EVALUATION OF MEMBRANE BIOREACTOR TECHNOLOGY AND DESALTING MEMBRANES FOR WASTEWATER REUSE

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ABSTRACT

The City of Rio Rancho and MWH have recently completed a pilot-testing program to evaluate MBR technology followed by reverse osmosis (RO) membranes during operation on municipal wastewater. The pilot testing program is part of an overall water reuse plan being implemented by the City of Rio Rancho, NM to conserve water supplies through recycling of wastewater currently being discharged to the Rio Grande River. The primary objective of this study was to demonstrate that MBR technology can meet local water reuse goals for commercial, landscape irrigation, and industrial uses, as well as surface water discharge requirements. In addition, the study focused on demonstrating that RO membranes can operate on MBR effluent to produce high quality purified water for groundwater recharge. Lastly the study evaluated the ability of MBR and RO processes to remove selected emerging contaminants, including endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs). In order to meet project objectives pilot system consisting of MBR/RO was operated over a 6-month period. During this time a water quality sampling plan was implemented to cover a wide range of inorganic and organic contaminates regulated under the Safe Drinking Water Act and New Mexico Water Quality Commission. Results from the study showed that MBR consistently produced a high water quality suitable for industrial and irrigation non-potable uses and provided a robust pretreatment to RO. In addition, product water from the overall treatment train met all federal and state regulations. Lastly most EDC and PPCP compounds were removed through the MBR/RO process to concentration levels below analytical detection.

KEYWORDS

Membrane Bioreactor, Reverse Osmosis, Water Reclamation, Reuse

INTRODUCTION

The City of Rio Rancho is the fastest growing and fourth largest city in New Mexico. The City currently relies heavily on groundwater for water supplies. To sustain water needs, the City has undertaken a feasibility study to develop a Water Reuse Strategy that will significantly expand the use of reclaimed water (RW), reduce groundwater withdrawals, and provide advanced treatment for aquifer recharge. The approach for the strategy is to advance best management practices for the use of reclaimed wastewater to sustain the community's limited water supply and provide a path towards self determination and better local control in managing those resources.

Membrane treatment processes are proving to be promising technologies for wastewater purification and reclamation. The membrane bioreactor (MBR) is a leading edge technology currently being used in countries around the world for water reclamation. MBRs couple conventional activated sludge processes with low-pressure membranes. The membrane portion of the MBR is comprised of microfiltration (MF) or ultrafiltration (UF) membranes, eliminating the need for final clarifiers as required in conventional activated sludge processes. The application of MBR technology for water reclamation offers several benefits over conventional methods including consistent and superior effluent water quality, reduced land requirements, ease of operation, and increased volumetric loading. An additional benefit of MBR technology is that it provides excellent pretreatment to desalting membranes such as RO, which are being increasingly used to reclaim wastewater for indirect potable reuse applications such as reservoir augmentation and aquifer recharge.

The City of Rio Rancho undertook this study, with funding provided by the New Mexico Department of finance and New Mexico Environment Department, to investigate using an integrated membrane system (IMS), consisting of MBR/RO to produce high quality reclaimed water for non potable and advanced water repurification for aquifer recharge.

METHODOLOGY

Pilot Set Up

The overall pilot treatment train evaluated during this study consisted of an 0.8 mm rotary drum prescreen (Waste Tech Inc.), Zenon MBR pilot unit and a two-stage RO pilot system. The MBR pilot system was equipped with two aerobic tanks, one 1600 gal (6.1 m^3) and one 1,000 gal (3.8 m^3), one 1600-gal (6.1 m^3) anoxic tank and a two 185-gallon (0.7 m^3) ZenoGem membrane units (identified as FS112 and FS120). Each of the membrane units contains one ZW 500C membrane cassette, which is composed of 3 submerged membrane elements.

The reverse osmosis (RO) pilot system used throughout this study was contained within a forty-five foot long semi-trailer which houses the plant and an enclosed laboratory/office area, all of which is HVAC controlled. During initial testing period, the process was configured with two single stage treatment trains to allow for the simultaneous evaluation of RO membranes from two different suppliers. RO membrane suppliers participating in this study include GE Osmonics, Saehan, Toray and Hydranautics. Specifications for the RO membranes being tested in this study are provided in Table 1.

Table 1: RO Membrane Specifications

	OSMONICS	SAEHAN	TORAY	HYDRANAUTICS
Commercial designation	AK4040	RE 4040-FRM	TML-10	ESPA2-4040
Membrane material	Polyamide (thin-film composite)	Polyamide (thin-film composite)	Polyamide (thin-film composite)	Polyamide (thin-film composite)
Operating pH range	4-11	3-10	2-11	3-10
Maximum feedwater turbidity	1 NTU	< 1 NTU	1 NTU	1 NTU
Maximum feedwater SDI (15 min)	5.0	< 5.0	5.0	5.0
Maximum operating temperature	113 F (C)	113 F (45 C)	113 F (C)	113 F (45 C)
Maximum Feed Water Chlorine Concentation	<0.1 ppm	<0.1 ppm	none	<0.1 ppm
Maximum operating pressure	600 psig	600 psig	600 psig	600 psig
Nominal membrane surface area	85 ft^2	85 ft^2	85 ft^2	85 ft^2
Spiral Wound configuration				
Element length	40.0 inches	40.0 inches	40.0 inches	40.0 inches
Element diameter	4.0 inches	4.0 inches	4.0 inches	3.95 inches
Permeate channel diameter (outer)	0.75 inches	0.75 inches	0.75 inches	0.75 inches

Pilot Testing Protocol

Pilot testing for this study was performed in two distinct phases. Phase I testing (6/04-10/04) consisted of operating all four RO membranes on MBR effluent at a feed water recovery of 50 %. At the end this testing period, the top performing membrane (based on rejection and flux decline) was selected for further testing. Phase II testing (11/04-12/04) evaluated the performance during of the selected RO membrane during operation at increased feed water recovery (i.e. 75%). The ability of the MBR system to produce water suitable for RO was assessed by monitoring the net operating pressure of the various RO membranes tested under constant permeate flow conditions.

Water Quality Sampling Plan

In order to meet the project objectives an extensive water quality sampling plan was implemented during the project period. Specifically, the MBR process was evaluated to meet reclaimed water quality standards and applicable requirements for irrigation, industrial and commercial uses. A specific list of agencies and requirements is provided below:

- New Mexico Environment Department (NMED) Class 1A Reclaimed Water Quality Standards.
- Industrial Water Quality Monitoring.
- NPDES.

In addition, the overall MBR/RO process was evaluated to determine if it meets water quality standards for the ground water discharge. A specific list of agencies and requirements is provided below:
- Safe Drinking Water Act Standards (SDWA) and 20.7.10 (NMAC).
- New Mexico Water Quality Control Commission Standards, 20.6.2 (NMAC).
- Wastewater, (NMED, March 2004).

Additionally, during Phase II testing, a target list containing twenty-nine (29) EDCs and PPCPs were also measured in the raw wastewater, MBR effluent and RO effluent. The compounds selected include those commonly found in secondary wastewater such as caffeine and ibuprofen along with compounds identified in literature as being commonly found in the environment (Kolpin, 2002). In addition the compounds selected have a wide variety of physical/chemical properties. All EDCs and PPCPs analysis were performed at the Southern Nevada Water Authority (SNWA) research laboratory under the direction of Dr. Shane Snyder. The SNWA laboratory is equipped with state of the art equipment for detecting emerging contaminants including LC/MS/MS (liquid chromatograph/mass spectrometer) and GC/MS/MS (gas chromatograph). Dr. Snyder has performed analysis for several key projects requiring measurements of emerging contaminants in the US (Snyder, 2001 & Vanderford et al., 2003).

RESULTS

RO Performance

Phase I

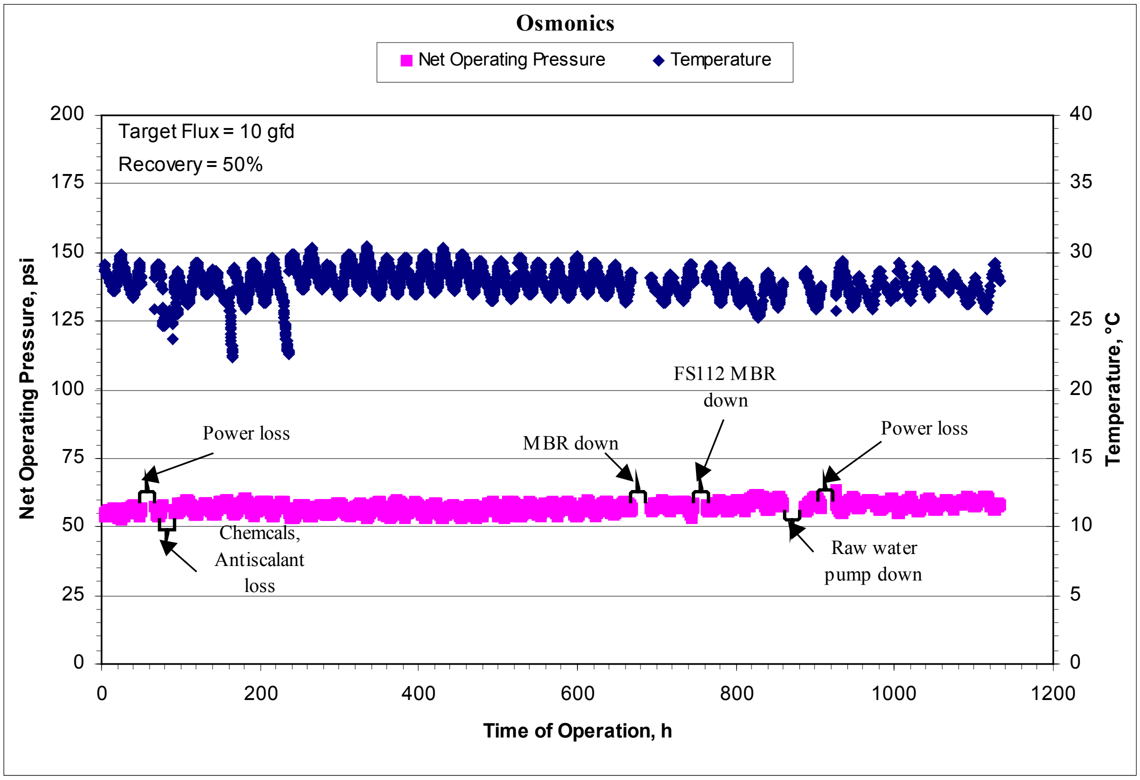
Operational performance data collected from the four RO membranes tested are presented in **Figures 1-4**. As shown the net operating pressure (psi) consistently measured for each supplier measured during operation at 10 gfd and 50% recovery follows: GE Osmonics= 60; Hydranautics=75; Toray = 80 and Saehan = 50. Based on observed specific flux decline rates, all RO membranes tested exhibited minimal or no fouling during runtimes ranging from 600 – 1,150 hours.

Conductivity profiles measured across each RO membrane during Phase I during are shown in **Figures 5-8**. Based on these results, the average conductivity rejection (%) of each supplier follows: GE Osmonics= 98.4; Hydranautics=97.8; Toray =98 and Saehan = 97.2.

Based on Phase I results the GE Osmonics AK4040 membrane was selected for further testing during Phase II. This decision was based on the membranes relatively low net operating pressure, consistent productivity (no decrease in specific flux) and relatively high conductivity rejection

Phase II

Figures 9 and 10 present operational performance and conductivity profile data, respectfully measured from the GE Osmonics AK4040 membranes under constant operating conditions (12 gfd, 75% recovery). As shown in **Figure 9**, the specific flux of the AK4040 membranes showed a slight decrease during the 450 hours of operation, indicating some membrane fouling occurred.



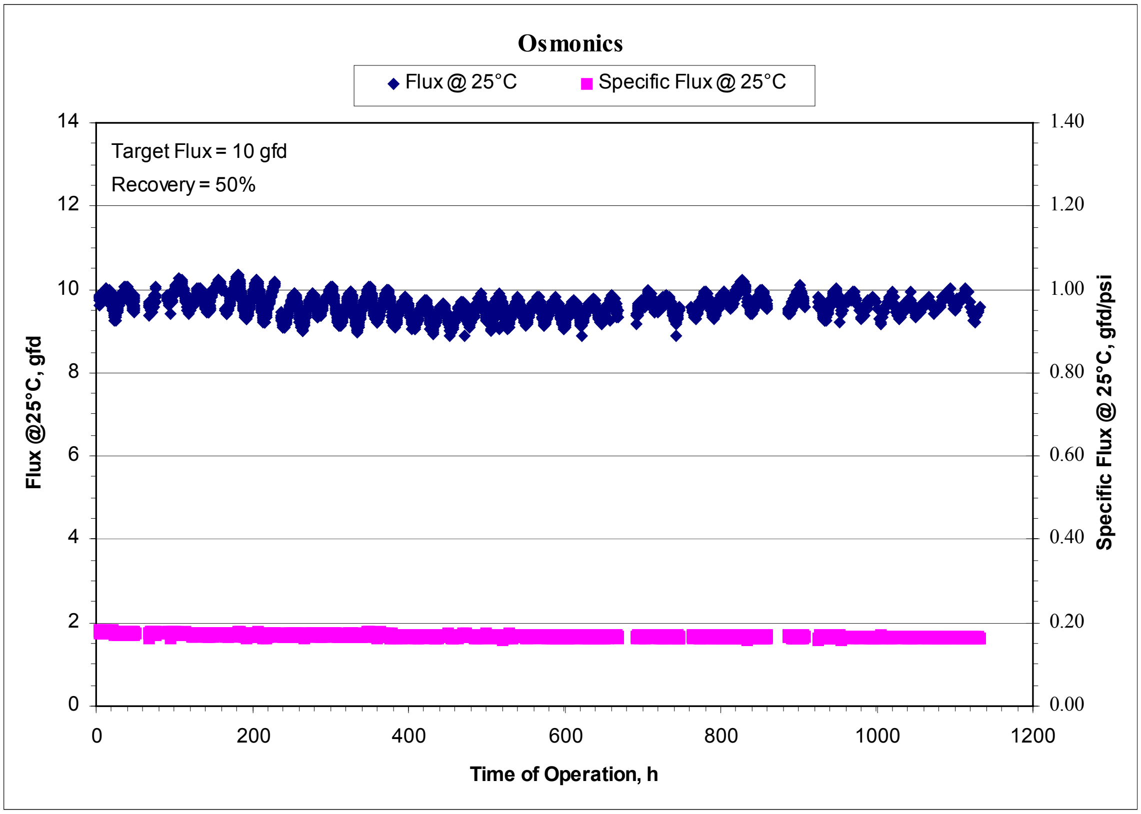


Figure 1 GE Osmonics AK4040 Membrane Perfromance During Phase I Testing

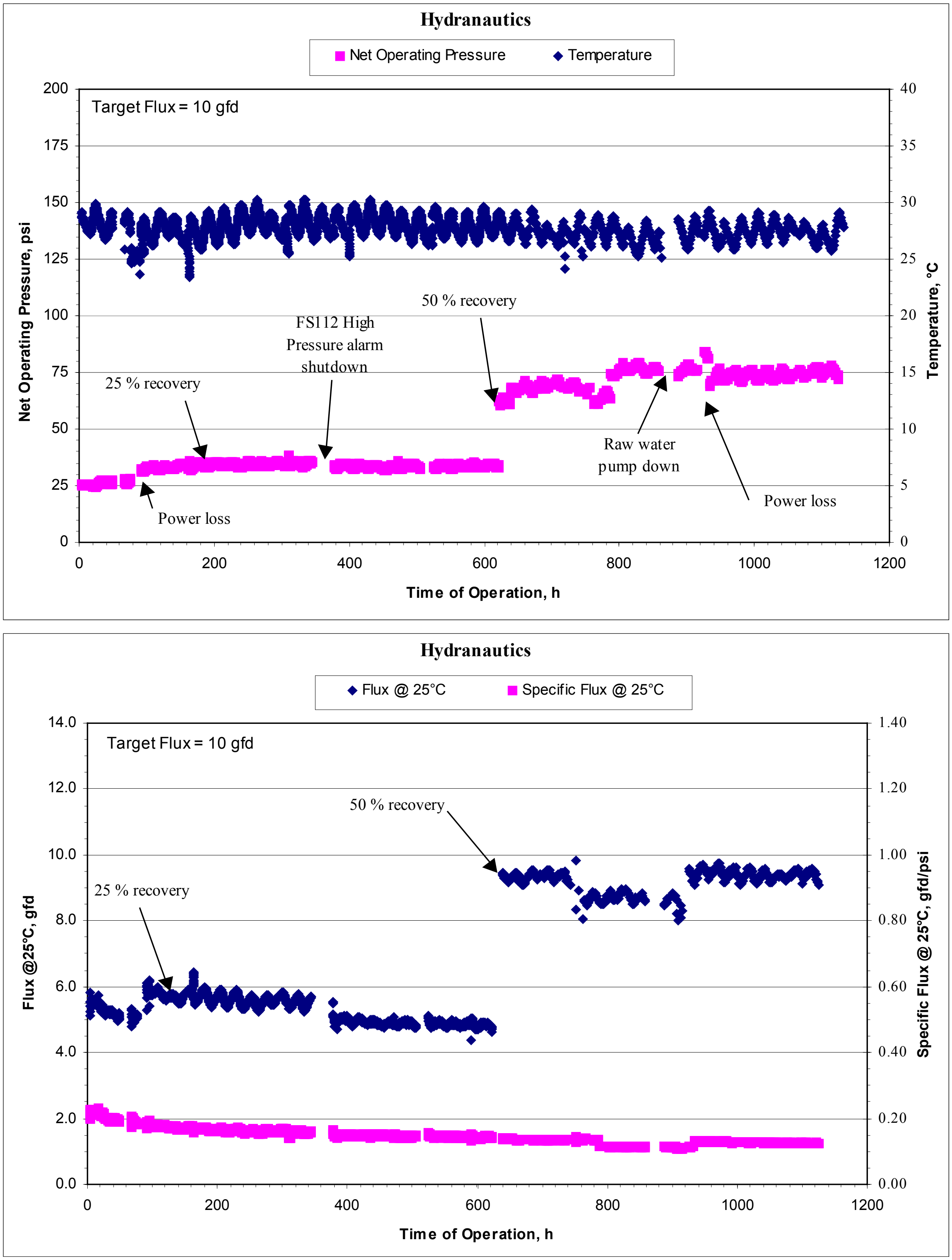


Figure 2 Hydranautics ESPA2-4040 Membrane Perfromance During Phase I Testing

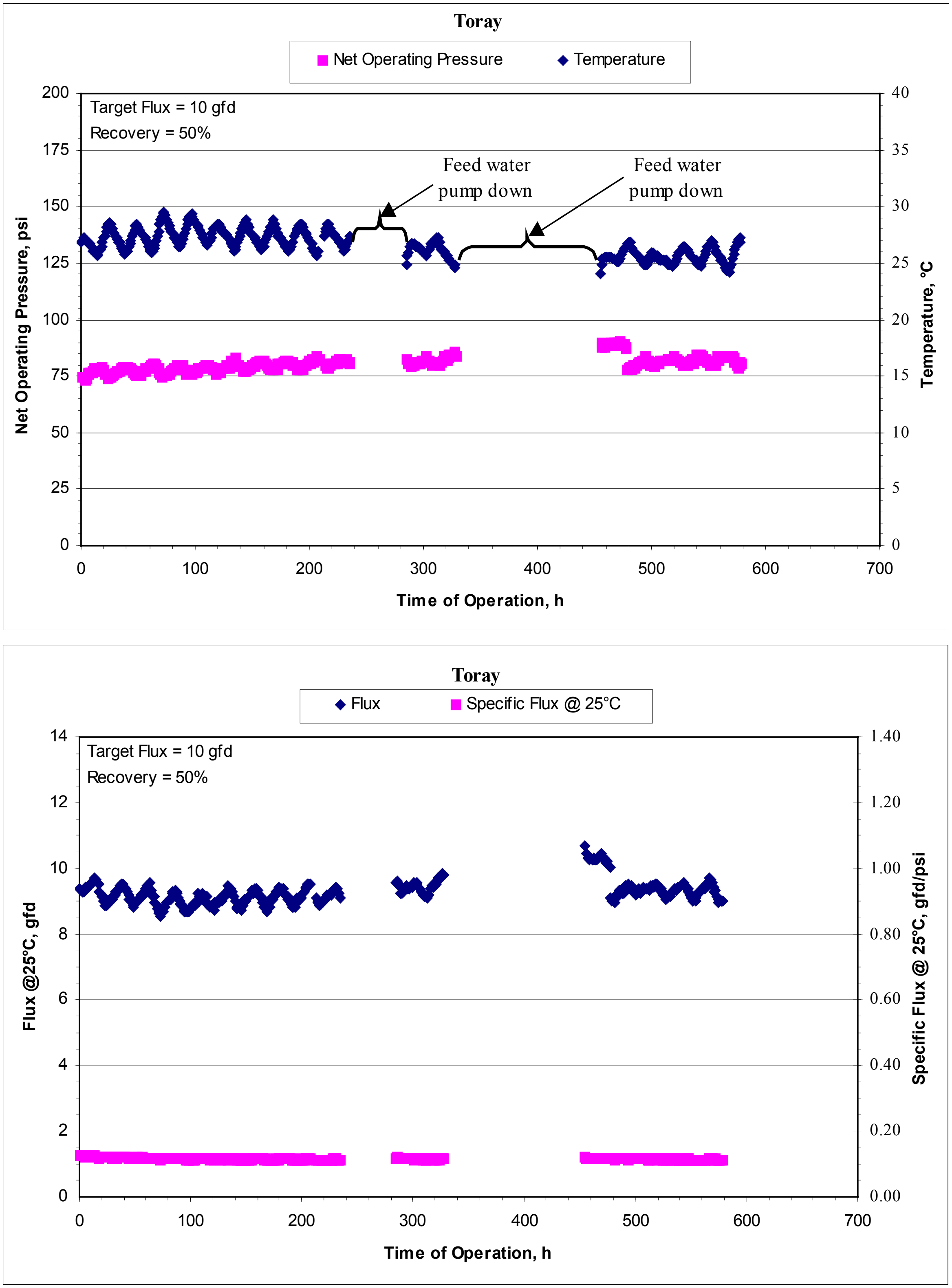
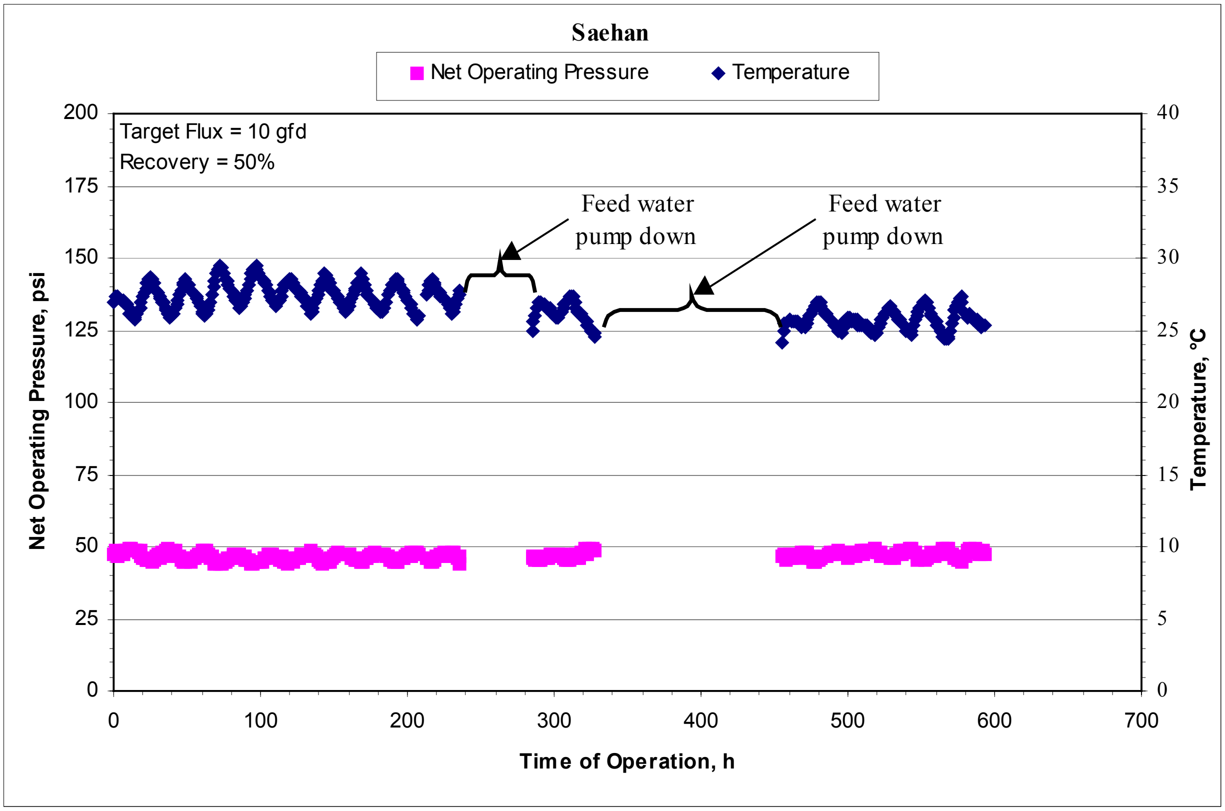


Figure 3 Toray TML-10 Membrane Perfromance During Phase I Testing



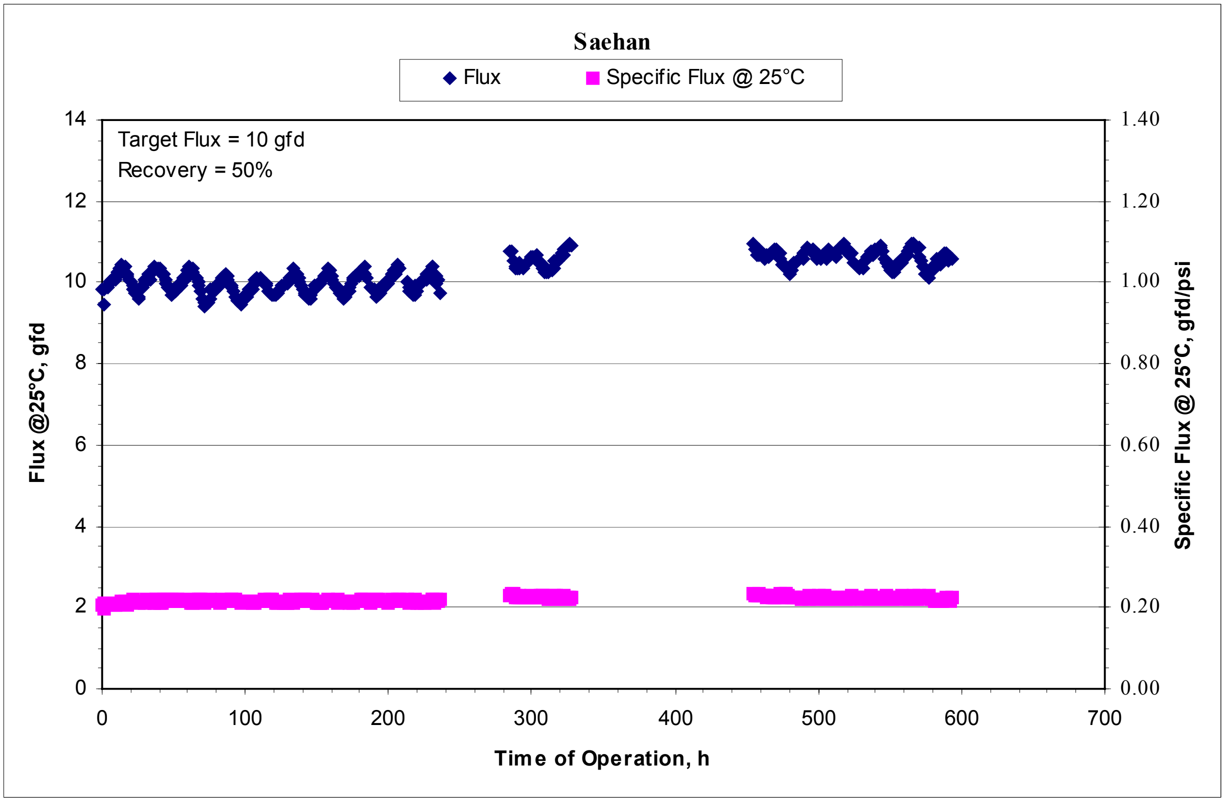


Figure 4 Saehan BLR-4040 Membrane Perfromance During Phase I Testing

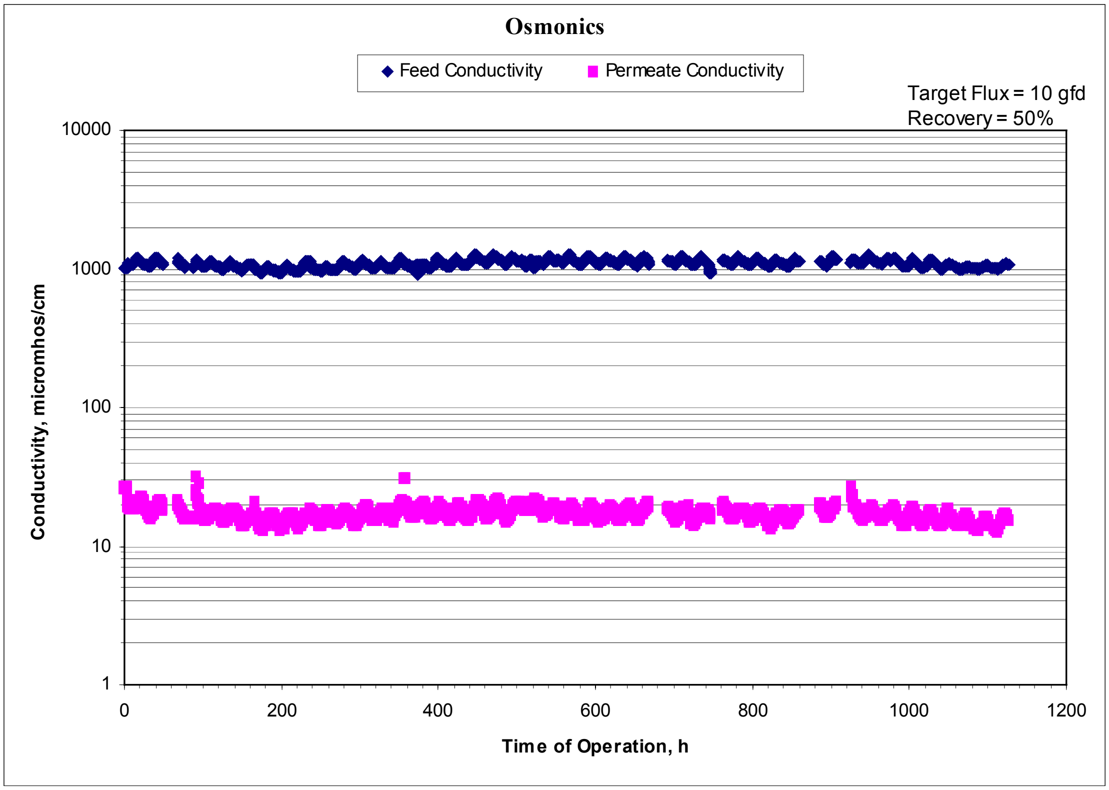


Figure 5: Conductivity profile across the GE Osmonics AK4040 Membrane (Phase I)

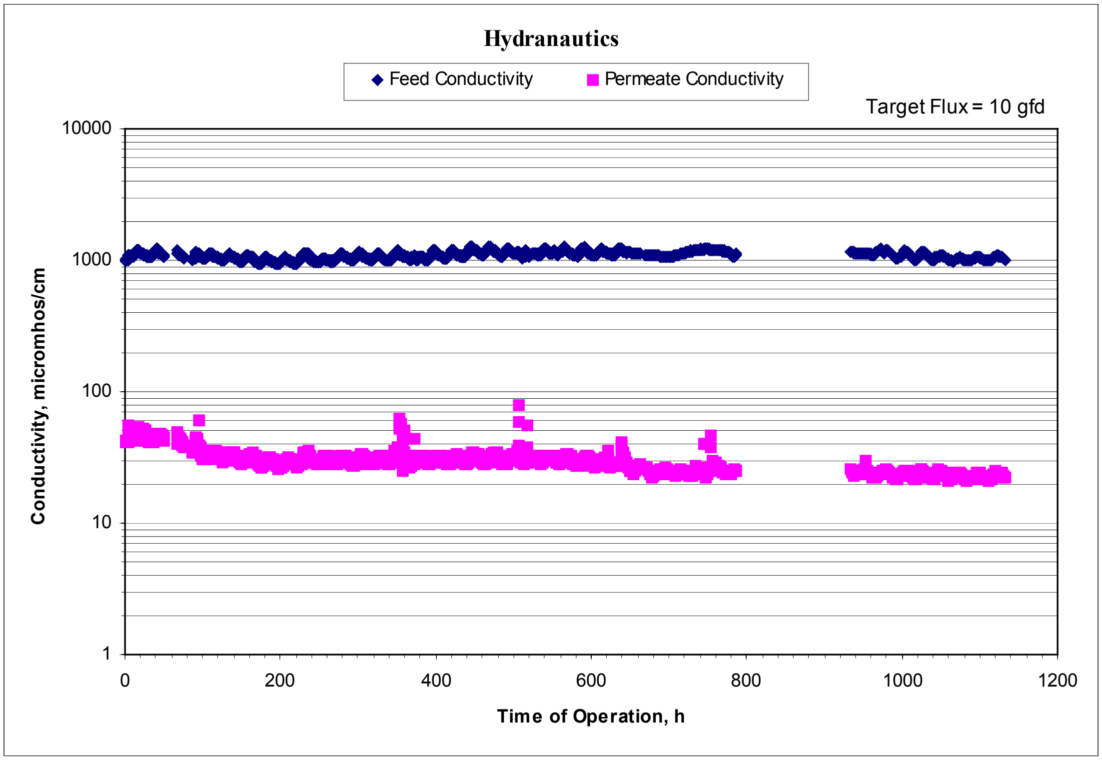


Figure 6: Conductivity profile across the Hydranautics ESPA2-4040 Membrane (Phase I)

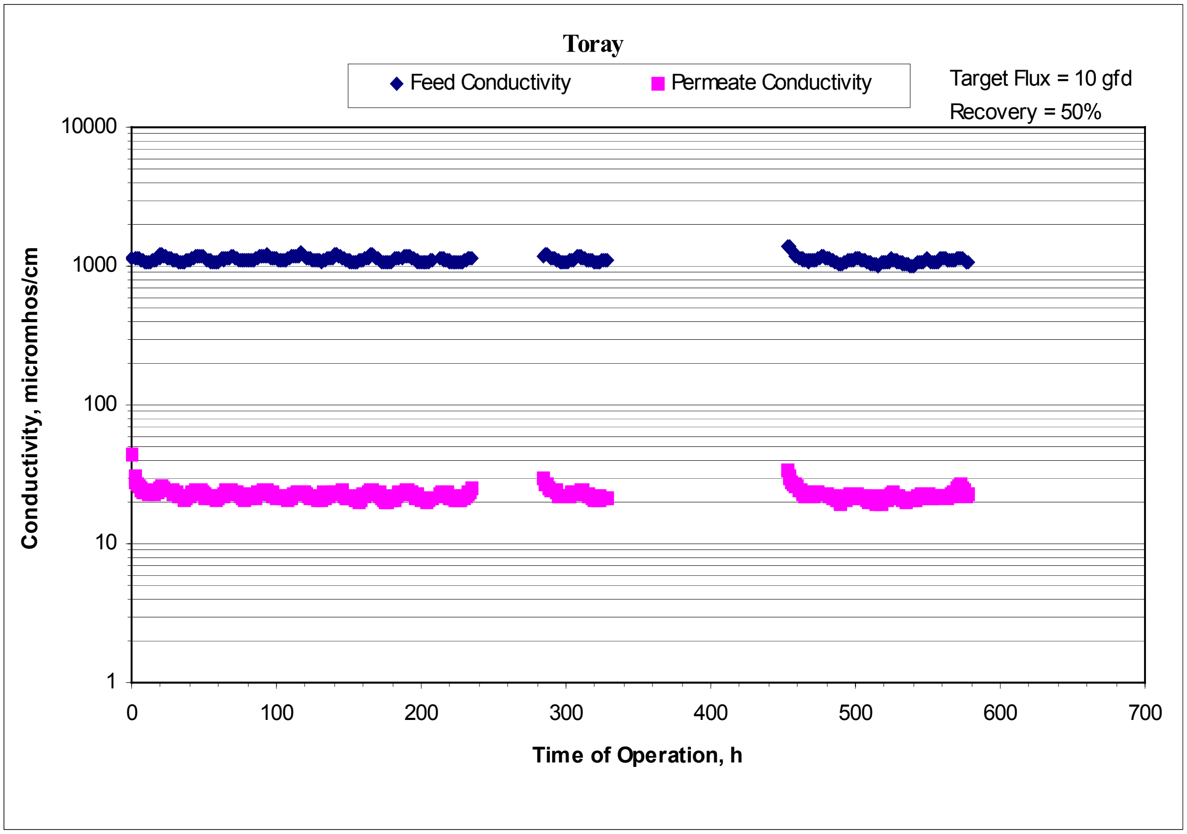


Figure 7: Conductivity profile across the Toray TM10 Membrane (Phase I)

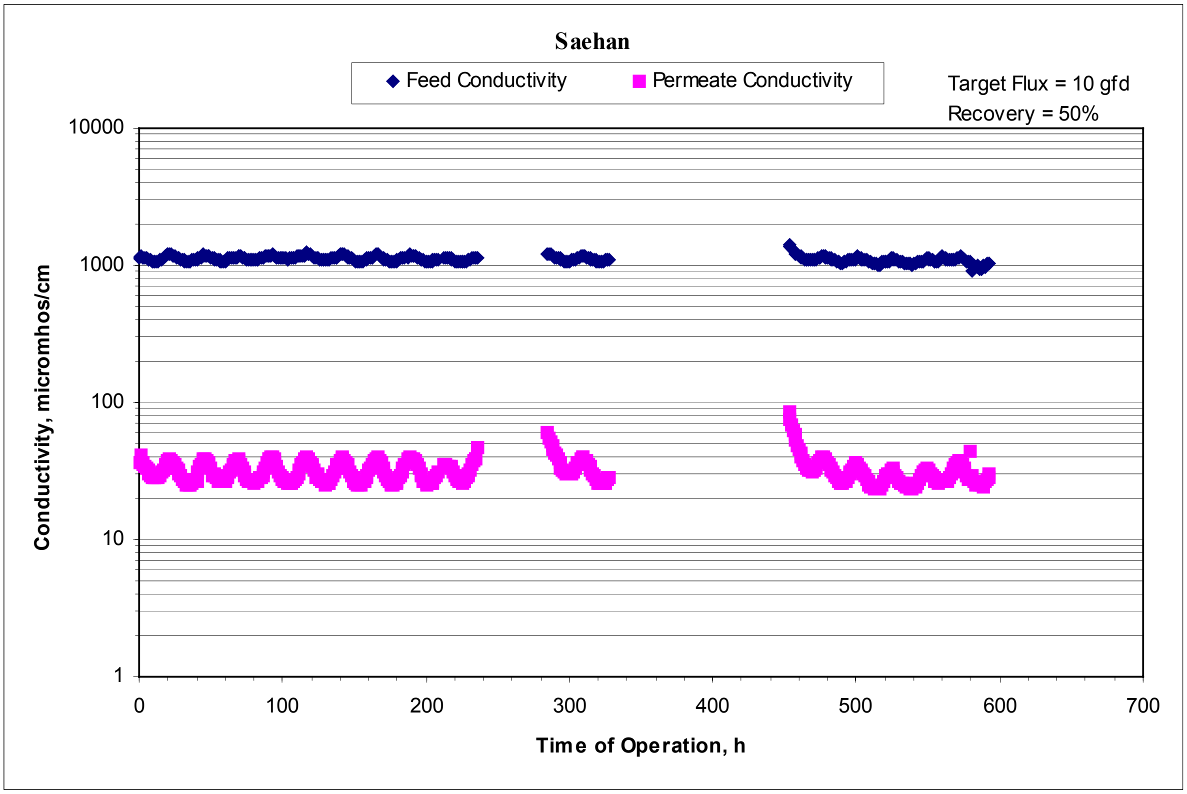
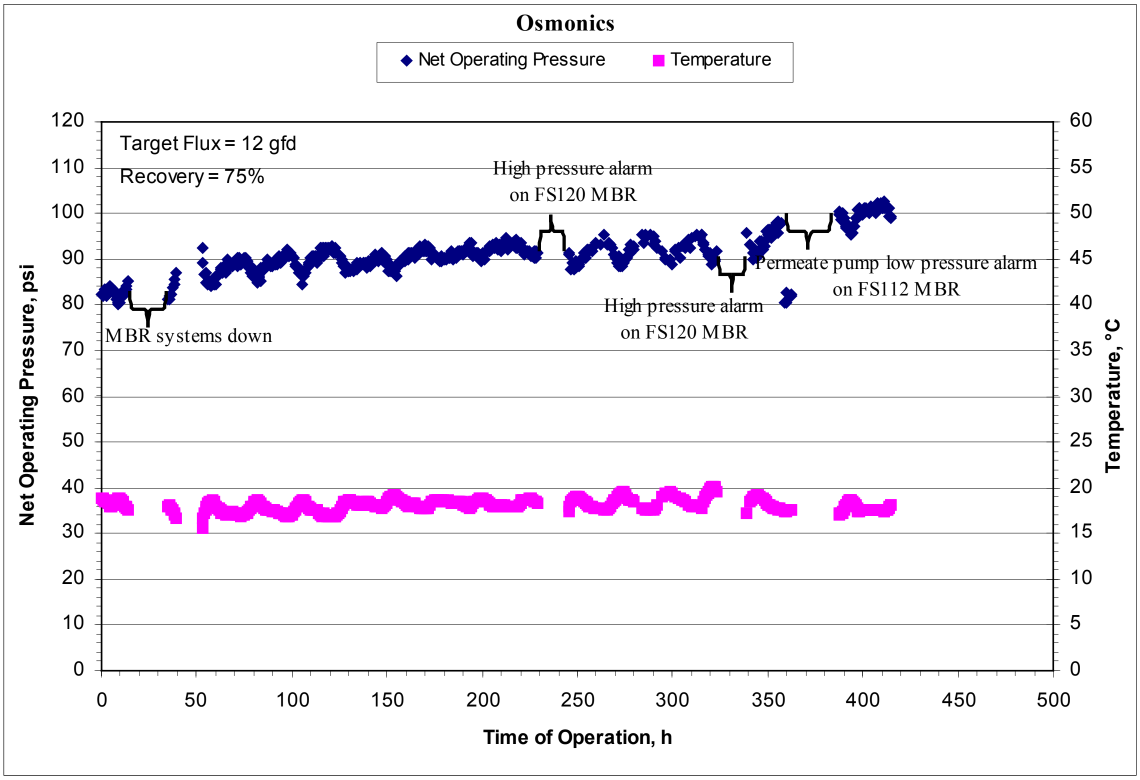


Figure 8: Conductivity profile across the Saehan 4040 BLR Membrane (Phase I)



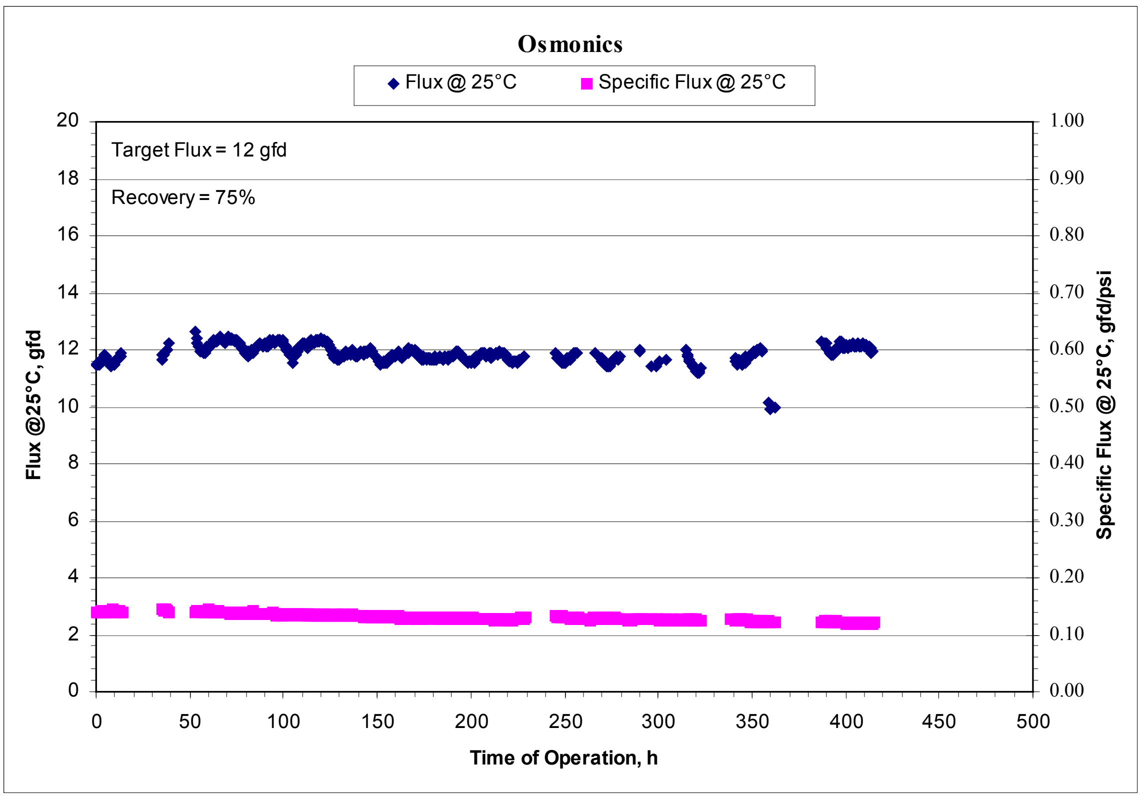


Figure 9 GE Osmonics AK4040 Membrane Perfromance (Phase II Testing)

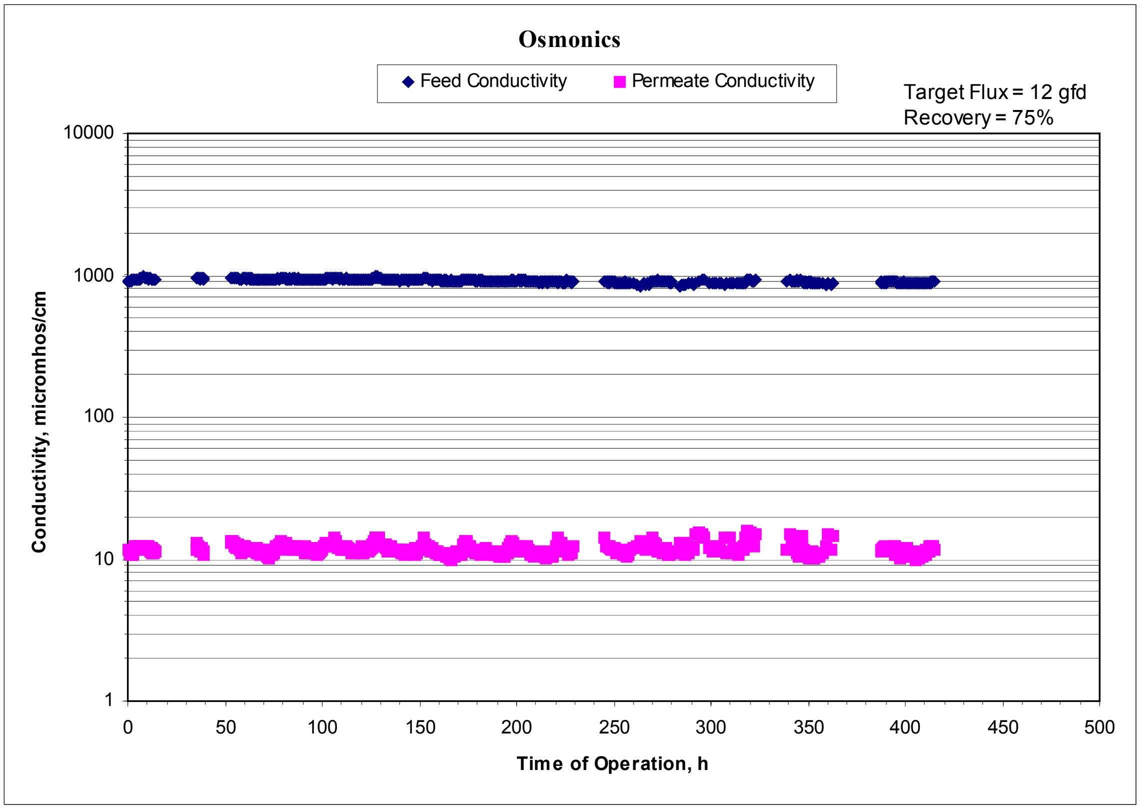


Figure 10: Conductivity profile across the GE Osmonics AK4040 Membranes (Phase II)

Water Quality Analysis

State & Federal regulations

Results from the water quality analysis showed that the combined MBR/RO process met all state and federal drinking water regulatory goals established at the onset of testing. Contaminants listed covered by these regulations include a wide variety of inorganic and organic compounds. In general the inorganic compounds include metals, anions, cations, hardness, silica and other physical parameters such as color, odor and turbidity. The organic compounds include a wide range of herbicides, pesticides, semi-volatile and volatile analytes.

EDC & PPCPs

The EDC and PPCP analytical results measured from MBR/RO process train are presented in Table 2. Most EDC and PPCP compounds were removed through the MBR/RO process to concentration levels below analytical detection. Therefore, RO treatment at 75% recovery appears, from this limited sampling event, to be effective at removing the majority of these compounds. The only compound detected in the RO permeate was tri-2-chloroethyl-phosphate (TCEP) for the sample collected on December 7th, 2004. TCEP is a flame retardant that is used in the production of liquid unsaturated polyester resins, textile back-coating formulations, PVC compounds, cellulose ester compounds, and coatings.

Table 2. Emerging Contaminants Water Quality Data for Integrated MBR/RO Samples Collected from City of Rio Rancho pilot facility in December 2004

				MBR Influent		RO Influent (MBR Effluent)		RO Effluent (Osmonics - 75% Recovery)	
Analyte	Category	Use	Units	12/1/04	12/7/04	12/1/04	12/7/04	12/1/04	12/7/04
Acetaminophen	Pharmaceutical	Analgesic	ng/L	199	392	<5.0	<10	<1.0	<1.0
Hydrocodone	Pharmaceutical	Analgesic	ng/L	76	81	54	85	<1.0	<1.0
Ibuprofen	Pharmaceutical	Analgesic	ng/L	1980	1990	33	169	<1.0	<1.0
Triclosan	Pharmaceutical	Antibiotic	ng/L	44	50	17	33	<1.0	<1.0
Trimethoprim	Pharmaceutical	Antibiotic	ng/L	92	199	101	250	<1.0	<1.0
Meprobamate	Pharmaceutical	Anti-anxiety	ng/L	251	309	205	339	<1.0	<1.0
Diclofenac	Pharmaceutical	Anti-arthritic	ng/L	28	32	32	38	<1.0	<1.0
Erythromycin-H_2O	Pharmaceutical	Antibiotic	ng/L	34	50	50	90	<1.0	<1.0
Sulfamethoxazole	Pharmaceutical	Antibiotic	ng/L	883	1490	667	1800	<1.0	<1.0
Gemfibrozil	Pharmaceutical	Anti-cholesterol	ng/L	660	701	357	698	<1.0	<1.0
Dilantin	Pharmaceutical	Anti-convulsant	ng/L	236	259	206	310	<1.0	<1.0
Fluoxetine	Pharmaceutical	Anti-depressant	ng/L	15	17	9.0	23	<1.0	<1.0
Naproxen	Pharmaceutical	Anti-inflammatory	ng/L	1710	2660	66	467	<1.0	<1.0
Carbamazepine	Pharmaceutical	Anti-seizure	ng/L	243	367	199	410	<1.0	<1.0
Pentoxifylline	Pharmaceutical	Blood thinner	ng/L	<5.0	<10	<5.0	<10	<1.0	<1.0
Diazepam	Pharmaceutical	Muscle Relaxant	ng/L	<5.0	<10	<5.0	<10	<1.0	<1.0
Iopromide	Pharmaceutical	X-ray contrast agent	ng/L	233	564	186	1230	<1.0	<1.0
Caffeine	Personal Care	Stimulant	ng/L	2270	7140	223	1650	<10	<10
DEET	Personal Care	Insect repellant	ng/L	74	365	16	20	<1.0	<1.0
Oxybenzone	Personal Care	Sunscreen	ng/L	37	50	5.7	16	<1.0	<1.0
TCEP	Pesonal Care	Flame Retardant	ng/L	218	291	180	334	<10	30
Estriol	Steroid	Estrogen	ng/L	<25	<5.0	<25	<5.0	<5.0	<5.0
Estrone	Steroid	Estrogen	ng/L	72	70	13	21	<1.0	<1.0
Estradiol	Steroid	Estrogen	ng/L	8.1	17	<5.0	<1.0	<1.0	<1.0
Progesterone	Steroid	Estrogen	ng/L	<5.0	6.4	<5.0	<1.0	<1.0	<1.0
Ethynylestradiol	Steroid	Synthetic estrogen	ng/L	<5.0	32	<5.0	<1.0	<1.0	<1.0
Testosterone	Steroid	Androgen	ng/L	<5.0	<1.0	<5.0	<1.0	<1.0	<1.0
Androstenedione	Steroid	Androgen	ng/L	30	25	<5.0	2.6	<1.0	<1.0

CONCLUSIONS

The following conclusions were made from this study:

- The MBR process met requirements for non potable and industrial reuse applications
- MBR process consistently produced water suitable for treatment by RO
- RO membranes from multiple suppliers operated successfully during operation on municipal wastewater pretreated by MBR.
- The combined MBR/RO process effectively met all state and federal drinking water standards
- Most of the EDC and PPCP compounds measured were removed through the MBR/RO process to concentration levels below analytical detection

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