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ADVANCED MEMBRANE TECHNOLOGY FOR WATER RECLAMATION

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. The raw water 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 6 MGD of low salinity water by blending 4 MGD of RO permeate with 2 MGD 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 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 processing of municipal effluent. It consists of capillary microfiltration and ultrafiltration. The new membrane pretreatment technology, in a capillary configuration, is capable to produce RO feed water of much higher quality then the conventional pretreatment process. Better feed water quality enables more reliable and more efficient operation of the RO systems. This paper will describe process design, operational results and economics of wastewater reclamation by reverse osmosis using conventional and advanced capillary pretreatment technology.

ARLINGTON DESALTER

The schematic process flow diagram of the Arlington Desalter is given in Fig. 1. Feed water 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, provision exists for passing 2 MGD 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, is used as feed for the RO system. The RO Feed water 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 Feed water is pressurized to approximately 210 psi 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 flux rate of the membranes is about 14 gfd. 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. The 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 or direct disposal to the ocean

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 Hydranautics 8060-HSY-CAB2, 8" diameter, 60" long, 510 ft2 nominal membrane area, made of blended cellulose acetate membrane material. The RO units operate at 85% permeate recovery. Feed water at Water Factory 21, even after tertiary treatment has a very high fouling potential. Foulants existing in the RO feed at Water Factory 21 consist mainly of dissolved organics and biological fragments (algae and bacteria). The common indicator of RO feed water quality, the Silt Density Index, is not even measurable in the local feed water. TOC and COD are in the range of 10 - 20 ppm, in addition to a high concentration of biological debris. Due to high concentration of ammonia in the raw water, chlorination produces chloramine in a concentration of approximately 10 ppm in the RO feed. In spite of this adverse feed water 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. At this lower flux rate long term stable performance has been maintained.

MEMBRANE PERFORMANCE

Figures 3, 4, 5 and 6 contain performance of subunit 2C, for the period of April ’89 until February ’91. 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. 4). The product flow was maintained at the level of 580 GPM (Fig 6). Membrane fouling and its affect on productivity was initially compensated by increasing feed pressure to a maximum agreed upon value of 350 psig (Fig. 5). 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 of operation, 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. The objective of application of reverse osmosis technology at the Factory 21 Plant is to reduce concentration of harmful constituents in the water. This is necessary because product water after underground injection mixes to some extend with potable water aquifer. Table 1 contains representative composition of the effluent obtained from the Orange County Sanitation District, RO permeate and Water Factory 21 blended effluent. Maximum concentration limits of corresponding constituents is also included for comparison. According to operational data the quality of Water Factory 21 effluent was always in compliance with the regulatory quality limits.

CONVENTIONAL PRETREATMENT

The municipal effluent after secondary treatment contains high concentration of colloidal particles, suspended solids and dissolved organics. The municipal treatment process usually includes biological treatment (activated sludge clarification) which results in high level of biological activity in the effluent. Prior to RO this water has to be treated to reduce concentration of colloidal and solid particles and arrest biological activity. The tertiary pretreatment process applied currently at Water Factory 21, shown in Fig. 2, outlines the typical configuration of conventional pretreatment for wastewater applications. 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 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. On the average, this simplified pretreatment produces effluent of lower quality then after the lime clarification process, but the equipment is significantly smaller and simpler to operate. The feed water after a conventional pretreatment has a high fouling potential. It is not uncommon that RO membranes would experience 25% - 30% per year average flux decline, even with frequent membrane cleaning.

ADVANCED MEMBRANE 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 (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. 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 15 to 30 psi. 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 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 long and 8 - 13 in diameter. In actual field operation, a single module can produce 8,000 - 40,000 gallons 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 for over two years now (30). Results are promising and large commercial installations are under advanced planning stages. 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 simplifies the pretreatment system and reduces the use of chemicals. It is capable to produce feed water with a very low concentration of colloidal particles and bacteria. This improved quality of the feed water enables use of polyamide composite membranes for treatment of municipal effluent and operate RO membranes at higher permeate flux rate. These systems will benefit from better performance of current generation of composite membranes: higher salt rejection and lower operating pressure.

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 $0.27/m^3 or $1.4 per kgallon. The cost of reclaiming municipal waste water, based on the process used in Water Factory 21 is estimated to be about $$0.32/m^3 or $1.21/kgallon. The cost of water reclamation compares favorably with other alternatives of augmentation of Southern California water supply. 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 $0.19/m^3 or $0.72 per acre foot. 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 $0.82/m^3 or $3.1/kgallon. 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.

CONCLUSIONS

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.

REFERENCES

1. Evaluation of Membrane Processes and their Role in Wastewater Reclamation, Final Report of Contract for US Department of Interior OWRT, David Argo and Martin Rigby, November 30, 1981.

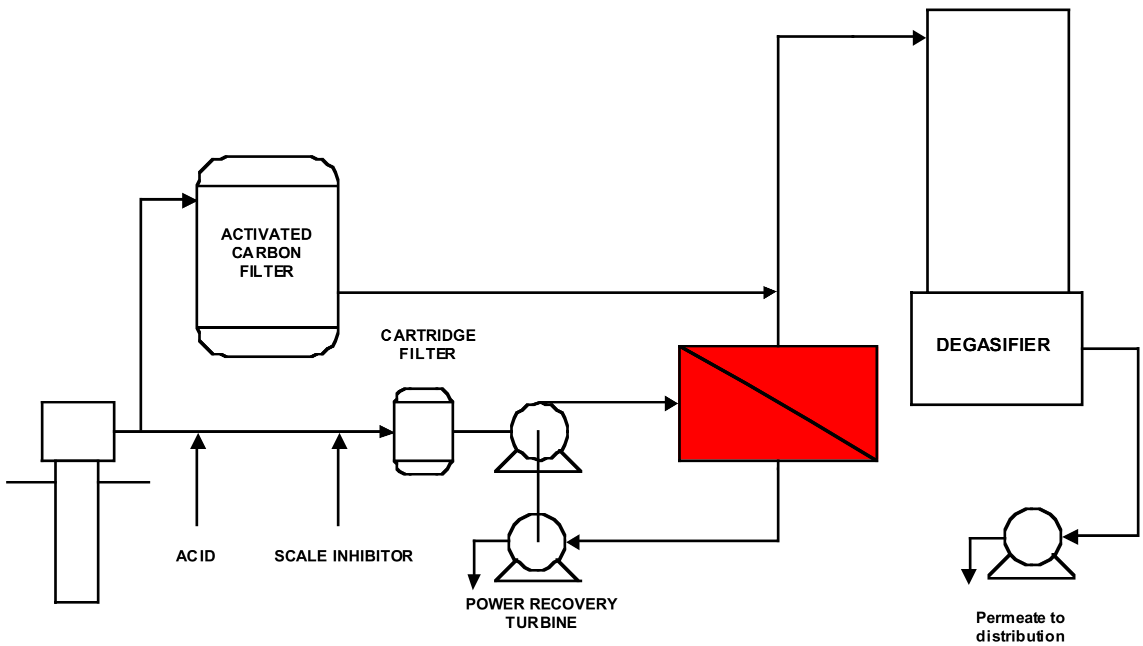
2. Municipal Wastewater Reclamation and Reverse Osmosis, Richard G. Sudak, William Dunivin and Martin G. Rigby, Proceedings of the National Water Supply Improvement Association 1990 Biennial Conference, Florida August 1990, p. 225.

3. Membrane Processes in Water Reuse, J. Lozier and R. Bergman, Proceedings of Water Reuse Symposium, Denver, Colorado 1994.

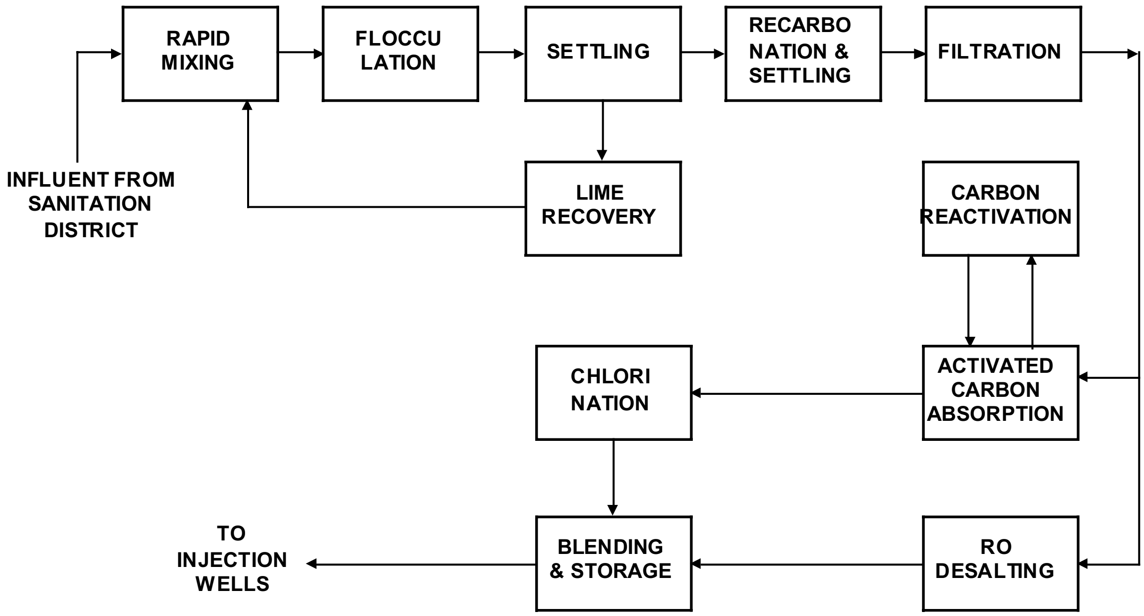
Table 1. Representative results of water quality at Water Factory 21.

Constituent	Influent from OCSD	RO product water	WF-21 blended product	Regulatory limits
Tot. nitrogen, ppm	31	2.7	3	10
Boron, ppm	0.85	0.52	0.4	0.5
Chloride, ppm	256	29	57	120
Conductivity, uS	1,848	150	419	None
Fluoride, ppm	1.4	0.16	0.4	1.0
pH	7.5	6.9	7.2	6.5 - 8.5
Sodium, ppm	231	21	65	115
Sulfate, ppm	300	1.4	37	125
Tot. Hardness, ppm	298	4.7	34	180
Cyanide, ppb	33.4	2.3	6.3	
TDS, ppm	1067	82	232	500
Color, color units	34.6	<5	11.1	None
Turbididty, JTU	6.2	<0.01	0.27	None
Coliform, MPN/100 ml	7.2E5	2.5	0.00	None
Arsenic, ppb	<5.0	<5.0	<5.0	50
Barium, ppb	93.5	1.1	6.6	1000
Cadmium, ppb	9.3	0.07	0.2	100
Chromium, ppb	33	0.82	0.5	50
Copper, ppb	49.3	3.9	4.9	1000
Iron, ppb	113.8	2.8	22.2	300
Lead, ppb	4.7	0.6	0.1	50
Manganese, ppb	56	0.1	2.1	50
Mercury, ppb	0.3	0.3	0.4	2
Selenium, ppb	<5.0	<5.0	<5.0	10
Silver, ppb	1.6	0.1	0.2	50
COD, ppm	53.4	0.8	3.5	30
TOC, ppm	14.7	0.7	1.4	None
THM s, ppb	6.0	2.7		100

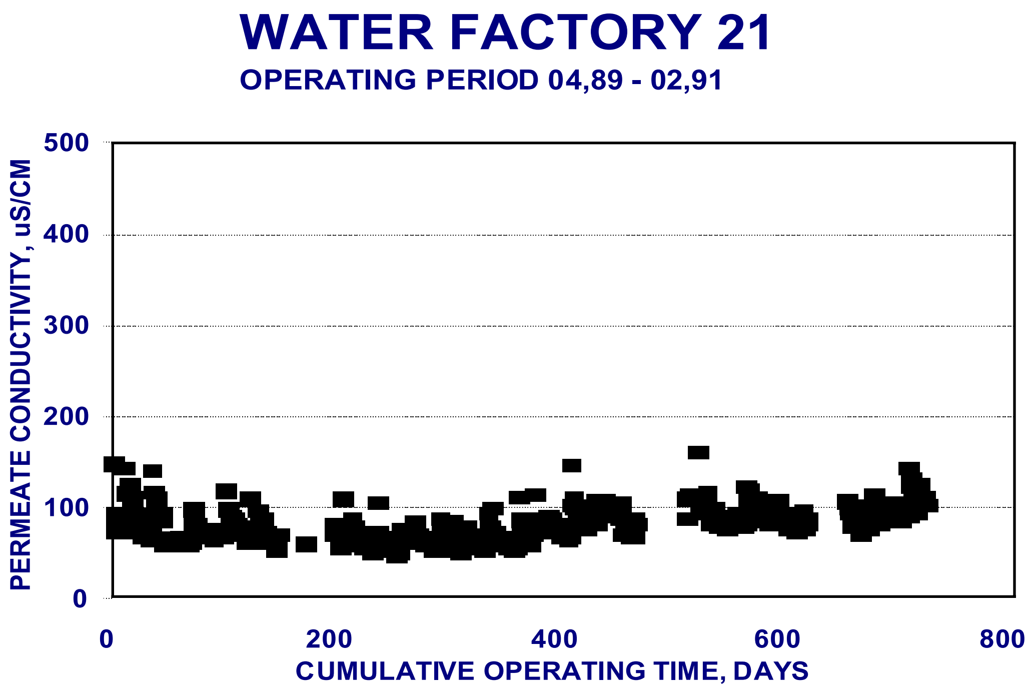
Data provided by the Water Factory 21.



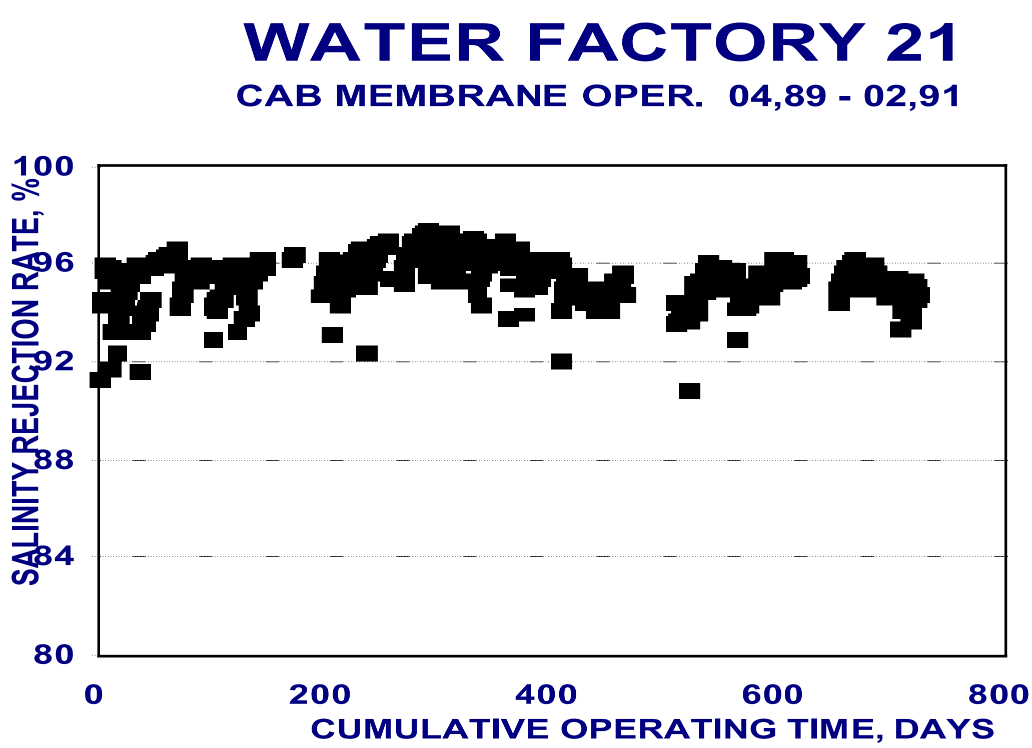
Flow diagram of a RO system at Arlington



WATER FACTORY 21 WASTEWATER RECLAMATION SYSTEM FLOW DIAGRAM



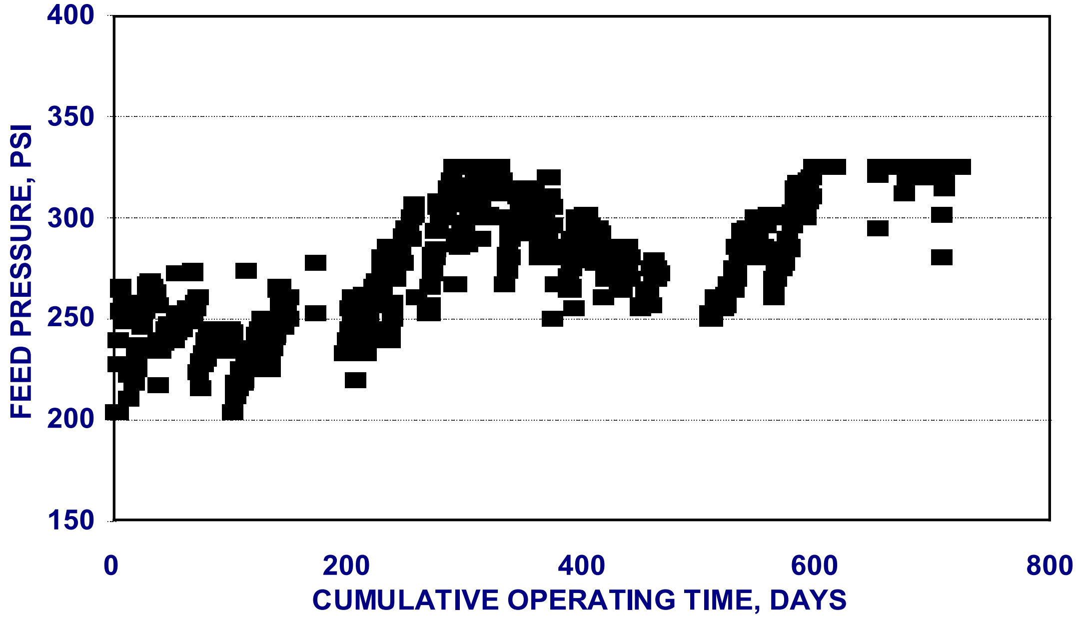
WATER FACTORY 21
OPERATING PERIOD 04,89 - 02,91
PERMEATE CONDUCTIVITY, uS/CM
500
400
300
200
100
0
0
200
400
600
800
CUMULATIVE OPERATING TIME, DAYS



WATER FACTORY 21
CAB MEMBRANE OPER. 04,89 - 02,91
SALINITY REJECTION RATE, %
100
96
92
88
84
80
0
200
400
600
800
CUMULATIVE OPERATING TIME, DAYS

WATER FACTORY 21

CAB MEMBRANE OPER. 04,89 - 02,91



WATER FACTORY 21

OPERATING PERIOD 04,89 - 02,91