



Mark Wilf Ph. D. and Steven Alt

## REDUCTION OF MEMBRANE FOULING AND IMPROVING ELEMENTS INTEGRITY IN MUNICIPAL WASTEWATER RECLAMATION.

### Abstract

Municipal effluent, after secondary treatment, contains high concentrations of suspended particles, colloids and high level of biological activity. Application of membrane technology for treatment of municipal wastewater requires very extensive pretreatment prior to the RO process. The conventional multi-step treatment approach, based on disinfection, flocculation, clarification and media filtration, still produces RO feed water with very high fouling potential. Extensive field results from pilot and commercial RO system operation indicate high fouling rates, regardless of the nature of membrane material: cellulose acetate or composite polyamide. Membrane cleaning has to be applied very frequently in order to maintain the design product capacity. 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 a much lower concentration of colloidal and suspended particles than can be produced in a conventional pretreatment process. The fouling rate of the RO membranes operating on capillary effluent has been reduced significantly. The fouling rate has been reduced even more by introduction of new generation of low fouling composite membranes. In new, low fouling membranes, the surface of the salt rejection layer has been modified to make it more hydrophilic and reduce its affinity to dissolved organics. Field results of operation of the low fouling membranes indicate that the fouling rate is very low, comparable with that observed in operation with clean well water. For the emerging field of wastewater reclamation for potable application, integrity of RO elements is an important factor. One solution to improve barrier integrity is new design of membrane elements. The new design consists of encapsulation of individual elements in pressure vessels without the use of o-rings. This new element configuration enables on line determination of system integrity and reduces the possibility of permeate contamination by feed borne pathogens. The paper will describe properties of low fouling membrane technology and present results of its

application with conventional and capillary pretreatment. Performance in municipal wastewater reclamation applications will be compared with that of conventional membrane technology. Field results and RO system design using encapsulated elements will be discussed as well.

## Conventional pretreatment

In RO systems operating on conventionally treated municipal effluent, membrane fouling results in decrease of permeate flux. It demonstrate itself in significant increase of the feed pressure required to maintain the design permeate flow.

The municipal effluent after secondary treatment contains high concentration of colloidal particles, suspended solids and dissolved organics. The secondary treatment process usually includes biological treatment (activated sludge clarification) which results in high level of biological activity in the effluent. Prior to RO process this water has to be treated to reduce concentration of colloidal and solid particles and arrest biological activity. A typical configuration of conventional pretreatment is shown in Fig. 1, which outlines the tertiary pretreatment process applied currently at 5 mgd RO reclamation plant located at Water Factory 21 (WF 21), Orange County, California. The current pretreatment process is a result of evolution, improvements and simplification of the original design (1). The pretreatment consists of flocculation, lime clarification, recarbonation with CO<sub>2</sub> and settling and slow gravity filtration. The biological activity is controlled applying chlorination. Lime clarification is a very effective process in improving feed water quality, but is expensive, requires large area and produces sludge, which can be difficult to disposal. In some smaller systems the lime clarification and gravity filtration is replaced by in line flocculation followed by two-stage pressure filtration and cartridge filtration. At Water Factory 21 plant, RO membranes made of cellulose acetate material, which was membrane of choice for majority of the reclamation systems, experienced rapid fouling during operation. Fig 2 and 3 contain the results of operation of cellulose acetate (CA) membranes at Water Factory 21. The feed pressure (Fig. 2), initially at about 200 psi, in matter of days had to be increased to about 260 psi, in order to maintain constant permeate production. Within short period of operation the feed pressure had to be further increased to above 300 psi. The feed pressure had to be increased continuously, regardless of frequent membrane cleaning, conducted every 2 — 3 weeks. Unlikely water permeability, the salt rejection remained stable (Fig. 3) at the level of 94 — 96%. Extensive field tests have been conducted at WF 21 to evaluate the applicability of composite membranes for water reclamation. The incentives were significantly higher water permeability, therefore lower feed pressure and power cost, and higher salt rejection. Representative results of operation of polyamide composite ultra low pressure ESPA membranes at WF 21 are included in Fig 4, 5 and 6. The feed pressure of ESPA membranes started at much lower values, 60 psi compared to 200 for CA membranes (Fig 4). However, within short period of time feed pressure had to be increased over 300 psi in order to maintain the design permeate flow. This corresponds to over 80% decline of specific flux. Frequent cleanings have not help to mitigate the flux decline. Similar to operation of CA membranes, salt rejection of ESPA membranes remained stable (Fig 5) at the level of 97%. This is remarkable consider that the feed water contains 2 — 6 ppm of total chlorine, in the form of chloramines. Most likely presence of chloramines in the RO feed

water controlled biological activity and prevented bacterial growth in the RO elements. The pressure drop (Fig 6.) across the elements remained stable during the operational period of over two years. The above results of rapid membrane fouling and flux decline clearly indicate that conventional pretreatment is not effective process for producing RO feed of sufficient quality from municipal effluents.

### Membrane pretreatment

Use of membranes as a definite barrier in the RO pretreatment process have 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, which consists of 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 (3), is based on a fat 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.

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 5 to 20 psi. The major advantage of new pretreatment method 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. In municipal wastewater reclamation applications the new backwashable capillary pretreatment replaces lime clarification, media filtration and cartridge filters. The filtrate produced by capillary technology is practically free of colloidal material. However, little reduction of TOC is obtained. Performance of ESPA elements operated on municipal effluent, treated with capillary membranes, is shown in Fig 7. The feed pressure started at about 70 psi and rapidly increased to about 140 psi. Afterwards it leveled off and fluctuated with changes of feed water temperature during the operating period of year and a half. The initial decline of water permeability is substantial, about 60%. However significant, it is considerably lower than the flux decline of about 85% experienced in operation of

the same membrane type followed the conventional pretreatment. Use of capillary membranes as a pretreatment of RO feed enables application of composite membranes for water reclamation. This enables operation at lower feed pressure and produce water of lower salinity than it is possible using cellulose acetate membranes.

#### Low fouling RO membranes

Compared to the conventional composite polyamide, the low fouling composite (LFC1) membranes, introduced recently, are characterized by hydrophilic membrane surface and less negative surface charges compared to the conventional composite polyamide. It is expected that hydrophilic character of the membrane surface reduces rate of adsorption of organic matter present in the feed water. The LFC1 membrane elements were operated on municipal effluent, pretreated with capillary membranes, at Water Factory 21 and at San Pasqual Water Treatment Facility. The results obtained at San Pasqual are shown in Fig 8. The specific flux of LFC1 membranes is lower than the specific flux of ESPA membranes. Therefore, the initial feed pressure was about 90 psi, which is slightly higher than starting pressure of ESPA membranes at similar operating conditions. However, the feed pressure remained stable during the operating period. The elements operated at the flux rate of 12 gfd. At the end of the operating period the flux rate has been stepwise increased to 17 gfd. Such flux rate is considered very high for wastewater applications. The RO units in wastewater are usually designed to operate at average permeate flux rate of 10 gfd. Fig. 9 shows calculated values of specific flux. The results indicate that after the initial decline of about 15%, the specific flux remained stable during the operating period. Due to stability of performance, the membrane elements were not cleaned during the whole operating period of eight months. At the end of operating period the LFC1 elements were removed and tested at the nominal test conditions. The test results are summarized in Table 1. Compared to the ex-factory test data the average flux decline after eight months of field operation was about 10%. Cleaning procedure, consisting of recirculation of 0.5% NaOH solution, resulted in complete restoration of permeate flux.

#### High integrity element design

In wastewater reclamation the integrity of membrane barrier and ability to reject pathogens is becoming an important issue. In spiral wound configuration, in addition to potential passage through membrane defects, feed-permeate leaks can be formed due to damaged inter-connectors o-rings. To reduce possibility of leaks through the o-ring surfaces, Hydranautics developed encapsulated element configuration. The design shown in Fig. 10 consists of encapsulating single elements and eliminating o-rings completely. In this design the permeate tube extends beyond enclosure of the pressure vessel therefore, prevents possible contamination of permeate by feed water born pathogens. Encapsulated design also enables convenient, on line testing of integrity of individual elements, either

Table 1 Performance change of Hydranautics LFC1 elements during operation on the UF treated municipal effluent at San Pasqual plant. Operating period April 98 — November 98

Position during test operation	Ex-Factory		After Operation		After Cleaning	
	Rejection	Flux, gpd	Rejection	Flux, gpd	Rejection	Flux, gpd
Encapsulated Element Configuration						
Lead	99.5	1629	99.6	1512	Not cleaned	Not cleaned
Middle	99.5	1629	99.6	1466	99.4	1788
Tail	99.5	1684	99.6	1499	99.4	1788
Average	99.5	1647	99.6	1492	99.4	1788
Change %			+20	-9.4	+20	+8.5
Standard Element Configuration						
Lead	99.6	1908	99.5	1629	Not cleaned	Not cleaned
Middle	99.6	1908	99.6	1596	99.2	2317
Tail	99.6	2082	99.6	1578	99.2	1708
Average	99.6	1966	99.6	1601	99.2	2012
Change, %			0.0	-18.5	+100	+2.3
Averg. change, %			+10	-14	+60	+5

using particle counters or applying vacuum hold test. The encapsulated element configuration has been tested in field operation in parallel to the standard elements. Both performance and integrity has been evaluated in field conditions. The results confirmed high integrity of the encapsulated design. The tests include evaluation of MS2 virus rejection by the capillary pretreatment and spiral wound membrane elements. The results are shown in Fig. 11 and 12. The tests indicate a 5 log virus reduction by each membrane barrier.

### Summary

Membrane fouling encountered in wastewater reclamation systems is related to quality of the feed water and nature of membrane polymer. The results indicate that both fouling components: colloidal particles and dissolved organic matter participate in formation of fouling layer on the membrane surface. This fouling

process, designated as composite fouling (4), affects mainly water permeability. Table 2 summarizes permeate flux decline due to fouling for various membrane — pretreatment configuration. It is evident that by applying UF membrane pretreatment, fouling rate is reduced. The major effect of applying membrane pretreatment is reduction of concentration of particulate matter in the feed water. Therefore reduction in the fouling rate can be attributed in this case to reduction of cake layer formation on the membrane surface or its higher permeability. MF and UF membrane pretreatment has little affect on concentration on organic matter in the feed water. Natural organic matter has high affinity to hydrophobic

Table 2,

Membrane type	CA	ESPA1	ESPA1	LFC1
Pretreatment type	Conventional	Conventional	Capillary	Capillary
Specific flux, initial	0.07 gfd/psi	0.24 gfd/psi	0.24 gfd/psi	0.17 gfd/psi
Specific flux, stabilized	0.04 gfd/psi	0.04 gfd/psi	0.10 gfd/psi	0.15 gfd/psi
Flux decline,	40%	85%	60%	12 %

membrane material (5,6, 7). It is most likely that its absorption is responsible for observed flux decline of composite membranes in wastewater system utilizing membrane pretreatment. Hydrophilic membrane material has much lower affinity to dissolved organics (5), therefore, flux decline is much lower. Consequently membranes with hydrophilic surface can operate at higher flux rates. The fouling process in wastewater reclamation system does not result in any significant increase of pressure drop. This is because biological activity is reduced due to presence of chloramines in the feed water. Use of capillary pretreatment provides additional barrier, which reduces passage of bacteria to the RO system. The new design of RO elements results in increased barrier integrity, comparable with the capillary elements.

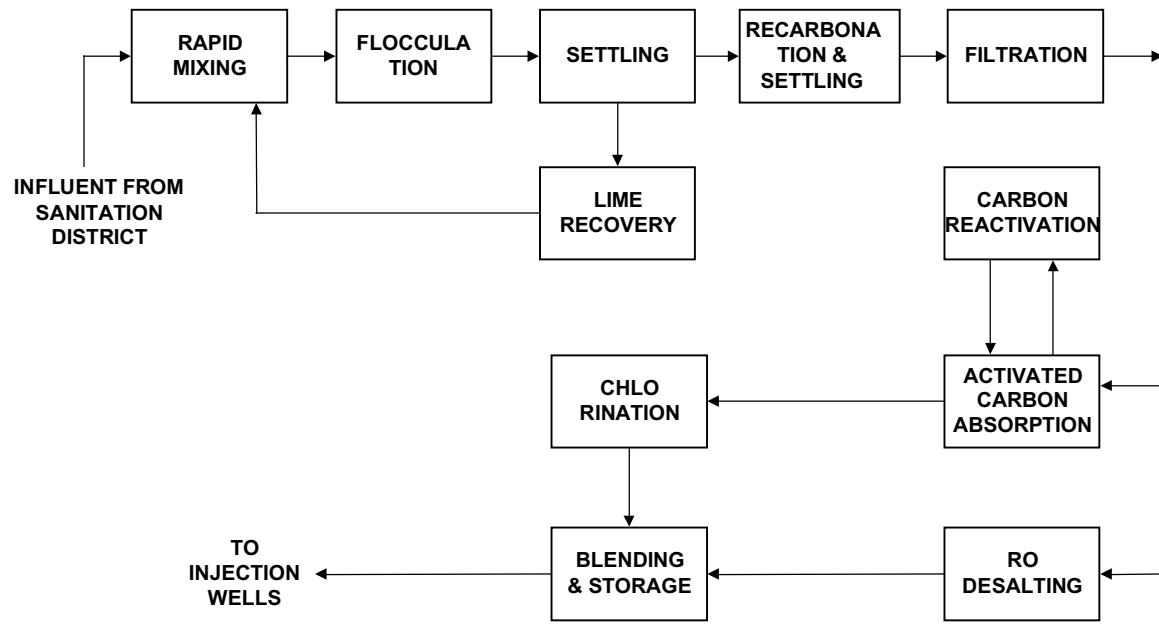
#### Acknowledgements

Hydranautics gratefully acknowledges the financial support provided by Bureau of Reclamation for part of the work described in the above paper. Cooperation from the City of San Diego in providing test site and operational support is also acknowledged. Hydranautics also appreciates the virus seeding study conducted by Montgomery Watson Engineering Company.

## References

1. Richard G. Sudak, William Dunivin and Martin G. Rigby, Municipal Wastewater Reclamation and Reverse Osmosis, Proceedings of the National Water Supply Improvement Association 1990 Biennial Conference, FL, August 1990, p. 225.
2. J. Lozier and R. Bergman, Membrane Process in Water Reuse, J. Lozier and R. Bergman, Proceedings of Water Reuse Symposium, Denver, CO, 1994.
3. G. L. Leslie, W. R. Mills, W. R. Dunivin, M. P. Wehner and R. G. Sudak, Performance and Economic Evaluation of Membrane Processes for Reuse Applications, Proceedings of ADA Conference, Williamsburg, VA, 1998, p. 299.
4. H. Winters, Use of critical conversion value (CCV) to predict bacterial and organic fouling potential of seawater reverse osmosis (RO) membranes, Proceedings of IDA Conference, Madrid (1998).
5. E. C. Devitt and M. R. Weisner, Natural Organic Matter and Membrane Fouling, , Proceedings of ADA Conference, Williamsburg, VA, 1998, p. 132.
6. X. Zhu and M. Elimelech, Fouling of Reverse Osmosis Membranes by Aluminum Oxide Colloids. Journal of Environmental Engineering, December 1995, pp. 884 — 892.
7. S. Hong and M. Elimelech, Fouling of Nanofiltration Membranes by Natural Organic Matter, Proceedings of ADA Conference, Monterey, CA, 1996, p. 717.

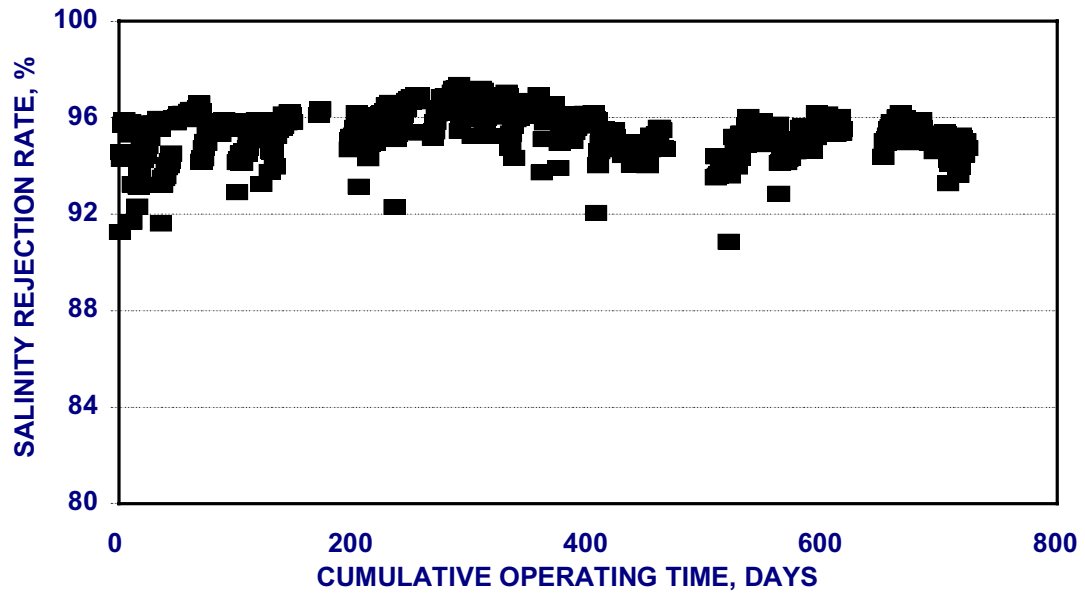




WATER FACTORY 21 WASTEWATER RECLAMATION SYSTEM FLOW DIAGRAM

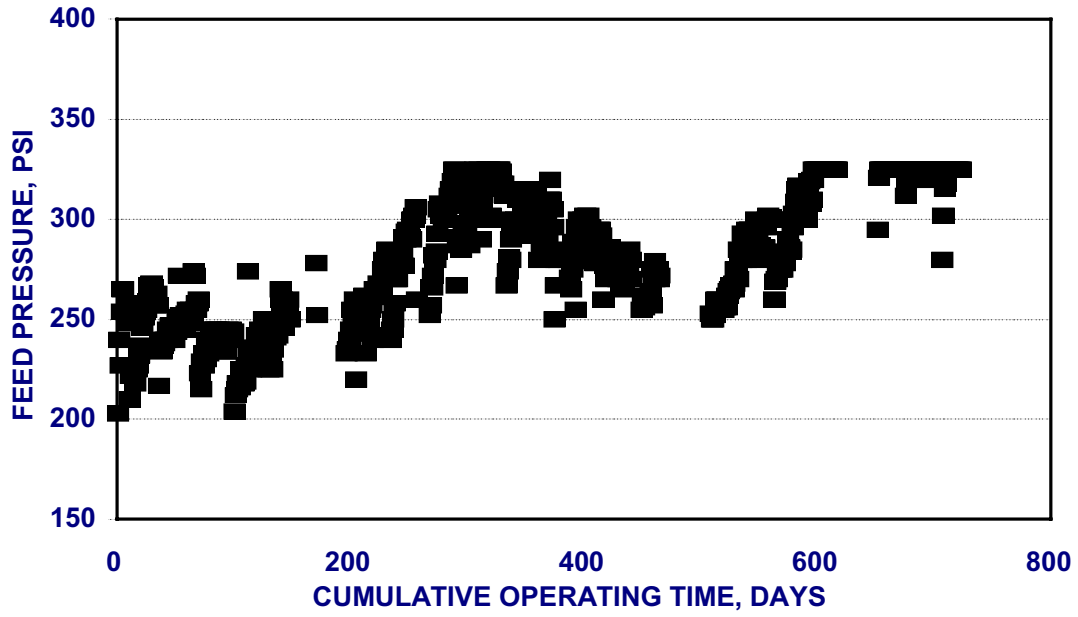
# WATER FACTORY 21

CAB MEMBRANE OPER. 04,89 - 02,91

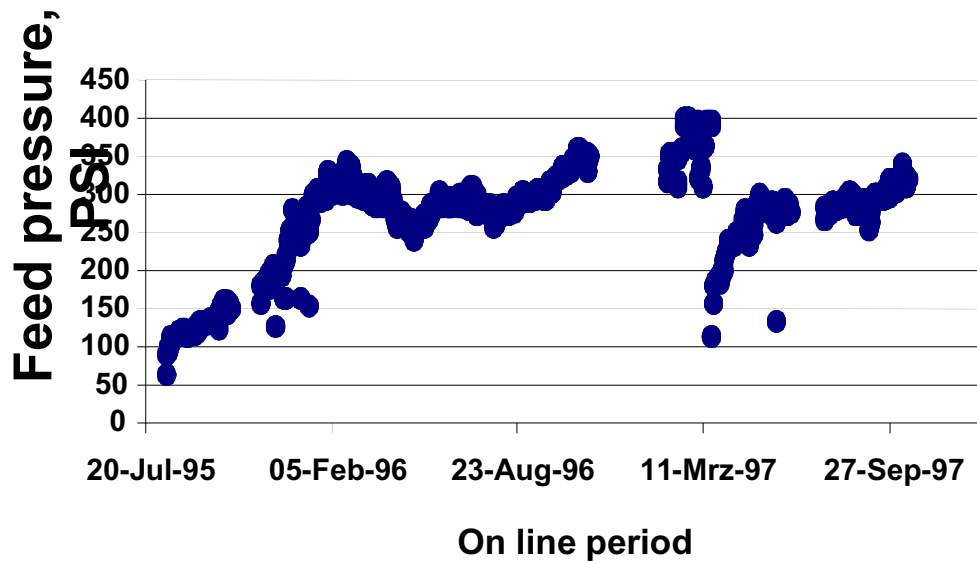


# WATER FACTORY 21

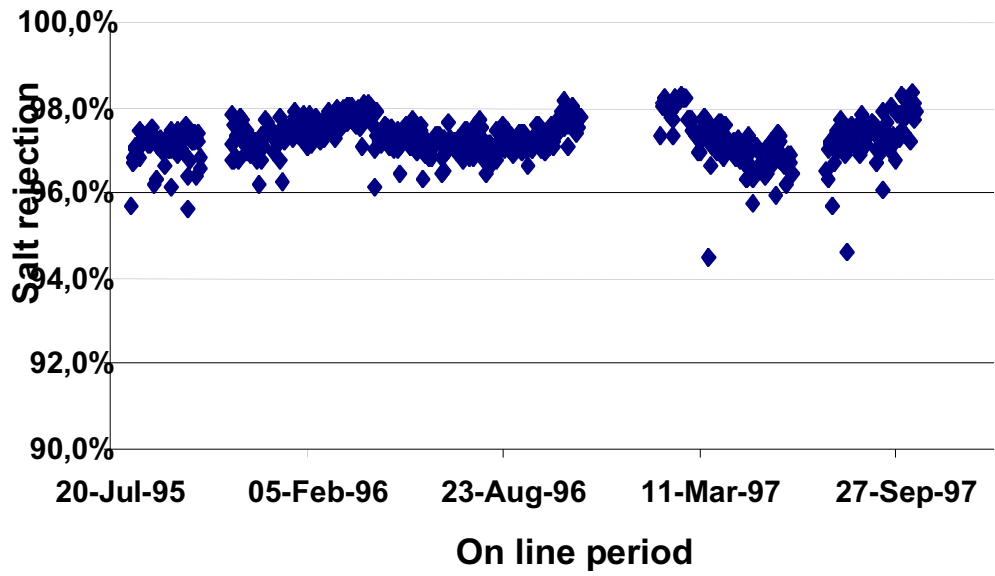
CAB MEMBRANE OPER. 04,89 - 02,91



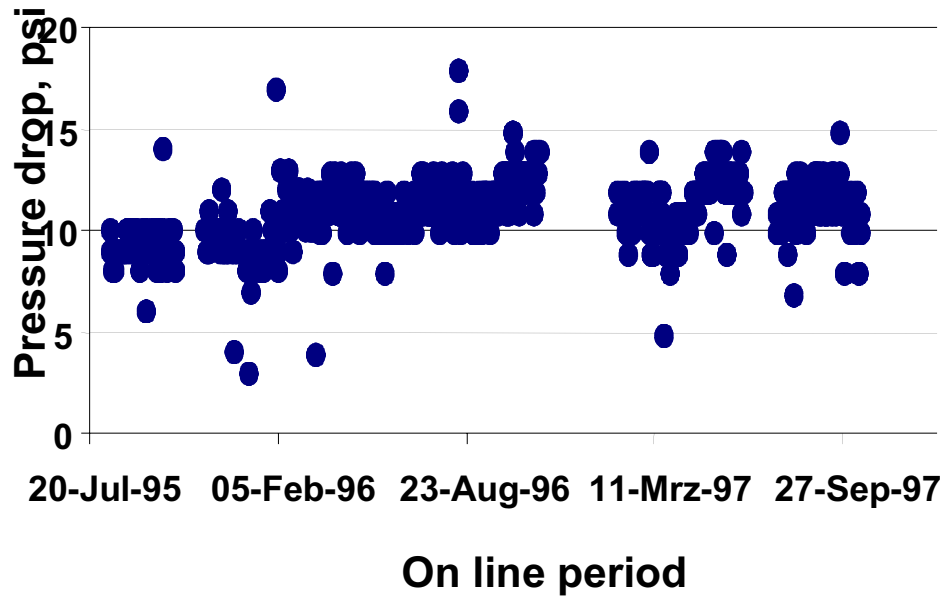
## OPERATION OF ESPA 400 ft<sup>2</sup>ELEMENTS AT WATER FACTORY 21



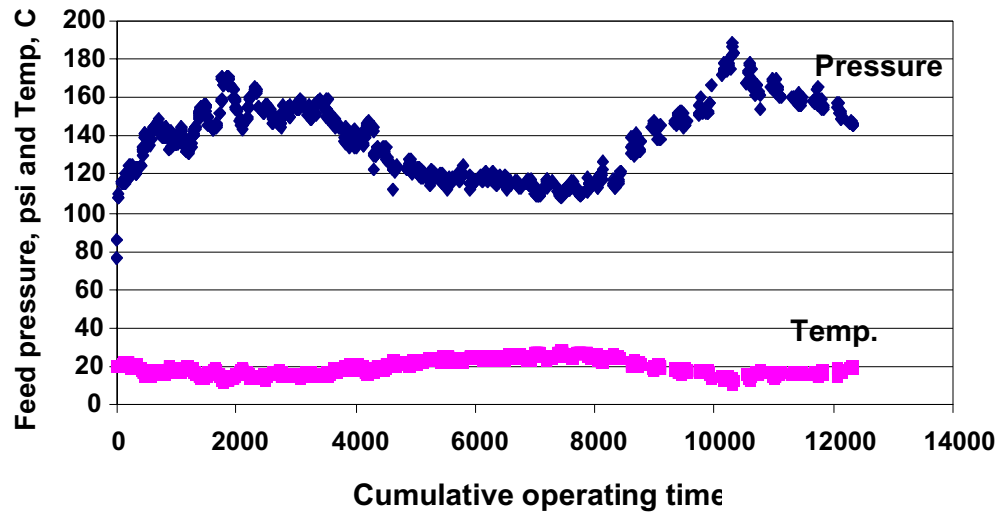
## OPERATION OF ESPA ELEMENTS AT WATER FACTORY 21



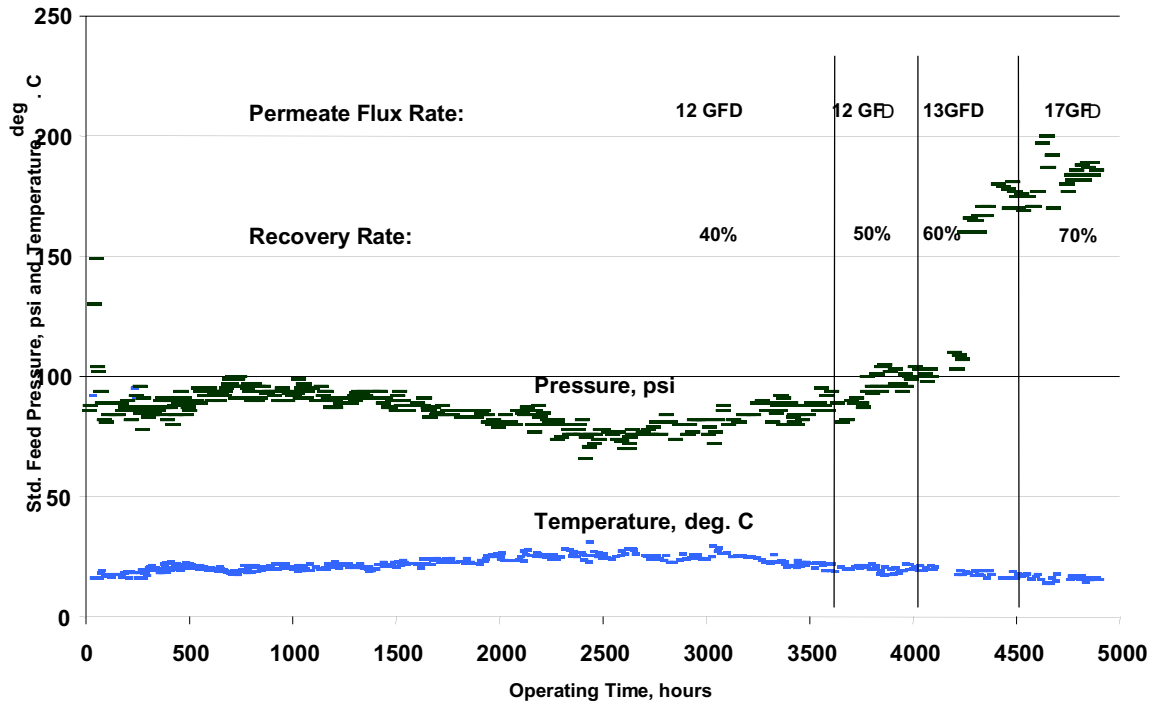
## OPERATION OF ESPA 400 ft<sup>2</sup> ELEMENTS AT WATER FACTORY 21



### ESPA Performance at San Pasqual Test Site, 10,9

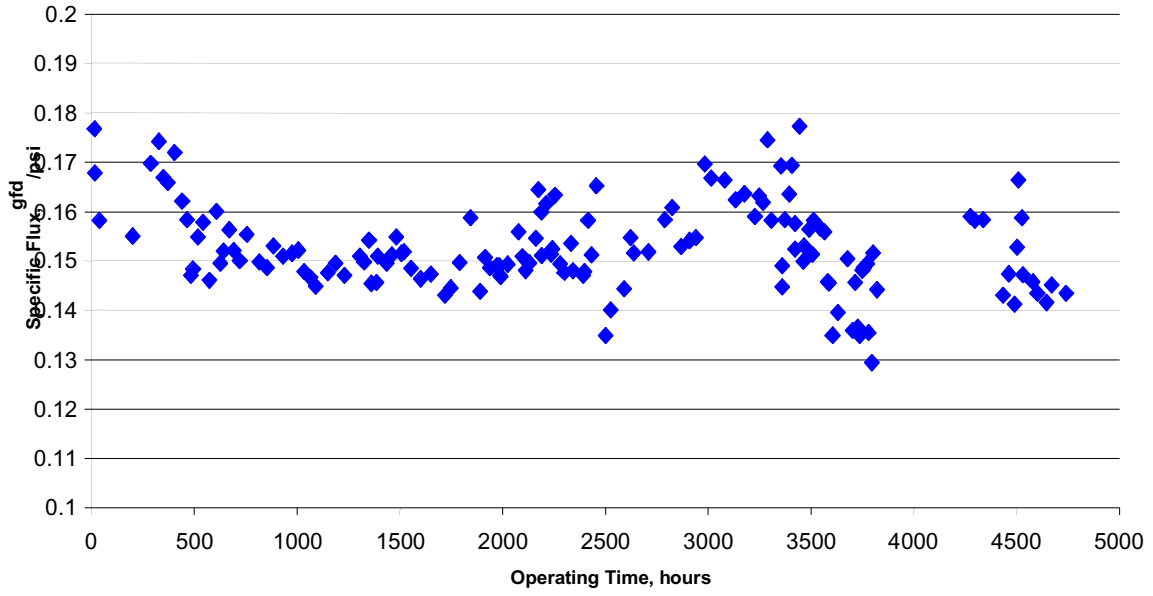


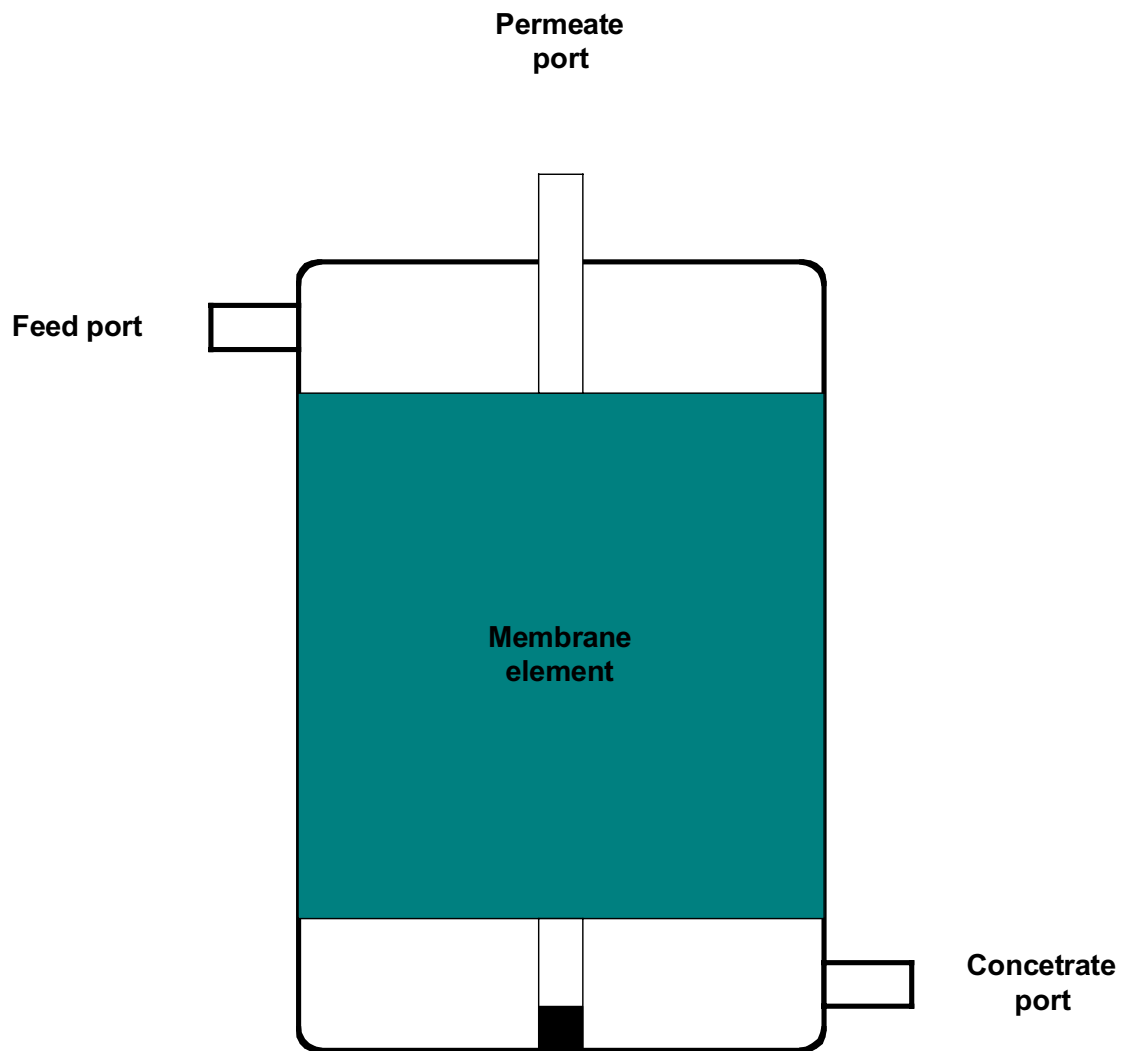
**SAN PASQUAL SITE**  
**Municipal Effluent Treated with capillary UF Pretreatment, LFC1**  
**Standard Configuration Membrane Element**





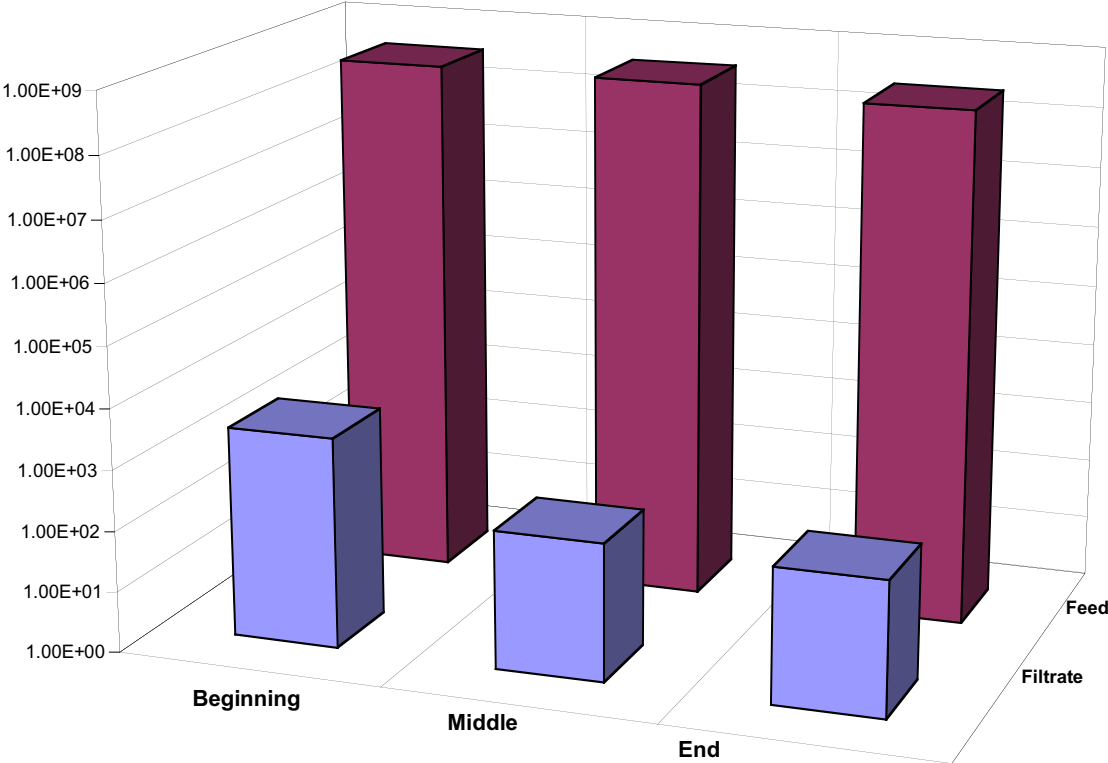
**SAN PASQUAL SITE**  
**Operating on Wastewater**  
**Capillary UF Pretreatment**  
**Standard Configuration RO Membrane Elements**  
**Apr98 to Nov98**





**Encapsuled spiral wound element configuration**

**Virus rejection by Hydranautics capillary UF membranes.  
High fouling conditions.**



### Virus rejection by Hydranautics RO LFC1 membranes.

