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WASTEWATER RECLAMATION USING UF/RO TECHNOLOGY

INTRODUCTION

Two major areas of applications of RO membrane technology for wastewater reclamation are processing of water from underground aquifer contaminated with industrial or agricultural drainage and treatment of municipal wastewater. Membrane processing of contaminated aquifer usually does not differ from a conventional brackish RO application. This type of raw water usually contains low concentration of suspended solids and low level of biological activity. It requires therefore a relatively simple pretreatment process. The RO systems are design to operate at a high permeate flux rate and long term, stable membrane performance are obtained. The investment and operating cost values are similar to the economic parameters of typical brackish water RO systems. An example of such application is the Arlington Desalter, located in Riverside County, California. It commenced operation in 1990. This system processes agricultural drainage water of about 1000 ppm TDS salinity, which contains high concentration of NO₃ (100 ppm). The plant produces 6MGD (22,700 m³/day) of low salinity water by blending 4 MGD (15,100 m³/day) of RO permeate with 2 MGD (7,570 m³/day) of ground water. The blending ratio is determined by the limit of nitrate ion concentration in the blend water, which has to be below 40 ppm. The second area of application: membrane treatment of municipal waste water, requires very extensive pretreatment prior to the RO process. The municipal effluent contains high concentration of suspended particles, colloids and high level of biological activity. An example of such a system is RO plant known as "Water Factory 21" in Orange County, California. It commenced operation in the late-seventies. This RO system has 5 MGD (18,900 m³/day) of product capacity and reduces salinity of municipal wastewater after tertiary treatment. Product water after blending is injected into local aquifers to prevent seawater intrusion. Recently a new pretreatment technology has been introduced for RO processing of municipal effluent. It consists of backwashable microfiltration and ultrafiltration membrane elements in a capillary configuration. This new membrane pretreatment technology is capable to maintain stable performance of filtrate flow and operating pressure in operation with heavy fouling feed water. The capillary technology produces RO feed water of a very high quality. The capillary filtrate has much lower

concentration of colloidal and suspended particles than can be produced in a conventional pretreatment process. The better feed water quality enables more reliable and more efficient operation of the RO systems. Extensive pilot study of new pretreatment technology has been conducted for number of years with very promising results. Some future large RO systems for reclamation of municipal wastewater are being design to utilize the capillary pretreatment technology. This paper will describe process design, operational results and compare economics of wastewater reclamation by reverse osmosis using conventional and advanced capillary pretreatment technology.

ARLINGTON BASIN DESALTER

The Southern California Arlington Basin contains approximately 300,000 acre feet (430 million m³) of water. The ground water in this basin has degraded by agricultural leachate from historic citrus grove farming operations. The agricultural drainage has increased salt concentration to a level that this ground water is no longer usable for domestic purposes. Because of poor ground water quality, all pumping has been discontinued in the area. This resulted in impaired ground water seeping to the surface and draining into the Santa Ana River and other adjacent ground water basins, thereby degrading downstream water supplies.

The Arlington Basin Desalting project was designed to provide 6 MGD (22,700 m³/d) of blended product water containing less than 500 ppm TDS by mixing 4 MGD (15,100 m³/d) of degassed permeate from the three RO trains (each rated at 1.333 MGD) with 2 MGD (7,570 m³/d) of ground water treated by granular activated carbon followed by aeration stripping. The RO system operates at a permeate recovery rate of 77%. The RO plant is designed to allow for expansion up to 8 MGD (30,300 m³/d), by addition of a fourth RO train. Plant data is summarized in Table 1.

Feedwater from the five local brackish wells is pumped to the plant site where it is split into two streams. Out of the total raw water flow of 7 MGD (26,500 m³/d), provision exists for passing 2 MGD (7570m³/d) through Granular Activated Carbon (GAC) filters, to remove dissolved organic compounds, mainly dibromochloropropane (DBCP). At present, due to lower than expected concentration of DBCP in the ground water, the GAC filters are bypassed and the blend stream is only treated by aeration stripping. The remaining flow, 5 MGD (18,900 m³/d), is used as feed for the RO system. The RO feedwater is treated by dosing of scale inhibitor and sulfuric acid to a pH of 6.9 and is filtered through 5 micron cartridge filters. After the filtration feedwater is pressurized to approximately 210 psi (1.45 MPa) with Afton vertical turbine pumps, the pressurized feed enters three parallel RO trains operating at 77% permeate recovery. Each train contains 44 pressure vessels, 8" diameter, in a two pass 33:11 array. The pressure vessels each contain six Hydranautics spiral wound, composite, membrane elements, model 8040-LSY-CPA2. The average water fluxrate of the membranes is 13.8 gfd (23 l/m²-hr). Permeate flow from the RO trains is combined with the blend stream at the ratio 2:1. The design blend ratio was based on the projected concentration of nitrate in the wells and in the permeate water, with a target concentration corresponding to California drinking water standard of not more than 40 ppm

of nitrate in the total plant effluent. This blended effluent is of potable water quality and flows to the storm water channel and eventually recharges the ground water basin. The concentrate stream from each RO train passes through an energy recovery turbine, which is a reverse running pump mechanically coupled with the high pressure pump.

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Table 1: ARLINGTON DESALTER PLANT DATA

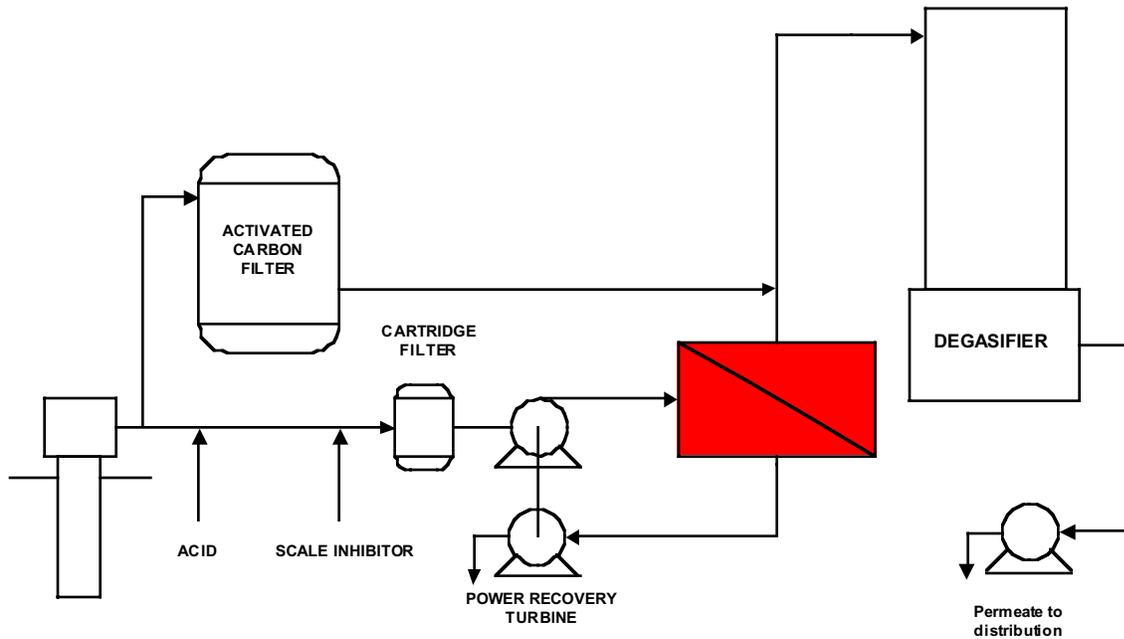
Start up date	July 1990
Plant Capacity	6 MGD (22,700 m ³ /day)
RO Permeate	4MGD (15,100 m ³ /day)
GAC Effluent (Blend Water)	2 MGD (7,500 m ³ /day)
Number of RO Trains	3
Number of Element per Train	264
Element Type	8040-LSY-CPA2
Permeate Recovery	77 %
Feed Water Type	Well water 1200 ppm TDS, 90 —100 ppm NO ₃ , 44 ppm SiO ₂
Product Water Quality (after blending)	< 500 ppm TDS, < 40 ppn NO ₃
Pretreatment	pH adjustment, scale inhibitor, cartridge filtration
Post- treatment	Degasifier
Design Feed Pressure	160 —205 psi (1.1 —1.4 MPa)

combined concentrate from the plant is conveyed to the Orange County Sanitation District through the Santa Ana Regional Interceptor (SARI) line. After mixing with municipal sewage, and primary and secondary treatment of the Sanitation District effluent is split for further treatment by OCWD Water Factory 21, or direct disposal to the ocean. The flow diagram for the Arlington Basin Desalter Plant is shown in Figure 1.

The RO unit incorporates innovative design features to assure efficient and stable plant operation. One of the features is the control of system output by permeate throttling. The objective of using permeate throttling rather than conventional feed throttling to control productivity is to eliminate loss of recoverable energy and maintain constant concentrate pressure to the power recovery turbine.

The other features are related to prevention of membrane scaling. One serious concern during system design was the projected high level of silica (37 ppm) in the ground

water. It is customary in RO technology to accept concentration of approximately 120-160 ppm



Flow diagram of a RO system at Arlington

of SiO_2 as a limit for safe operation in the concentrate. The kinetics of silica scaling is not well understood and no commercial silica scale inhibitor was available during the time of plant design. The initial requirement of permeate recovery of 80% would result in concentration of SiO_2 in the concentrate of about 180 ppm. Calculation, element by element, of silica concentration indicated that the customary limit of 160 ppm of SiO_2 would be exceeded at the 5th element of the second pass. From this point, the brine stream residence time in the system is about 10 seconds. It was estimated that during such short residence time, at a temperature of 21°C, no silica scale should be formed, especially considering the quality of the raw water, which has very low concentration of suspended solids, which could act as crystallization centers. Even though, at this condition, no silica precipitation was expected, as an additional safety feature, each RO train was equipped with a 4-inch diameter monitor tube. The monitor tube contains a single 4-inch element and operates on the concentrate stream from the RO train as feedwater. The assumption was that silica scaling, if any, would start in this monitor tube, giving early warning to change the operating conditions.

PLANT OPERATION

The RO system at the Arlington desalter was commissioned in September 1990. The composition of feed and permeate as analyzed from samples taken during acceptance test are presented in Table 2. The RO plant still operates with the original load of

Hydranautics CPA2 membrane elements, installed in 1990. The plant performances are within specifications in respect of quantity and water quality.

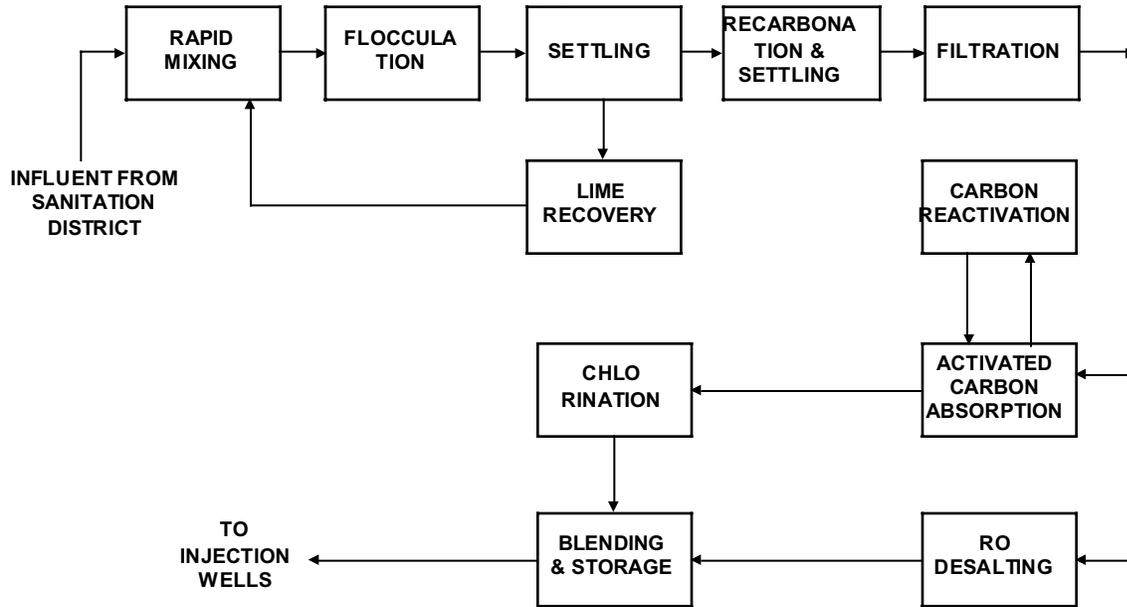
Table2: WATER ANALYSIS DURING THE ACCEPTANCE TEST

Constituent	RO Feedwater, g/m ³	RO Permeate, g/m ³	Salt Passage, %	Blended Water, g/m ³
Calcium	140	0.3	0.22	0.33
Magnesium	42	0.01	0.02	0.15
Sodium	168	7.1	4.21	66
Potassium	3.8	0.2	5.22	1.5
Bicarbonate	367	8.4	2.72	140
Chloride	162	2.3	1.44	60
Sulfate	243	0.6	0.21	89
Nitrate	93	8.3	8.96	37
Fluoride	0.41	0.1	24	0.2
Silica	40	0.1	0.25	15
TDS	1260	28	2.21	460

RO SYSTEM AT FACTORY 21

The objective of operation of Water Factory 21, water treatment facility, is to produce water for underground injection to prevent seawater intrusion into the fresh water aquifer. The flow diagram of the current treatment process is shown in Figure 2. The influent received from the Sanitation District passes the treatment stages of lime clarification, recarbonation, chlorination and media filtration. After media filtration, one-third of the stream is directed to the RO system. The rest of the media filtration effluent passes through granulated, activated carbon bed, and after chlorination is blended with the RO permeate. The early pilot study of different membrane module configurations has indicated that spiral wound and tubular configuration modules were least affected by fouling. Spiral wound configuration technology was selected for the above system because of better economics (investment cost and power consumption). In spite of continuous testing program of commercially available membrane elements conducted on site, cellulose acetate membrane elements in a spiral wound configuration seem to be the membrane of choice for treatment of municipal wastewater. This type of membrane element has been continuously specified for all subsequent membrane replacements at Water Factory 21. The RO unit consists of six banks of membrane elements arranged in three pass array: 24:12:6 pressure vessels, each containing four elements. The membrane elements are 8" diameter, 60" long, 510 ft² nominal membrane area. The RO unit operates at 85% permeate recovery. Feedwater at Water Factory 21, even after tertiary treatment has a very high fouling potential. Type of foulants existing in the RO feed at Water Factory 21 have been extensively documented (1). The common indicator of RO feedwater quality, the Silt Density Index, is not even

measurable in the local feedwater. TOC and COD are in the range of 10 - 20 ppm, in addition to a high concentration of biological debris. Chlorination produces chloramine in a concentration of approximately 10 ppm in the RO

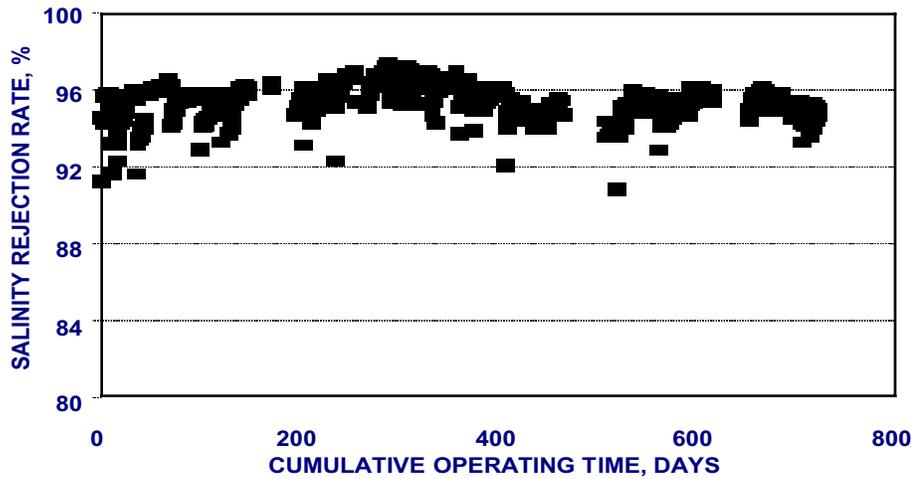


WATER FACTORY 21 WASTEWATER RECLAMATION SYSTEM FLOW DIAGRAM

feed. In spite of this adverse feedwater quality, the membrane performance is relatively stable, the key factor being sustaining desired water flux by effective membrane cleaning procedures. Initially, the RO system was designed with 35 pressure vessels per unit, which resulted in water flux of 12.4 gfd. At this flux rate, an irreversible flux decline was experienced. To maintain rated product flow, seven pressure vessels were added to each unit, which resulted in reducing the average flux rate to about 10 gfd (1). Figures 3 & 4 contain performance of subunit 2C, for the period of April '89 until February '91. This unit commenced operation after most of the initial problems had been solved. This unit still operates with the original load of membrane elements. The rejection rate is very stable and a salinity reduction of 94% - 96% is obtained consistently (Fig. 3). The product flow was maintained at the level of 580 GPM. Membrane fouling and its affect on productivity was initially compensated by increasing feed pressure to a maximum agreed upon value of 350 psig (2.41 MPa) (Fig. 4). After 275 days, this maximum feed pressure was reached for the first time during the first period of low feed temperature; the winter of 1989, the required feed pressure dropped during the warmer months corresponding to 350 days through 550 days as indicated in Figure 5, product flow had declined between 10% to 14%. As a result of subsequent cleaning, permeate flow could be usually restored to rated system flow by cleaning membrane elements with a cleaning solution containing sodium tripolyphosphate, EDTA and anionic detergent. Membrane cleaning was conducted about every three to four weeks.

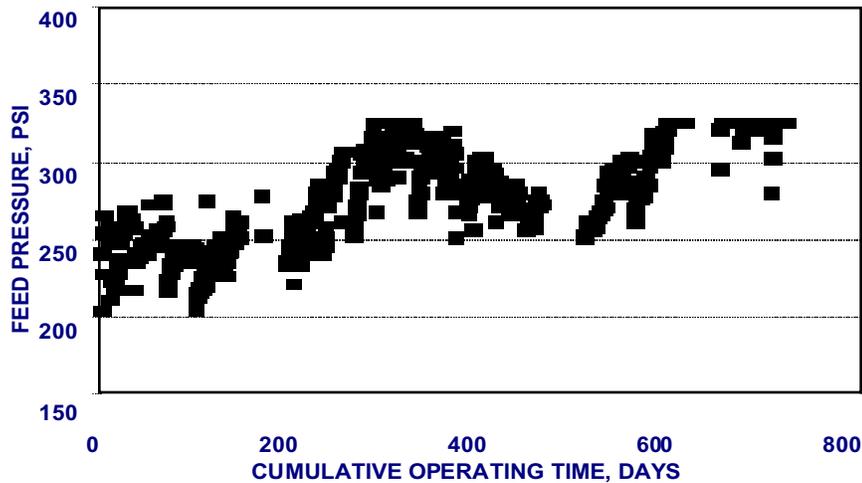
WATER FACTORY 21

CAB MEMBRANE OPER. 04,89 - 02,91



WATER FACTORY 21

CAB MEMBRANE OPER. 04,89 - 02,91



WATER COST

The capital cost of the Arlington Desalter project was approximately \$14,000,000, which was obtained through a State of California Drainage Loan. The estimated annual cost, including capital return and operating cost, is \$2,000,000. Assuming annual production

of 1980 million gallons of blended water, the specific water cost is \$330 per acre foot ($\$0.27/\text{m}^3$). The cost of reclaiming municipal waste water, based on the process used in Water Factory 21 is estimated to be about \$390/acre foot ($\$0.32/\text{m}^3$) (2). The cost of water reclamation compares favorably with other alternatives of augmentation of Southern California water supply (3). About one-third of the water demand of Southern California is supplied from local wells. The rest is imported from Northern California through the aqueduct systems. Both water sources are limited, and they are affected by the annual precipitation level. The rate of Metropolitan Water District, which governs the water distribution in Southern California, for imported treated water is \$230 per acre foot ($\$0.19/\text{m}^3$) (3). The additional water supply for Southern California can be produced by desalination programs. Due to limited local availability of brackish water, only seawater desalination can provide a significant volume of new water. The cost of water from a large scale seawater desalination system is estimated to be in the range of \$1000 per acre foot ($\$0.83/\text{m}^3$) (3). Considering the fact that most of the water used in Southern California is used once and discharged to the ocean, and the cost of alternative water supplies using advanced treatment technology combined with membrane desalting, is not significantly higher than the cost of imported water; water reclamation looks like a very economically attractive alternative provided public acceptance can be established for this procedure.

ADVANCED PRETREATMENT

Use of membranes as a definite barrier in the RO pretreatment process has been proposed in the past (2). Ultrafiltration (UF) and microfiltration (MF) membranes have the ability to produce feed water of significantly better quality than the conventional pretreatment process based on lime clarification, followed by media and cartridge filtration. However, the conventional, spiral wound configuration of ultrafiltration membrane elements was not suitable for treatment of highly fouling waste water. UF elements could not operate at high flux rates without severe fouling of membrane surfaces and plugging of feed channels. High cross flow feed velocities, required to reduce concentration polarization, resulted in high power consumption. Membrane cleaning, frequently required, was cumbersome and not very effective in restoring permeate flux. New microfiltration and ultrafiltration technology offered recently (4) is based on a flat capillary membrane configuration. The capillary bore is of 0.7 - 0.9 mm diameter. Outside diameter of the capillary is in the range of 1.3 - 1.9 mm. Membrane material consists of polypropylene, sulfonated polyether sulfone or cellulose acetate. In some elements design configuration the feed - permeate flow direction is outside - in, others have inside - out direction.

There are two common novel properties of the new commercial capillary equipment;

1. Frequent, short duration, automatically sequenced flushing (or backflushing in some models) of the capillary fibers, which enables to maintain stable permeate flux rates with little off-line time.
2. Ability to operate at a very low cross flow velocity, or even in a direct filtration flow (dead end) mode.

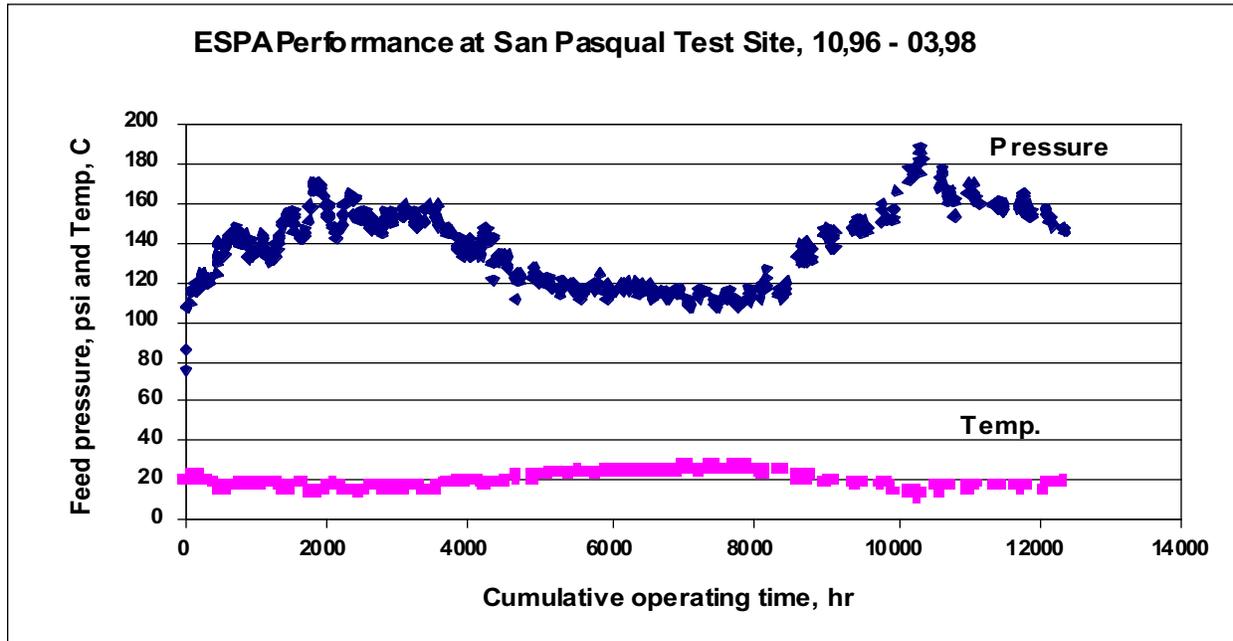
The off-line time due to pulse cleaning is very short, comparable to off line time of conventional filters due to filter backwashing. The frequent pulse cleaning results in a

stable permeate flux rates. The feed pressure is in the range of 1 to 2 bar. Operation at low feed pressure and low cross flow or in a direct filtration mode results in high recovery rates and very low power consumption, of about 0.4 kWhr/kgallon (0.1 kWhr/m³) of filtrate. The membrane type is either microfiltration (nominal pore size 0.2 micron) or ultrafiltration (molecular weight cut off 100,000 - 200,000 Dalton). The dimensions of capillary ultrafiltration modules are in the range of 40 - 52 (100 - 130 cm) long and 8 - 13 (20 - 32 cm) in diameter. In actual field operation, a single module can produce 8,000 - 40,000 gallons (30 - 150 m³/day) of filtrate. This new capillary technology has been developed for treatment of potable water, which originates from surface sources. Compared to a conventional water treatment technology, it offers modular design, high output capacity from a small foot print, no need for continuous handling and dosing of chemicals, and limited labor requirements. The major advantage, however is inherent to membrane technology: the existence of a membrane barrier between feed and permeate which enables a several log reduction of colloidal particles and pathogens. The above technology has been extensively tested and a large number of systems, mainly based on microfiltration membranes, are already in operations. Following the success in potable water applications, the capillary technology has been proposed and tested as a potential pretreatment for RO systems operating on highly fouling water. One of the first targets was RO processing of municipal effluents. The objective was to replace the expensive and cumbersome conventional tertiary effluent treatment and increase the current level of design flux rate of the RO system. The field test have been conducted since 1995 (5). Results are promising and large commercial installations are under advanced stages of design and construction. Another area of applications is RO pretreatment of low salinity surface feed. One of the objectives here is again the replacement of conventional pretreatment. In addition, it is expected that adding a second membrane barrier (in addition to the RO membrane) will reduce the presence of pathogens in the permeate to a level that will eliminate the need for continuous disinfection of potable water with strong oxidants. The field tests confirmed feasibility of such design. Large capacity systems, combining capillary UF with RO technology are currently being designed. The cost of the capillary membrane pretreatment is estimated to be similar to the cost of the extensive conventional pretreatment which is usually required for the municipal waste water. Use of capillary technology will simplify the pretreatment system and reduce the use of chemicals. It is capable to produce feed water with a very low concentration of colloidal particles and bacteria.

OPERATION OF COMPOSITE MEMBRANES AT SAN PASQUAL, CALIFORNIA

The San Pasqual Wastewater Treatment Facility City of San Diego conducted an extensive program of testing of feasibility of complete reclamation of municipal waste water using hybrid technology. The objective was to produce effluent of potable water quality in a multistage treatment process. This includes use of capillary MF/UF membrane pretreatment followed by composite RO membranes, ion exchange, UV sterilization and chlorination. Pilot operation was conducted during a period of 18 months (10,96 — 03,98). During that time performance of equipment of various

manufactures was tested. The composite RO membranes, operating on tertiary municipal effluent treated with capillary membranes, maintained stable performance in respect of permeate flux and salt rejection. RO membranes also maintained good integrity of the membrane barrier demonstrating about 5 log reduction of viruses. Fig. 5 contains result of operation of Hydranautics ESPA membranes, which operated at a permeate flux rate of 12 gfd (20 l/m²-hr). The stability of water permeability, as

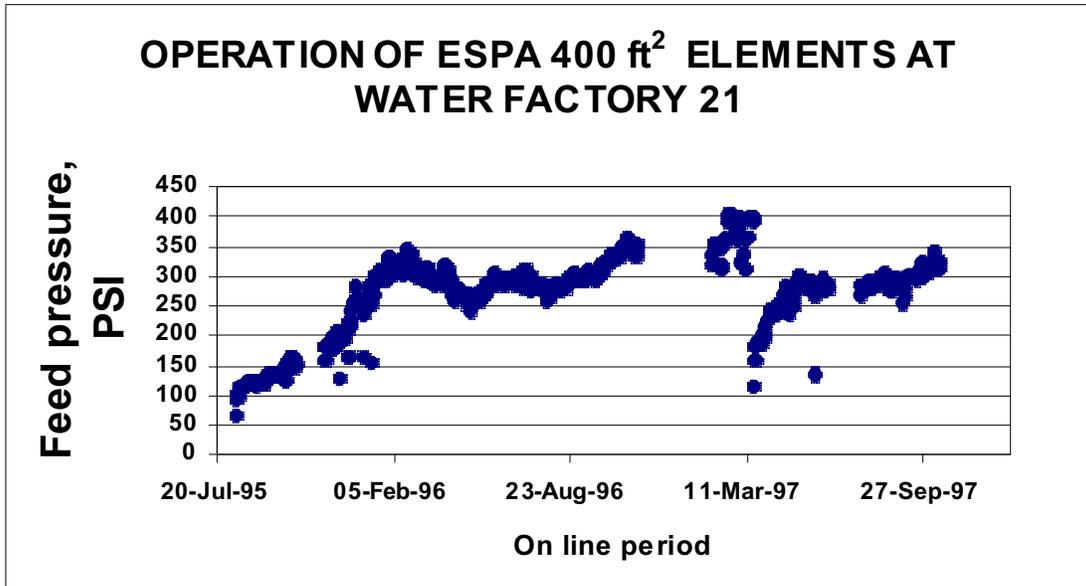


indicated by feed pressure, was much better than during operation of the same membranes on a tertiary effluent after the conventional pretreatment. Fig 6 contains results of operation of the same (ESPA) membranes at Water Factory 21, Orange County, California, at a similar operating conditions using conventional pretreatment of the feed water. The flux decline rate at Water Factory 21 was much higher than it was experienced at San Pasqual, where the capillary membrane technology was used as feed pretreatment. The feed pressure range at San Pasqual was 140 —160 psi (0.95 —1.1 MPa). For the corresponding operating period at Water Factory 21 the feed pressure had to be increased to about 250 psi (1.7 MPa) to maintain the design permeate flux.

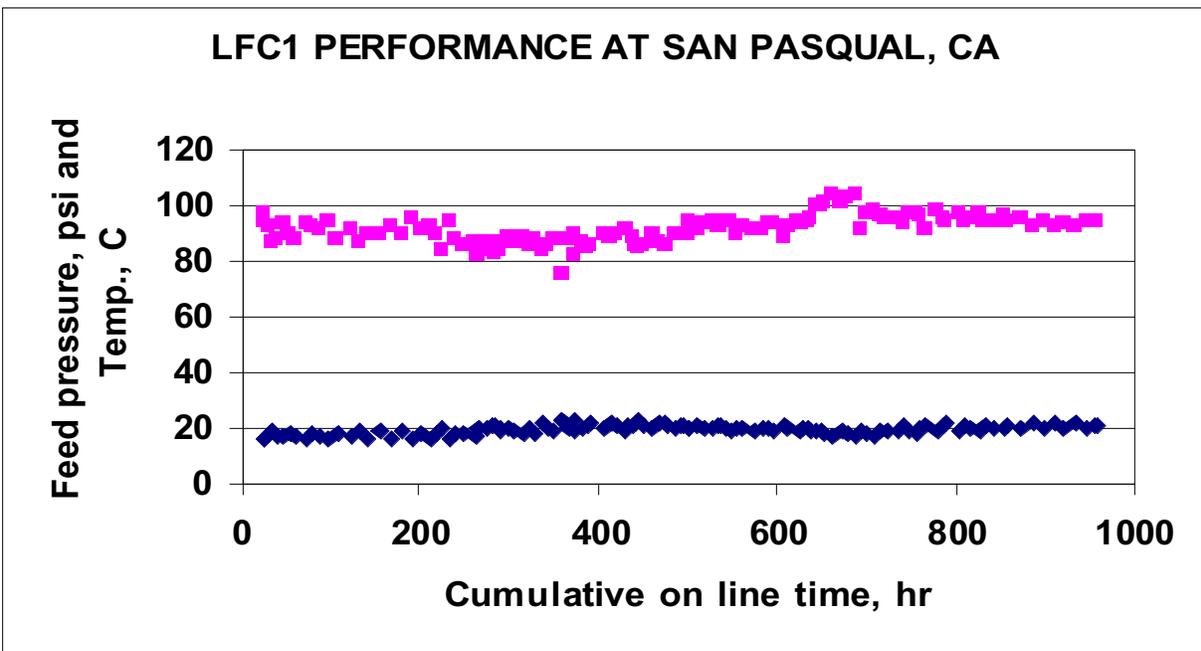
OPERATION OF LOW FOULING MEMBRANES AT SAN PASQUAL, CALIFORNIA

In the second stage of the pilot operation Hydranautics tested performance of the new, low fouling membrane type: LFC1. The experimental setup included capillary back-washable ultra-filtration membrane unit as a pretreatment followed by RO pilot unit equipped with 4 diameter LFC1 elements. The LFC1 membrane is made of a fully aromatic polymer, with a hydrophilic membrane surface. Because of the hydrophilic character of the membrane surface, its affinity to dissolve organics is much lower than of the conventional polyamide membrane. The capillary UF and RO

pilot unit equipped with the LFC1 membranes commenced operation in April 98. Fig. 7 shows the performance of the LFC1 membranes operating on tertiary effluent treated with UF

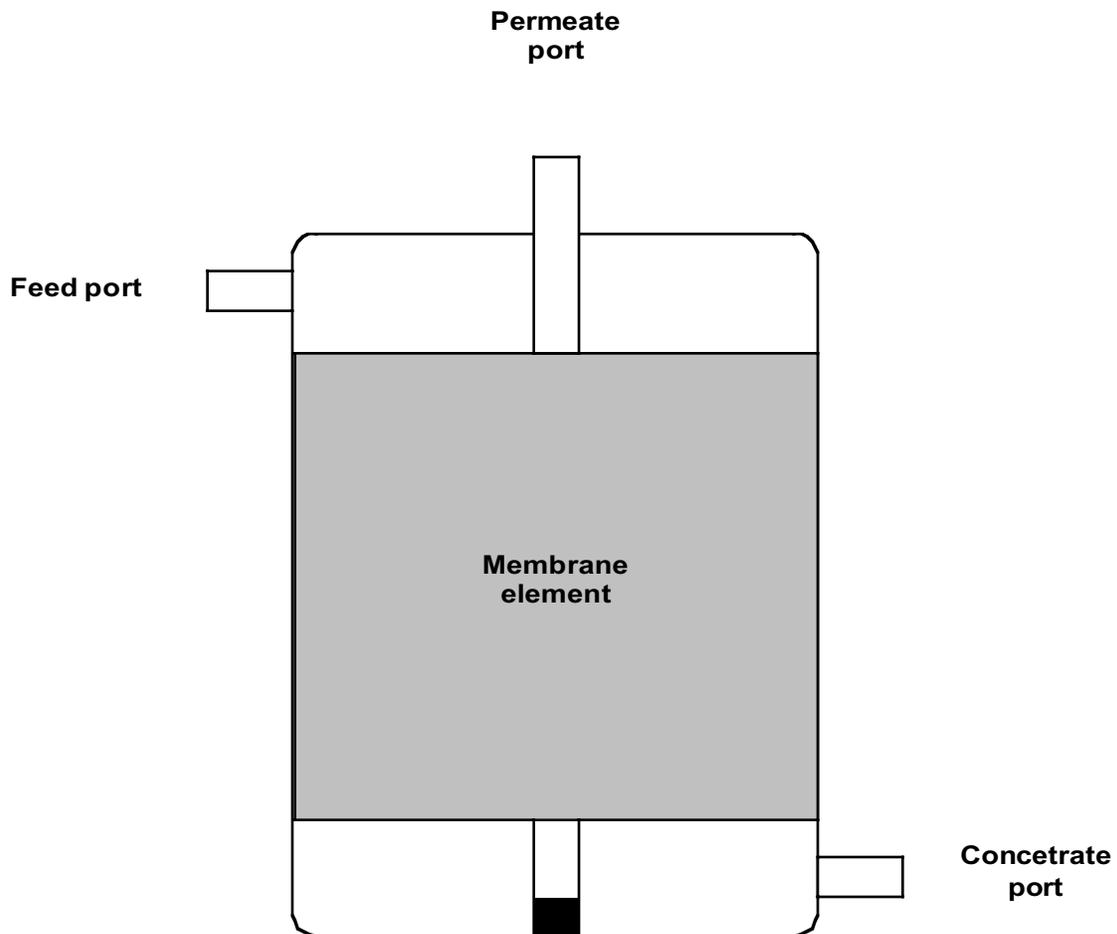


capillary membranes. The feed pressure was in the range of 80 —100 psi (0.5 —0.7 MPa), which is significantly lower than the feed pressure required for the ESPA



membranes operated at similar conditions. Also the initial step decline of specific flux usually experienced with conventional composite membranes has not been

observed with the LFC1. At the San Pasqual test site two configurations of LFC1 membrane elements were tested in two parallel lines. One system included conventional membrane elements. The other system included spiral wound membranes in encapsulated elements configuration. The encapsulated configuration has been developed by Hydranautics to improve the integrity of RO systems for wastewater reclamation applications. Fig 9 shows the encapsulated configuration, which eliminates



Encapsulated spiral wound element configuration

need for o-ring seals and therefore reduces possibility of permeate contamination by the constituents in the feed water. The encapsulated configuration enables testing the integrity of the individual elements on line, by applying vacuum or particle count test. This element configuration could improve system reliability by providing convenient way of identifications of leaking elements. Integrity tests conducted during the pilot operation confirm advantages of encapsulated configuration for maintaining and monitoring membrane system integrity.

SUMMARY

Combination of advanced water treatment and membrane desalination technology can be used effectively to treat municipal effluent and agricultural drainage water to reduce contaminants level to potable water quality.

The cost of reclaimed water, produced by applying currently available advanced treatment technology, is only slightly higher than the cost of water imported to Southern California. It is significantly lower than an alternative of water augmentation by desalting seawater.

Utilization of back-washable capillary technology as a pretreatment for municipal wastewater produces feed water of significantly better quality than the conventional pretreatment. The capillary pretreatment enables application of composite polyamide membranes for wastewater reclamation.

The newly developed low fouling polyamide membrane, LFC1, has low affinity to dissolved organics. In combination with capillary pretreatment it enables stable operation at low feed pressure in treating highly fouling water sources.

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