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APPLICATION OF UF COMBINED WITH A NOVEL LOW FOULING RO MEMBRANE FOR RECLAMATION OF MUNICIPAL WASTEWATER.

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Abstract

Membrane fouling encountered in reclamation of municipal wastewater represents serious design and operational concern. Fouling occurs because the 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 is being used in 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 of treating secondary effluent and maintaining stable performance of filtrate flow and operating pressure. The capillary technology produces RO feed water of a very high quality with a much lower concentration of colloidal and suspended particles than can be produced in a conventional pretreatment process. In reclamation plant that use membrane pretreatment, the fouling rate of the RO membranes operating on capillary effluent has been reduced significantly.

Fouling of the RO has been reduced even more by introduction of new generation of low fouling composite membranes (LFC1). In 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 in municipal wastewater reclamation systems indicate that the fouling rate is very low, comparable with that observed in RO operation with clean well water. The low fouling rate is attributed to a lower rate of adsorption of dissolved organics on the LFC1 hydrophilic membrane surface. Apparently, in the low fouling membranes, the bonding between the adsorbed organic layer and the membrane surface is relatively weak.

This 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. Results of operation of capillary UF membrane pretreatment on municipal secondary effluent and optimization of operating parameters will be described as well.

Conventional Pretreatment

In RO systems operating on conventionally treated municipal effluent, membrane fouling results in a decrease of permeate flux. This demonstrates itself as a 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 the 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 the 19 mld 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 CO2 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 dispose of. 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 14 bar, had to be increased to about 18 bar in matter of days, in order to maintain constant permeate production. Within a short period of operation the feed pressure had to be further increased to above 21 bar. The feed pressure had to be increased continuously, regardless of frequent membrane cleaning, conducted every 2 – 3 weeks. Unlike the 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 the much lower value of 4 bar compared to 14 bar for CA membranes (Fig 4). However, within a short period of time feed pressure had to be increased over 21 bar 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 considering that the feed water contains 2 – 6 ppm of total chlorine, in the form of chloramines. Most likely, the 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.

UF 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. However, the conventional, spiral wound configuration of ultrafiltration membrane elements was not suitable for treatment of highly fouling wastewater. 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 ultrafiltration technology offered recently (3), is based on a 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 for backflushing is very short, compared to the off line time of conventional filters for filter backwashing. The frequent backwashing results in stable permeate flux rates. The feed pressure is in the range of 0.3 to 1.5 bar. 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. Secondary effluent has very high fouling potential and application of capillary technology requires suitable membrane type and operating conditions to obtain reliable performance. It has been found in field conditions that capillary membranes made of hydrophilic polymers are less prone to fouling by dissolved organics then the conventional hydrophobic type. Still, even with hydrophilic capillary membranes the operating interval between cleaning is too short, hardly exceeding a few days. However, the operating intervals can be significantly increased, by adding flocculant to the secondary effluent, ahead of the capillary system.

Figure 7 shows the results of operation of Hydranautics HYDRAcap^{TM} capillary unit at the San Luis Rey (Oceanside, CA) wastewater reclamation plant. The figure shows values of feed pressure required to maintain constant filtrate flow. The unit operated in dead end mode at a flux rate of 55 lmh. Initially, a very steep increase of feed pressure was observed within a number of days. Membrane cleaning was required every 3 – 5 days. However, after implementing a low level addition of ferric chloride to the UF feed water, the operating intervals without cleaning was extended to over 30 days. The reason for such a significant performance improvement is not clear at this point. It can be speculated that ferric hydroxide forms a highly permeable spongy layer on the capillary surface that adsorbs organic material and attracts colloidal particles. During the backwash step this layer is lifted from the membrane surface and flushed out from the capillaries. Tests are under way to get a better understanding of this process. 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 8. The feed pressure started at about 4.8 bar and rapidly increased to about 9.6 bar. Afterwards it leveled off and fluctuated with changes of feed water temperature during the operating period of one and a half years. The initial decline of water permeability is substantial at about 60%. However significant, it is considerably lower than the flux decline of about 85% experienced in operation of the same membrane type following conventional pretreatment. Use of capillary membranes as a pretreatment of RO feed enables application of composite membranes for water reclamation. This allows operation at lower feed pressure and produces water of lower salinity than 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 a hydrophilic membrane surface and less negative surface charge compared to the conventional composite polyamide. It is expected that the hydrophilic character of the membrane surface reduces the 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 9. The specific flux of LFC1 membranes is lower than the specific flux of ESPA membranes. Therefore, the initial feed pressure was about 6.2 bar, 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 20 lmh. At the end of the operating period the flux rate has been increased incrementally to 29 lmh. Such a flux rate is considered to be very high for wastewater applications. The RO units in wastewater are usually designed to operate at an average permeate flux rate of 17 lmh. Fig. 10 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%. The cleaning procedure, consisting of recirculation of 0.5% NaOH solution, resulted in complete restoration of permeate flux.

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, lmh	Rejection	Flux, lmh	Rejection	Flux, lmh
Array 1						
Lead element	99.5	7.58	99.6	7.04	Not cleaned	Not cleaned
Middle element	99.5	7.58	99.6	6.82	99.4	8.32
Tail element	99.5	7.84	99.6	6.98	99.4	8.32
Average	99.5	7.66	99.6	6.94	99.4	8.32
Change %			+20	-9.4	+20	+8.5
Array 2						
Lead element	99.6	8.88	99.5	7.58	Not cleaned	Not cleaned
Middle element	99.6	8.88	99.6	7.43	99.2	10.78
Tail element	99.6	9.69	99.6	7.34	99.2	7.95
Average	99.6	9.15	99.6	7.45	99.2	9.36
Change, %			0.0	-18.5	+100	+2.3
Average change, %			+10	-14	+60	+5

Membrane Elements Integrity

In wastewater reclamation the integrity of the membrane barrier and the ability to reject pathogens is becoming an important issue. The integrity of spiral wound RO elements is tested by applying a vacuum hold test. In conventional spiral wound elements this test can only be applied before loading elements into the RO system. The integrity of capillary UF and MF elements can be tested while elements are installed in the system. The most common test used with capillary modules is the pressure hold test. It consists of applying air pressure and monitoring pressure decay. In the framework of this study integrity of the system was determined by evaluating MS2 virus rejection by the UF and RO elements. The results of the test are shown in Fig 11 and 12. The results indicate a 5 log virus reduction by each membrane barrier.

Commercial Installations

One of largest commercial plants utilizing LFC membranes is the Bedok Wastewater Reclamation Plant, located in Singapore. The Bedok plant commenced operation in April 2000. The feed water consists of secondary municipal effluent, which is treated with capillary microfiltration unit. Scale inhibitor and sulfuric acid is added to the effluent of the MF unit. Feed pH is maintained at about 6. The RO unit consists of two trains each producing 5,000 m3/day. The design flux rate is 18.7 l/m2-hr (11 gfd). The RO trains configuration consists of a three stage array: 28:14:8 pressure vessels, 6 elements per vessel. The design recovery rate is 85%.

During the initial operating period some scaling was encountered in the third stage of the RO units. Scale was determined to be composed mainly of calcium phosphate. Cleaning with citric acid was successful in restoring membrane performance. The scaling was attributed to improper selection of scale inhibitor. After changing the scale inhibitor type a stable performance were obtained.

Even though the feed water originates from municipal effluent, LFC membrane performance is very stable in respect of feed pressure. Feed pressure is within projected range of 8 – 10 bar (116 – 145 psi). No pressure drop increase is observed. Biological activity is controlled by maintaining a chloramine residual (about 2 ppm) in the feed water to the RO unit. In spite of presence of chloramines in the feed water, salt rejection of LFC membranes is very stable and higher than projected.

Summary

Membrane fouling encountered in wastewater reclamation systems is related to the 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 the 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 configurations. It is evident that by applying UF membrane pretreatment, the fouling rate is reduced. The major effect of applying membrane pretreatment is the reduction of the concentration of particulate matter in the feed water. Therefore reduction in the fouling rate can be attributed in this case to the 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 membrane material (5,6, 7). It is most likely that its absorption is responsible for the observed flux decline of composite membranes in a 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 a hydrophilic surface can operate at higher flux rates.

The fouling process in wastewater reclamation systems does not result in any significant increase of pressure drop across the membranes. This is because biological activity is significantly reduced due to presence of chloramines in the feed water. Use of capillary pretreatment provides an additional barrier, which reduces the passage of bacteria to the RO system. The design concept of using LFC membranes to treat municipal effluent, developed in pilot units, has been successfully applied in operation of large commercial RO systems. Long term stable performance in respect of feed pressure and salt rejection has been demonstrated. Biological activity, usually a major problem in wastewater reclamation applications, has been effectively controlled by presence of chloramines.

Table 2, Effect of pretreatment technology on specific permeate flux for various types of RO membranes

Membrane type	**Cellulose acetate**	**ESPA1 (polyamide)**	**ESPA1 (polyamide)**	**LFC1 (low fouling)**
Pretreatment type	**Conventional**	**Conventional**	**Membrane (capillary)**	**Membrane (capillary)**
Specific flux, initial	**1.7 lmh.bar**	**5.9 lmh.bar**	**5.9 lmh.bar**	**4.2 lmh.bar**
Specific flux, stabilized	**1.0 lmh.bar**	**1.0 lmh.bar**	**2.5 lmh.bar**	**3.7 lmh.bar**
Flux decline,	**40%**	**85%**	**60%**	**12 %**
Operating P, bar feed pressure at 17 lmh flux rate bar	**14 - 24**	**20 - 24**	**10 - 13**	**7 - 11**
Power consumption, kwhr/m3	**5.0 – 6.0**	**5.0 – 6.0**	**2.5 – 3.2**	**1.7 – 2.7**

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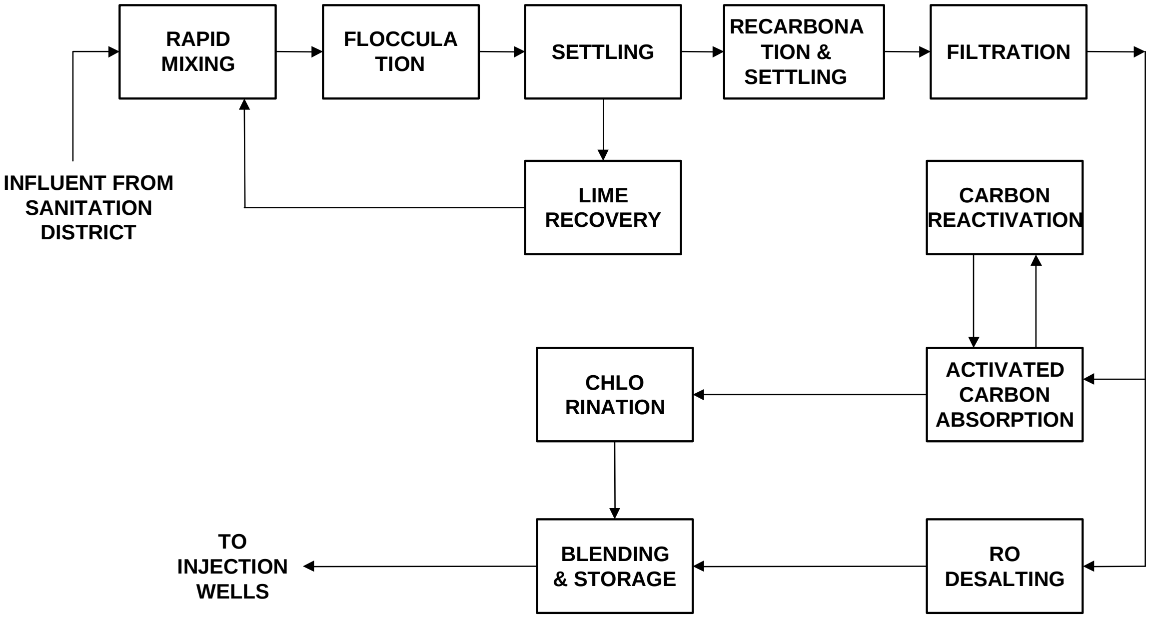

WATER FACTORY 21 WASTEWATER RECLAMATION SYSTEM FLOW DIAGRAM

Figure 1

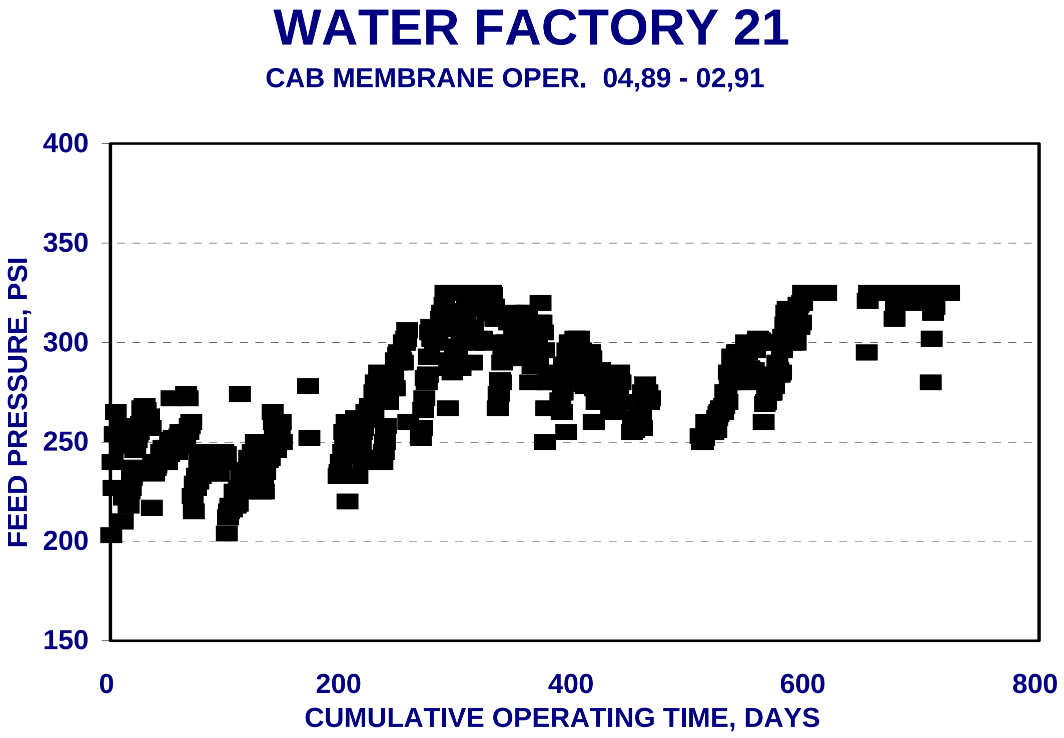

Figure 2

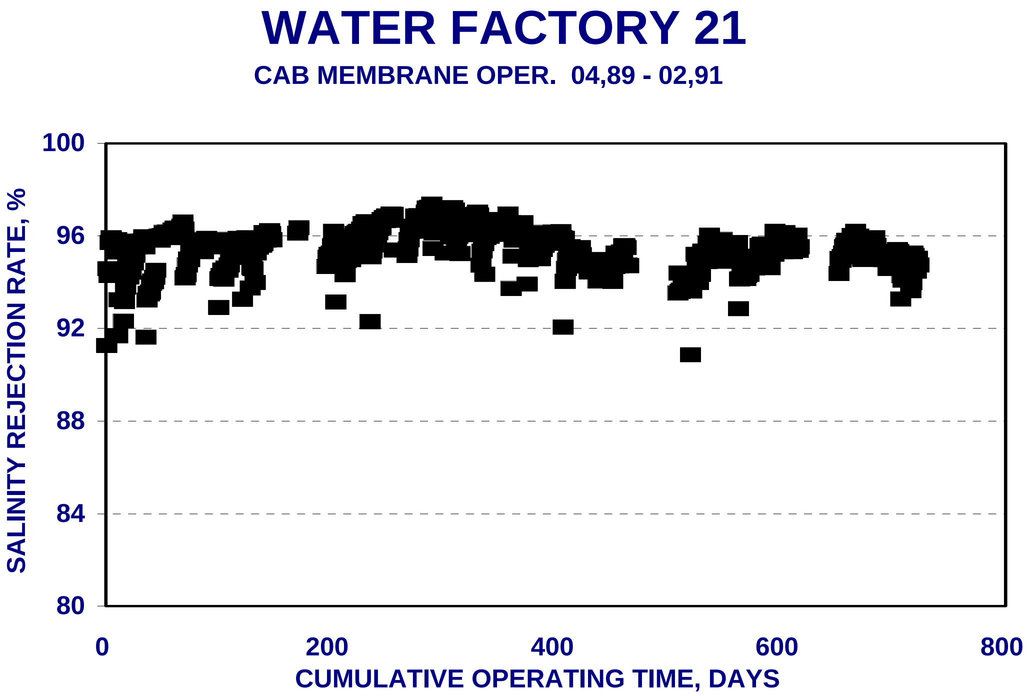

Figure 3

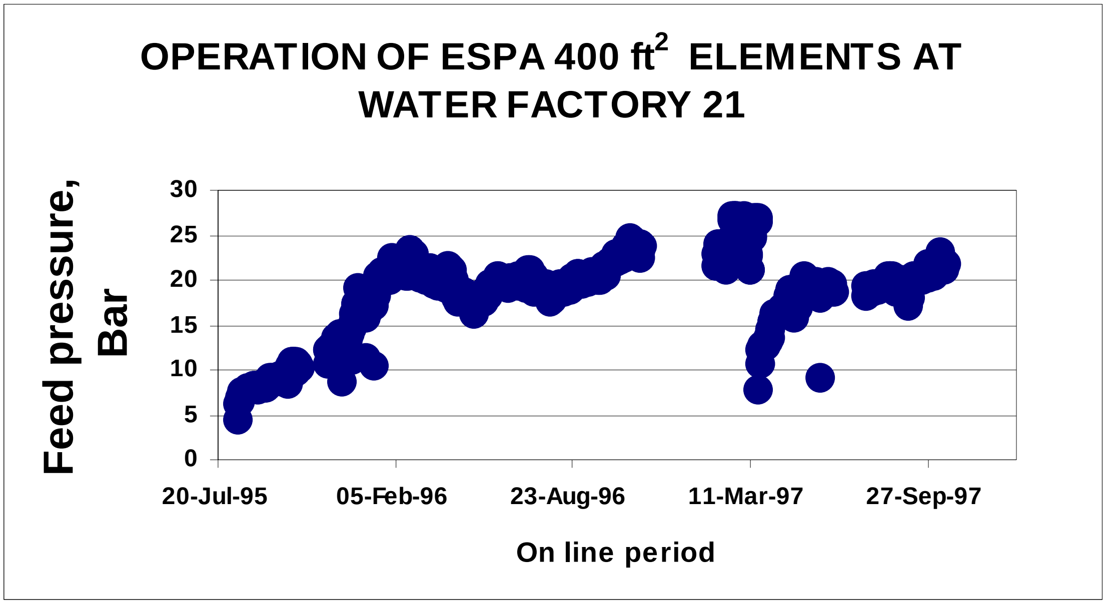

Figure 4

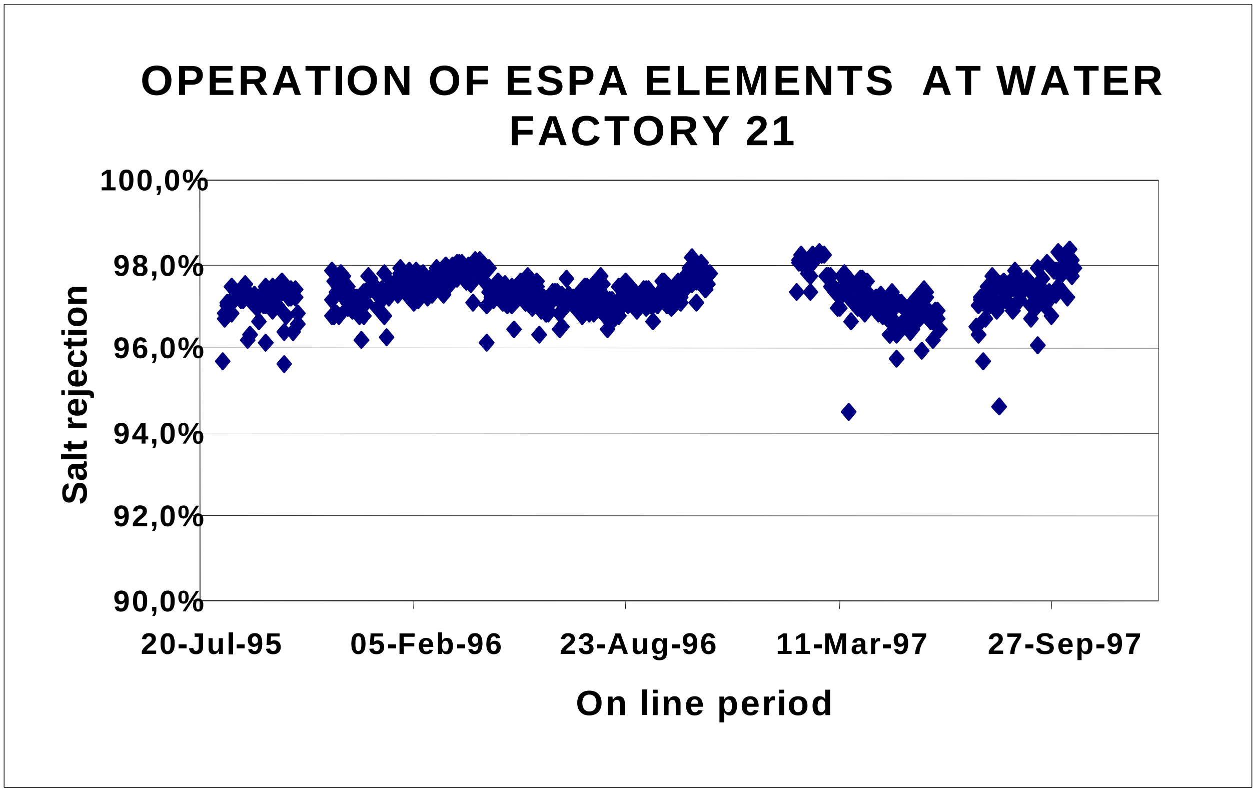

Figure 5

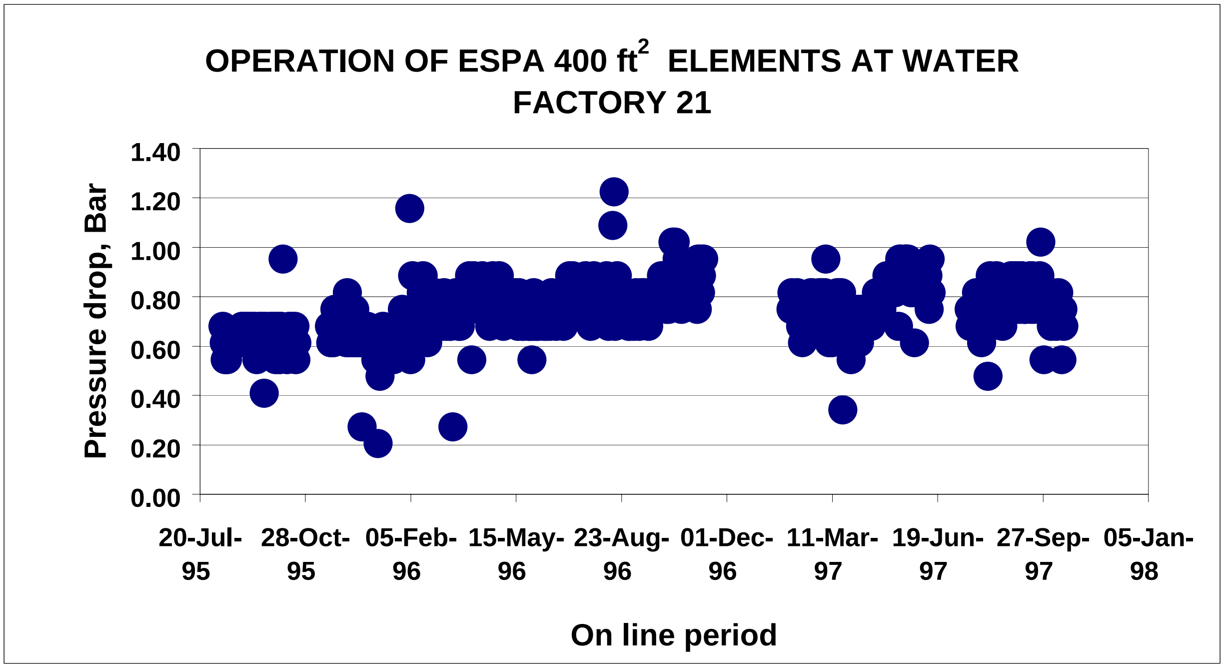

Figure 6

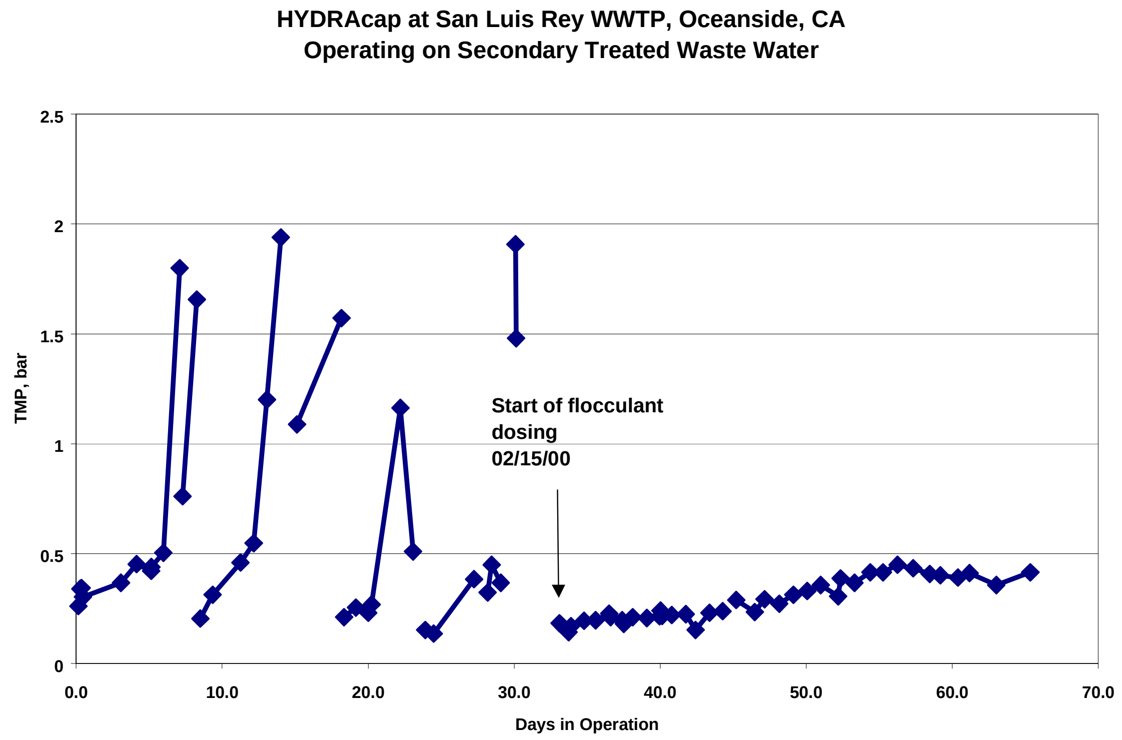

Figure 7

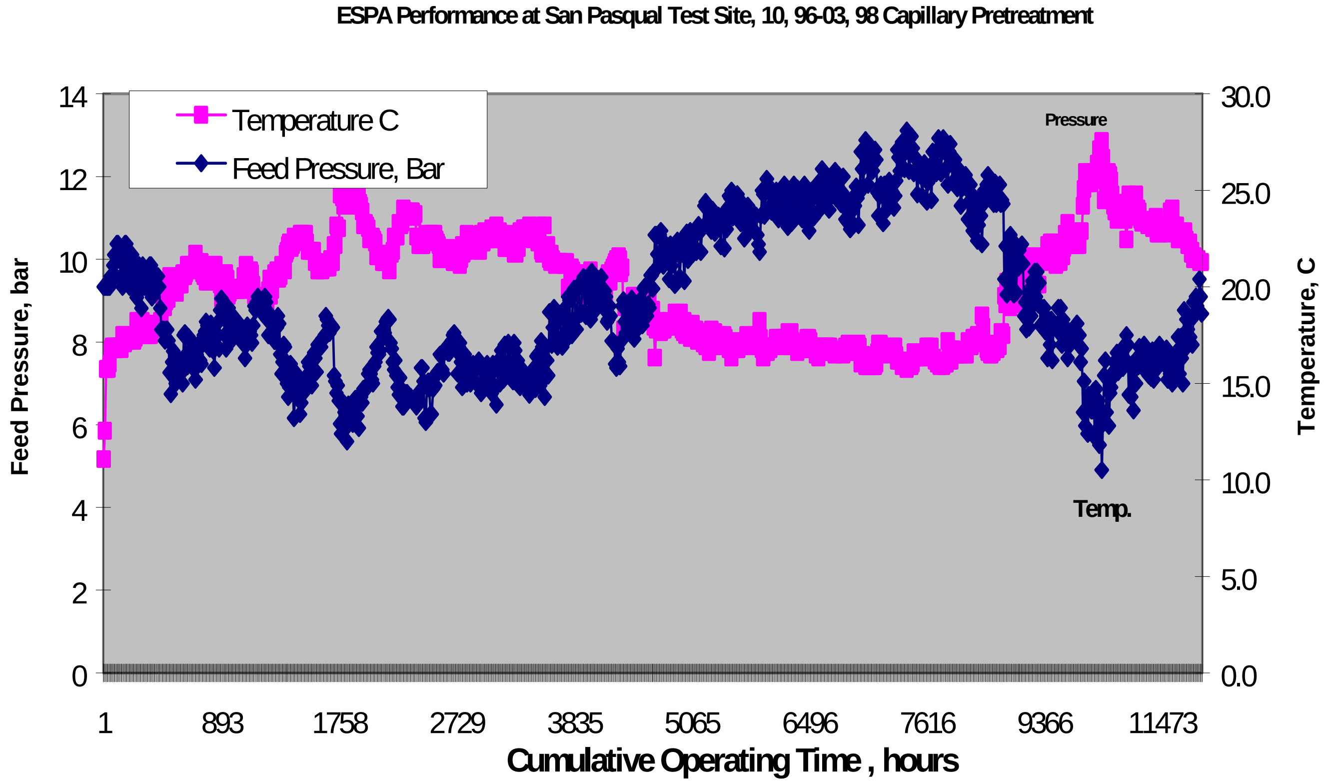

Figure 8

LFC1 OPERATION AT SAN PASQUAL SITE
Municipal Effluent Treated with Capillary UF Pretreatment, Standard Configuration Membrane Element, April 98 - Nov 98

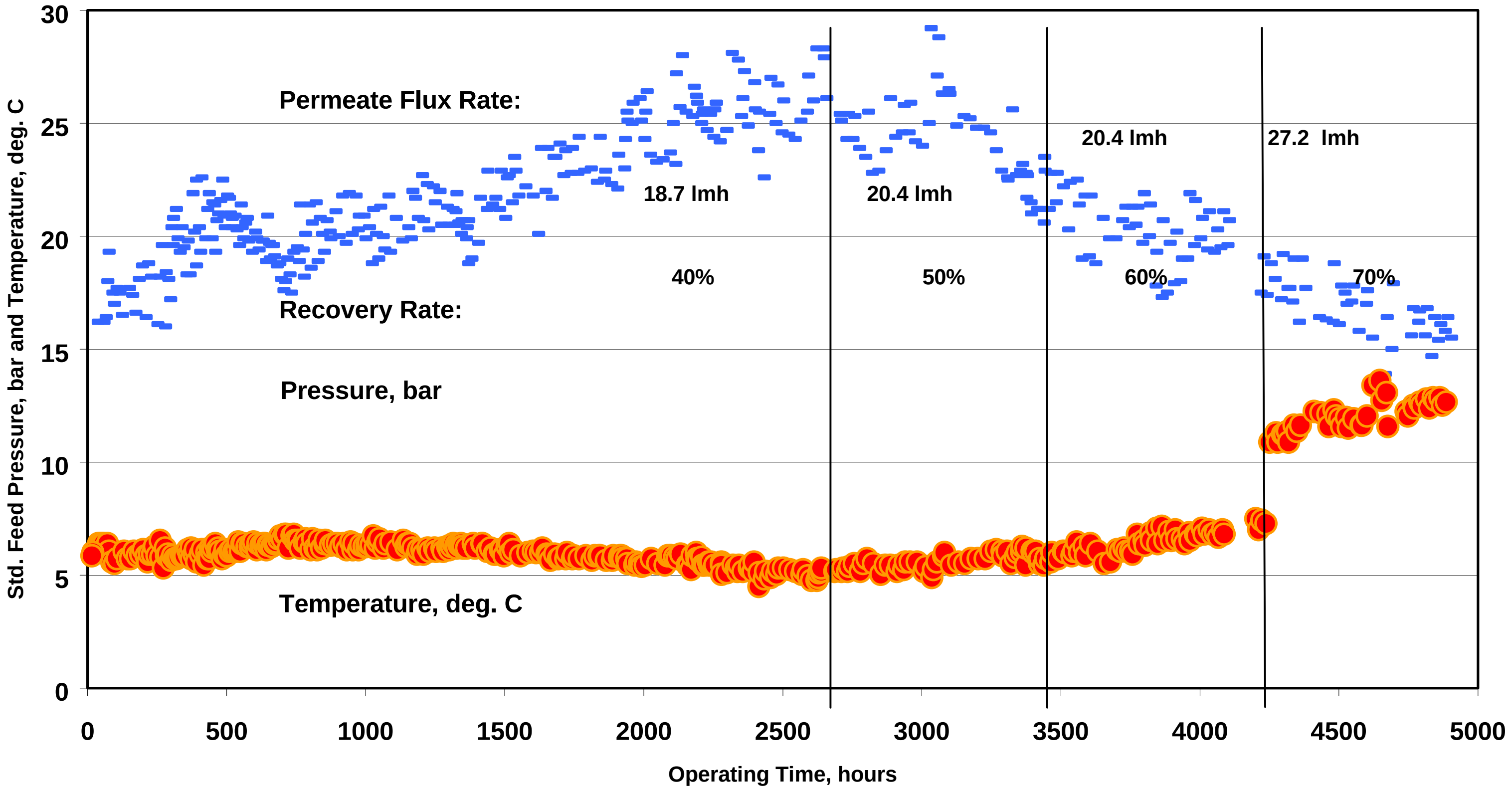

Figure 9

SAN PASQUAL SITE
Wastewater Effluent, Capillary UF Pretreatment
Encapsulated LFC1 Membrane Elements
Apr98 to Nov98

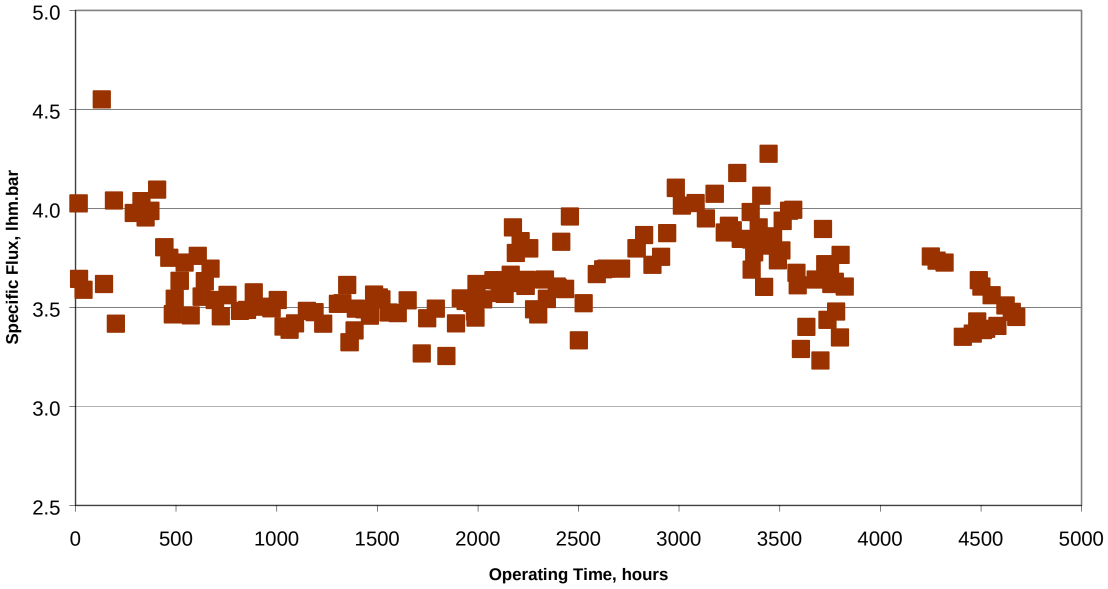

Figure 10

Virus rejection by Hydranautics RO LFC1 membranes.

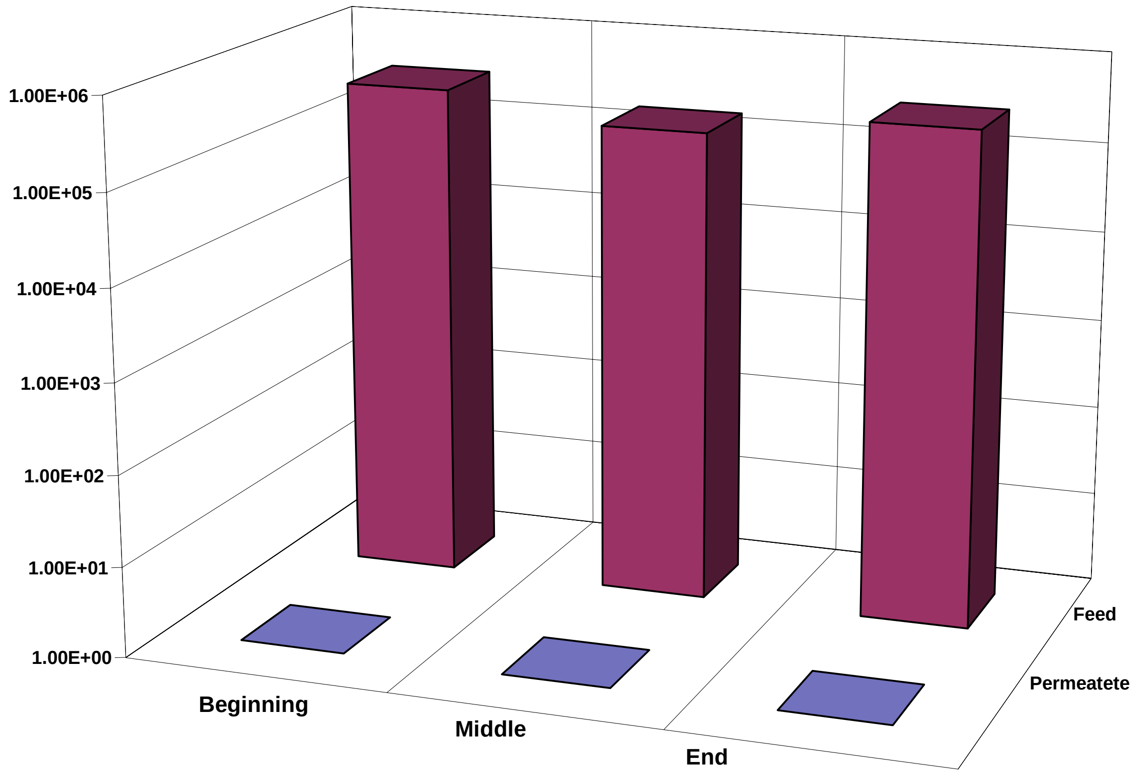

Figure 11

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

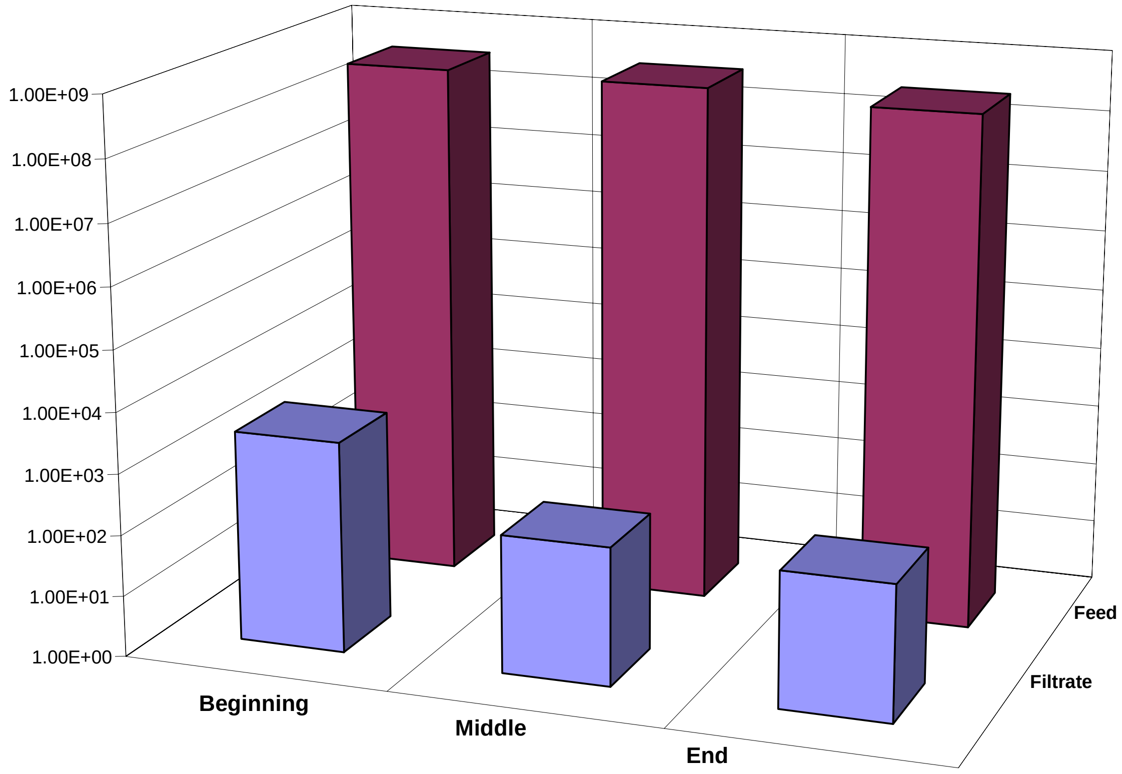

Figure 12