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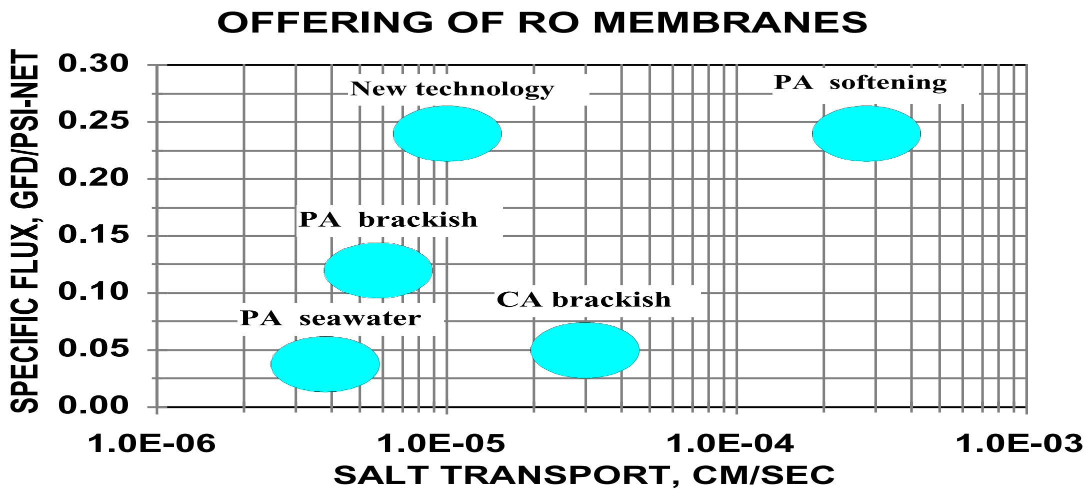
Application of RO Desalting Technology for Potable Water Production in USA

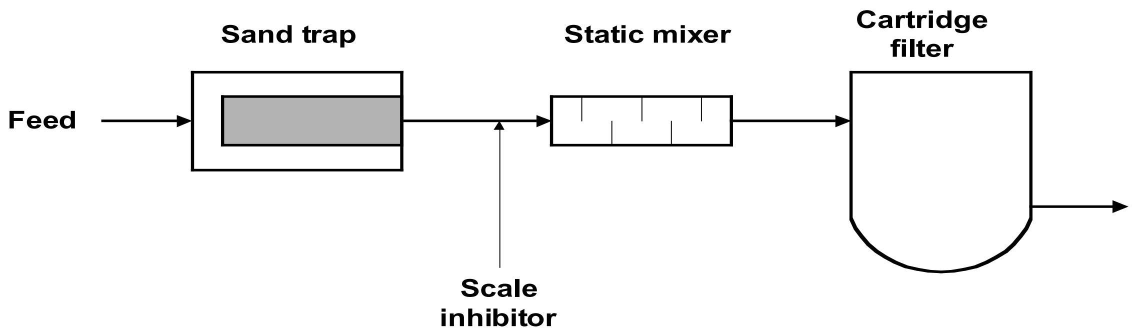
Introduction

Application of RO desalting technology in USA for potable water production has been developed in parallel to the improvement of performance of commercial RO membranes and better economics of the desalting process. The initial RO installations were limited to treatment of relatively high salinity brackish well water in areas of rapid population grow, mainly in Florida (1). With time and development of suitable membrane technology, applications were expanded to membrane softening, seawater desalting and wastewater reclamation. The initial desalting systems were mainly based on cellulose acetate membranes in a spiral wound configuration. Few of early systems utilized hollow fiber membrane elements made of polyamide polymers. The pretreatment of feed water included pH adjustment to prevent carbonate scaling. The current RO systems use, almost exclusively, composite aromatic polyamide membranes in a spiral wound configuration. Scaling control method has shifted from the acid addition to application of organic scale inhibitors based on polyacrylic acid derivatives. More recently a significant improvement of membrane performance has been achieved. A new generation of composite polyamide RO membranes has been introduced at the beginning of 1995. The new membrane material is characterized by a very high specific water flux, about double the flux of the current generation of polyamide composite brackish membranes. This new membrane technology achieves flux rates comparable or higher than the existing softening (nanofiltration) membranes, while maintaining low salt transport characteristics (high salt rejection), similar to the conventional composite polyamide brackish membranes. Membrane elements, made of the new membranes, have been extensively tested at numerous field sites and they are currently being used in large commercial plants (2). The new, low pressure membrane technology, expanded offering of commercial membranes and enabled reduction of power consumption of the desalting process. Fig. 1 contains summary of membrane performance of current membrane offering in terms of specific flux (gfd/psi-net) and salt transport (cm/sec). The graph also contains the relative position of the new membrane type introduced recently. The new membrane materials have a similar range of specific permeate flux as obtained from softening membranes. The salt passage characteristic, on the other hand, is similar to that of the composite brackish membranes. Compared to the conventional brackish technology the new membrane enables operation of RO systems at reduced feed pressure while producing required permeate quality.



Evolution of RO system design.

Pretreatment of feed water from brackish well initially included number of process steps. RO system equipped with cellulose acetate membranes utilized chlorine to protect membranes from biological degradation. Feed pH was maintained in the range of 5 — 6 to reduce hydrolysis rate. Sand filters and cartridge filters ware used to reduce concentration of suspended solids. RO systems were design to operate at limited recovery rate to maintain concentration of sparingly soluble salts below their saturation limits. Introduction of composite polyamide membranes and development of organic scale inhibitors resulted in significant simplification of the pretreatment process. It was realized that well water is sufficiently filtrated by passing through the aquifer and additional media filtration step is not required. The usual configuration of pretreatment system, which included media filtration followed by cartridge filtration, was simplified to include only cartridge filtration. The polyamide membrane material is not degradable by bacteria and has very broad range of pH stability. For this reason chlorination of the feed water was eliminated and feed pH could be maintain at a higher level then with the cellulose acetate membranes. This resulted in reduction of acid addition rate. New organic scale inhibitors enabled further reduction of acid dosing or in some cases replaced it completely. The effectiveness of organic scale inhibitors in prevention scale formation enabled increase of the conversion rate in the RO plants. The resulting pretreatment system for well water feed, as shown in fig 2, was simplified to include only a sand trap, scale inhibitor dosing and cartridge filtration. In parallel variable speed drive motor controllers and power recovery equipment became more affordable and is being widely used in the RO systems. Use of the above equipment resulted in additional reduction of power consumption of the RO process. At some locations supply of feed water from brackish well is limited. With increasing demand for desalination system for potable water production, other feed water sources have to be utilized. These



Pretreatment of well water in brackish RO unit

include treatment of surface water, seawater desalting or even reclamation of municipal effluents. Feed water pretreatment in RO systems treating surface water or municipal effluent, is more extensive that applied to the well water. It may include chlorination, coagulation, clarification and multistage media filtration. Even such extensive pretreatment does not always produce feed water of adequate quality to prevent membrane fouling. In these applications, RO systems are design to operate at low flux rate and membrane cleaning has to be applied frequently to maintain permeate flux at acceptable level. Currently new membrane technology in a capillary configuration has been introduced as a pretreatment for RO systems treating feed water with high fouling potential (3). New capillary technology offered recently is based on a large ID capillary membrane configuration. The capillary bore is 0.7 - 0.9 mm diameter. Membrane material consists of polypropylene, sulfonated polyether sulfone or cellulose acetate.

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

1. A 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. The ability to operate at a very low cross flow velocity, or even in a direct flow (dead end) mode.

The off-line time due to pulse cleaning is very short, comparable the to off line time of conventional filters due to filter backwashing. The frequent pulse cleaning results in stables permeate flux rates. The feed pressure is in the range of 1.0 to 2.0 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 0.1 kWhr/m3 of filtrate. This new capillary technology has been developed to treat potable water, which originates from surface sources. Compared to the conventional treatment technology, it offers modular design, high 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 capillary 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. Results were very promising and enabled use of composite membranes in this type of application and maintain stable performance. Today number of municipal wastewater reclamation systems include capillary technology as a pretreatment for the RO units.

Large RO plants in US producing potable water.

Traditionally RO plants for potable applications were located in southern part of US, close to sea shore, where populations is experiencing rapid grow and potable water supply is limited. Majority of potable RO plants are operating in Florida. However, additional large RO plants are located in other parts of US usually operating to improve quality of the existing water supply. Representative summary of large RO plants in US is included in table 1. In Florida two basic types of feed water quality for desalting is available: high salinity water originating from the deep Floridan aquifer and low salinity water infiltrating from the surface in to a shallow surfacial aquifer.

RO plants operating on high salinity water from the Floridan aquifer are in the category of brackish application and high salt rejection brackish membranes are used to reduce salinity. The raw water is of good quality in respect of colloidal and suspended solids and only a limited pretreatment is required. The recovery rate is usually limited by the concentration of calcium sulfate and it is in the range of 65 — 80%.

The feed water originating from the surfacial aquifer is of low salinity, but contains high concentration of dissolved organics, iron and relatively high hardness. Treatment of this water fells in the category of softening application. The objectives are to reduce harmful constituents such as trihalometane formation potential (THMFP), color, hardness and iron. The softening membranes with nominal rejection rate of 90% — 95% are used this systems. The softening systems operate at low pressure, of about 10 bar, and high recovery rate of 90%. The ground water in Florida is usually anaerobic (contains hydrogen sulfite). To prevent H_2S oxidation and formation of elemental sulfur on membrane surface, the feed water supply lines and the RO systems are design to prevent exposure of the feed water to the atmosphere. The membranes in softening systems usually suffer some degree of flux decline due to fouling by dissolved organics. Membrane softening plants in Florida are gradually replacing lime softening installations. The advantage of membrane technology over the conventional treatment process is related to its comparable economics, operational flexibility and ability to reduce THMFP, hardness, color and iron in a single treatment step with much lower environmental impact.

Outside Florida the RO technology is used for additional potable applications, which include remediation of contaminated potable water supply, seawater desalting and wastewater reclamation.

LOCATION	FEED WATER TYPE	CAPACITY AND RECOVERY	MEMBRANE TYPE
ARLINGTON, CA	WELL WATER, 1000 PPM TDS, 100 PPM NO3, 40 PPM SIO2	22,500 M3/DAY, 77%	BRACKISH (CPA2)
BRIGHTON, CO	WELL WATER, 700 PPMTDS, 66 PPM NO3, 25 PPM SIO2	15,000 M3/DAY, 80%	BRACKISH (CPA2)
CAPE CORAL, FL	WELL WATER, 1500 PPM TDS	26,500 M3/D, 85%	BRACKISH (CPA2)
COLIER COUNTY, FL	WELL WATER, 600 PPM TDS	45,500 M3/D, 90%	SOFTENING (PVD1)
DUNEDIN, FL	WELL WATER, 500 PPM TDS	36,000 M3/DAY, 85%	SOFTENING (PVD1)
ENGLEWOOD, FL	WELL WATER, 5800 PPM TDS,	7,500 M3/DAY, 70%	BRACKISH (CPA2)
FORT MYERS, FL	FILTRATED RIVER WATER, 500 PPM TDS	45,500 M3/DAY, 90%	SOFTENING (ESNA)
INDIAN RIVER, FL	WELL WATER, 850 PPM TDS	22,700 M3/DAY, 80%	BRACKISH + SOFTENING
JUPITER, FL	WELL WATER, 5700 PPM TDS,	34,000 M3/DAY, 75%	BRACKISH (CPA2, ESPA)
ST LUCIE, FL	WELL WATER, 550 PPM TDS, HIGH Fe	3,800 M3/DAY	SOFTENING (ESNA)
MOUNT PLEASANT, SC	WELL WATER, 1000 PPM TDS	17,000 M3/DAY	BRACKISH (CPA2)
VERO BEACH, FL	WELL WATER, 1000 PPM TDS	7,600 M3/DAY, 85%	BRACKISH (CPA2)
OCEANSIDE, CA	WELL WATER, 1500 PPM TDS	7,600 M3/DAY	BRACKISH (CPA2)

Examples of well remedial application project are Arlington Desalter, California and Brighton Plant, Colorado, which were built to reduce of nitrate concentration introduced to potable water sources by agricultural leachate (4).

Compared to the brackish applications, seawater desalting in US is very limited. In the past two large seawater desalting plants were built in Florida (5) and California (6). However, after short period of operation both were replaced by a less expensive, conventional water supply alternatives, and they are presently idle. Number of small capacity seawater desalting units operate at the coastal

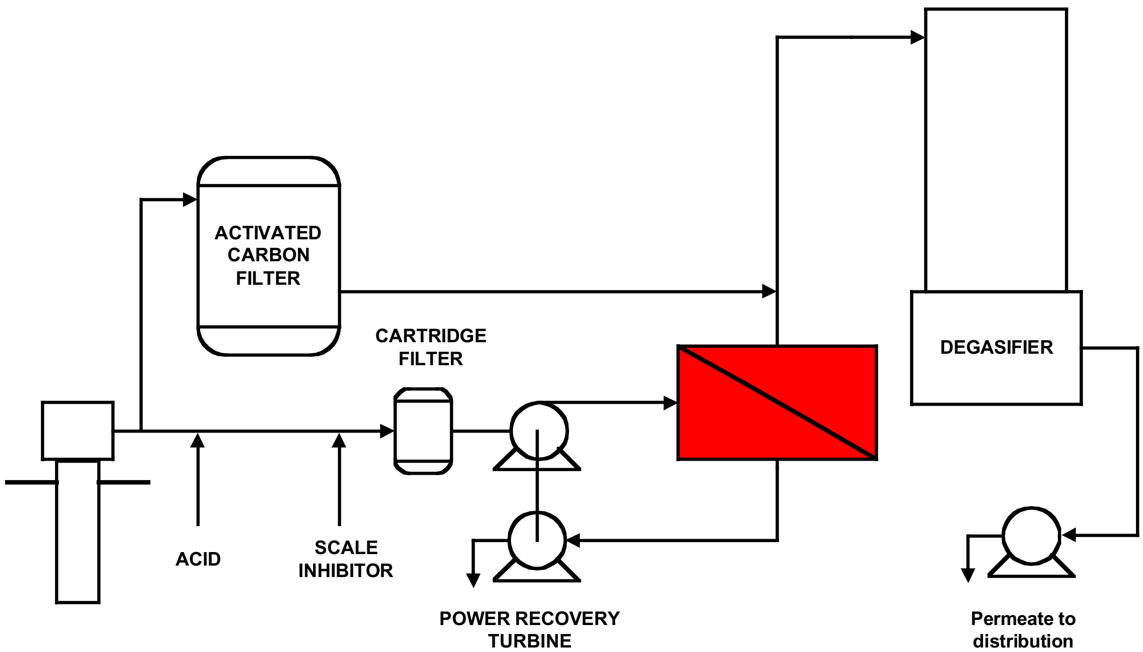
communities in southern part of US. Due to shortage of brackish water in coastal areas, large seawater desalting plants are recently being considered again. The largest one is the 80,000 m3/day project being evaluated for the city of Tampa, Florida. The plant is scheduled to be built in three years (2000) and project conditions require successful bidder to finance the construction, operate the plant and sell water to the city.
Municipal wastewater reclamation, using RO technology, was conducted in US on limited scale for over 20 years. The largest project is the Orange County Water District, California, 20,000 m3/day RO plant, which treats municipal effluent after tertiary treatment (4). The RO permeate after blending is injected into coastal aquifer to prevent seawater intrusion. This water eventually blends with the potable aquifer of the Orange County area. This RO plant operates for about 15 years and it is currently in the process of expansion to the capacity of 80,000 m3/day. During expansion the presently used conventional pretreatment, which includes lime clarification and sand filtration, will be replaced by backwashable capillary technology. Recently, City of San Diego, California, initiated project of construction of 80,000 m3/day treatment plant. The plant will apply multiple membrane barrier concept to treat municipal effluent and produce water of potable quality water which will be send directly to potable water reservoirs. The multiple membrane barrier configuration includes capillary membrane pretreatment followed reverse osmosis desalting. The project is now in the pilot study stage, testing the ability of combined membrane technologies to completely retain pathogens (viruses and bacteria). The results, after one year of field testing, indicate that the proposed equipment configuration is capable to reliably produce effluent within the potable quality limits.

Case studies.

The projects described bellow represent major directions of desalination activities for potable applications in US.

Arlington Basin Desalter, Arlington, California

The ground water in the Southern California Arlington 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. The Arlington Basin Desalting project initiated, as a solution to this problem, to provide a clean water supply and to restore the ground water in the Arlington Basin to a usable condition. The RO system was designed to provide 22,500 m3/day of blended product water containing less than 500 ppm TDS by mixing 15,000 m3/day of degassifed permeate from the three RO trains (each rated at 5,000m3/day) with 7,500 m3/day of ground water treated by granular activated carbon followed by aeration stripping. The RO system operates at a permeate recovery rate of 77%. Plant flow diagram is shown on Fig 3. 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



Flow diagram of a RO system at Arlington

water flow of 26,500 m3/day, provision exists for passing 7,500 m3/day 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, 19,000 m3/day, 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 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 13.8 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 45 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 to 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 by OCWD Water Factory 21, or direct disposal to the ocean. 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.

Water quality at the Arlington Desalter.

Constituent	Feed water, ppm	RO permeate, ppm	Salt passage, %	Blended water, ppm
Calcium	140	0.30	0.22	23
Magnesium	42	0.01	0.24	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

The capital cost of the Arlington Desalter project was approximately $14,000,000. The estimated annual cost, including capital return and operating cost, is $2,000,000. Assuming annual production of 7,400,000 m3 of blended water, the specific water cost is \$0.27/m^3

RO Softening Plant at St. Lucie West, Florida

St. Lucie West, Florida Service District employed the first large scale reverse osmosis (RO) softening plant in the United States to remove high levels of hardness, color, iron, and trihalomethane (THM) precursors from its well water. The plant was originally designed and built by Hydranautics for a permeate capacity of 1 mgd, and operation commenced in April 1988. Initially, the plant utilized Hydranautics PVD1 softening membrane elements, which operated for 8 years without requiring any cleaning. In September 1996, the existing PVD1 membrane elements were replace by the new ESNA softening membrane elements introduced by Hydranautics.

Feedwater to the RO plant is pumped from shallow wells (approximately 70 ft deep), which are characterized by high levels of hardness, organics, THM precursors, color, and soluble iron (see table 3). Due to the need to reduce the high levels of these constituents and the fact that the raw water is characterized by low salinity, membrane softening technology was selected. Raw water is a fairly clean well water source, therefore, pretreatment to the RO plant consisted of sulfuric acid injection to control $CaCO_3$ scale potential, and five micron cartridge filtration. RO plant operates at 85% recovery rate. The soluble iron concentration in the raw water ranges from 2 - 4 ppm and potable water limits require iron level to be below 0.3 ppm. The PVD1 membrane, initially exhibited higher passage to iron. It was later learned that iron passage of the PVD1 membranes was a direct function of the sulfate ion concentration. The conversion of alkalinity to sulfate in the feed water resulted in an increase of iron

St. Lucie RO System, Summary of Plant Data

Initial startup	1988
Permeate capacity and recovery rate	1 MGD, 85%
Array	24:12 (7 elements per vessel)
Membrane type, initial load	PV derivatives, spiral wound, 8.5
Membrane replacement	1996
Membrane type, second load	ESNA, polyamide, softening, 8.5
Feed water source	Shallow wells
Feed water characteristics	TDS: 550 Hardness: 250 — 300 HCO3: 250 — 300 H2S: 0.4 — 1.0 Fe: 0.5 — 3.0 TOC: 23 — 30 Color: 80 — 100
Pretreatment	PH adjustment (scale inhibitor dosing), cartridge filtration
Post-treatment	Degasifier, Caustic soda and Calcium chloride addition, Chlorination
Design feed pressure	90 — 120 psi
Power consumption	< 1.4 kWh/Kgallon

rejection. Therefore, the feedwater was acidified with sulfuric acid to increase the sulfate ion concentration so that the permeate iron concentration would fall within the allowable potable water standards. To achieve this level, the RO plant required the injection of more than 650 kg/day of sulfuric acid, which amounted to an excess of $45,000 dollars per year; the addition also reduced the feedwater to a pH of 4. Due to the low permeate and concentrate pH, caustic soda (NaOH) injection was necessary to elevate the pH level to a neutral state. The amount of caustic soda used for both permeate and concentrate was in excess of 450 kg/day, which amounted to over $80,000 dollars per year.

In May 1996, 8 years after the PVD1 membranes were first installed, St. Lucie West Water District decided to replace PVD1 membranes with new softening membrane technology. After a successful biding Hydranautics ESNA membrane elements were selected based on a lowest operating cost. The advantages and savings that the ESNA membrane provided with respect to the original design with PVD1 membranes were significant as indicated in table 4. The ESNA design resulted in a substantial reduction in the feed operating pressures; moreover, unlike the bids submitted by competitors, the need for acid addition was eliminated, thus reducing demand for caustic soda and calcium chloride. Even with the decrease in feed pressure, the permeate flow was increased approximately 15%, with only a 5% addition in membrane area. The overall operating cost saving using ESNA membranes results in excess of $100,000/year

Comparison of chemicals cost for PVD1 and ESNA membranes at St. Lucie Softening Plant

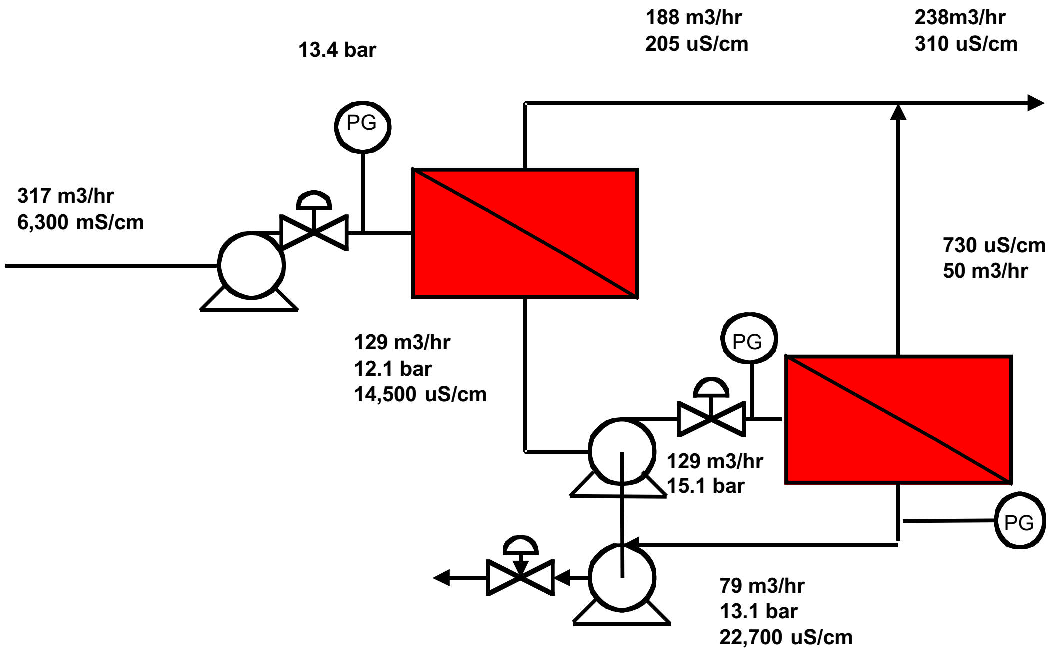
Cost component, $/1000m3	PVD1	ESNA
Acid	35.0	0.0
Caustic soda	62.1	0.0
Calcium Chloride	27.6	32.7
Scale inhibitor	0.0	10.3
Total cost, $/1000m3	124.7	43.0
Total cost, $/year	155,050	53,460

RO Softening Plant at Ft. Myers, Florida.

The City of Ft. Myers obtains raw water for municipal use from the local river. The river water contains substantial natural organic material, which was inadequately removed by conventional treatment process, consisting of aeration, lime softening, clarification, recarbonation and media filtration. Natural organic material remaining in the water after treatment, reacts with chlorine applied for disinfection to form haloganeted organics (THM) above the federal limit level. City of Ft. Myers decided to expand capacity of their water supply system and improve potable water quality by constructing of a membrane softening plant. In 1986 a pilot study was initiated to evaluate feasibility of membrane softening technology for producing desired water quality from the local feed water sources and to establish design parameters for the commercial plant. It has been demonstrated during the pilot study that the reduction of THMFP to a level below 50 ppb, using softening membranes was achievable. It has been also established that the softening system should operate at 90% recovery rate, average flux rate should be set at 15 gfd and net driving pressure should be maintained at 7 bar. Based on the results of pilot test and the biding process the project has been awarded to Hydranautics to design and built the 45,500 m3/day membrane softening plant and to provide PVD1 membrane elements. The river feed water to the plant is pumped from shallow wells and is filtrated with cartridge filters rated at 5u. Feed water pretreatment includes addition of organic scale inhibitor and acid. In order to minimize acid consumption acid is added in two points: before cartridge filters and to the concentrate stream after the first stage (feed to the second stage). Pressure vessels are arranged in a tree stage array. Feed pressure is developed by parallel pumps operating to a common first stage feed manifold. Permeate flow from individual stages is controlled by applying permeate backpressure. Since commencing operation in 1992, the RO plant provides rated performance in respect of permeate quality. Due to poor feed water quality membrane fouling is experienced by organics and ferrous carbonate scale, which requires frequent cleaning.

RO Plant at Jupiter, Florida

The RO plant at the town of Jupiter process well water from the Floridan aquifer of 2,500 — 5000 ppm TDS salinity. It operates at recovery rate of 78%. The Jupiter plant was built with the initial permeate capacity of 23,000 m3/day utilizing Hydranautics brackish CPA2 membrane elements. Feed water pretreatment is typical for Florida anaerobic water: scale inhibitor and acid addition followed by cartridge filtration. The plant commenced operation in 1990. In 1996 a capacity expansion program was initiated at the Jupiter plant. At that time an ultra-low pressure ESPA membrane has been introduced commercially by Hydranautics. The new membrane has specific flux twice as high as of the CPA2 membranes and therefore had a potential to significantly reduce pressure requirements of the desalting process. A pilot study was conducted to demonstrate performance stability and sufficient level of salt rejection of the new membranes. The pilot test results were positive and the 11,000 m3/day capacity expansion was executed using this novel membrane technology. Due to high specific flux of the new membranes the configuration of the new trains includes interstage booster (fig. 3). The interstage booster results in equalization of permeate flux between



Flow diagram of a RO unit equipped with ESPA membrane elements at the Jupiter plant

stages and better membrane performance by providing higher net driving pressure to the second stage elements. The interstage booster pump at the Jupiter plant is powered by a power recovery device driven by the energy of the concentrate stream. The use of ESPA membranes in place of initially specified conventional brackish elements resulted in lower operating pressure and lower energy consumption. The energy cost reduction is estimated to be about $110,000/ year or $10/m3-day permeate capacity.

Summary

Application of RO technology for potable water production in US is widely spread and covers all areas of membrane desalting: brackish, softening, seawater and waste water reclamation.
Continuous improvement of membrane technology results in better performance reliability and reduction of desalted water cost.

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