Check for updates

Evaluation of an integrated membrane system for water repurification

P. Gagliardo*, S. Adham, A. Olivieri*** and R. Trussell****

* Metropolitan Wastewater Department 600 B Street, Suite 500, San Diego, California, 92101-4587 USA

** Montgomery Watson, 555 East Walnut Street, Pasadena, California, 91101 USA

*** EOA, 1410 Jackson Street, Oakland, California, 94612 USA

Abstract An integrated membrane system was evaluated for water repurification. Performance evaluation of the membrane system was based on three criteria: flux and fouling, disinfection capability, and rejection of pollutants. Minimal membrane fouling was observed for all of the membranes employed in the study. Significant contaminant rejection was also achieved by the membrane system purifying the reclaimed water to meet and exceed drinking water standards. Wide range of virus rejection was observed for the membranes, which was dependent on the membrane type, manufacturer, and the fouling status. Overall, the results of this study demonstrated that the integrated membrane system is a very effective and reliable process for water repurification.

Keywords Membrane; reclamation; repurification

Water Science and Technology **Vol 43 No10 pp 219–224** © IWA Publishing 2001

Background

San Diego County Water Authority and the City of San Diego have been promoting the development of alternative water sources to reduce San Diego County's reliance on limited imported water supplies. Water repurification, in which reclaimed water receives additional advanced level treatment prior to its discharge to a potable water supply reservoir, is one of the alternatives that were seriously considered.

A Feasibility Study (Montgomery Watson 1994) was conducted in 1994 in which an advanced water treatment (AWT) system was proposed for the water repurification project. The California Department of Health Services (CDHS) issued a conditional approval of the project proposed in the Feasibility Study but requested that some issues be resolved through pilot demonstration. This request generated the creation of the Aqua 2000 Research Center (Aqua 2000) where pilot testing of the AWT system, which includes microfiltration (MF) or ultrafiltration (UF), reverse osmosis (RO), ion exchange, ozonation, and pipeline chlorination, was performed from 1995–1998. As pilot experiments were developed and performed, and results analyzed, it became more certain that the AWT system piloted could reliably and safely produce a drinking water quality product. (Montgomery Watson 1995, 1997; Soller *et al*. 1997) This paper will discuss the overall performance of the integrated membrane system based on results obtained in 1997 and 1998.

Methods

Experimental setup

A pilot-scale treatment train consisting of the various processes shown in Figure 1 was operated during the study. The membrane systems evaluated are described below.

Microfiltration membrane system. A microfiltration (MF) membrane system (Model 6M10C), that employs Memcor hollow fiber membranes was employed in the study (Memtec American Corp./Memcor Division, San Diego, CA.) Table 1 provides the specifi-

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest

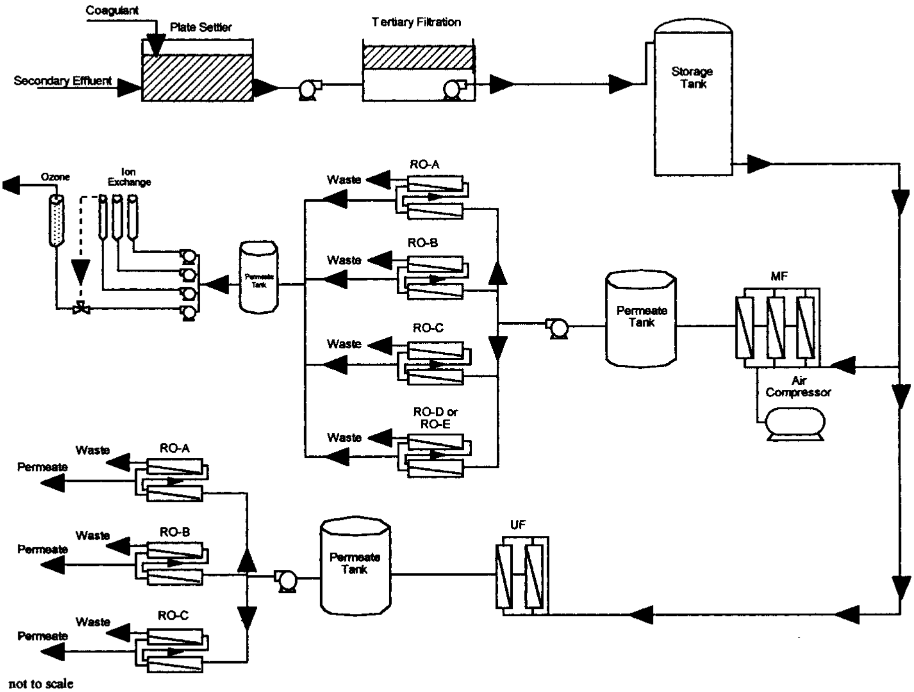

Figure 1 Schematic flow diagram of the AWT pilot treatment train

Table 1 Selected manufacturers specifications for the pretreatment membranes employed

	MF	UF
Commercial designation	Memcor	Aquasource
Membrane process	Microfiltration	Ultrafiltration
Membrane cutoff rating	0.2 µm	100,000 daltons
Membrane configuration	Hollow fiber	Hollow fiber
Membrane material	Polypropylene	Cellulosic Esters
Operating pH range	0.5–13.5	4–8.5
Maximum operating temperature	113°F (45°C)	95°F (35°C)
Free chlorine resistance	0.0 ppm	2 ppm continuous
Maximum operating pressure	15 psi (1 bar)	29 psi (2 bar)
Recommended operating pressure	3–15 psi (0.2–1.0 bar)	(5–29 psi) (0.3–2.0 bar)
Clean water specific flux	28 gfd/psi @ 68°F (688 L/h/m2/bar @ 20°C)	9.0 gfd/psi @ 68°F (220 L/h/m2/bar @ 20°C)
Recommended fiber flow velocity	0 ft/sec 0–3 ft/sec	(0 m/s) (0–0.9 m/s)
Periodic cleaning procedure	Air Backwash	Liquid backwash
Effective membrane surface area	160 ft2(15 m^2)	590 ft2(55 m^2)
Hollow-fiber configurations		
Flow configuration	transverse flow (out-in)	cross-flow (in-out)
Internal fiber/tube diameter	0.012 in (0.31 mm)	0.037 in (0.93 mm)
External fiber/tube diameter	0.022 in (0.50 mm)	0.066 in (1.67 mm)
Maximum effective backwash pressure	110 psi (7.6 bar)	36 psi (2.5 bar)

cations for the Memcor membranes. The MF pilot consists of a feed pump, a feed tank, an air compressor, and a recirculation loop which includes the membrane modules. Six membrane modules (160 ft^2, 15 m^2 ea.) were installed for the pilot plant. The pilot plant was operated without recirculation (i.e. direct flow) as recommended by the manufacturer. Compressed air (90 psi, 6.2 bar) is used to periodically backwash the membrane modules, which is a unique feature of the Memcor system design.

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest

Ultrafiltration membrane system. An ultrafiltration (UF) membrane system that uses Aquasource hollow fiber membranes will be employed in the study (Memtec American Corp./Memcor Division, San Diego, CA.) Table 1 provides the specifications for the Aquasource membranes. The UF membranes pilot plant consists of a feed pump, a recirculation pump, a backwash pump, and a recirculation loop which includes two membrane modules. The pilot plant was operated without recirculation. Permeate water dosed with approximately 5 mg/L free chlorine was used to periodically backwash the membrane modules.

Reverse osmosis membrane system. Four RO membrane systems were designed and constructed for the pilot testing program. Each pilot system contains two independent sets of pressure vessels with a single pass mode that allows parallel evaluation of two different RO membranes. Each set of pressure vessels can house a total of six 4” × 40” RO elements, three elements per single pressure vessel. Four types of RO membrane were evaluated in the study. Table 2 provides the specifications of the evaluated RO membranes. These RO membranes were evaluated simultaneously after MF and UF pretreatment, and thus two RO pilot units were located downstream of the MF unit and the other two will be located downstream of the UF system. The permeate of the RO membranes downstream of the UF system was directed to waste and the permeate of the RO membranes downstream the MF system was blended and then used as the feedwater to the subsequent treatment processes. The concentrate of all the RO membranes was directed to waste.

Results

Performance evaluation of the AWT system was based on three criterions: flux and fouling of the membrane systems, disinfection capability, and rejection of pollutants such as salts, organics and nutrients. Below is a summary of the project findings.

Flux and fouling. Figure 2 shows the operational pressure of three prequalified polyamide RO membrane employed during the testing. The membranes were operated for more than 8,000 hr at a flux of 12 gfd (20L/h/m^2). The net operating pressure of the membranes was mainly a function of temperature and no significant fouling (i.e. increase in pressure) was observed throughout the testing period. This indicate that low pressure membranes were very effective as a pretreatment process to the RO membranes removing most colloidal matter resulting in the low level of RO membrane fouling. In addition, it appears that the new generation of polyamide RO membranes employed are capable of handling the level

Table 2 Selected Manufacturers Specifications for the Reverse Osmosis Membranes Employed

	RO-A	RO-B	RO-C	RO-D
Manufacturer	Filmtec/Dow	Hydranautics	Fluid Systems	Fluid Systems
Commercial designation	BW30HP-8040	4040-UHA-ESPA	TFCL/M4820HR	TFCL/ULP
Membrane process	Reverse osmosis	Reverse osmosis	Reverse osmosis	Reverse osmosis
Membrane material	Polyamide (thin-film composite)	Polyamide (thin-film composite)	Polyamide (thin-film composite)	Polyamide (thin-film composite)
Operating pH range	2.0–11.0	3.0–10.0	4.0–11.0	4.0–11.0
Maximum feedwater turbidity	1.0 ntu	1.0 ntu	1.0 ntu	1.0 ntu
Max. feedwater SDI (15 min)	5.0	4.0	4.0	4.0
Maximum operating temp.	113°F (45°C)	113°F (45°C)	113°F (45°C)	113°F (45°C)
Free chlorine resistance	< 0.1 ppm	< 0.1 ppm	0.0 ppm	0.0 ppm
Maximum operating pressure	600 psi (40 bar)	600 psi (40 bar)	600 psi (40 bar)	600 psi (40 bar)

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest

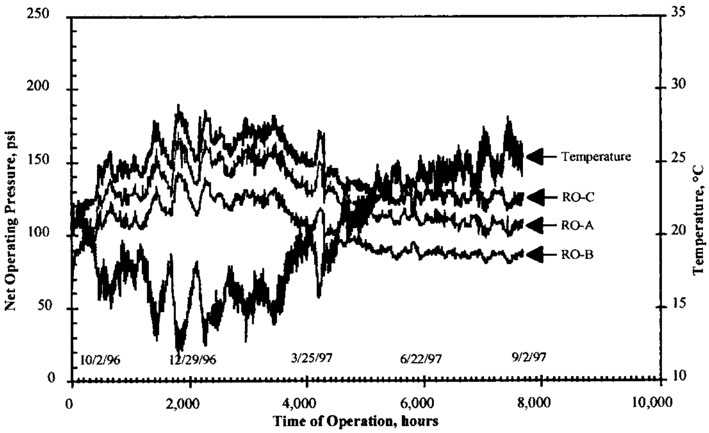

Figure 2 Net operating pressure for reverse osmosis membranes with microfiltration pretreatment

and type of organics present in San Diego wastewater with minimal fouling. No significant fouling was also observed for the pretreatment membranes.

Disinfection capabilities

Special challenge experiments with parasites and MS2 virus were conducted on the various membranes employed. All membranes were able to reject *Giardia* and *Cryptosporidium* to below the detection limits of the assay, achieving more than 4.7 log removal. The UF membranes rejected most of the seeded virus, when membranes were not compromised, to below the detection limits of the assay achieving more than 6 logs rejection. The log removal of virus by the MF membrane varied from 0.0 to 3.3 depending on fouling status of the membranes. The log removal of virus by the different RO membranes, surprisingly, varied from 2.1 to > 5.9 logs depending on the membrane type (Table 3). For example RO-A was able to reject the seeded virus to below the detection limits achieving > 5.3 log rejection (mean) while RO-C rejected only 2.8 log (mean), with the virus being recovered in the permeate. Throughout the testing period, no total or fecal coliforms were detected in any of the RO permeates.

Several techniques were evaluated to monitor the integrity of the membrane systems. For example, the vacuum test was conducted on each RO membrane element prior to installation to the pilot units. Higher vacuum loss values may indicate that imperfections are present in the membrane element. Figure 3 shows the distribution of the vacuum test results for three of the RO membranes employed. RO-A resulted in the lowest vacuum leak per element (avg. 0.07 bar/min) while RO-C resulted in the highest vacuum leak per element. These data may indicate that RO-A has fewer imperfections than RO-C, which is consistent with the virus rejection data, presented above. The correlation between the virus rejection data and the vacuum test results is shown in Figure 4. Good correlation was observed which

Table 3 Summary of MS2 virus removal by RO membranes

Membrane	Count	Influent G.Mean (pfu/mL)	Permeate G.Mean (pfu/mL)	Log Removal Mean	Log Removal Median	Log Removal Range
RO-A	9	2.3×10^5	$< 1.2\times10^0$	> 5.3	> 5.7	4.1 – > 5.9
RO-B	9	4.5×10^5	$< 1.3\times10^1$	> 4.6	4.4	3.7 – 5.7
RO-C	9	2.3×10^5	3.4×10^2	2.8	3.0	2.1 – 3.3
RO-D	9	4.5×10^5	1.9×10^2	3.4	3.3	2.9 – 4.3

Note: Detection limit = 1 pfu/mL

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest

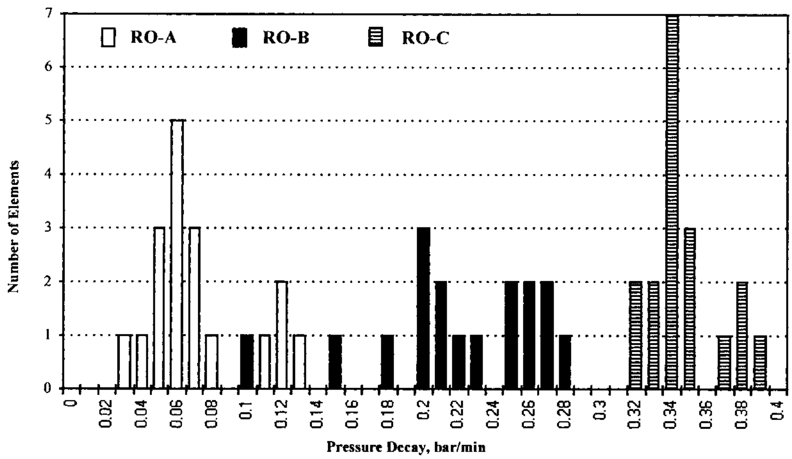

Figure 3 Vacuum-hold test pressure frequency distribution

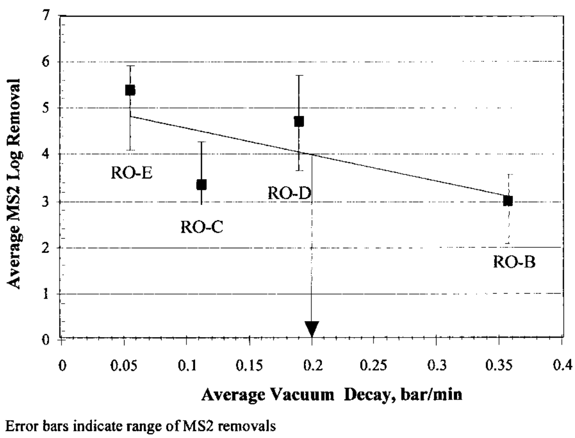

Figure 4 Relationship between vacuum decay and rejection of MS2 virus by RO

confirms that the vacuum test can be used as an effective tool to evaluate the integrity of the RO elements.

Rejection of contaminant

Several water quality parameters were routinely monitored from the influent and effluent of all RO membranes. Table 4 presents the influent and effluent concentrations of selected water quality parameters. Overall, significant rejections (90 – >99%) were observed for salts, nutrients, and total organic carbon (TOC). Figure 5 shows the TOC profile in the feed and permeate of RO-A. The feed TOC was approximately 7,000 ppb while the permeate was below 70 ppb, achieving more than 2 logs removal. The increase of TOC in the RO permeate was a result of higher feed water temperatures causing more solute transport across the membranes.

Samples were also collected from the RO permeate and analyzed for all drinking water quality parameters that are regulated at the State and/or Federal level. The RO permeate water quality was below the drinking water standards level for all parameters.

Conclusions

The results of this study demonstrated that the integrated membrane system is a very effec-

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest

Table 4 Influent and effluent concentrations of selected water quality parameters

Parameter	Inf	MF	UF	MFRO
Organics				
TOC (mg/L)	9.1	7.8	6.9	0.03
UV_{254} (cm^{-1})	0.15	0.12	0.12	0.01
Nitrogen				
Ammonia (mg/L-N)	12.1	11.6	12.3	0.54
Nitrate (mg/L-N)	5.9	5.8	5.2	0.18
Nitrite (mg/L-N)	1.7	1.8	1.6	0.05
Metals				
Calcium (mg/L)	74	77	73	<1.0
Manganese (ug/L)	71	69	60	<1.1
Sodium (mg/L)	204	208	204	<1.1
Iron (ug/L)	248	52	51	<50
Pathogens				
Total Coliform (MPN/100mL)	6.4×10^3	nd	nd	nd
Fecal Coliform (MPN/100mL)	3.0×10^3	nd	nd	nd
Coliphage (pfu/100mL)	3.3×10^3	<6.9	<1.1	nd

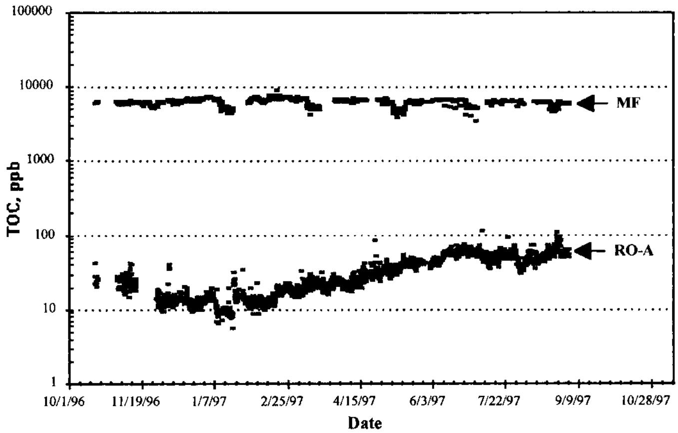

Figure 5 Typical TOC profile for the reverse osmosis membranes

tive and reliable process for water repurification. Minimal membrane fouling was observed for all of the membrane employed in the study. Significant contaminant rejection was achieved by the membrane system purifying the reclaimed water to meet and exceed drinking water standards. Wide range of virus rejection was observed for the membranes, which was dependent on the membrane type, manufacturer, and the fouling status. Various membrane integrity-monitoring techniques were evaluated and an attempt was made to correlate their response to the microbial challenge experiments.

References

Montgomery Watson (1994). *Water Repurification Feasibility Study*. Final Report prepared for San Diego County Water Authority. June 1994.

Montgomery Watson (1995), *Advanced Treatment Pilot Study*. Final Report prepared for the City of San Diego, December 1995.

Montgomery Watson (1997), *Membrane Prequalification Pilot Study*. Final Report prepared for the City of San Diego, October 1997.

Soller, J.A., Olivieri, A.W., Eisenberg, D.M., Eisenberg, J.N. and Cooper, R.C. (1997). *Microbial Challenge Studies at Aqua 2000 Research Center and Estimation of Process Train Performance with Respect to Microbial Agents*. Prepared by the Public Health Institute, EOA, Inc., BioVir, and Montgomery Watson, for the City of San Diego, Dec. 1997.

Downloaded from http://iwaponline.com/wst/article-pdf/43/10/219/428740/219.pdf
by guest