LOW FOULING REVERSE OSMOSIS MEMBRANES: EVIDENCE TO THE CONTRARY ON MICROFILTERED SECONDARY EFFLUENT

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ABSTRACT

Orange County Water District (OCWD) has been in the forefront of water reuse since the 1960s being one of the first agencies to focus on demineralization of municipal wastewater. Early efforts focused on distillation processes and then changed to reverse osmosis (RO) in the 1970s. OCWD began operation of Water Factory 21 in Fountain Valley, California in 1976, which uses a three stage pretreatment process ahead of RO to reclaim secondary effluent from the Orange County Sanitation District. Now that Water Factory 21 is nearing the end of its useful life, OCWD is planning the Groundwater Replenishment (GWR) System as its replacement. The GWR System will use microfiltration (MF) as pretreatment to RO followed by Ultraviolet (UV) Irradiation. As part of the project, OCWD has been testing thin film composite RO membranes to qualify them for the GWR System, which will have a RO capacity of 70 mgd. Additionally, OCWD has tested low fouling membranes to determine if they would offer additional benefits to the project.

West Basin Municipal Water District (WBMWD), similar to OCWD, has been in the forefront of reclamation having installed a conventional pretreatment system including lime clarification, recarbonation and filtration ahead of RO in 1995 for supplementing the seawater intrusion barrier. Subsequent to that, WBMWD was the first agency to install full-scale MF and RO facilities for treating secondary wastewater effluent for injection into the seawater intrusion barrier at the West Basin Water Recycling Plant in El Segundo, CA in July 1997. Since that time, WBMWD has continued to expand their water reclamation and recycling facilities and have installed three additional MF/RO systems with a combined capacity of approximately 25 mgd. Since the installation of the existing MF/RO systems, WBMWD has continued to perform additional RO membrane pilot tests to determine the operating parameters and characteristics of the membranes. WBMWD is continually looking for the next membranes that will offer lower operating cost with better salt rejection.

Both agencies recently conducted independent studies to determine if the latest RO membranes to hit the market, which claimed to be low fouling or fouling resistant membranes, actually achieved better operating characteristics and lower operating pressures than previous thin film composite membranes. In 2001-2002, OCWD tested three low fouling membranes on microfiltered secondary effluent from Orange County Sanitation District. In 2001-2002, WBMWD under a research grant, operated two

different low fouling membranes in parallel for a period of seven months; and compared the performance of these membranes with regular thin film composite membranes on full-scale MF/RO facilities.

This paper will focus on OCWD and WBMWD and why both agencies continue to pilot test RO membrane before and after their projects are completed. The paper will address the results of the testing from both agencies, which have shown that the low fouling membranes did not operate at lower operating pressure than the previous membranes. Additionally, the paper will focus on the differences in the fouling characteristics of RO membranes for two different wastewater sources.

AGENCY DESCRIPTIONS

Orange County Water District (OCWD)

Orange County Water District, located in Fountain Valley, California is responsible for the protection and management of the vast local groundwater basin in northern and central Orange County. The groundwater basin supplies 75% of the water to the more than 20 Cities and agencies in Orange County the remaining 25% is imported from the Colorado River and the State Water Projects. The agency operates various facilities including the Arlington Desalter, which desalts brackish groundwater for potable use. They own and operate Water Factory 21, which treats secondary effluent for injection into the seawater intrusion barrier. Additionally they operate the Green Acres Project, which utilizes media filters to treat secondary effluent for irrigation. OCWD is also responsible for maintaining the seawater intrusion barrier facilities and inland recharge basins and facilities.

OCWD is one of the agencies, which has pioneered the reclamation of municipal wastewater effluent to decrease dependence on imported water at the Water Factory 21 treatment plant. While optimizing operations of the advanced water treatment plant over time, OCWD has continued to look ahead to the water needs of the surrounding region. In the mid 1980s, the agency began planning for the next treatment system to replace Water Factory 21. Since that time, the District has researched membrane filtration as pretreatment to reverse osmosis and established that it is the most effective and economical treatment. In addition, the District has continued to test the latest RO membranes to establish operating and fouling characteristics, and permeate water quality. Successful demonstration test results have allowed the District to conceive their latest endeavor known as the Groundwater Replenishment (GWR) System.

The Groundwater Replenishment System is a joint project between OCWD and Orange County Sanitation District (OCSD), also located in Fountain Valley, California. The project implements an advanced water treatment facility (AWTF) utilizing membrane filtration (MF) as pretreatment to a reverse osmosis (RO) system, which is followed by ultraviolet (UV) irradiation for treatment of secondary effluent from the OCSD Plant No. 1. The project will be constructed in three (3) phases and will ultimately have a treatment capacity of 130 mgd. Under the first phase of the project, the GWR System will treat secondary effluent from the OCSD presently discharged to the ocean. The system will reclaim 70 mgd to augment local aquifers and to supply the seawater intrusion barrier. This project benefits OCSD in that they will not have to build additional

outfall capacity and it benefits the community by supplying a source of high quality drought proof water for recharge, infiltration and other potential uses. OCWD and OCSD have worked together in a joint effort to plan and implement the Groundwater Replenishment System based on the research efforts of OCWD and the combined project benefits.

West Basin Municipal Water District (WBMWD)

West Basin Municipal Water District located in Carson, California is a water wholesaler responsible for buying water from the Metropolitan Water District and selling it to 17 surrounding Cities and unincorporated areas of southern Los Angeles County. They are not responsible for managing the local groundwater basins, however they use water from the basin as part of their supply. The groundwater basin supplies 33% of the potable water in the area. The remaining 67% is imported from the Colorado River and the State Water Project. WBMWD assists by supplying water to maintain the seawater intrusion barrier to prevent the ingress of seawater into the groundwater caused the extraction of water from the basin. Additionally, WBMWD has various facilities to treat different types of water for potable, irrigation and industrial uses. They own and operate both potable groundwater treatment and water reclamation facilities, which utilize advanced water treatment processes. The following Table 1 summarizes the treatment facilities, processes, and capacities.

TABLE 1

WBMWD Treatment Facilities, Processes and Capacities			
Water Treatment Facility	***Type of Water Treated***	***Process***	***Capacity, mgd***
Marv Brewer Desalter	Groundwater	Potable, RO	1.0
El Segundo Water Recycling Plant			
Title 22	Secondary Effluent	Conventional Filtration	30
Barrier Facility Phase 1	Secondary Effluent	Conventional Lime/RO	5.0
Phase 2 - Seawater Barrier	Secondary Effluent	MF Pretreatment/RO	2.5
Phase 3 Low Pressure Boiler	Secondary Effluent	MF Pretreatment/RO	4.3
Phase 3 High Pressure Boiler	RO Permeate from Low Pressure RO	Second Pass RO	2.3
Chevron Cooling Water	Tertiary Effluent (Title 22)	Biological Nitrogen Removal Process	3.5
Mobil Boiler Feed Facility	Tertiary Effluent (Title 22)	MF Pretreatment/RO	3.2
Carson Regional Water Recycling Plant	Tertiary Effluent (Title 22)	MF Pretreatment/RO	5.0

WBMWD is currently planning the next expansion (Phase IV) of the El Segundo Water Recycling Plant to supply additional reclaimed water to the seawater intrusion barrier. The expansion will replace the existing 5.9 mgd of conventional RO pretreatment with a MF system and will expand the MF and RO treatment capacity by 8.5 mgd. The agency has recently completed pilot testing of the latest MF pretreatment systems to develop design criteria and to qualify them for the expansion. WBMWD has also recently completed testing of the latest low fouling or fouling resistant RO membranes to determine if they could provide additional benefit to the existing RO systems and the planned expansion by reducing operating pressures with equal or improved water quality.

WBMWD has additionally embarked upon plans to be one of the first agencies to implement a seawater desalination plant along the West Coast. WBMWD is currently conducting a pilot test program to test MF pretreatment of seawater ahead of an RO system. The pilot testing will develop design criteria for both the MF and RO system treating the local seawater.

RO MEMBRANE TESTING OBJECTIVES

RO technology has developed over the years into a mature operating process in which the actual equipment arrangements do not significantly change except for sizing and actual layout based on project needs. However, a continuing area of change in the RO process is in the membrane chemistry. Similar to the MF and UF industries, the membrane manufacturing market is very competitive and the manufacturers continue to come out with new membrane products. The membrane process continues to see additional advances in the area of low fouling or fouling resistant membranes. Various manufacturers have begun producing membranes that are advertised to be resistant to some types of fouling and operate at lower feed pressures.

Both OCWD and WBMWD have recently concluded independent testing of these types of membranes to determine their applicability to the proposed projects and for the existing WBMWD systems. The objectives of the RO membrane tests were somewhat different since the needs of the two agencies are different. For instance, OCWD is currently in the design phase of the GWR System Project and WBMWD is already operating approximately 20 mgd of RO membrane.

OCWD is interested in testing RO membranes to meet the following objectives:

1. To determine membranes that will be acceptable for operation in the GWR System on microfiltered secondary effluent and will provide the following:
    a. Lowest possible operating pressure to reduce operating costs
    b. To determine if the fouling characteristics of the membranes will minimize the need for cleaning
    c. To determine if the membranes will achieve equal or better salt rejection.
2. With plans for a facility with such a large capacity (70 mgd), it is imperative that OCWD consider only membrane suppliers with successful operating experience on microfiltered secondary wastewater effluent and

manufacturers with the ability to manufacture a large quantity of membranes (approximately 15,000 in approximately 6 months).

3. RO membranes for the GWR System will be selected during the competitive bidding process for the construction of the facility. Therefore more than 1 manufacturer is necessary to ensure competitive pricing. The qualifying criteria for consideration on the project is as follows:
   a. The membranes will be polyamide composite membranes.
   b. The membranes must have demonstration tested with 8 inch by 40 inch elements in the demonstration facilities at Water Factory 21 for a minimum of 5000 hours.
   c. The membrane must have operated over the 5000 hours with a specific flux of 0.07 gfd/psi or greater without cleaning more than one time.
4. OCWD is currently designing the GWR System to meet the following product water quality objectives listed in Table 2.

Table 2
OCWD Water Quality Objectives

Constituent	Proposed DHS Limits
Total Organic Content (TOC), mg/l	<0.5 goal of 0.3 August 2, 2002 Draft Groundwater Recharge Reuse Regulations
Total Nitrogen, (as N), mg/l	<5 proposed <3 mg/l August 2, 2002 Draft Groundwater Recharge Reuse Regulations

West Basin is interested in the same general objectives, however their motives are different. WBMWD is operating approximately 20 mgd of existing RO treatment facilities and is continuing to expand the treatment capacity. Therefore, they are looking ahead to the next membrane replacements and to future expansion projects. The following are the objectives of the WBMWD RO membrane tests:

1. To determine membranes that will be acceptable for operation in various systems on microfiltered secondary and tertiary wastewater effluent and will provide the following:
   a. Lowest possible operating pressure to reduce operating costs
   b. To determine if the fouling characteristics of the membranes will minimize the need for cleaning
   c. To determine if the membranes will achieve equal or better salt rejection.
2. RO membranes for WBMWD will be selected by competitive bidding process for the replacement elements and for the future construction of the Phase 4 facilities, therefore more than 1 manufacturer is necessary to ensure competitive pricing.

4. WBMWD has various product water quality requirements at the different treatment facilities. The following tables 3,4 and 5 list the different water quality objectives for the various facilities:

Table 3
WBMWD Water Recycling Plant Water Quality Objectives

Constituent	Proposed DHS Limits
Total Organic Content (TOC), mg/l	<0.5 goal of 0.3 August 2, 2002 Draft Groundwater Recharge Reuse Regulations
Total Nitrogen, (as N), mg/l	<5 proposed <3 mg/l August 2, 2002 Draft Groundwater Recharge Reuse Regulations

Table 4
WBMWD Mobil Refinery Water Quality Objectives

Constituent	Limits for Mobil Refinery
Conductivity, µS/cm	<50 annual average
Total Organic Content (TOC), mg/l	<0.7 weekly average 1.5 maximum
Ammonia, mg/l	<1.9 average
Silica, mg/l	<1.0 weekly average
Sodium, mg/l	<6.8 average
Chloride, mg/l	<3.2 average
Nitrate (as N), mg/l	<0.2 average
Nitrite (as N), mg/l	<0.3 average

Table 5
WBMWD Carson RWRP Water Quality Objectives

Constituent	Limits for ARCO Refinery
Calcium, mg/l	<2 instantaneous <1 rolling average
Magnesium, mg/l	<1 instantaneous <1 rolling average
Ammonia, mg/l	<5 instantaneous <4 rolling average
Silica (SiO_2), mg/l	<2 instantaneous <1 rolling average
Total Dissolved Solids, mg/l	<50 instantaneous <35 rolling average

RO MEMBRANE TESTING

OCWD RO Membrane Testing

OCWD began pilot testing polyamide composite membranes on a microfiltered secondary effluent in 1992. The District tested cellulose acetate membrane from Koch Membrane Systems (previously Fluid Systems), TFC-HR membrane from Koch, ESPA2 membrane from Hydranautics and DOW FilmTec BW30-4040FR membrane. The success of the pilot testing led to the implementation of a 0.5 mgd demonstration facility at OCWD which has been used for testing RO membranes ever since.

For the GWR System project, the following Table 6 outlines the membranes that have been pilot tested and demonstration tested. The table includes testing of both standard membranes and the low fouling membranes for qualification for the GWR System project. In all tests, microfiltered secondary effluent was used to feed the RO membranes.

Table 6

OCWD RO Membrane Pilot and Demonstration Test Program				
Manufacturer	**Membrane**	Test Unit	Test Period	Type
Koch	**TFC-HR**	8" Demo. Unit	Aug. 1996 – Dec. 2000	Standard
Hydranautics	**ESPA2**	8" Demo. Unit	Feb. 2001-April 2002	Standard
DOW/FilmTec	**BW30-400FR**	8" Demo. Unit	May 2002 - June 2002	Low Fouling
DOW/FilmTec	**XLE-440**	8" Demo. Unit	Aug. 2002 - Feb. 2003	Standard
DOW/FilmTec	**XLE-4040FR**	4" DOW Pilot	June 2001-March 2002	Low Fouling
Hydranautics	**LFC1-4040**	4" OCWD Pilot	June 2001-Feb. 2002	Low Fouling

Koch Membrane Systems TFC-HR

In 1996, OCWD began demonstration testing the Koch Membrane Systems TFC-HR membrane downstream of a US Filter Memcor Continuous Microfiltration (CMF) unit and subsequently a Pall Microza MF Unit. The membrane operated in a 9:6:3 array of 7 element pressure vessels at a flux rate between 10 and 12 gfd. From 1996 through early 2001, the membrane exhibited the ability to operate at feed pressures between 150 and 200 psi. The membranes also showed the ability to be recovered by standard cleaning procedures with a cleaning frequency of approximately 4 to 6 months. Table 7 outlines the RO Demonstration operating information:

TABLE 7

TFC-HR Operating System Properties	
Membrane Type:	Koch Membrane Systems TFC-HR
RO System:	OCWD 8 inch Demo. Unit
Feed Source:	Memcor and Pall MF effluent
Array:	9:6:3, 126 elements
Element Dimensions:	8-inches x 40 inch, 330 ft^2
Total Membrane Area:	41,580 ft^2
RO Train Recovery:	85%
RO Train Flux Rate:	10-12 gfd

Hydranautics, ESPA2

In late 2000, OCWD began a test program to demonstration test one of the acceptable membranes from the pilot testing at a system recovery of 87.5%. The testing was going to determine if the membranes could operate at the higher recovery for the GWR System to reduce the amount of concentrate in the waste stream. The membranes were competitively bid and OCWD subsequently purchased 84 ESPA2 membrane elements from Hydranautics to test in the demonstration system in a 6:4:2 array with 7 element pressure vessels. These membranes had previously been successfully pilot tested on this application, and had exhibited successful long-term performance at other large-scale wastewater reclamation facilities including the WBMWD Water Recycling Plant. - The feed source for this unit was the Pall microfiltration demonstration system. Table 8 shows the operating parameters of the demonstration test.

TABLE 8

ESPA2 Operating System Properties	
Membrane Type:	Hydranautics ESPA2
RO System:	OCWD 8 inch Demo. Unit
Feed Source:	Pall MF Demo effluent
Array:	6:4:2, 84 elements
Element Dimensions:	8-inches x 40 inch, 400 ft^2
Total Membrane Area:	33,600 ft^2
RO Train Recovery:	85%
RO Train Flux Rate:	12 gfd

The testing began in February 2001. Within the first three weeks of testing it was evident that there was scaling of the third stage of the RO train. The membranes were cleaned with a citric acid solution and returned to their original state. The test continued and the scaling reoccurred. The recovery was subsequently reduced to 85% and the scaling continued. The scaling was analyzed and determined to be calcium phosphate. The membranes were cleaned once again and the feed pH was readjusted from 6.5 to 6.0 to reduce the calcium phosphate scaling potential. Due to the schedule constraints, the membrane test at 87.5% was never continued. The membranes performed successfully for 5000 hours at 85% recovery for the remainder of the test, which was completed in April 2002. The operating pressures remained below 210 psi for the

duration of the test and the membrane exhibited the ability to be cleaned with standard cleaning procedures. The permeate water quality also exhibited low TDS values less than 25 mg/l for the duration of the test. This test qualified the Hydranautics ESPA2 membrane for the GWR System project.

DOW/FilmTec, BW30-400FR

Subsequent to the ESPA2 Testing, the 8-inch Demonstration RO Unit was used to test the DOW/FilmTec BW30-400FR, which was a fouling resistant membrane. The test proved to be unsuccessful since the membrane fouled to a specific flux of less than 0.07 gfd/psi within the first 800 hours of testing. This was not anticipated since the original pilot testing at OCWD in 1992, at Scottsdale in 1993 and at the City of San Diego had all shown on a 4-inch pilot test that the membrane would work well on microfiltered effluent. Table 9 shows the operating parameters of the demonstration test.

TABLE 9

BW30-400FR Operating System Properties	
Membrane Type:	DOW/FilmTec BW30-400FR
RO System:	OCWD 8 inch Demo. Unit
Feed Source:	Pall MF Demo Effluent
Array:	3:2:1, 42 elements
Element Dimensions:	8-inches x 40 inch, 400 ft^2
Total Membrane Area:	16,800 ft^2
RO Train Recovery:	85%
RO Train Flux Rate:	12 gfd

DOW/FilmTec, XLE-440

Since the BW30-400FR membrane did not qualify for the GWR System by performing a successful demonstration test, OCWD allowed DOW/FilmTec to propose an alternative membrane to test in the 8-inch Demonstration Unit. DOW/FilmTec selected the XLE-440 product, which is a standard product that is not fouling resistant. The membrane elements were operated in the OCWD 8-inch Demonstration unit during the testing. The unit was configured in a 3:2:1 array with 7 elements per pressure vessel. The feed source for this unit was the Pall membrane filtration demonstration unit. Table 10 includes additional properties for this system.

Table 10

XLE-440 Operating System Properties	
Membrane Type:	DOW/FilmTec XLE-440
RO System:	OCWD 8 inch Demo. Unit
Feed Source:	Pall MF Demo Effluent
Array:	3:2:1, 42 elements
Element Dimensions:	8-inches x 40 inch, 440 ft^2
Total Membrane Area:	18,480 ft^2
RO Train Recovery:	85%
RO Train Flux Rate:	12 gfd

As of the writing of this paper, the XLE-440 demonstration test has completed approximately 2000 hours of testing and is scheduled for completion in February 2003 if the membrane exhibits acceptable fouling characteristics.

OCWD Low Fouling RO Membrane Tests

During the ESPA2 8-inch Demonstration Testing, OCWD began a pilot test program to determine if the Low Fouling or Fouling Resistant membranes could offer any benefits to the GWR System. OCWD had one 4-inch pilot test unit, which was configured in a 2:2:1:1 array of 3 element pressure vessels. Additionally, DOW/FilmTec supplied a 4-inch pilot test trailer to allow multiple RO membrane tests to be conducted simultaneously.

DOW/Filmtec XLE-4040-FR

DOW/Filmtec XLE-4040-FR membrane elements were operated in the Dow 4-inch pilot unit during the testing from June 2001 to March 2002. Dow selected the XLE-FR membranes to determine if they would offer a lower lifecycle cost than the TFC-HR and the ESPA2 membranes. If they had been successful in meeting this goal, they would have been required to supply membranes for the demonstration unit. The pilot unit was configured in a 2:1 array with 6 elements per pressure vessel. The feed source for this unit was the Pall membrane filtration demonstration unit. Table 11 includes additional properties for this system. The XLE-FR membrane was the only low fouling membrane to perform well during pilot testing.

TABLE 11

XLE-4040-FR Operating System Properties	
Membrane Type:	DOW/Filmtec XLE-FR
RO System:	DOW/Filmtec 4 inch Pilot Unit
Feed Source:	Pall MF effluent
Array:	2:1, 18 elements
Element Dimensions:	4-inches x 40 inch, 82 ft^2
Total Membrane Area:	1,476 ft^2
RO Train Recovery:	75%
RO Train Flux Rate:	12 gfd

Hydranautics LFC1-4040

Hydranautics LFC1-4040 membrane elements were operated in the OCWD 4-inch pilot unit from June 2001 to February 2002. The unit was configured in a 2:2:1:1 array with three elements per vessel. The feed source for this unit was the US Filter 32S10T CMF-S demonstration unit. All other properties for this system are located in Table 12. LFC1-4040 was tested for over 5000 hours but failed to qualify for the project as it demonstrated unacceptable specific flux decline.

TABLE 12

LFC1-4040 Operating System Properties	
Membrane Type:	Hydranautics LFC1
RO System:	OCWD Pilot Unit
Feed Source:	CMF-S Demo (32S10T) MF Effluent
Array:	2:2:1:1, 18 elements
Element Dimensions:	4-inches x 40 inch, 85 ft^2
Total Membrane Area:	1,530 ft^2
RO Train Recovery:	75%
RO Train Flux Rate:	12 gfd

The following Table 13 shows the average RO feedwater quality for the duration of the pilot and demonstration testing:

TABLE 13

OCWD Pilot and Demonstration RO Feedwater Quality		
Parameter	Average Expected/Actual	Range Expected/Actual
Total Alkalinity (mg/L as $CaCO_3$)	254 / 262	214-278 / 227-292
Silica (mg/L as SiO_2)	16.83 / 22.1	3.2-21.9 / 18.3-26.4
Total Hardness (mg/L as $CaCO_3$)	230 / 282	97 – 310 / 220-370
TDS (mg/L)	909 / 987	828-988 / 814-1820
Turbidity (NTU)	0.1 / 0.22	0 – 0.2 / 0.1-0.6
TOC (mg/L)	9.62 / 10.6	6.83-14.5 / 8.3-12.9
pH (Units)	6.5 / 6.0	--
Temperature (°C)	27.8 / 24.6	22.9-29.2 / 22.2-28.2

WBMWD RO Membrane Testing

WBMWD has been operating full-scale MF and RO membranes at their El Segundo Water Recycling Plant since 1997 when the first full-scale 2.5 mgd facilities came online to treat secondary effluent to supplement the seawater intrusion barrier. West Basin was the first agency to use polyamide composite membranes downstream of MF for reclamation of secondary effluent. Since that time, the District has expanded their MF/RO capacity from 2.5 mgd to approximately 15 mgd. All of the facilities, which use MF as pretreatment use polyamide composite RO membranes.

In 2001, WBMWD began pilot testing low fouling or fouling resistant RO membranes as part of a research grant which would determine the net benefits such as reduced fouling rates, better ability to be cleaned and the reduced energy costs of the different types of membranes compared with the existing standard membranes. More specifically, the purpose of the test was to determine and compare the fouling characteristics of the low

fouling RO membranes to the standard membrane on microfiltered secondary effluent. During the test, two (2) new 'low fouling" RO membranes were tested side by side against a standard reverse osmosis membrane at the West Basin Water Recycling Facility in El Segundo, California.

Three pressure vessels in the first stage of a full-scale operating RO train were retrofitted to provide individual flow, pressure and conductivity monitoring. In each of two vessels, seven low fouling membranes were loaded, with each vessel containing one membrane type. The third vessel was loaded with ESPA2, a standard - membrane that is a thin film composite membrane proven to work effectively on microfiltered secondary effluent, although it is not "low fouling."

Vessel No. 1 was the standard RO membrane and was loaded with 7 new Hydranautics ESPA2 membrane elements. The RO membranes had the following operating characteristics listed in Table 14:

TABLE 14

ESPA2 Operating System Properties	
Demo. Test Period:	November 2001-July 2002
Membrane Type:	Hydranautics ESPA2
RO System:	WBMWD WRP Train 3 Demo
Feed Source:	CMF System
Array:	1 Press. Vessel, 7 elements
Element Dimensions:	8-inches x 40 inch, 400 ft^2
Total Membrane Area:	2,800 ft^2
RO Train Recovery:	64%
RO Train Flux Rate:	11,13 gfd

Vessel No. 2 had 7 new Hydranautics LFC1, low fouling membranes installed in the pressure vessel. The membranes were operated as indicated in Table 15:

TABLE 15

LFC1 Operating System Properties	
Pilot Test Period:	November 2001-July 2002
Membrane Type:	Hydranautics LFC1
RO System:	WBMWD WRP Train 3 Demo
Feed Source:	CMF System
Array:	1 Press. Vessel, 7 elements
Element Dimensions:	8-inches x 40 inch, 400 ft^2
Total Membrane Area:	2,800 ft^2
RO Train Recovery:	64%
RO Train Flux Rate:	11,13 gfd

Vessel3 had 7 new DOW/FilmTec BW30-365FR fouling resistant membranes installed in the pressure vessel. The membranes were operated as indicated in Table 16:

TABLE 16

BW30-FR Operating System Properties	
Pilot Test Period:	November 2001-July 2002
Membrane Type:	DOW/FilmTec BW30-365FR
RO System:	WBMWD WRP Train 3 Demo
Feed Source:	CMF System
Array:	1 Press. Vessel, 7 elements
Element Dimensions:	8-inches x 40 inch, 365 ft^2
Total Membrane Area:	2,555 ft^2
RO Train Recovery:	62%
RO Train Flux Rate:	11 gfd

The following Table 17 presents the average RO feed water quality during the demonstration period.

TABLE 17

WBMWD Acidified RO Feedwater Quality		
Parameter	Average	Range -
Total Alkalinity (mg/L as $CaCO_3$)	159	138-180
Silica (mg/L as SiO_2)	22	22-22
Total Hardness (mg/L as $CaCO_3$)	185	/ 180-190
TDS (mg/L)	615	560-670
TOC (mg/L)	10.5	10-11
pH (Units)	6.45	5.6-6.8
Temperature (°C)	24.5	21-30.9

RO MEMBRANE TESTING RESULTS

OCWD RO Membrane Testing Results

With the exception of the Koch Membrane System TFC-HR which was operated over a 3 year period, each of the pilot and demonstration tests at OCWD was ran for over 5000 hours with the following results:

1. The specific flux for the TFC-HR for the first 5000 hours of operation was comparable to, or higher than the specific flux of the three low fouling membranes.
2. ESPA2 qualified for the GWR System project, demonstrating exceptional fouling rates and acceptable salt rejection. Despite several scaling events for the ESPA2, the testing demonstrated that the specific flux of the ESPA2 remained higher than all three low fouling membranes, throughout the 5000 hour test.
3. DOW/FilmTec BW30-400FR membrane was tested and exhibited a rapid decline in the specific flux indicating an extremely high amount of fouling within the first 800 hours of testing. The testing was terminated and the membrane was determined to be unacceptable for the GWR System project.

4. Dow/FilmTec XLE-440 membrane continues to test as of this writing. A cleaning was scheduled after approximately 2000 hours to maintain the specific flux above 0.07 gfd/psi.
5. The low fouling membrane LFC1 demonstrated an unacceptable fouling rate when compared with the ESPA2 product from the same manufacturer.
6. The fouling resistant XLE-FR membrane demonstrated a specific flux similar to the TFC-HR and the ESPA2 membranes and was considered for further testing in the 8-inch demonstration unit. However, since the product was a prototype and was not commercially available, DOW/FilmTec chose not to demonstration test the 8-inch XLE-FR membrane. Dow/FilmTec expressed a desire to only consider the membrane if it would have exhibited characteristics which would have given the product a commercial advantage. Since the product was not tested in the 8-inch demonstration unit for a period of 5000 hours, XLE-FR was not considered acceptable for the GWR System project.
7. All membrane permeate conductivities remained at or below 50 µS/cm during the pilot and demonstration testing. Additionally, TOC and Total Nitrogen were within the required project limits.

The following Figure 1 shows the specific flux decline of the standard TFC-HR, ESPA2 and XLE-440 membranes. Figure 2 shows the specific flux decline of the "low fouling" membranes. Figure 3 shows a comparison of the specific flux decline of the standard membranes and the low fouling membranes over 5000 hours.

FIGURE 1

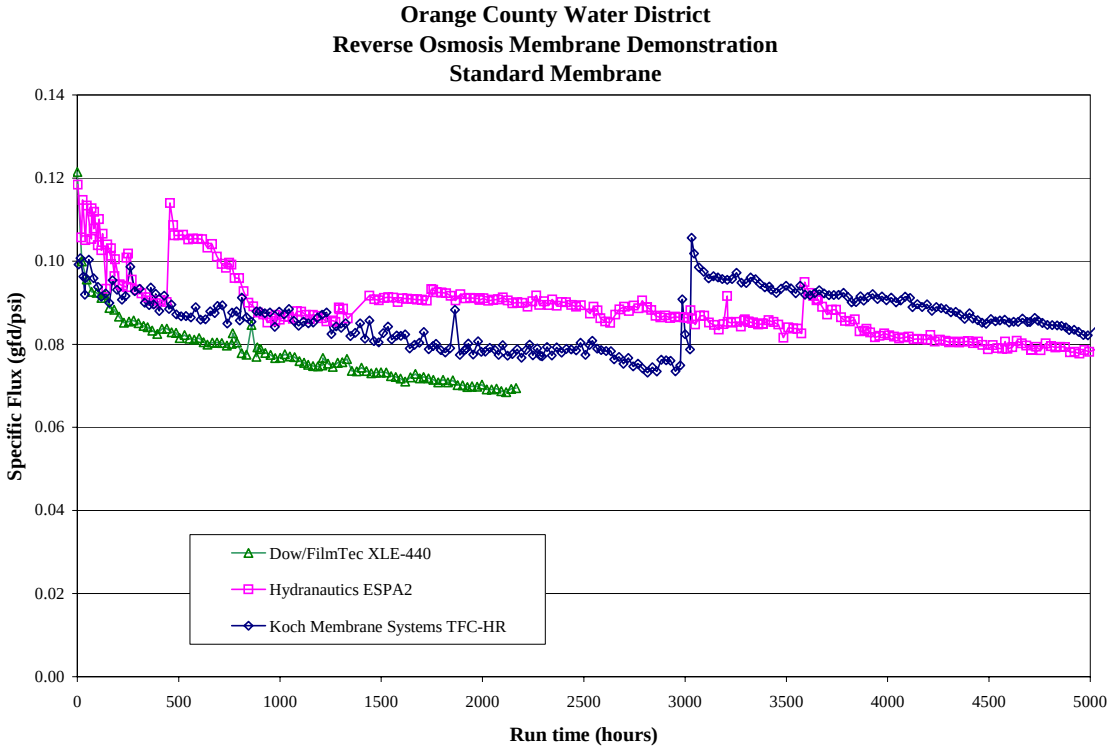


FIGURE 2

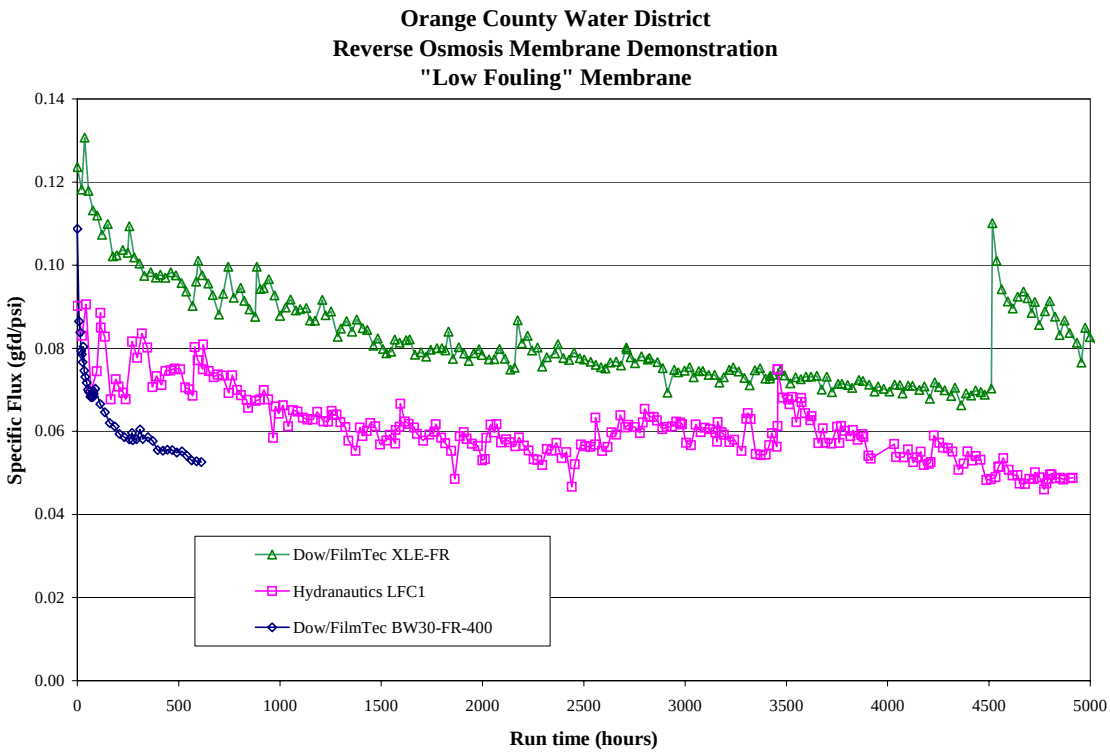
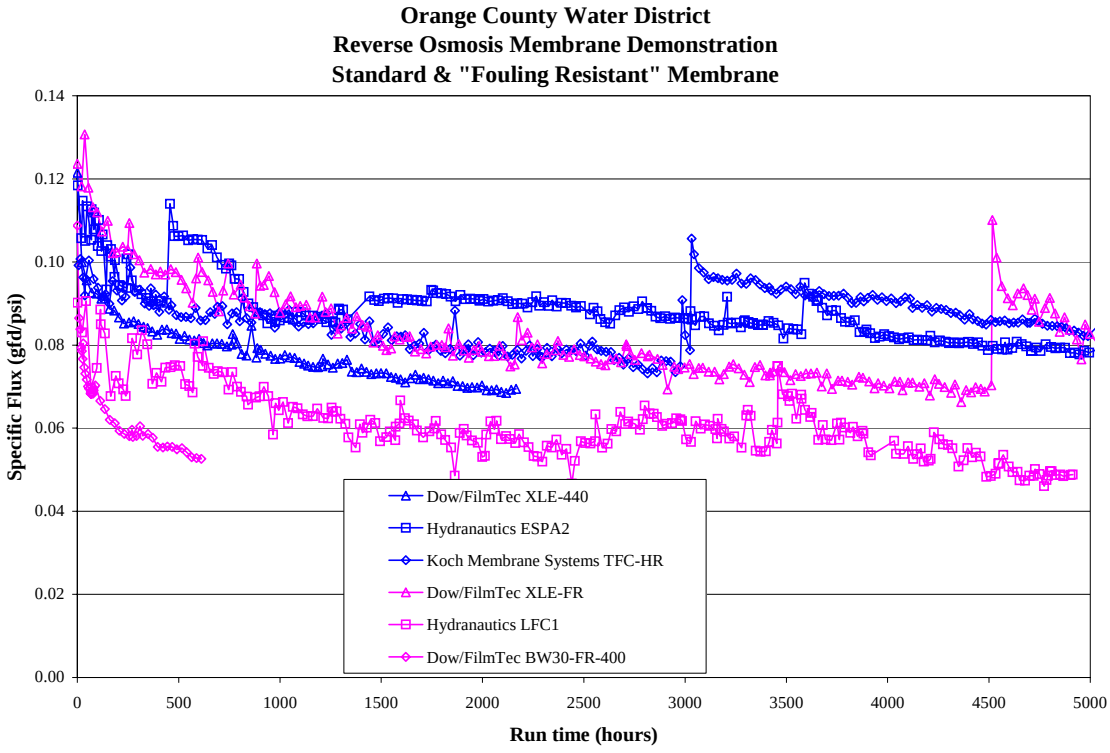


FIGURE 3



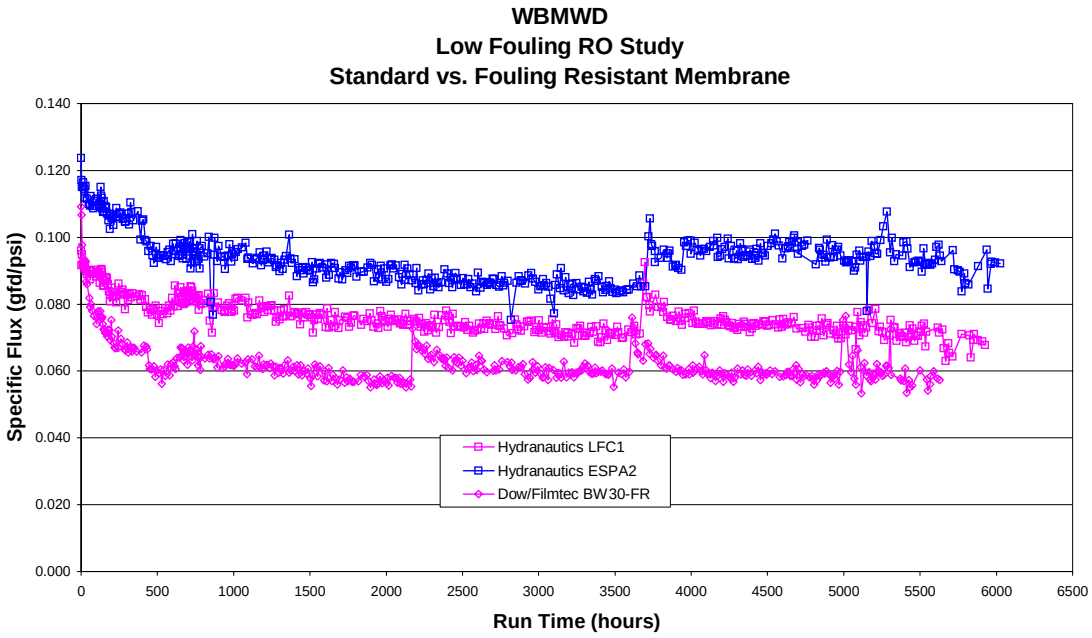
WBMWD RO Membrane Testing Results

The low fouling demonstration test was run for over 6000 hours at WBMWD with the following results:

1. The ESPA2 specific flux started at a higher value, and also remained higher than either low fouling membrane throughout the entire test, demonstrating that the standard membrane was the most economical.
2. Hydranautics LFC1 initially fouled at a similar rate to ESPA2, the control membrane. However, ESPA2 maintained a higher specific flux.
3. The fouling rate of the DOW/FilmTec BW30-FR membrane was greater than either Hydranautics membrane.
4. Cleaning was most successful on the standard membrane.
   a. ESPA2 cleaned to 80% of its initial permeability and retained this permeability for 1500 hours after cleaning.
   b. LFC1 also cleaned to 80% of initial permeability, but lost 12% over the remaining 1500 hours of the study.
   c. DOW/FilmTec BW30-FR cleaned only to 65% of initial permeability.
5. All membranes produced similar permeate water quality with conductivities less than 50 µS/cm.

The following Figure 4 shows a comparison of the specific flux decline of the control membrane and the low fouling membranes over 6000 hours.

FIGURE 4

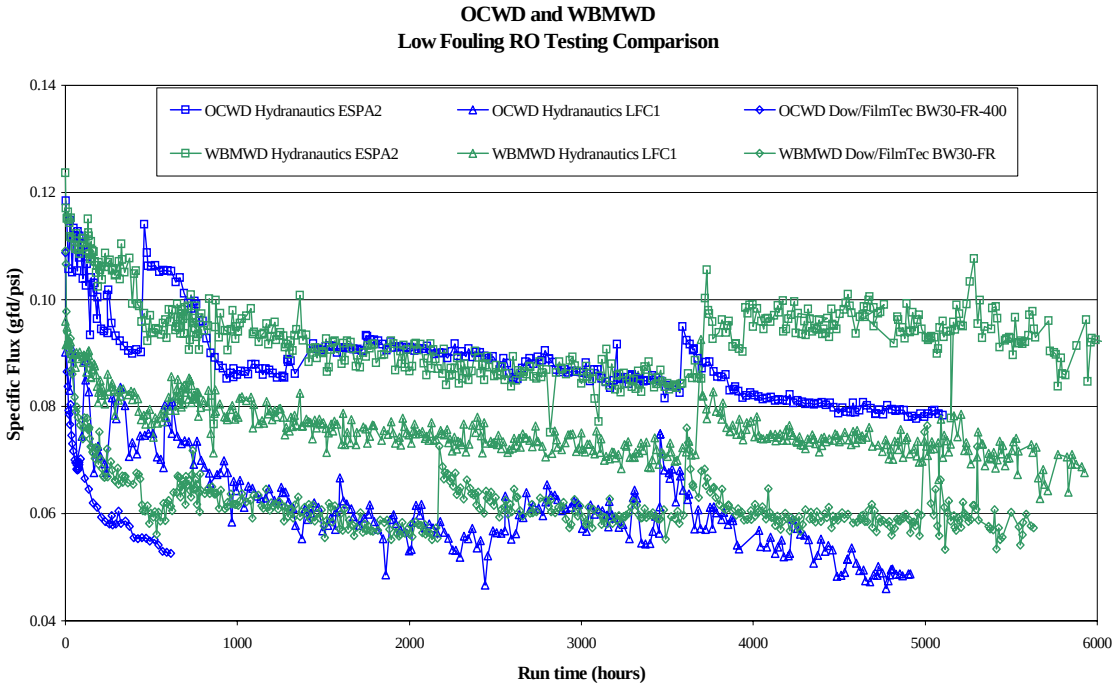


COMPARISON OF OCWD AND WBMWD RESULTS

The following Figure 5 shows a comparison of the similar membranes tested at each facility. From the information presented in Figure 5, the following conclusions were drawn:

1. The membranes at the two separate facilities were of similar chemistry and quality since the same membranes began operation at the same specific flux.
2. The different microfiltered wastewater effluent of different origins produced different fouling rates. For instance, at OCWD, the LFC1 membrane exhibited a more rapid decrease in the specific flux than the same LFC1 membrane at WBMWD indicating a higher fouling rate. The same comparison was made for the BW30-FR membrane, which exhibited the highest fouling rate of the membranes tested on microfiltered secondary effluent. The performance of the BW30-FR membrane was not expected since the membrane had been successfully pilot tested and had performed acceptably on microfiltered secondary effluent.
3. The fouling rates of the "low fouling" or "fouling resistant" membranes did not exhibit better operating characteristics such as lower operating pressures or lower fouling than the standard thin film composite membranes when operated on a microfiltered secondary effluent. It should be clearly stated that the test results from the two agencies are not intended to imply that the RO membranes in these studies will not operate at lower fouling rates on other types of source waters. The results clearly show that the membranes did not exhibit better operating characteristics in the applications described above.
4. Lastly, it can be concluded from the results on these specific wastewaters, that additional research and development is necessary to produce a RO membrane that can exhibit better operating characteristics on a microfiltered secondary effluent.

FIGURE 5



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