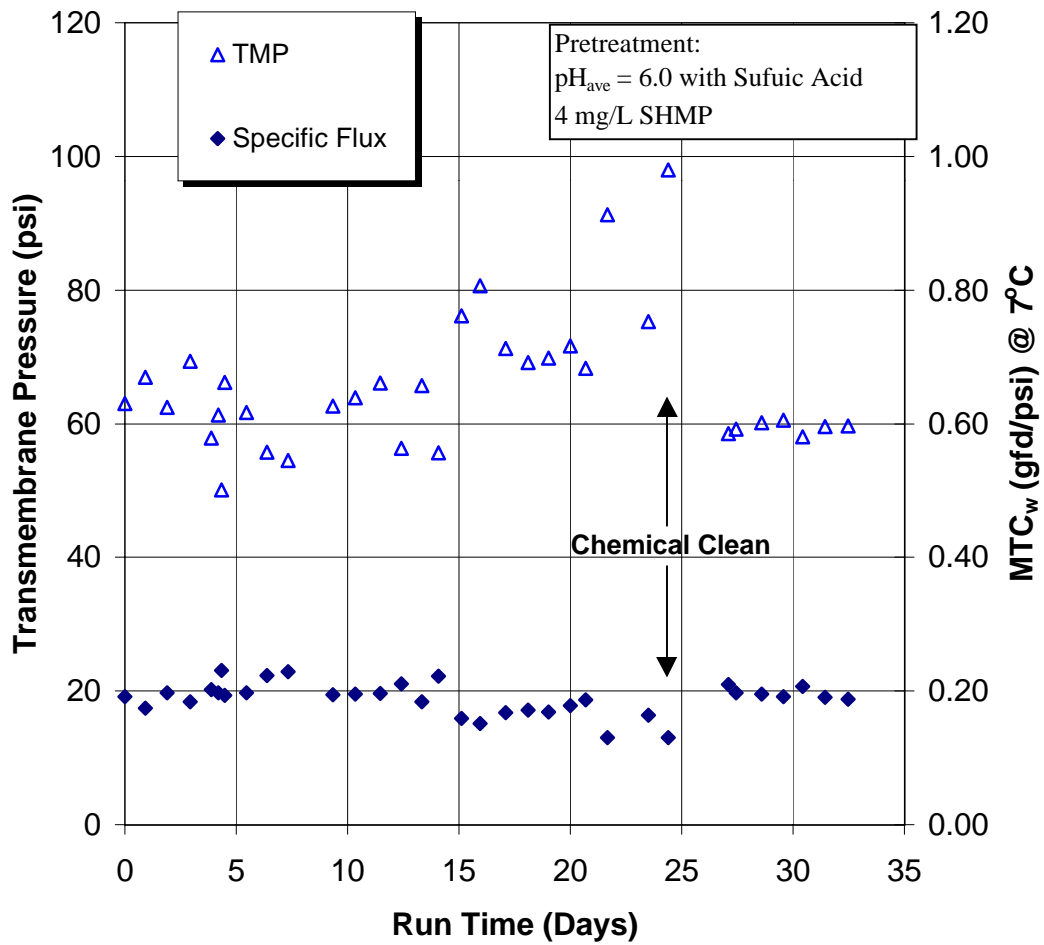
**B-22-1 (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #2
At 12 L / hr.m² @ 13 °C, 75% Recovery**

Testing with the ESNA membrane was performed at a flux of 20 L/hr.m² at T_{ave} and a 75% recovery. The ESNA membrane operated at a TMP of approximately 60-psi as seen in Figures 14 and 15. Particle fouling triggered the first chemical cleaning as indicated on day 26 in Figure 14. Again, PAC broke through pilot scale filters prior to NF and rapidly fouled the membrane. However, chemical cleaning during the second quarter of ESNA evaluation was attributed to inorganic fouling and ineffective anti-scalant addition due to the hydrolysis of SHMP.

The NF200B membrane operated in a manner similar to that of the ESNA. During the first quarter of SEBST evaluation, the TMP ranged from 50 psi to 90 psi from beginning to end as shown in Figure 16. Particle fouling was successfully controlled during the first quarter by scouring the membrane using high recirculation velocities for a short period of time. The second quarter of testing lead to results that are reported in Figure 17. Chemical cleaning was required after 20 days of operation. Subsequently, two additional cleanings were required during the last 15 days of testing. As with the second quarter of ESNA evaluation, fouling was attributed to inadequate scale inhibition by SHMP at elevated temperatures.

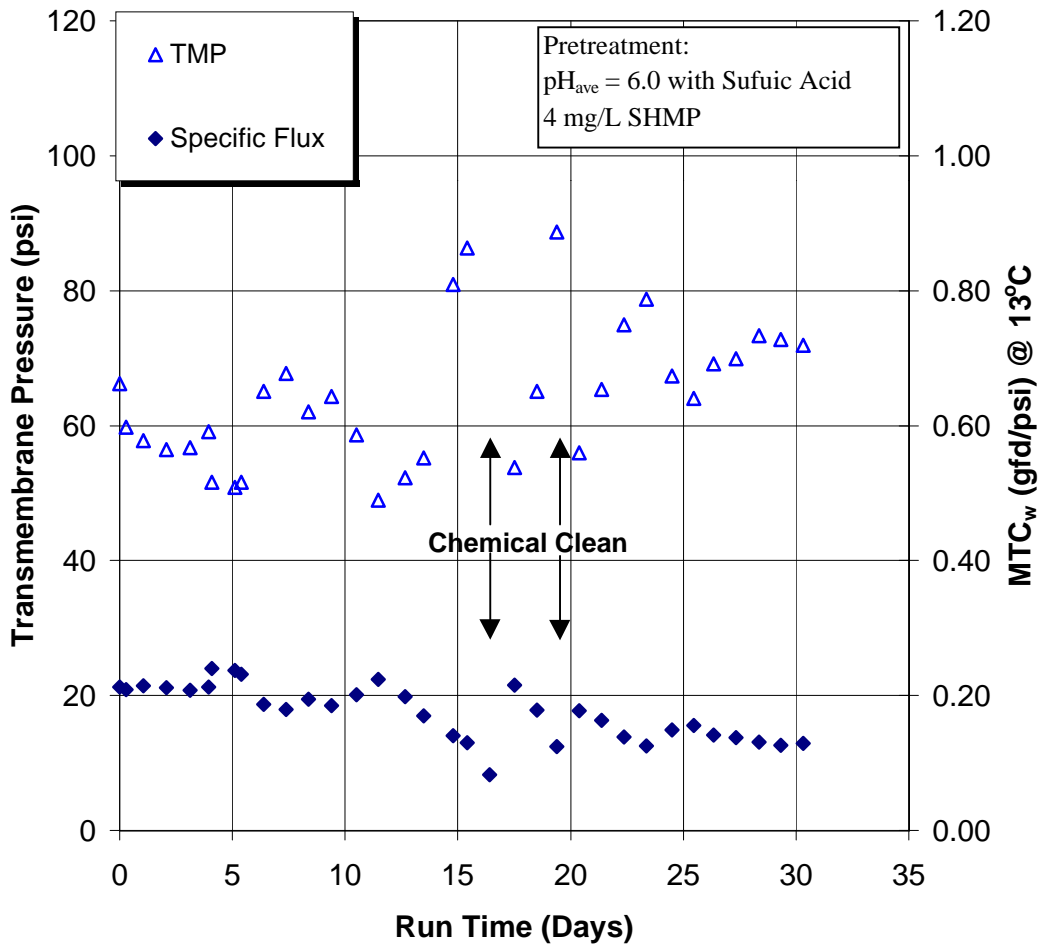
Rates of MTC_w decline were calculated for each membranes based on the negative slope of daily operating values between chemical cleaning intervals as seen in Figures 10 – 17. Based on cleaning criterion (15% MTC_w decline), an average cleaning interval was calculated using these MTC_w decline rates. Rates of MTC_w decline and calculated chemical cleaning intervals are reported in Table 11.

Figure 14



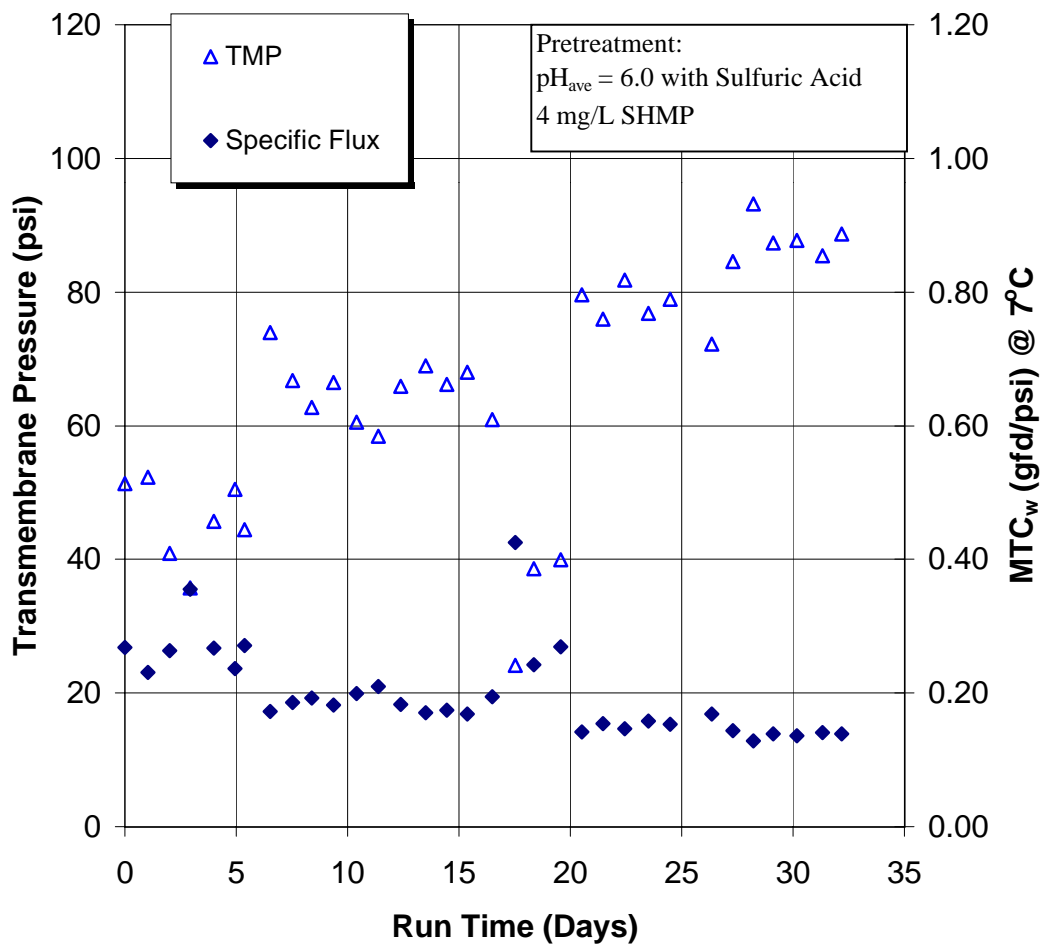
ESNA (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #1
At 12 gfd @ 7°C, 75% Recovery

FIGURE 15



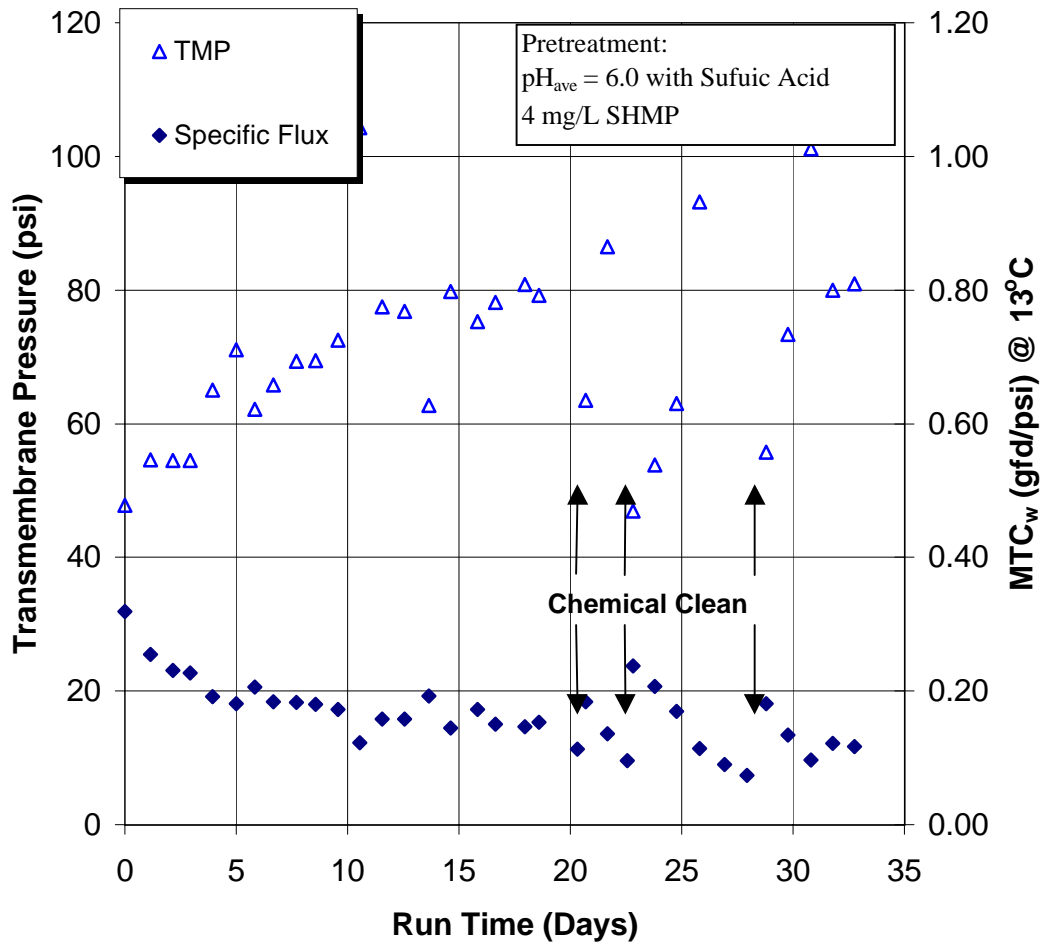
ESNA (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #2
At 12 L / hr.m² @ 13 °C, 75% Recovery

Figure 16



**NF200B (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #1
At 12 gfd @ 7 °C, 75% Recovery**

Figure 17



**NF200B (SEBST) Transmembrane Pressure
and Specific Flux for Quarter #2
At 13.5 gfd @ 13 °C, 75% Recovery**

Table 11. Membrane productivity and cleaning

Membrane Quarter	Average Rate of MTC _w Decline L/hr.m ² .bar.day (gfd/psi.day)	Average Cleaning Interval days	Initial MTC _w L/hr.m ² .bar (gfd/psi)	Final MTC _w L/hr.m ² .bar (gfd/psi)	MTC _w After Cleaning L/hr.m ² .bar (gfd/psi)
Sepa MS Quarter 1	-7.1 x 10 ⁻³ (-2.9 x 10 ⁻⁴)	41	1.97 (0.08)	1.47 (0.06)	1.72 (0.07)
Sepa MS Quarter 2	-1.5 x 10 ⁻² (-6.3 x 10 ⁻⁴)	24	2.46 (0.1)	1.72 (0.07)	NC
B-22-1 Quarter 1	-1.6 x 10 ⁻² (-6.8 x 10 ⁻⁴)	20	2.22 (0.09)	0.49 (0.02)	1.47 (0.06)
B-22-1 Quarter 2	-4.2 x 10 ⁻² (-1.7 x 10 ⁻³)	16	5.91 (0.24)	5.66 (0.23)	NC
ESNA Quarter 1	-5.4 x 10 ⁻² (-2.2 x 10 ⁻³)	20	4.68 (0.19)	3.20 (0.13)	5.17 (0.21)
ESNA Quarter 2	-5.1 x 10 ⁻² (-2.1 x 10 ⁻³)	15	5.17 (0.21)	3.20 (0.13)	5.17 (0.21)
NF200B Quarter 1	-9.8 x 10 ⁻² (-4.0 x 10 ⁻³)	10	6.65 (0.27)	3.44 (0.14)	NC
NF200B Quarter 2	-6.6 x 10 ⁻² (-2.7 x 10 ⁻³)	13	5.91 (0.24)	2.71 (0.11)	4.43 (0.18)

NC = No cleaning performed during quarter

These data summarize the hydraulic operation of each membrane in a manner that is suitable for determining design criteria. Also, calculated chemical cleaning intervals would likely vary according to pretreatment practices. Comparison of lime softening followed by granular filtration to alternative pretreatments (i.e. conventional treatment/granular filtration and UF or MF) for NF would also provide data critical to design and will be evaluated as part of a second phase of this collaborative research project.

Permeate And Feed Water Blending

There are three water treatment goals that must be weighed when evaluating NF as a polishing treatment of softened Missouri River water. Reduction of DBP precursors such as TOC, removal of atrazine and disinfection are all accomplished through nanofiltration. If the goal of NF in water treatment was solely reduction of DBPs and/or atrazine, then feed water and permeate water may be blended to achieve a blended water quality that meets regulatory guidelines. However, should water be blended, then any disinfection achieved through NF would be negated.

The first quarter of SEBST evaluation did not produce a concentration of DBPs in the feed water that would require NF. In the second quarter, Stage II concentrations for both trihalomethanes and haloacetic acids were exceeded within a 10% factor of safety. Table 12 lists the maximum permeate to total water blend ratios and calculated blended water quality for each membrane based on DBP feed and permeate water monitoring results from the second quarter of SEBST evaluation.

Table 12. Blending ratios and blended water quality for controlling DBPs

Membrane	Controlling Treatment Objective	Value of Listed Parameter at Blend Ratio to Achieve Controlling Treatment Objective				
		Permeate: Total Flow Blend Ratio	TOC (mg/L)	SDS-THM4 (µg/L)	SDS-HAA5 (µg/L)	SDS-TOX (µg Cl ⁻ /L)
Sepa MS	SDS-HAA5 27 µg/L	0.52	1.5	24.3	27.0	NA
B-22-1	SDS-HAA5 27 µg/L	0.47	1.7	28.3	27.0	NA
ESNA	SDS-THM4 32 µg/L	0.23	2.1	36.0	23.0	NA
NF200B	SDS-THM4 32 µg/L	0.40	1.8	36.0	13.4	NA

NA: Not available, permeate concentrations below minimum detection level

A similar scenario may be constructed for atrazine blending. With a 10% factor of safety applied to the maximum contaminant level (MCL) for atrazine ($MCL_{\text{atrazine}} = 3.0 \mu\text{g/L}$), blended water quality atrazine concentrations would be targeted for a concentration of 2.7 µg/L. Table 13 lists the concentrations of atrazine in NF feed and permeate waters from each membrane along with the flux and cross flow velocity employed.

**Table 13
Atrazine blend ratios and hydraulic operating conditions**

Membrane	Feed Concentration µg/L	Permeate Concentration µg/L	Permeate: Total Flow Blend Ratio	Flux gfd	Cross Flow Velocity ft/s
Sepa MS	6.0	0.05	0.55	12	1.5
B-22-1	6.28	2.15	0.87	12	NA
ESNA	4.2	0.63	0.42	12	0.7
NF200B	5.56	2.79	> 1.0	12	1.3

NA: Not available, manufacturer could not provide the data necessary for calculation

From this we can see that the ESNA membrane provides the blended water quality necessary which requires the least amount of nanofiltration. Operation of the NF200B did not produce a concentration of atrazine that met the target concentration of 2.7 µg/L. This ultimately produced a permeate blend ratio greater than 1.0 which is not feasible.

Cost Analysis

Based on study objectives such as atrazine and DBP precursor removal and the ability to operate cost effectively, the Hydranautics ESNA was selected for the yearlong pilot study, fulfilling KCMWSD's ICR treatment study requirement. As a result, only the ESNA membrane was considered for pricing purposes.

This ICR study served as compliance for the Missouri River water treatment facility of WDN01JC (ICR Plant No. 380). This facility is rated for a 94-MGD capacity. To implement NF as a polishing treatment for existing lime softening processes, the plant capacity would be reduced to 84.6 MGD assuming all water would be treated by NF operating at a 90% recovery. The investment required to implement NF as a polishing treatment for lime softening is 55.8 million dollars. This value includes capital costs, building costs and pre- and post-treatment implementation costs.

A summary of all factors included in pricing a NF system for implementation are presented in Table 14. The plant factor is a value representing the utilization of plant capacity over the course of one year and was calculated as based on the total water diverted from the Missouri River in 1997.

Table 14. Calculation of Investment and Water Cost

DESIGN PARAMETERS			
Plant capacity, MGD	84.6	Labor rate, \$/hr	30
Design flux, gfd	15	Additional staff, # people	10
Investment, \$	55.8 mil.	Plant life, years	30
Interest rate, %	10	Membrane life, years	5.0
Plant factor, %	40	Membrane cost, \$/element	600
Engineering & Administration (as % of investment)	20.0	Number of elements	13794
Contingency (as % of investment)	10.0	Inhibitor cost, \$/lb	3.71
Power Cost, \$/kWhr	0.044	Inhibitor dosing, mg/L	4.0
Power consumption, kWhr/kgal	3.06	Acid cost, \$/lb	0.07
Maintenance (as % of investment)	3.0	Acid dosing, mg/L	104.7
WATER COSTS			
Capital cost, \$/kgal	0.48		
Engineering & administration fees, \$/kgal	0.10		
Contingency, \$/kgal	0.05		
Power cost, \$/kgal	0.13		
Labor cost, \$/kgal	0.02		
Chemical cost, \$/kgal	0.18		
Membrane replacement cost, \$/kgal	0.13		
Maintenance, \$/kgal	0.14		
TOTAL WATER COST, \$/kgal	1.23		

WDNo1JC currently charges its customers \$3.06 per 1000 gallons of water produced. Implementation of NF as a polishing treatment to existing unit processes would likely increase the total cost of water by at least 40% over the current value. Therefore, the estimated cost of water treated by an integrated NF – lime softening system would be \$4.29 per 1000 gallons of finished water.

SECTION V. QA/QC SUMMARY

Quality Assurance (QA) and Quality Control (QC) measures conducted during this study were performed in accordance to the procedures outline in the *DBP/ICR Analytical Methods Manual*. Of particular interest to the ICR treatment studies were the methods associated with measuring and reporting DBPs and DBP precursors including TOC, Bromide, TOX, THMs, and HAAs. Calibration procedures that were employed by the Kansas City Missouri Water Services Laboratory (KCMWSL) (ICR Lab # ICRMO004) for each of these analytes are summarized in the following:

CALIBRATION SUMMARY

Total Organic Carbon (TOC). Calibration for TOC samples, measured using Standard Method 5310B, was performed on a daily basis. Calibration consisted of two blank (distilled deionized water) injections followed by injection of a low, medium and high level calibration standard. Preparation of low level calibration standards was performed after blank samples had been analyzed. The low level calibration standard was prepared at a concentration equal to twice the detected concentration obtained from the blank analysis, which was never less than 0.2 mg/L. Prepared separately from the calibration standards, low, medium and high level check standards were analyzed to verify calibration. Medium and high level (calibration and check) standard concentrations were 4 and 10 mg/L respectively.

After all calibration standards had been analyzed, a low-level calibration check standard was analyzed. Two injections of this standard were analyzed and used to compute a relative percent difference (RPD) which was required to be $\leq 20\%$. After the low level check standard had successfully verified the instrument calibration, 10 ICR treatment study samples were analyzed in duplicate (as laboratory duplicates). RPDs for samples whose measured concentration were ≤ 2.0 mg/L were required to be $\leq 20\%$ while samples whose concentrations exceeded 2 mg/L only required an RPD $\leq 10\%$.

Once 10 ICR treatment study samples had been analyzed, a medium or high level check standard was then analyzed. The RPD of the medium and high level check standard was required to be $\leq 10\%$. If the RPD of the medium or high-level check standard did not meet this criteria, the previous 10 samples would be reanalyzed. If any of the pervious 10 ICR treatment study samples failed to meet the acceptance criteria with respect to sample RPD, the sample was then included in the next 10 ICR treatment study samples to be analyzed in duplicate. This procedure of analyzing 10 ICR treatment study samples followed by a check standard was repeated until 30 treatment study samples had been analyzed. After analyzing 30 treatment study samples, a medium or high level check standard was analyzed, which marked the end of analyses under the current calibration.

Bromide

Calibration for Bromide samples, measured using EPA Method 300.0, was performed on a daily basis. Calibration consisted of two blank (distilled deionized water) injections followed by injection of a low, medium and high level calibration standard. Prepared separately from the calibration standards, low, medium and high level check standards were analyzed to verify calibration. Low, medium and high level (calibration and check) standard concentrations were 0.02, 0.10 and 0.30 mg/L respectively.

After all calibration standards had been analyzed, a low-level calibration check standard was analyzed. One injection of this standard was analyzed and used to compute a surrogate recovery (detector response/average calibration curve detector response). For the low-level calibration check standard, the surrogate recovery was required to be between 50 and 150%. After the low level check standard had successfully verified the instrument calibration, 10 ICR treatment study samples were then analyzed as laboratory duplicates.

Following the analysis of 10 ICR treatment study samples, a medium or a high-level calibration check standard was analyzed. If the surrogate recovery of the check standards ranged between 90 and 110%, analysis of the next 10 ICR treatment study samples could then proceed. If the check standard surrogate recovery exceeded the specified range, all 10 ICR treatment study samples would be reanalyzed. The process of analyzing 10 ICR treatment study samples, followed by a medium or high level check standard was continued until all the samples had been analyzed. The very last sample analyzed was always a check standard. No more than 30 ICR treatment study samples would be analyzed in a single day. This number was never reached in practice.

Total Organic Halogen (TOX)

Calibration for TOX samples, measured using Standard Method 5320 B, was performed multiple times randomly throughout each day samples were analyzed. Calibration consisted of three blank injections (two laboratory and one system blank) followed by injections of low, medium and high NaCl standards whose concentrations were 25, 200 and 500 respectively. Prior to injection of standardized NaCl solutions, background concentrations of blanks were checked and made sure not to exceed 0.8 µg Cl⁻/L and 12.5 µg Cl⁻/L for laboratory and system blanks respectively.

After all calibration standards had been analyzed, a low-level calibration check standard was analyzed. One injection of this standard was analyzed and used to compute a surrogate recovery (detector response/average calibration curve detector response). For the low-level calibration check standard, the surrogate recovery was required to be between 75 and 125%. After the low level check standard had successfully verified the instrument calibration, 7 ICR treatment study samples were then analyzed as laboratory duplicates.

Following the analysis of 7 ICR treatment study samples, another laboratory blank was analyzed. If the interference concentration did not exceed 0.8 µg Cl⁻/L, a medium or a high-level calibration check standard was analyzed. If the surrogate recovery of the check standards ranged between 85 and 115%, TOX analyses for the day were complete. If the laboratory blank exceeded its maximum allowable interference concentration, or if the check standard surrogate recovery exceeded the specified range, all 7 ICR treatment study samples would be reanalyzed (if possible) the next day. The very last sample analyzed each day was always a check standard.

Trihalomethanes (THMs)

Calibration for THM samples, measured using EPA Method 502.2, was performed on a daily basis. Calibration consisted of one laboratory blank injection followed by injection of a low, medium and high level calibration standard. Prepared separately from the calibration standards, low, medium and high level check standards were analyzed to verify calibration. Low, medium and high level (calibration and check) standard concentrations were 1, 20 and 40 µg/L respectively.

After all calibration standards had been analyzed, a low-level calibration check standard was analyzed. One injection of this standard was analyzed and used to compute a surrogate recovery (detector response/average calibration curve detector response). For the low-level calibration check standard, the surrogate recovery was required to be between 50 and 150%. After the low level check standard had successfully verified the instrument calibration, 10 ICR treatment study samples were then analyzed as laboratory duplicates.

Once 10 ICR treatment study samples had been analyzed, a medium or high level check standard was then analyzed. The surrogate recovery of the medium or high level check standard was required to be 80 to 120%. If the surrogate recovery of the medium or high-level check standard did not meet this criteria, the previous 10 samples would be reanalyzed. This procedure of analyzing 10 ICR treatment study samples followed by a check standard was repeated until 30 treatment study samples had been analyzed. After analyzing 30 treatment study samples, a medium or high level check standard was analyzed, which marked the end of analyses under the current calibration. While this procedure was understood as practice, on no occasion did the laboratory ever analyze more than 30 ICR treatment study samples.

Haloacetic Acids (HAAs)

Calibration for HAA samples, measured using Standard Method 6251 B, was performed on a daily basis. Calibration consisted of one laboratory blank injection followed by injection of a low, medium and high level calibration standard. Prepared separately from the calibration standards, low, medium and high level check standards were analyzed to verify calibration. Low, medium and high level (calibration and check) standard concentrations were 1 (2 for MCAA), 20 and 40 µg/L respectively. Although BDCAA, CDBAA and TBAA are not recognized as accepted analytes by the ICR using Standard

Method 6251 B, they were reported by the KCMWSL with an MDL equal to 1 µg/L. These HAAs were included due to the fact that the chemists at the KCMWSL had great success in achieving superior surrogate recoveries for these compounds over a wide range of concentrations including very low concentrations (lower than the MCL).

After all calibration standards had been analyzed, a low-level calibration check standard was analyzed. One injection of this standard was analyzed and used to compute a surrogate recovery (detector response/average calibration curve detector response). For the low-level calibration check standard, the surrogate recovery was required to be between 50 and 150%. After the low level check standard had successfully verified the instrument calibration, 10 ICR treatment study samples were then analyzed as laboratory duplicates.

Once 10 ICR treatment study samples had been analyzed, a medium or high level check standard was then analyzed. The surrogate recovery of the medium or high level check standard was required to be 80 to 120%. If the surrogate recovery of the medium or high-level check standard did not meet these criteria, the previous 10 samples would be reanalyzed. This procedure of analyzing 10 ICR treatment study samples followed by a check standard was repeated until 30 treatment study samples had been analyzed. After analyzing 30 treatment study samples, a medium or high level check standard was analyzed, which marked the end of analyses under the current calibration. While this procedure was understood as practice, on no occasion did the laboratory ever analyze more than 30 ICR treatment study samples.

Performance Evaluation (PE) Study Results

In accordance with the ICR, the KCMWSL conducted PE studies to verify that the Laboratory was performing in a manner that was acceptable to the EPA for the purpose of reporting ICR monitoring results. Table 15 summarizes the results of the PE study conducted by the KCMWSL as the analyses pertain to the ICR treatment study. While the results in these PE studies indicate that the laboratory was performing in a satisfactory manner, the PE studies were conducted as an internal challenge only. All ICR monitoring samples (treatment study samples excluded) were shipped out and analyzed by Montgomery Watson Laboratories.

Table 15. US EPA ICR Performance Evaluation (PE) Study Summary

		Method Number	True Value	Measured Value	% Recovery
PE Study #6 2/20/98	UV ₂₅₄ (cm ⁻¹)	5910	0.435	0.415	95%
	TOC (mg/L)	5310C	4.70	4.91	104%
	TOX (µg Cl ⁻ /L)	5320B	50.5	NR	
	Bromide (µg/L)	EPA 300.0	169	NR	
	Haloacetic Acids	6251B			
	MCAA (µg/L)		6.05	9.40	155%
	MBAA (µg/L)		11.9	15.40	129%
	DCAA (µg/L)		12.0	9.68	81%
	TCAA (µg/L)		9.03	6.86	76%
	BCAA (µg/L)		5.96	5.57	93%
	DBAA (µg/L)		15.1	12.70	84%
	Trihalomethanes	EPA 502.2			
	Chloroform (µg/L)		36.5	34.70	95%
	BDCM (µg/L)		32.2	34.50	107%
	CDBM (µg/L)		14.7	14.60	99%
	Bromoform(µg/L)		26.5	23.80	90%
PE Study #7 4/29/98	UV ₂₅₄	5910	0.361	0.347	96%
	TOC	5310C	1.22	1.38	113%
	TOX	5320B	188	173	92%
	Bromide	EPA 300.0	448	NR	
	Haloacetic Acids	6251B			
	MCAA		5.94	5.32	90%
	MBAA		11.1	9.41	85%
	DCAA		24.0	17.40	73%
	TCAA		15.0	12.70	85%
	BCAA		12.1	9.77	81%
	DBAA		14.0	12.30	88%
	Trihalomethanes	EPA 502.2			
	Chloroform		17.0	16.70	98%
	BDCM		11.0	9.90	90%
	CDBM		28.1	27.90	99%
	Bromoform		18.2	17.00	93%
PE Study #8 8/22/98	UV ₂₅₄	5910	0.072	0.070	97%
	TOC	5310C	2.62	3.10	118%
	TOX	5320B	80.3	73.0	91%
	Bromide	EPA 300.0	325	NR	
	Haloacetic Acids	6251B			
	MCAA		13.0	9.99	77%
	MBAA		16.0	12.50	78%
	DCAA		14.2	11.10	78%

Table 15 (continued)

		Method Number	True Value	Measured Value	% Recovery
	TCAA		8.03	6.35	79%
	BCAA		5.07	4.02	79%
	DBAA		18.0	14.60	81%
	Trihalomethanes	EPA 502.2			
	Chloroform		54.1	51.20	95%
	BDCM		25.0	23.20	93%
	CDBM		14.0	12.20	87%
	Bromoform		7.00	5.61	80%
PE Study #9 3/9/99	UV ₂₅₄	5910	0.223	0.212	95
	TOC	5310C	4.19	4.20	100
	TOX	5320B	92.9	93.0	100
	Bromide	EPA 300.0	91	NR	
	Haloacetic Acids	6251B			
	MCAA		11.1	8.63	78
	MBAA		9.11	6.47	71
	DCAA		8.01	6.05	76
	TCAA		12.0	9.62	80
	BCAA		7.05	5.31	75
	DBAA		5.00	4.11	82
	Trihalomethanes	EPA 502.2			
	Chloroform		32.2	27.60	86
	BDCM		15.0	12.90	86
	CDBM		9.10	6.50	71
	Bromoform		2.98	1.80	60

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APPENDIX A

Treatment Plant Design Data
Process Train 1 & 2

Unit Process	Process Description
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 1,504,000 Short Circuiting Factor: 0.3 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 38 Stage Liquid Volume (gal): 1,504,000
Sedimentation	Surface Area (ft^2): 97,404 Liquid Volume (gal): 13,856,000 Baffling Type: UN Short Circuiting Factor: 0.3
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl_2 Dose Rate (mg/L): 5.00 Chemical Type: Anhydrous Ammonia Measured as: NH_3 Dose Rate (mg/L): 1.2
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 3,888,000 Short Circuiting Factor: 0.4 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 71 Stage Liquid Volume (gal): 3,888,000
Sedimentation	Surface Area (ft^2): 161,200 Liquid Volume (gal): 19,344,000 Baffling Type: UN Short Circuiting Factor: 0.4
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl_2 Dose Rate (mg/L): 5.00 Chemical Type: Anhydrous Ammonia Measured as: NH_3 Dose Rate (mg/L): 1.2

Unit Process	Process Description
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 3,106,400 Short Circuiting Factor: 0.3 Baffling Type: UN Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 103 Stage Liquid Volume (gal): 3,106,400
Sedimentation	Surface Area (ft^2): 98,800 Liquid Volume (gal): 11,822,400 Baffling Type: UN Short Circuiting Factor: 0.3
Filtration	Surface Area (ft^2): 33,600 Liquid Volume (gal): 1,109,000 Total Media Depth (in): 45 Media Type: Sand Minimum Water Depth To Top of Media (ft): 3.5 Depth From Top of Media to Top of Backwash Trough (ft): 2.0
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl_2 Dose Rate (mg/L): 0.1
Clear Well	Surface Area (ft^2): 81,300 Liquid Volume (gal): 7,500,000 Minimum Liquid Volume (gal): 2,000,000 Baffling Type: Average Short Circuiting Factor: 0.4 Covered Indicator Code: Yes

Treatment Plant Design Data
Process Train 3

Unit Process	Process Description
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 752,000 Short Circuiting Factor: 0.3 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 28 Stage Liquid Volume (gal): 752,000
Sedimentation	Surface Area (ft^2): 52,780 Liquid Volume (gal): 9,882,000 Baffling Type: UN Short Circuiting Factor: 0.3
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl_2 Dose Rate (mg/L): 5.00 Chemical Type: Anhydrous Ammonia Measured as: NH_3 Dose Rate (mg/L): 1.2
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 1,944,000 Short Circuiting Factor: 0.4 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 71 Stage Liquid Volume (gal): 1,944,000
Sedimentation	Surface Area (ft^2): 80,600 Liquid Volume (gal): 9,672,000 Baffling Type: UN Short Circuiting Factor: 0.4
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl_2 Dose Rate (mg/L): 5.00 Chemical Type: Anhydrous Ammonia Measured as: NH_3 Dose Rate (mg/L): 1.2
Flocculation Basin	Type of Mixer: Mechanical Liquid Volume (gal): 3,152,000 Short Circuiting Factor: 0.4 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 105 Stage Liquid Volume (gal): 3,152,000

Unit Process	Process Description
Sedimentation	Surface Area (ft ²): 30,600 Liquid Volume (gal): 3,777,400 Baffling Type: UN Short Circuiting Factor: 0.4
Filtration	Surface Area (ft ²): 16,632 Liquid Volume (gal): 886,000 Total Media Depth (in): 45 Media Type: Sand Minimum Water Depth To Top of Media (ft): 5.5 Depth From Top of Media to Top of Backwash Trough (ft): 4.0
Disinfection	Chemical Type: Chlorine Gas Measured as: Cl ₂ Dose Rate (mg/L): 0.1
Clear Well	Surface Area (ft ²): 81,300 Liquid Volume (gal): 7,500,000 Minimum Liquid Volume (gal): 2,000,000 Baffling Type: Average Short Circuiting Factor: 0.4 Covered Indicator Code: Yes

Design Plant Chemical Parameters

Chemical Name	Measured As	Train 1 & 2 Dose (mg/L)	Train 3 Dose (mg/L)
Ferric Sulfate	Fe ₂ (SO ₄) ₃ .9H ₂ O	6.00	6.00
Organic Polymer – Coagulant Aid	Magnifloc 587C	1.20	1.20
Powdered Activated Carbon	C	2.40	2.40
Potassium Permanganate	KMnO ₄	0.60	0.60
Ferric Sulfate	Fe ₂ (SO ₄) ₃ .9H ₂ O	6.00	6.00
Calcium Hydroxide	Ca(OH) ₂	196.00	196.00
Chlorine Gas	Cl ₂	5.00	5.00
Anhydrous Ammonia	NH ₃	1.20	1.20
Carbon Dioxide	CO ₂	37.00	37.00
Ferric Sulfate	Fe ₂ (SO ₄) ₃ .9H ₂ O	6.00	6.00
Powdered Activated Carbon	C	2.40	2.40
Sodium Hexametaphosphate (SHMP)	Na(PO ₃) ₆	0.50	0.50
Chlorine Gas	Cl ₂	5.00	5.00
Anhydrous Ammonia	NH ₃	1.20	1.20
Organic Polymer – Filter Aid	Magnifloc 587C	0.06	0.60
Sodium Hexametaphosphate (SHMP)	Na(PO ₃) ₆	0.60	0.60
Chlorine Gas	Cl ₂	0.10	0.10
Hydrofluorosilic Acid (HFS)	F	0.60	0.60

APPENDIX B

Manufacturer Reported Membrane Characteristics Sepa MS

General Information

Membrane manufacturer	Sepa Osmonics
Membrane trade name	Sepa MS
Membrane element model number	S4040
Molecular weight cutoff (Daltons)	< 300
Membrane material	Polysulfone with a polyamide active layer
Membrane construction	Thin-film composite
Membrane hydrophobicity	Hydrophilic
Membrane charge	Neutral

Design Parameters

Element size	3.9" x 40"
Active membrane area of element used (ft ²)	85
Design flux (gfd)	22
Net driving pressure at the design flux (psi)	220
Water mass transfer coefficient, MTC _w (gfd/psi)	
Temperature at which the MTC _w was determined (°C)	25
Maximum flow rate to the element (gpm)	15
Minimum flow rate to the element (gpm)	4
Total width of all membrane envelopes in the element (ft)	3.3
Feed spacer thickness, (ft)	0.002
Active membrane area of the equivalent 8" x 40" element (ft ²)	
Purchase price for an equivalent 8" x 40" element (\$)	

Additional Information

Design cross-flow velocity (ft/s)	Not measured
Required influent to permeate flow rate ratio	6
Maximum element recovery (%)	15, but depends on application
Variability of design flux (%)	
Rejection of reference solute and conditions of test	1500 mg/L NaCl
Variability of rejection of reference solute (%)	32
Standard testing recovery (%)	15
Standard testing pH	7
Acceptable range of operating pressures	250 psi
Acceptable range of operating pH values	2 – 12
Typical pressure drop across a single element (psi)	
Maximum permissible SDI	5
Maximum permissible turbidity (ntu)	1
Chlorine/oxidant tolerance	0.0 mg/L

Purification Products B-22-1

General Information

Membrane manufacturer	Purification Products
Membrane trade name	B-22-1
Membrane element model number	
Molecular weight cutoff (Daltons)	~ 200
Membrane material	Polyamide
Membrane construction	Composite
Membrane hydrophobicity	
Membrane charge	

Design Parameters

Element size	4" x 40"
Active membrane area of element used (ft ²)	64
Design flux (gfd)	
Net driving pressure at the design flux (psi)	
Water mass transfer coefficient, MTC _w (gfd/psi)	
Temperature at which the MTC _w was determined (°C)	
Maximum flow rate to the element (gpm)	
Minimum flow rate to the element (gpm)	
Total width of all membrane envelopes in the element (ft)	
Feed spacer thickness, (ft)	
Active membrane area of the equivalent 8" x 40" element (ft ²)	
Purchase price for an equivalent 8" x 40" element (\$)	

Additional Information

Design cross-flow velocity (ft/s)	
Required influent to permeate flow rate ratio	
Maximum element recovery (%)	
Variability of design flux (%)	
Rejection of reference solute and conditions of test	
Variability of rejection of reference solute (%)	
Standard testing recovery (%)	
Standard testing pH	
Acceptable range of operating pressures	
Acceptable range of operating pH values	
Typical pressure drop across a single element (psi)	
Maximum permissible SDI	
Maximum permissible turbidity (ntu)	
Chlorine/oxidant tolerance	

Hydranautics ESNA

General Information

Membrane manufacturer	Hydranautics
Membrane trade name	ESNA
Membrane element model number	ESNA-4040
Molecular weight cutoff (Daltons)	200-300
Membrane material	Polyamide
Membrane construction	Composite
Membrane hydrophobicity	Hydrophilic
Membrane charge	Negative

Design Parameters

Element size	3.94" x 40"
Active membrane area of element used (ft ²)	85
Design flux (gfd)	12
Net driving pressure at the design flux (psi)	75
Water mass transfer coefficient, MTC _w (gfd/psi)	0.14
Temperature at which the MTC _w was determined (°C)	25
Maximum flow rate to the element (gpm)	16
Minimum flow rate to the element (gpm)	4
Total width of all membrane envelopes in the element (ft)	14
Feed spacer thickness, (ft)	.0010
Active membrane area of the equivalent 8" x 40" element (ft ²)	400
Purchase price for an equivalent 8" x 40" element (\$)	600

Additional Information

Design cross-flow velocity (ft/s)	0.6 – 1.0
Required influent to permeate flow rate ratio	Dependant upon array and feed water
Maximum element recovery (%)	15
Variability of design flux (%)	15
Rejection of reference solute and conditions of test	85-95%; 500 mg/L NaCl
Variability of rejection of reference solute (%)	85-95%
Standard testing recovery (%)	15
Standard testing pH	6.5 – 7.0
Acceptable range of operating pressures	Less than or equal to 400 psi
Acceptable range of operating pH values	3.0 – 10.0
Typical pressure drop across a single element (psi)	12 psi max
Maximum permissible SDI	4
Maximum permissible turbidity (ntu)	1
Chlorine/oxidant tolerance	0.0 mg/L

Dow FilmTec NF200B

General Information

Membrane manufacturer	Dow FilmTec
Membrane trade name	NF200B
Membrane element model number	NF200B-4040
Molecular weight cutoff (Daltons)	400
Membrane material	Polypiperazine
Membrane construction	Thin-film composite
Membrane hydrophobicity	Hydrophobic
Membrane charge	Negative

Design Parameters

Element size	4" x 40"
Active membrane area of element used (ft ²)	79
Design flux (gfd)	16.5
Net driving pressure at the design flux (psi)	70
Water mass transfer coefficient, MTC _w (gfd/psi)	0.235
Temperature at which the MTC _w was determined (°C)	25
Maximum flow rate to the element (gpm)	16
Minimum flow rate to the element (gpm)	4
Total width of all membrane envelopes in the element (ft)	3.2
Feed spacer thickness, (ft)	0.0023
Active membrane area of the equivalent 8" x 40" element (ft ²)	400
Purchase price for an equivalent 8" x 40" element (\$)	700

Additional Information

Design cross-flow velocity (ft/s)	Not measured
Required influent to permeate flow rate ratio	Not measured
Maximum element recovery (%)	15, but depends on application
Variability of design flux (%)	-15% to +20%
Rejection of reference solute and conditions of test	<45% rejection of CaCl ₂ ; 70 psi, 500 mg/L CaCl ₂
Variability of rejection of reference solute (%)	<45%
Standard testing recovery (%)	15
Standard testing pH	8.0
Acceptable range of operating pressures	0 to 600 psi
Acceptable range of operating pH values	3.0 – 10.0
Typical pressure drop across a single element (psi)	3 – 5 psi
Maximum permissible SDI	5
Maximum permissible turbidity (ntu)	1
Chlorine/oxidant tolerance	0.1 mg/L

APPENDIX C

Cleaning Procedures
(As recommended by Hydranautics)

Membrane Element Foulant Symptoms

Foulant	General Symptoms	Response
Calcium Precipitates (carbonates and phosphates, generally found at the concentrate end of the system)	A marked decrease in salt rejection and a moderate increase in NDP. Also, a slight decrease in system production.	Chemically clean the system with Solution 1.
Hydrated Oxides (iron, nickel, copper, etc.)	A rapid decrease in salt rejection and a rapid decrease in NDP. Also a rapid decrease in system production.	Chemically clean the system with Solution 1.
Mixed Colloids (iron, organics, and silicates)	A slight decrease in salt rejection and a gradual increase in NDP. Also, a gradual decrease over several weeks in system production.	Chemically clean the system with Solution 2.
Calcium Sulfate (generally found at the concentrate end of the system)	A significant decrease in salt rejection and a slight to moderate increase in NDP. Also, a slight decrease in system production.	Chemically clean the system with Solution 2.
Organic Deposits	Possible decrease in salt rejection and a gradual increase in NDP. Also, a gradual decrease in system production.	Chemically clean the system with Solution 2. For heavy fouling, use Solution 3.
Bacterial Fouling	Possible decrease in salt rejection and a marked increase in NDP. Also, a marked decrease in system production.	Chemically clean the system with either of the solutions, depending on possible compounding fouling.

Summary of Recommended Cleaning Solutions

Solution	Ingredient	Quantity per 100 Gallons (379 Liters)	pH Adjustments
1.	Citric Acid RO Permeate (Chlorine-Free)	17.0 pounds (7.7 kg) 100 gallons (379 liters)	Adjust to pH 3.0 with ammonium hydroxide (NH ₄ OH)
2.	Sodium Tripolyphosphate Tetrasodium EDTA (Versene 220 or equal) RO Permeate (Chlorine-Free)	17 pounds (7.7 kg) 7 pounds (3.18 kg) 100 gallons (379 liters)	Adjust to pH 10.0 with Sulfuric Acid (H ₂ SO ₄) or hydrochloric acid (HCl)
3.	Sodium Tripolyphosphate Sodium Dodecylbenzene Sulfonate RO Permeate (Chlorine-Free)	17 pounds (7.7 kg) 2.13 pounds (0.97 kg) 100 gallons (379 liters)	Adjust to pH 10.0 with sulfuric acid (H ₂ SO ₄) or hydrochloric acid (HCl)

APPENDIX D

Summary of SEBST Operation

Sepa MS – Quarter #1

Date	Remarks
3/4/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
3/21/98 – 3/24/98	Kansas City Missouri Water Services Dept. needed to cut the power to the pilot plants to perform plant maintenance
3/29/98	Chemical Clean; Powdered Activated Carbon (PAC) broke through the cartridge filter and fouled the membrane; Citric acid wash (pH = 2), cartridge filter replaced.
4/6/98	Chemical Clean; PAC broke through the cartridge filter and fouled the membrane; Citric acid wash (pH = 2), cartridge filter replaced.

Sepa MS – Quarter #2

Date	Remarks
5/21/98	Switched from SHMP to Hypersperse SI 300
6/3/98 – 6/17/98	Kansas City Missouri Water Services Dept. needed to cut the power to the pilot plants to perform plant maintenance
6/23/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant
6/29/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant
6/30/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant

B-22-1 – Quarter #1

Date	Remarks
3/2/98 – 3/5/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
3/21/98 – 3/24/98	Kansas City Missouri Water Services Dept. needed to cut the power to the pilot plants to perform plant maintenance
3/29/98	Chemical Clean; Powdered Activated Carbon (PAC) broke through the cartridge filter and fouled the membrane; Citric acid wash (pH = 2), cartridge filter replaced.
4/1/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
4/6/98	Chemical Clean; PAC broke through the cartridge filter and fouled the membrane; Citric acid wash (pH = 2), cartridge filter replaced.

B-22-1 – Quarter #2

Date	Remarks
5/16/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
5/21/98	Switched from SHMP to Hypersperse SI 300
6/3/98 – 6/17/98	Kansas City Missouri Water Services Dept. needed to cut the power to the pilot plants to perform plant maintenance
6/19/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
6/23/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant
6/29/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant
6/30/98	Electrical storm power outage; tripped low pressure alarm and shut down pilot plant

ESNA – Quarter #1

Date	Remarks
1/17/98	System shut down due to low pH alarm
1/27/98	System shut down due to low pH alarm
1/30/98	Powdered Activated Carbon (PAC) broke through the cartridge filter; Cartridge filter replaced
2/3/98	System shut down due to low pH alarm
2/5/98 – 2/6/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
2/8/98	System shut down due to low pH alarm
2/9/98 – 2/20/98	Chemical Clean; PAC broke through the cartridge filter and fouled the membrane; no chemicals were immediately on hand; Citric acid wash (pH = 2) cartridge filter replaced

ESNA – Quarter #2

Date	Remarks
4/11/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
4/18/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
4/19/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
5/2/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane
5/5/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane
5/12/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane

NF200B – Quarter #1

Date	Remarks
1/30/98	Concentrate valve was not re-opened after direct flow measurement; System operated at 100% recovery overnight
2/2/98	Powdered Activated Carbon (PAC) broke through the cartridge filter; Cartridge filter replaced
2/5/98 – 2/6/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump

NF200B – Quarter #2

Date	Remarks
5/1/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane
5/4/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane
5/5/98	Low pressure alarm shut the system down; Low pressure caused by loss of power (blown fuse) to the booster pump
5/10/98	Chemical Clean; Rapid hydrolysis of SHMP to ortho-phosphate at elevated temperatures caused CaCO ₃ scale to foul membrane