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CITY OF CAPE CORAL
REVERSE OSMOSIS WATER TREATMENT FACILITY

Technical Report No. 01-08-1997

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ABSTRACT

A model reverse osmosis water treatment plant in Cape Coral, Florida, U.S.A., with a design capacity of 15 million gallons per day (MGD), is introduced in detail. This technical paper presents the plant's historical development, present status, future plan, personnel, reverse osmosis technology, daily plant operation, facility design, water treatment processes, chemical treatment, plant performance, operating costs and possible process alternations or improvements.

Entire Cape Coral water treatment system includes the production units or train operations, such as, pretreatment (acidification, anti-scalant additions and pre-filtration by use of cartridge filters), reverse osmosis (RO), degasification, disinfection and neutralization. With applications of sulfuric acid for acidification, and a scale inhibitor for scale prevention, certain impurities in raw well water can be kept in liquid form prior to the subsequent water treatment processes. Cartridge filtration removes suspended particulates; while RO mainly removes chlorides (salts) and total hardness at Cape Coral water treatment system. The capability of RO for removal of 97 % to 99 % of salts, color, bacteria, virus, colloidal suspensions and other toxic organic and inorganic substances has been demonstrated. In Cape Coral RO operations, spiral membranes are used in all 18 production units. Ten of these production units operate at 234 psi. Eight of the newer generation spiral membranes operate at 160 psi. The average chlorides are reduced from 600 ppm to 62 ppm. The 62 ppm product water is then blended with influent feed water, bringing the chlorides up to 150 ppm. It is important to note that finished water is blended with 10 % to 15 % influent feed water. After RO, between 15 to 25 % of the RO influent becomes the RO reject (concentrate) brine water which is discharged into a receiving salt water lake. The RO product water is then treated with an air stream by degasification for removing hydrogen sulfide and carbon dioxide gases at low pH. Finally chlorine and sodium hydroxide are dosed as the disinfectant and neutralizing agent, respectively.

Typical chemical treatment requires 130 ppm of sulfuric acid, 3 ppm of scale inhibitor (Flocon-100), 10 ppm of chlorine and 40 ppm of sodium hydroxide. Average free residual chlorine and average plant effluent turbidity are 1.82 ppm and 0.66 NTU, respectively. Normally there are 17 full-time employees working on site at the plant. The main power

source is electricity. In 1996, the average water production cost including chemical treatment, operating labor, power consumption, and plant administration is estimated to be US$ 0.73 per 1,000 gallons. The total cost including water production, RO membrane replacement and capital investment is estimated to US$ 1.25 per 1,000 gallons.

(Key Words) Water Treatment, Membrane Technology, Pretreatment, Acidification, Scale Prevention, Reverse Osmosis, Brine Discharge, Degasification, Disinfection, Neutralization, Process Design, Performance Data, Treatment Costs, Cape Coral, Florida, USA.

ESTABLISHMENT AND DEVELOPMENT

In 1976, the City of Cape Coral, Florida, USA, began construction of the Reverse Osmosis Water Production Facility. This facility began operation in 1977 with a total production capability of 3 million gallons per day (MGD). Operating equipment included six reverse osmosis (RO) units and a single 5 million gallon (MG) storage tank. Here one MGD equals to 3.785 million liters per day (MLD). One MG equals to 3.785 million liters (ML)

In 1980, the City expanded the facility by installing four additional RO units and second five million gallon storage tank. The RO plant's increased production capability was now rated at 5 MGD. At this time, the City was experiencing problems with its Lime Plant. There were many private wells drawing their water from the same aquifer (the upper Hawthorne) as the Lime Plant. Salt water intrusion (salts contaminating the wells) was also beginning.

Faced with these two problems, the City was also experiencing yearly water shortages during the winters (the City's dry season). These problems made the City realize it had to find another source of water to replace the Lime Plant. The RO expansion in 1984 was the logical answer to help relieve the demand on the upper aquifer. Since the RO Plant wells were supplied from the lower aquifer, the City began its RO Plant expansion.

Today the RO Plant's total production capability is rated at 15 MGD (15 x 3.785 MLD) of which 6 MGD can be produced by Plant 1, and 9 MGD can be produced by Plant 2, as indicated in Table 1 (Ref. 1). The City has a total of eighteen water production units. On site storage has been increased to fifteen million gallons. The City now has a total storage capacity of eighteen million gallons. The Lime Plant, now just a pumping station, has a two million gallon storage tank. Van Loon, another pumping station, is equipped with an one million gallon storage tank. Figure 1 is a bird's-eye view of the present RO Plant at the City of Cape Coral, Florida. USA. Figure 2 shows the location of the RO Plant. (Ref. 1)

The City is considering an additional RO Plant of 15 MGD (15 x 3.785 MLD) for the northern end of the City.

If and when this facility is constructed, the City would consider the following additional storage sites and capacities, 5 MG (5 x 3.785 ML) at the new plant and 5 MG at Burnt Store Road.

The City has implemented one of the largest reuse systems for residential use in the United States.

PRODUCTION UNITS OR TRAIN UNITS FOR WATER TREATMENT

Raw Well Water

The water entering the water treatment plant is the City's raw well water. Average characteristics of the raw well water are: pH, 7.7; total hardness, 500 ppm (parts per million) as calcium carbonate; calcium hardness, 190 ppm as calcium carbonate; magnesium hardness, 310 ppm as calcium carbonate; conductivity, 2400 ms/cm; total dissolved solids, 1534 ppm; chlorides, 600 ppm; and fluorides, 2 ppm. One ppm is equal to one mg/L (milligram per liter)

Entire Cape Coral water treatment system for treating the raw well water in order to meet the drinking water standards of both the US Environmental Protection Agency (USEPA), and the Florida Department of Environmental Protection (FDEP) includes the unit operations and unit processes of: acidification, scale prevention, cartridge filtration, reverse osmosis (RO), degasification, disinfection and neutralization.

Acidification and Scale Prevention for Pretreatment

With applications of sulfuric acid for acidification, and a scale inhibitor (Flocon-100 Antiscalant) for scale prevention, certain impurities in raw well water can be kept in liquid form prior to the subsequent water treatment processes.

Sulfuric acid feed systems are designed to directly apply a 98 percent solution to the raw well water through a metering system that includes standby metering pumps. Usually the City purchases acid in bulk, which must be stored in fiberglass reinforced tanks.

Complete dispersion of scale inhibitor is accomplished in very little time (in seconds) and with appropriate velocity gradients. The velocity gradient is related to the amount of energy imparted to the water during mixing of water and scale inhibitor.

Chemicals, such as sulfuric acid, scale inhibitor (Flocon-100), and caustic are pumped into small day tanks, which are in chemical rooms for daily use.

The 1996 costs for the required average sulfuric acid dosage of 130 ppm (parts per million) is US$ 0.03 per 1,000 gallons, and for the required average scale inhibitor dosage of 3 ppm is also US$ 0.03 per 1,000 gallons. One gallon is equal to 3.785 liters.

Addition of sulfuric acid and scale inhibitor is commonly referred to as "pre-treatment". The pre-treatment effluent is termed "feed water".

Cartridge Filters for Pre-filtration

After pre-treatment by acidification and scale prevention, the raw well water becomes the feed water. The feed water then passes through a series of cartridge filters for removing suspended particulates, such as, microbes, dirt, sand, silt, turbidity, etc..

Cartridge filtration is considered an emerging technology suitable for removing suspended matter from water. These cartridge filters are similar to the swimming pool filters, and are mechanically simple for easy operation.

The cartridge filters use ceramic or polypropylene microporous filter elements that are packed into pressurized housings. They are operated by the physical process of straining the water through porous filter elements and can exclude particles down to less than one micron. The ease of operation and maintenance of cartridge filters makes them very attractive for small water systems with treatment capacity equal to or below 15 MGD (15 x 3.785 MLD).

Reverse Osmosis

Cartridge filtration removes suspended particulates; while RO mainly removes chlorides (salts) and total hardness at Cape Coral water treatment system.

About 12.57 % of the cartridge filter effluent becomes the "by-pass stream" which by-passes the RO units and goes to the post-treatment facilities directly. The remaining about 87.43 % of the cartridge filter effluent becomes the "feed water" which is fed to the reverse osmosis (RO) units for RO membrane filtration and subsequent post-treatment. The average pH of the cartridge filter effluent or the feed water (after pretreatment and cartridge filtration) is 5.91.

RO is one of many membrane technologies involving the use of semipermeable membranes to exclude 97 % to 99 % of salts, color, bacteria, virus colloidal suspensions and other chemical compounds from raw water. (Refs. 1 and 2)

RO is the opposite of "osmosis", which is a process occurring in nature. Osmosis is described as the transport of water in a solution through a semipermeable membrane from one side of lesser concentration to the side of higher concentration. However, RO is accomplished by applying a pressure to a concentrated solution forcing the pure water to flow through the semipermeable membrane to the dilute side. Figure 3 shows the difference between osmosis and RO (Refs. 1 and 3).

While both Plant 1 and Plant 2 adopt spiral wound membranes for their RO units (see Table 1, Figures 4 and 5), the membrane elements of Plant 1 were manufactured by Fluid Systems, and the membrane elements of Plant 2 were manufactured by Hydranautics. Each RO pressure vessel holds three membrane elements.

Although RO can almost remove all impurities for production of pure water, the RO units of the City are mainly used to remove chlorides (salts), total hardness and many other undesirable substances. The capability of RO for removal of 97 % to 99 % of salts, color, bacteria, virus, colloidal suspensions and other toxic organic and inorganic substances has been demonstrated.

In Cape Coral RO operations, spiral membranes are used in all 18 production units. Ten of these production units operate at 234 psi. Eight of the newer generation spiral membranes operate at 160 psi. The average chlorides are reduced from 600 ppm to 62 ppm. The 62 ppm product water is then blended with influent feed water, bringing the chlorides up to 150 ppm. It is important to note that finished water is blended with 10 % to 15 % influent feed water. Normal drinking water should have no more than 250 ppm of chlorides as mandated by the Florida Department of Environmental Regulation. Therefore, the chloride concentration at the level of 150 ppm (15 mg/L) is acceptable.

The total hardness can be reduced from 500 ppm (as calcium carbonate) to 80 ppm (as calcium carbonate) after blending.

After RO treatment, between 15 to 25 % of the influent feed water becomes the RO reject (i.e. the brine or brine concentrate shown in Figures 4 and 5) which is discharged into a receiving salt water lake. The average characteristics of the RO reject or brine concentrate are: pH, 6.8; total hardness, 2500 ppm as calcium carbonate; calcium hardness, 850 ppm as calcium carbonate; magnesium hardness, 1650 ppm as calcium carbonate; conductivity, 9000 ms/cm; total dissolved solids, 6390 ppm; chlorides, 2550 ppm; and fluorides, 1.6 ppm. This highly concentrated RO reject is discharged from the RO system by way of the brine line, and is also called "waste stream".

The brine concentrate, treated with chlorine and oxygen to maintain environmental standards, although highly concentrated with impurities, sustains a concentration lower than that of the salt water lake it empties into. The brine is evenly diffused throughout the lake using an intricate series of submersed spray nozzles. The brine or RO reject is not drinkable nor is suitable for irrigation due to the high salt and impurity concentration.

After RO treatment, between 75 % to 85 % of the feed water becomes the RO product water (shown in Figures 4 and 5, and Table 1) which has low concentrations of total hardness, conductivity, total dissolved solids, chlorides and fluorides. The RO product water is also called "permeate stream".

Degasification, Chlorination and Neutralization for Post-treatment

The RO product water (i.e. the permeate stream) and the by-pass stream are both further treated with an air stream by degasification for removing hydrogen sulfide and carbon dioxide gases at low pH. The principal design considerations for degasification process (also known as the "aeration" process) are air-to-water ratio, number of degasifiers, and hydraulic loading rate. Removal efficiency of degasification improves with increases in air-to-water ratios and increasing number of degasification units. (Refs. 1 and 3)

Finally chlorine and sodium hydroxide are dosed as the disinfectant and neutralizing agent, respectively.

Chlorine is an excellent disinfectant and oxidant. It provides a stable residual for the water distribution system. At an average chlorine dosage of 10 ppm, the chlorination cost of the City is estimated to be US$ 0.01 per 1,000 gallons. Average free residual chlorine and average plant effluent turbidity are 1.82 ppm and 0.66 NTU, respectively.

The City's RO Water Treatment Facility has been designed to use liquid sodium hydroxide for finished water neutralization. The plant feeds a premixed 50 % solution containing 6.38 pounds of sodium hydroxide per gallon. To store a 15-day supply of this sodium hydroxide stock solution, the plant uses fiberglass reinforced tanks. The sodium hydroxide solution is kept indoors or in heated tanks to avoid crystallization of the solution that occurs at or below 12.2 degree C (54 degree F). A dual headed metered pump is used to deliver the sodium hydroxide solution to the point of application.

At an average sodium hydroxide dosage of 40 ppm, the neutralization cost is estimated to be US$ 0.03 per 1,000 gallons.

The average characteristics of the finished water (the plant effluent) after the post-treatment of degasification, chlorination and neutralization are excellent: pH, 8.8; total hardness; 80 ppm as calcium carbonate; calcium hardness, 30 ppm as calcium carbonate; magnesium hardness, 50 ppm as calcium carbonate; conductivity, 575 ms/cm; total dissolved solids, 313 ppm; chlorides, 150 ppm; fluorides, 0.7 ppm; residual chlorine, 1.82 ppm; and turbidity, 0.66 NTU.

It should be noted, however, the total dissolved solids (TDS) removal efficiency of RO is very high. Average TDS concentration of the RO produce water (i.e. permeate stream) is only 111 ppm. A higher TDS concentration (313 ppm average) in the finished water (i.e. plant effluent) is mainly contributed by the by-pass stream as well as the chemical addition in the post-treatment steps.

COSTS FOR WATER TREATMENT

Chemical Treatment Costs

Typical chemical treatment requires 130 ppm (parts per million) of sulfuric acid, 3 ppm of scale inhibitor (Flocon-100), 10 ppm of chlorine and 40 ppm of sodium hydroxide. The total chemical treatment costs are US$ 0.1 per 1,000 gallons for all four chemicals together.

Labor, Power and Miscellaneous Costs

The Florida Department of Environmental Protection requires that all water plant operators be licensed. The operators at the Cape Coral Plant are required to be licensed within 18 months of their hire date. The levels of licenses held at the RO Plant vary from Level C to Level A. Level A is the highest level an operator can attain. Each level requires special training and State testing to advance. Also, an operator must have the required number of years of actual on the job experience before he or she can apply to the State of Florida to take an advancement examination. The City of Cape Coral presently has: five A-level operators (including Chief), one B-level operator, and five C-level operators.

Normally there are 17 full-time employees (Chief, operators, technician, analyst, supervisor, mechanic, and electricians) working on site at the plant. The labor cost is estimated to be US$ 0.19 per 1,000 gallons.

The main power source is electricity and the power cost is about US$ 0.34 per 1,000 gallons.

The miscellaneous costs including purchase orders, office supplies, etc. amount to US$ 0.1 per 1,000 gallons.

Total Water Production Cost and Grand Total Costs

In 1996, the average water production cost including chemical treatment, operating labor, power consumption, and miscellaneous plant administration is estimated to be US$ 0.73 per 1,000 gallons of water produced.

The grand total cost including water production, RO membrane replacement and capital investment is estimated to US$ 1.25 per 1,000 gallons of water produced.

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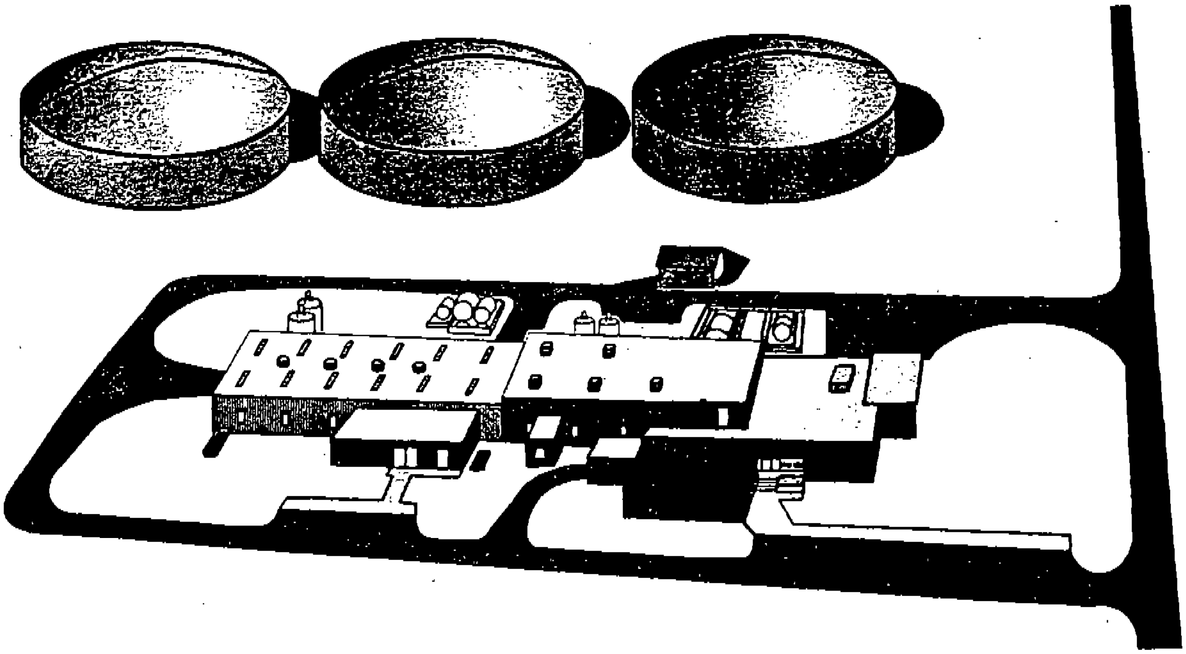


FIGURE 1.

A BIRD'S-EYE VIEW OF THE CITY OF CAPE CORAL REVERSE OSMOSIS WATER TREATMENT FACILITY.

THE CITY OF CAPE CORAL REVERSE OSMOSIS WATER TREATMENT FACILITY IN FLORIDA, U.S.A.

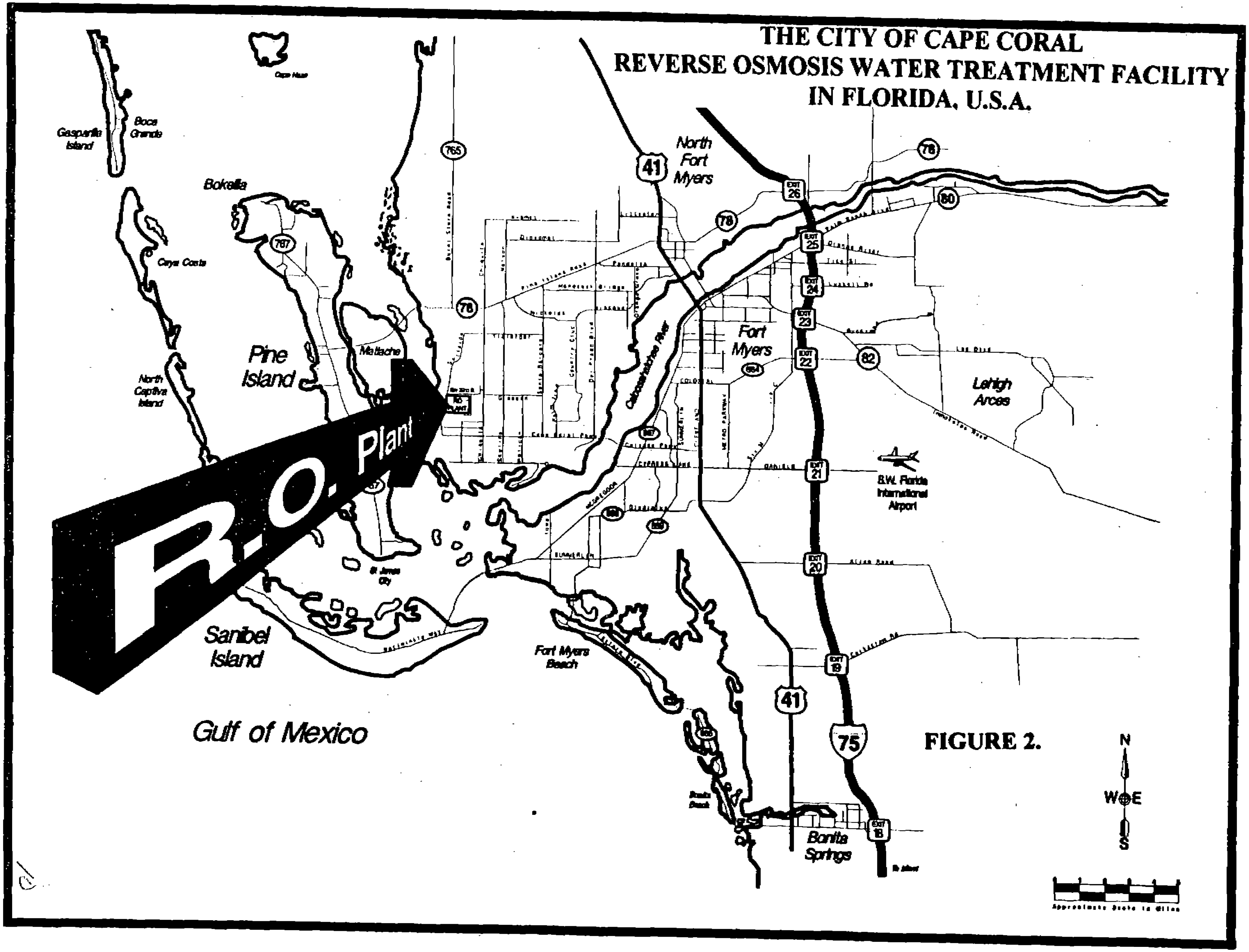
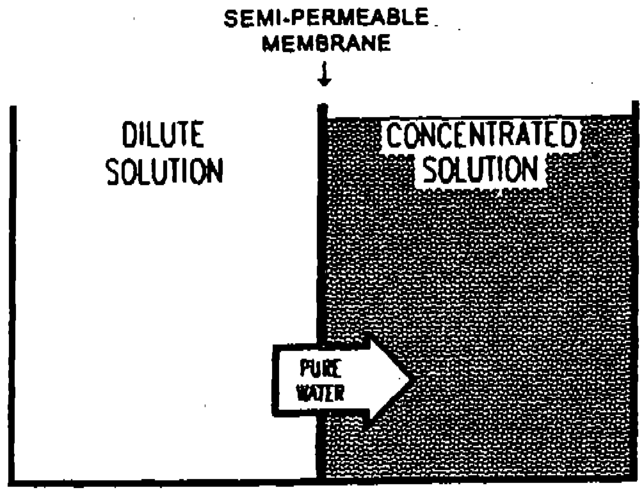


FIGURE 2.

OSMOSIS



REVERSE OSMOSIS

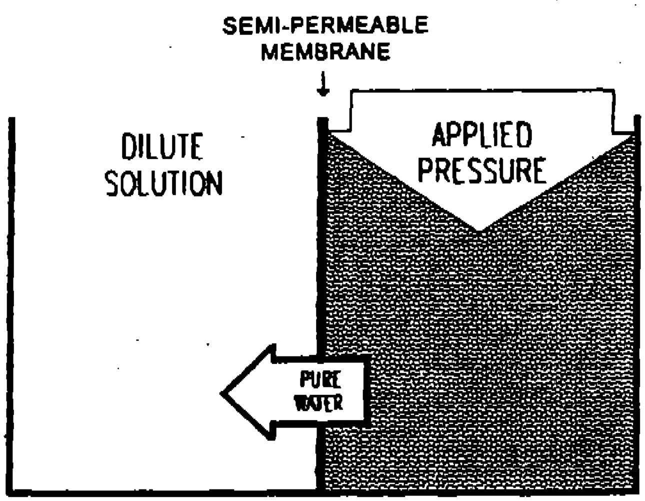


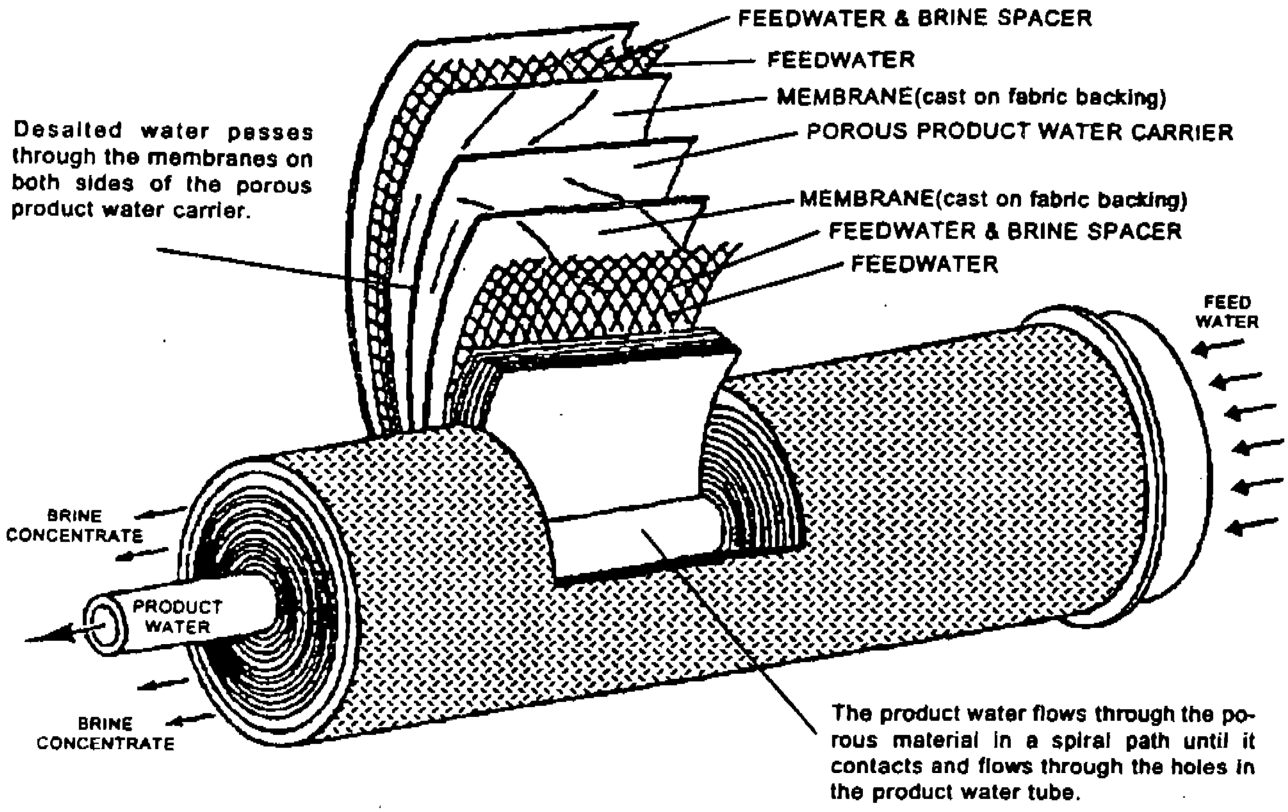
FIGURE 3.

DIFFERENCE BETWEEN OSMOSIS AND REVERSE OSMOSIS.

FIGURE 4.

SPIRAL MEMBRANE, MEMBRANE ELEMENT AND PRESSURE VESSEL OF THE CITY'S REVERSE OSMOSIS FACILITIES.

SPIRAL MEMBRANE CUT-AWAY



A PRESSURE VESSEL WITH 3-MEMBRANE ELEMENT

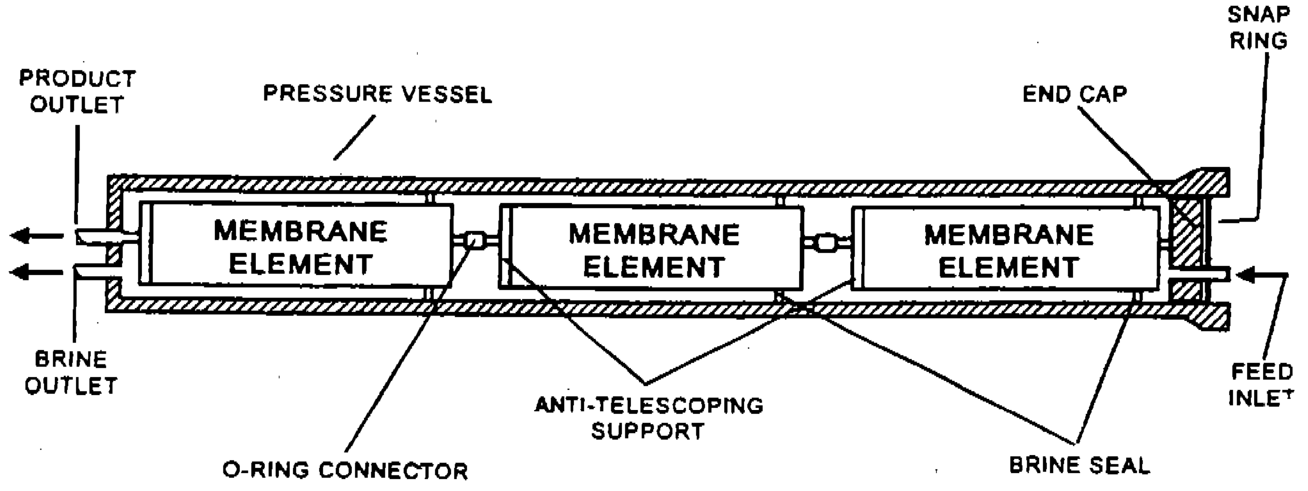
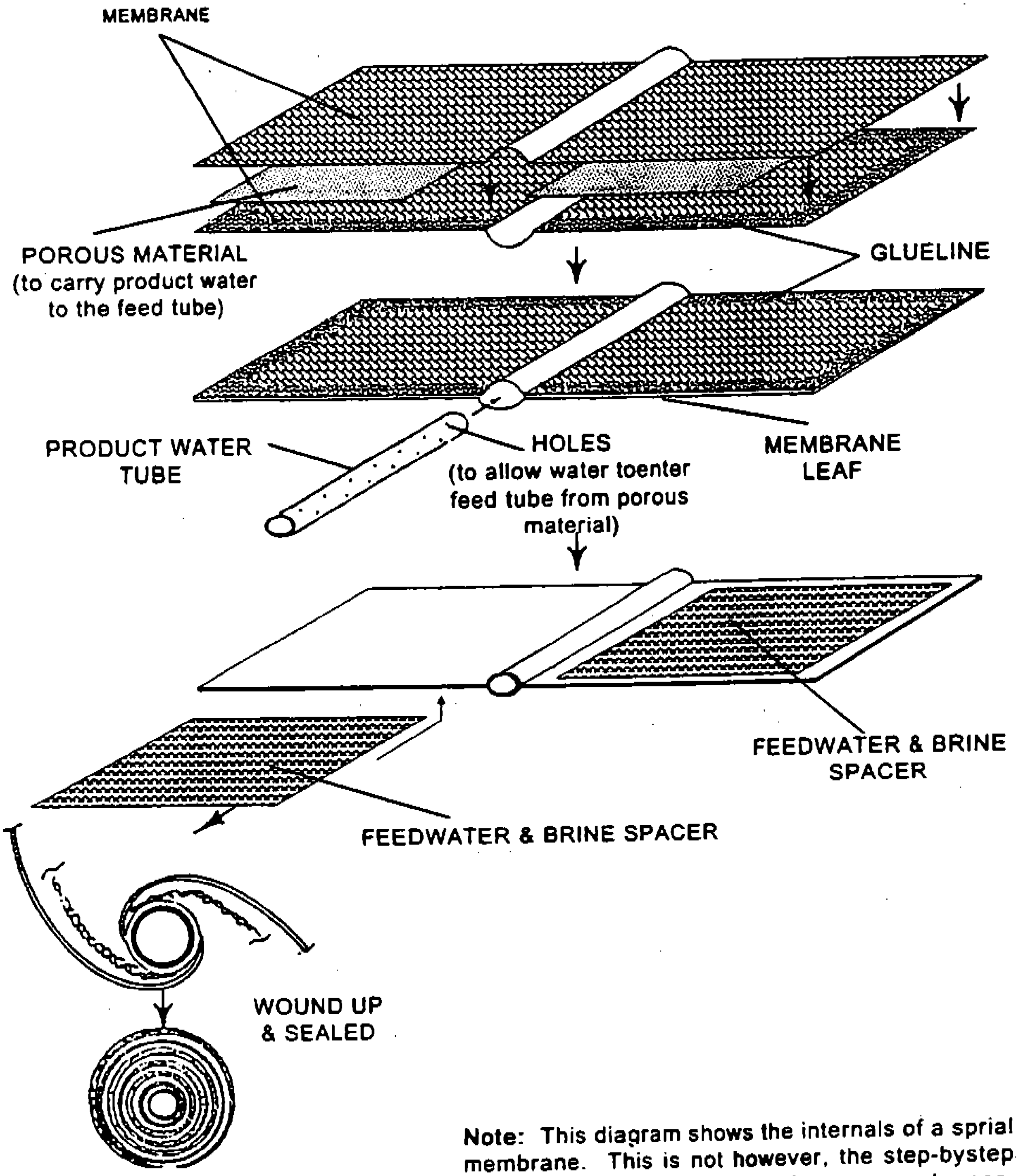


FIGURE 5.

INTERNAL CONSTRUCTION OF A SPIRAL MEMBRANE UNIT.



Note: This diagram shows the internals of a sprial membrane. This is not however, the step-bystep method by which a factory manufactures membranes.

TABLE 1.

DESIGN FEATURES OF THE CITY'S REVERSE OSMOSIS FACILITIES.

PLANT 1

Plant Data:

Production Capability	6 MGD
Raw Water Supply	Lower Hawthorn Aquifer
	Brackish Water
	10 Wells (approx. 700 feet deep)

Production Unit Data:

Number of Production Units	10	
Operating RO Pressure	250 psi	
Recovery	75%	
Pressure Vessel Array	10	(1st Stage)
	7	(2nd Stage)
	4	(3rd Stage)
# of Elements per Vessel	4	
# of Elements per Prod. Unit	84	

Membrane Element Data:

Manufacturer	Fluid Systems
Model Number	8021 LP
Configuration	Spiral Wound
Type	Thin Film Composite
Minimum Salt Rejection	97.5%

PLANT 2

Plant Data:

Production Capability	9 MGD
Raw Water Supply	Lower Hawthorn Aquifer
	Brackish Water
	12 Wells (approx. 700 feet deep)

Production Unit Data:

Number of Production Units	8	
Operating RO Pressure	160 psi	
Recovery	85%	
Pressure Vessel Array	16	(1st Stage)
	8	(2nd Stage)
# of Elements per Vessel	7	
# of Elements per Prod. Unit	168	

Membrane Element Data:

Manufacturer	Hydranautics
Model Number	8040-LSY-CPA2
Configuration	Spiral Wound
Type	Thin Film Composite Polyamid
Minimum Salt Rejection	99.0 %