ELECTRODIALYSIS FOR DESALTING HAWAIIAN BRACKISH GROUND WATER: A FIELD STUDY

by

L. Stephen Lau

James C.S. Chou

Technical Report No. 41

July 1970

The programs and activities described herein were supported in part by funds provided by the University of Hawaii, Honolulu Board of Water Supply and Ionics, Inc.

ABSTRACT

A field study was made to evaluate the applicability and problems of desalting brackish ground water from basaltic and reef limestone aquifers in Honolulu, Hawaii with the electrodialysis process. The three-week study indicated that the brackish water at both sites was upgraded to potable quality and the rejection of ionized salts was above 80 percent. No pretreatment was necessary. Both the average production and rejection rates were about 420 gpd. An economic evaluation was not determinable from the short-term results.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Occurrence and Distribution of Brackish Ground Water in Hawaii

Brackish or saltish water is commonly recognized as distasteful and unfit for drinking and most other uses. In Hawaii, a large but undetermined quantity of brackish water is known to occur in the underground and is generally a renewable and easily accessible resource.

The salt water that forms the base of a Ghyben-Herzberg lens, a ground-water body of fresh water quality, has essentially the composition of ocean water (Mink, 1961). Through tidal fluctuations, seasonal and secular variations of natural recharge of water, extraction of ground water, and other mixing mechanisms, vertical movements are created in these water bodies to cause effective mixing which results in a body of brackish water that varies from a few feet to over a thousand feet containing within it a gradual transition from potable water at the top to salt water at the bottom.

Under hydrostatic conditions and for a thin mixing zone, a reasonably accurate estimate of the top of this transitional zone may be made by employing the Ghyben-Herzberg principle which states that for each foot of fresh water head above the sea level datum, there is an additional 40 feet of fresh water in the lens before reaching a depth where salt water with normal ocean water density is encountered. Where the mixing zone is thick, this principle gives a depth to where the 50 percent of fresh and salt water occurs (Lau, 1967). In Hawaii, the "50 percent point" rule seems to apply (Cox, 1955, Visher and Mink, 1964). There exists no method for estimating the thickness of a zone of mixture by a mere knowledge of the fresh water head in the vicinity (Lau, 1967). Under natural conditions, the depth of the mixing zone decreases while its thickness tends to increase toward the coast (Lau, 1962).

The areal distribution of brackish ground water in the Hawaiian Islands is not accurately known but its general location has long been identified as indicated in the classical volumes of geology and ground-water-resources for each Hawaiian island: Maui (Stearns and Macdonald, 1942), Lanai (Stearns, 1940), Hawaii (Stearns and Macdonald, 1946), Oahu (Stearns and Vaksvik, 1935), Kauai (Macdonald, Davis, and Cox, 1954). However, no known inventories of brackish ground water have been made for the Hawaiian Islands.

Geologic formations, known as caprock, exist along the coasts of older islands such as Kauai and Oahu. These sedimentary rocks which were created by marine sediments, such as reef limestone and mud, and by terrestrial sediments deposited in alternating layers on a basalt basement. When not cemented, the reef limestone forms good aquifers, and the water in it is loosely called caprock water. The quality of caprock water varies over a range but is generally classified as brackish.

Measured salinity profiles along a vertical in the transitional zone in Hawaii (Lau, 1967) are summarized in Table 1.

In basaltic formations where caprock is absent, the lens tends to be thin and ground water, which is highly susceptable to mixing and tidal influence, becomes brackish. In the Maui isthmus, the thickness of the lens is only tens of feet. Where the flux of fresh ground water is small, as in Kawaihae, Hawaii, the lens diminishes or ceases to exist near the shoreline and ground water does not become fresh until a considerable distance inland from the shore where the tidal influence lessens and natural recharge occurs. In these lenses, the ocean water has direct access to the formation from both the bottom and the coastline and, hence, brackish water is continuously produced.

In basaltic formations where caprock is present, the communication between the lens water and the ocean water is usually assumed to be small. Because the caprock, acting as a barrier, prevents fresh water from escaping into the ocean, the lens tends to become thick as in the Honolulu plain. However, the entire lens is still underlaid by salt water and the opportunity for creating brackish waters is always present. But because of the great depth to the brackish water, the lens in the Honolulu area is an unlikely source for desalting.

Within the caprock, the reef limestone formation usually thin layers on the order of a few tens of feet intercalated with tighter material such as mud and marl. Typical occurrence is found in Ewa, Oahu, (Cox and Lao, 1967). Knowledge about caprock water is somewhat lacking, but it may be surmised that within each of these formations, some kind of vertical

TABLE 1. SALINITY MONITORING IN HAWAIIAN COASTAL AQUIFERS.

										SALINITY-DEPTH CURVE			HEAD MEASUREMENT	
ISLAND	VICINITY	IDENTIFICATION	RESEARCH UNIT	YEAR	STATUS	BOTTOM OF HOLE (FT) BELOW M.S.L.	DISTANCE FROM COAST (FT)	AQUIFER TYPE	DEPTH TO BOTTOM OF CAPROCK (FT) BELOW M.S.L.	DEPTH TO 50% POINT (FT) B.M.S.L.	THICK-NESS OF MIXING ZONE (FT)	DEPTH TO 250 mg/1 CHLORIDE (FT) BELOW M.S.L.	FT. ABOVE M.S.L.	REMARK
MAUI	KAHULUI	FAIR GROUND DRILL HOLE	USGS	1937	DISCONT.	150	1,000	WATER TABLE	-	130	22	-	3.34	TIDAL VARIATION 0.18 FEET
MAUI	SPRECKELS-VILLE	EXPERIMENTAL WELL	HC&S	1955-1957	DISCONT.	212	2,500	WATER TABLE	-	80	10	-	2.00	TIDAL EFFICIENCY ABOUT 50%
OAHU	KALAUAO	TEST HOLE T-67	USGS	1960	ACTIVE	1,300	20	ARTESIAN	130	825	1,170	-	21.38	AT 3/4 MILE INLAND
OAHU	HONOLULU	BERETANIA-MONITOR WELL	BWS	1961	ACTIVE	1,480	6,000	ARTESIAN	450	1,225	900	850	23.77	FOR "AREA II"-AUGUST 1961
OAHU	HONOLULU	KAIMUKI MONITOR WELL	BWS	1961	ACTIVE	1,370	8,000	ARTESIAN	100	950	980	400	23.14	FOR "AREA I"-AUGUST 1961
OAHU	PUNALUU	RESEARCH WELL	BWS	1967	ACTIVE	920	700	ARTESIAN	150	820	210	710	22.60	

gradation of salinity can exist and that the formation can have hydraulic communication with the ocean. Hence, the opportunity for renewing brackish water would exist.

A second known source of brackish ground water in Hawaii is the returning irrigation water. In areas where sugar cane is irrigated by ditches, a large amount of irrigation water passes through the soils. After early reports (Mink, 1962, Lee, 1967), the Water Resources Research Center conducted a three-year study 1967-70 to identify the residual irrigation water percolating to the cumulating at the top of the basal lens in former and present sugar cane lands, namely, Pearl Harbor-Waipahu area, Oahu; Kahuku, Oahu; the Maui isthmus and the west side of West Maui, *i.e.*, Wailuku, Puunene and Lahaina. A general analysis of major constituents from the well waters sampled in the Pearl Harbor-Waipahu area gave evidences of a cyclical trend in concentration, either related to seasonal rainfall and irrigation practices, or both (Tenorio, *et. al.*, 1969). On Maui, the nitrate content in some well water was strongly related to irrigation practice (Tenorio, oral communication, 1970). Typically, the quality of these saline water bodies is high in chloride, sulfate, nitrate, and silica, but the saline degree is only on the order of a few hundred parts per million (ppm) in total solids. The extent of these saline water bodies in the studied areas can be estimated. The renewability of water quality is dependent largely on the continuance of the present irrigation practice.

Probable Needs for Desalting in Hawaii

Desalting has not been practiced on any Hawaiian island except for a small electrodialysis (500 gpd) unit in a resort establishment, Kona Village, Hawaii. The Board of Water Supply of the City and County of Honolulu together with the Hawaiian Electric Company has recently authorized Burns and Roe to study desalting feasibilities as part of a dual-purpose power and desalting plant using nuclear energy (HBWS annual report, 1968). The proposed plant is of large size (50 MGD) and is apparently intended as an aid for long range projection for existing modes of water resource development.

With the economic base shifting to tourism in the Hawaiian Islands, resorts and attendant development have been planned and built in heretofore undeveloped coastal areas; many of which are arid with no known suitable water sources easily accessible within close proximity of the developments. Water development from available surface water and fresh ground-water sources will require long, costly water transmission lines. The large water projects are often of a scale beyond the financial capability of most developers who then simply abandon or defer the idea of development.

Brackish water is of a quality unfit for drinking and most domestic uses. However, the brackish water in both the basalt and reef limestone has been extensively used for cooling and for industrial supplies developed by the industries themselves (U. S. Water Resources Council, 1968). These industries desire better quality water, but the cost of upgrading the quality must be economically feasible.

The brackish water, believed to be the result of the return of irrigation water, is a problem in ground-water development for a domestic supply. The brackish water is now either avoided by drawing water below the brackish water body where geologic formation provides a favorable separation or upgraded by dilution with water of better quality in the water distribution system. Another alternative is, of course, demineralization.

Membrane Processes for Desalting Brackish Water

Membrane processes for desalting are now well established and recognized and are particularly well suited for brackish water (Office of Saline Water, Saline Water Conversion Report). Efforts have been continued to advance reverse-osmosis and electrodialysis processes as low-cost brackish-water desalting methods. By 1969, many modular units of various capacities using both processes were commercially available, e.g. trailer-mounted 1,000 gpd to 50,000 gpd pilot RO plant by Aerojet-General Corp., DuPont 7,500 gpd Permasep, Ionics 500 gpd home unit.

GENERAL DESCRIPTION OF ELECTRODIALYSIS PROCESS

Electrodialysis is a process in which ions are transferred from one solution through an ion-selective membrane into another solution by electrolysis. One type of membrane is permeable to cations only while the other is permeable only to anions. Only salts which exist as cations and anions in saline water can be effectively removed by this process. The two ion-selective membranes are alternatively arranged in stacks separated by specially designed plastic spacers.

Besides the membrane stacks, the other major components of the system include: 1) electrodes at opposite ends of the stack to supply DC electric current uniformly across the membranes, 2) a DC power converter when only alternating current is available, 3) a pump to overcome the 30 to 60 psi of pressure drop of water through the stack, 4) a storage tank for the product water, 5) two feed-water filters which remove any suspended non-ionized substances greater than 20 microns, 6) an acid injector to prevent precipitation of basic salts, if required, and 7) electrical and mechanical devices for controlling the operation.

The progress of application in the last few years may be attributed to the development of cheaper and more durable membranes, improved flow compartment configuration, and more effective methods of preventing scaling on and polarization of the membranes. With accumulated knowledge through field experience and laboratory research, the equipment supplier is able to warrant comprehensive guarantees of plant capacity, amount of salts removed, consumption of electrical energy, and membrane life.

Except for some units smaller than 10,000 gpd, all the plants in operation were specially designed to suit each application. The basic data required for preliminary design are the capacity, the initial concentration of salts, and the degree of demineralization required. From such information, the total DC current, the total membrane area, and the resistance per stack may be estimated. To minimize the cost, there are other factors which must be considered for economic design such as: energy requirements for pumping water through the membrane stack, extent of instrumentation and control as required for smooth operation, space requirements, and the life of membranes and electrodes. According to the operation, the plant design may be classified as continuous process with several stages in series, batch recirculation process, and feed-and-bleed process. Since the electrodialysis process has been applied to desalting water on a large scale, a considerable amount of study has been done to optimize the plant design (Mintz, 1963).

TEST PROCEDURE

Sites Selected

Two study sites on Oahu were selected: Honolulu International Center (HIC) for caprock water and Honolulu Gas Co. (GasCo) for basalt water.

WELL 82-2A. The water tested at the HIC site is from Well 82-2A, located on the Diamond Head side of the Exhibition Hall, HIC and drilled on July 4, 1967 by Nat Whiton Drilling Co. into layered coral material.

Well Log 82-2A

Material	Depth, ft.
Top soil	0 - 1.0
Coral and clay fill	1.0 - 7.0
Black sand	7.0 - 9.3
Medium and hard coral	9.3 -14.7
Coral and brown clay	14.7 -25.0
Medium and hard coral	25.0 -41.0
Soft and medium coral	41.0 -59.0
Bottom of hole	59.0 -65.0

The water level is at a depth of 6 feet. The top 14.7 feet of the hole is cased and below it is an open hole. The well water is used for the fish ponds at HIC.

WELL 119. Well 119, at the GasCo site, is located in the Iwilei district near Honolulu Harbor and was drilled in 1923. The following selected information is from Drilled Well Records (Stearns and Vaksvik, 1938) for Well 119:

> Altitude 4 feet, depth 682 feet, diameter 10 inches, depth to the top of (basalt) aquifer 617 feet, depth to the bottom of the hole 682 feet. The water is for industrial cooling use only.

	Head, ft.	Chloride, ppm
December 12, 1923	28.22	266
December 11, 1924	26.40	272
November 18, 1925	26.22	290
December 27, 1926	24.34	307
October 25, 1927	25.57	311
November 20, 1928	29.12	311
December 24, 1929	27.77	311
December 30, 1930	30.07	320
December 17, 1931	28.32	324
December 16, 1932	31.30	314
November 17, 1933	28.28	323
December 22, 1934	27.96	333

Period

The HIC site was tested initially for about 4 to 5 hours per day from March 31 to April 5, 1970 and then continuously for 24 hrs/day from April 6 to April 20. The GasCo site was tested continuously from May 1 to May 9, 1970.

Equipment

The design of the unit used for this project is for continuous processing. The unit, Aquamite I, was supplied by Ionics, Inc. and had the following specifications:

Electrical requirements	115 volts AC
Minimum feed-water pressure	30 psig
Product water output	300 to 500 gpd
Rated average power consumption	10 kwh/100 g product
Weight of the unit	257 lb.
Dimension of the unit	24" x 24" x 48" high
Maximum TDS of feed water	5000 ppm
Number of flow stage	4
Number of electrical stage	2
Membrane size	9" x 10"

TEST PROCEDURE

Sites Selected

Two study sites on Oahu were selected: Honolulu International Center (HIC) for caprock water and Honolulu Gas Co. (GasCo) for basalt water.

WELL 82-2A. The water tested at the HIC site is from Well 82-2A, located on the Diamond Head side of the Exhibition Hall, HIC and drilled on July 4, 1967 by Nat Whiton Drilling Co. into layered coral material.

Well Log 82-2A

Material	Depth, ft.
Top soil	0 - 1.0
Coral and clay fill	1.0 - 7.0
Black sand	7.0 - 9.3
Medium and hard coral	9.3 -14.7
Coral and brown clay	14.7 -25.0
Medium and hard coral	25.0 -41.0
Soft and medium coral	41.0 -59.0
Bottom of hole	59.0 -65.0

The water level is at a depth of 6 feet. The top 14.7 feet of the hole is cased and below it is an open hole. The well water is used for the fish ponds at HIC.

WELL 119. Well 119, at the GasCo site, is located in the Iwilei district near Honolulu Harbor and was drilled in 1923. The following selected information is from Drilled Well Records (Stearns and Vaksvik, 1938) for Well 119:

> Altitude 4 feet, depth 682 feet, diameter 10 inches, depth to the top of (basalt) aquifer 617 feet, depth to the bottom of the hole 682 feet. The water is for industrial cooling use only.

	Head, ft.	Chloride, ppm
December 12, 1923	28.22	266
December 11, 1924	26.40	272
November 18, 1925	26.22	290
December 27, 1926	24.34	307
October 25, 1927	25.57	311
November 20, 1928	29.12	311
December 24, 1929	27.77	311
December 30, 1930	30.07	320
December 17, 1931	28.32	324
December 16, 1932	31.30	314
November 17, 1933	28.28	323
December 22, 1934	27.96	333

Period

The HIC site was tested initially for about 4 to 5 hours per day from March 31 to April 5, 1970 and then continuously for 24 hrs/day from April 6 to April 20. The GasCo site was tested continuously from May 1 to May 9, 1970.

Equipment

The design of the unit used for this project is for continuous processing. The unit, Aquamite I, was supplied by Ionics, Inc. and had the following specifications:

Electrical requirements	115 volts AC
Minimum feed-water pressure	30 psig
Product water output	300 to 500 gpd
Rated average power consumption	10 kwh/100 g product
Weight of the unit	257 lb.
Dimension of the unit	24" x 24" x 48" high
Maximum TDS of feed water	5000 ppm
Number of flow stage	4
Number of electrical stage	2
Membrane size	9" x 10"

Number of cell pairs	44
Storage tank capacity	150 gallons

The arrangement of the major components for normal operation is shown in Figure 1. Two filters were provided to remove particles larger

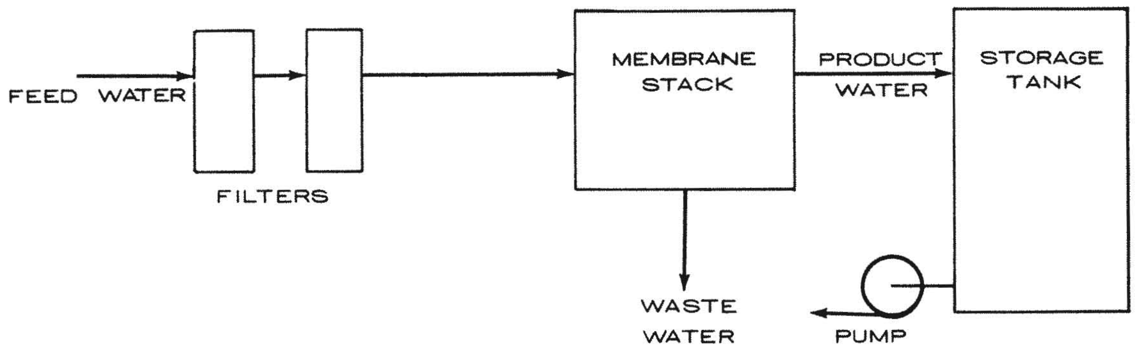


FIGURE 1. FLOW DIAGRAM FOR NORMAL OPERATION.

than 20 microns in diameter. One of them was an activated carbon core filter which removed taste and odor from the water and protected the membranes from any residual chlorine for a short period. There were two electrical stages with four electrodes in the membrane stack, one each placed at the start of the first flow stage, end of the second, start of the third, and end of the fourth. Each electrical stage provided current for two flow stages. The feed water first entered the first flow stage, then flowed through the second and third flow stages in series, and became product water when leaving the fourth flow stage. A timer and cam arrangement allowed the electrical polarity of the membrane stack to reverse every fifteen minutes. The reversal of polarity caused the deposits on the membrane to be flushed out, so that it was not necessary to add acid to the feed water. The unit was designed to produce 300 to 500 gallons of product water per day. The rate of production was controlled by manually setting a pressure reducing valve located along the feed-water line. To protect against the overheating of the membranes, a pressure sensing switch shut the unit down when the feed-water pressure dropped below the pre-set value of 25 psig. The DC power was provided through a diode rectifier. A transformer with a variable secondary coil allowed the adjustment of the current applied to the stack.

RESULTS

At the Honolulu International Center the pressure of the brackish water from the well was only 10 psig. It was necessary therefore to modify the system as shown in Figure 2. The product-water pump was con-

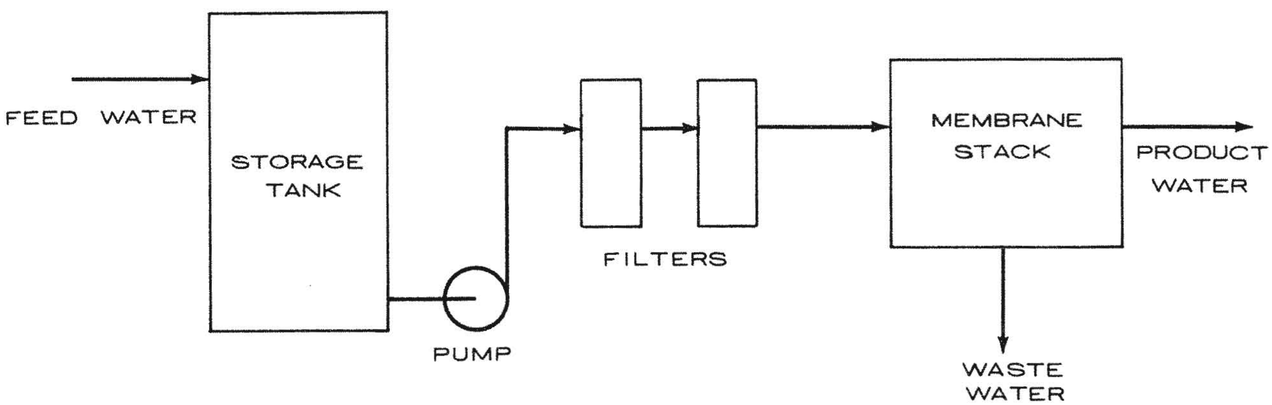


FIGURE 2. FLOW DIAGRAM FOR TEST AT HIC.

trolled by a pressure switch which was set to turn the pump on at 40 psig and off at 60 psig. At the average flow rate of 400 gpd of product water, the pump was deenergized and then restarted for every 30 seconds.

The line pressure of the brackish water at the Honolulu Gas Company was about 32 psig which simplified the operation of the unit by omitting the feed-water pump and storage tank.

When the unit was shut down over 4 or 5 days, care was taken to keep the stack wet by closing the inlet valve to filters and plugging the product and drain lines.

Besides filtration, no other pretreatment was required for the feed waters of either test site. At the HIC, the filters were changed once after two weeks of operation when the pressure drop across the filters reached the maximum limit of 5 psig. The fouling of the filter depends entirely upon the quality of the feed water. The general area of the HIC used to be swampy and is a fill. The used filter was brown in color and had a musty, organic odor. It might be interesting to note that a change of filters has not been required for a similar unit at the Kona Village Resort after 14 months of trouble-free operation.

Including time of preliminary testing of the unit with a sodium chloride solution in the Mechanical Engineering Laboratory at the University of Hawaii, the clock on the unit recorded 912 hours of operation. Throughout the entire period, no major trouble was encountered except for the low-line voltage at the HIC at the beginning of the test.

The efficiency of desalting can be seriously affected by the deposition of suspended solids, by iron and manganese precipitates, by slime and algae, by scaling due to calcium carbonate and calcium sulfate, and by the presence of oil and other organic matter. In general, the feed water should be filtered. There are cases for which special pretreatment must be prescribed, such as iron content in feed water over 0.3 ppm, residual chlorine over 0.2 ppm and silica over 55 ppm. The tests indicated that no special pretreatment was necessary for the brackish waters from the two test sites. The inspection of the unit operating at the Kona Village Resort also revealed that no pretreatment of the feed water there, other than filtration, was required.

The performance of the unit depends upon the temperature and flow rate of the feed water, the salts in the feed water, and the DC electrical current applied to the membrane stack. During the operation, both the flow rate of feed water and the electrical current could be easily adjusted to meet the desired quality of product water within a certain limit as specified by the equipment supplier.

The tested quality of the product water at both sites satisfies the U. S. Public Health Service Drinking Water Standards (Table 2). The averages of daily results at the two test sites are given in Tables 3 and 4. At each site, daily samples of feed water and product water were taken for a minimum of seven days of continuous operation at the same test setting. The fraction of salts removed was found to be consistently within 5 percent

ECONOMIC CONSIDERATION

Desalting water by electrodialysis was unknown before 1954. By

TABLE 2. U.S. PUBLIC HEALTH DRINKING WATER STANDARDS, 1962.

CHARACTERISTICS*	U.S.P.H. LIMIT NOT TO BE EXCEEDED	CAUSE FOR REJECTION
PHYSICAL		
COLOR	15 UNITS	-
TASTE	NOT OBJECTIONABLE	-
THRESHHOLD ODOR NUMBER	3	-
TURBIDITY	5 UNITS	-
CHEMICAL	mg/1	mg/1
ALKYL BENZENE SULFONATE	0.5	-
ARSENIC	0.01	0.05
BARIUM	-	1.0
CADMIUM	-	0.01
CHLORIDE	250	-
CHROMIUM (HEXAVALENT)	-	0.05
COPPER	1	-
CARBON CHLOROFORM EXTRACT	0.2	-
CYANIDE	0.01	0.2
FLUORIDE	0.7-1.2	1.4-2.4
IRON	0.3	-
LEAD	-	0.05
MANGANESE	0.05	-
NITRATE	45	-
PHENOLS	0.001	-
SELENIUM	-	0.01
SILVER	-	0.05
SULFATE	250	-
TOTAL DISSOLVED SOLIDS	500	-
ZINC	5	-

*MICROBIOLOGICAL STANDARDS NOT LISTED.

1967, more than one hundred and fifty plants had been installed throughout the world with capacities ranging from a few thousand gallons to over one half million gallons per day. A survey, made recently by El-Ramly, indicates that the total capacity of electrodialysis plants operating or under construction as of this time, is about 12.2 MGD (El-Ramly, 1970). The largest operating plant is at Siesta Key, Florida, which has a capacity of 1.2 MGD. A 5.07 MGD plant is under construction in Libya, Africa. Over 95 percent of the total capacity is attributed to the plants which deal with brackish waters having total dissolved solids (TDS) of 4,000 parts per million or less. These

TABLE 3. HIC WELL WATER, WELL 82-2A, HONOLULU, HAWAII.

	FEED	PRODUCT	REJECTION PERCENT	BRINE
TEST PERIOD 4/6/70 - 4/12/70 CONTINUOUS				
FLOW RATE (GPD)	830	415	50	415
TEMPERATURE, °F	76.5	78.9	-	78.9
TDS (PPM)	3,100	438	86	6,620
HARDNESS (PPM AS $CaCO_3$)	648	90	86	-
HCO_3 ALKALINITY (PPM AS $CaCO_3$)	338	97	71	-
CHLORIDE (PPM)	1,350	172	87	-
SULFATE (PPM)	63	24	62	-
NITRATE (PPM)	18	2.2	89	-
SODIUM (PPM)	745	105	86	-
CALCIUM (PPM)	68	6	91	-
MAGNESIUM (PPM)	117	22	81	-
POTASSIUM (PPM)	37	3	92	-
pH	7.7	7.2	-	8.5
SiO_2 (PPM)	43	43	0	43

1ST STAGE: 2.93 AMPS, 38.14 VOLTS

2ND STAGE: 1.10 AMPS, 30.70 VOLTS

POWER CONSUMPTION: 9.5 KWH/DAY

TABLE 4. GASCO WELL WATER, WELL 119, HONOLULU, HAWAII.

	FEED	PRODUCT	REJECTION PERCENT	BRINE
TEST PERIOD 4/27/70 - 5/9/70 CONTINUOUS				
FLOW RATE (GPD)	870	439	50	433
TEMPERATURE, °F	76.0	79.0	-	79.0
TDS (PPM)	965	193	80	2,130
HARDNESS (PPM AS $CaCO_3$)	441	62	86	-
HCO_3 ALKALINITY (PPM AS $CaCO_3$)	61	21	65	-
CHLORIDE (PPM)	520	64	88	-
SULFATE (PPM)	45	17	62	-
NITRATE (PPM)	1.7	0.4	76	-
SODIUM (PPM)	112	29	74	-
CALCIUM (PPM)	91	12	87	-
MAGNESIUM (PPM)	51	9	82	-
POTASSIUM (PPM)	5.0	0.9	82	-
pH	7.9	7.3	-	8.6
SiO_2 (PPM)	34	34	0	34

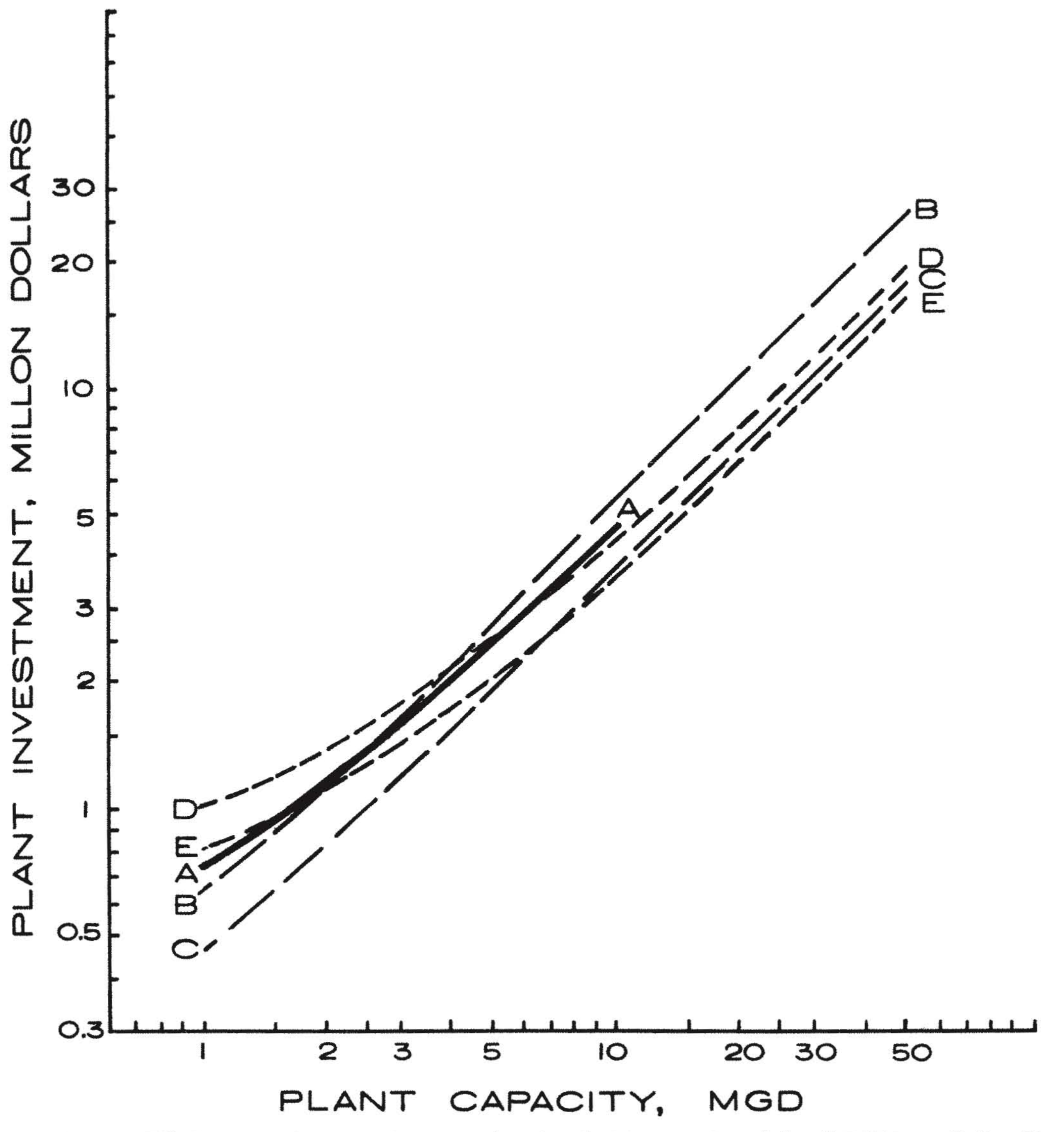
1ST STAGE: 0.9 AMPS, 25.41 VOLTS

2ND STAGE: 0.45 AMPS, 22.9 VOLTS

POWER CONSUMPTION (WITHOUT PUMPING): 2.4 KWH/DAY statistics infer that the cost of desalting brackish waters in the TDS range of 1,000 to 3,000 ppm by the electrodialysis process can be low enough now to compete with other methods of treating water.

The OWS has sponsored research and development in saline water conversion and in the economics of its application since the establishment of the agency in 1952. Many studies have been done to identify the important cost components of the various processes. However, rapidly changing technology, especially in the field membrane processes, has rapidly outdated the estimates of costs which need to be updated. The current studies point out that the membrane processes are considered the most economic for application to brackish water within the United States.

Since August 1969, the results of three detailed studies on economic and engineering analyses of the electrodialysis process have been published (Clark, 1969, Christodoulou, Olsson, and Monnik, 1969, and Porter and Cherney, 1969). The studies were carried out by three independent engineering research organizations under OSW contracts. The capital requirements and the total cost (capital cost plus operating cost) of producing fresh water are respectively summarized in Figures 3 and 4. Studies such as these involve considerable differences in system designs and cost variables. The close agreement among the three analyses, as indicated in Figures 3 and 4, enhances the degree of confidence of the cost reliability. Based on experience with plants designed for municipal and governmental uses (some now in operation for more than a decade), Katz of Ionics Inc. (Katz, 1968) also made similar estimates which were found in good agreement with others. The product water costs in Figure 4 were estimated according to the ground rules set by the OSW. The capital cost was calculated at an annual interest rate of 3.25 percent over an amortization period of 30 years, and the basic power cost was set at 7 mills per kwh. Allowing about 25 percent of the total cost for amortization and 15 percent for electrical power as summarized for a 10 MGD plant by Christodoulou, Olsson, and Monnik (1969), the effect of high interest and power cost on the product water cost can be approximated. In Hawaii, the allocation of power cost to the various consumers served by a central power company varies according to the services. The rate schedules are further complicated by the steps of



LINE AA --- FROM OSW PROGRESS REPORT 495, FEED TDS 2500 PPM
LINE BB FROM OSW PROGRESS REPORT 488, FEED TDS 3610 PPM
LINE CC --- FROM OSW PROGRESS REPORT 488, FEED TDS 2000 PPM
LINE DD --- FROM OSW PROGRESS REPORT 470, FEED TDS 3610 PPM
LINE EE --- FROM OSW PROGRESS REPORT 470, FEED TDS 2000 PPM

FIGURE 3. ESTIMATE OF PLANT INVESTMENT OF LARGE PLANT.

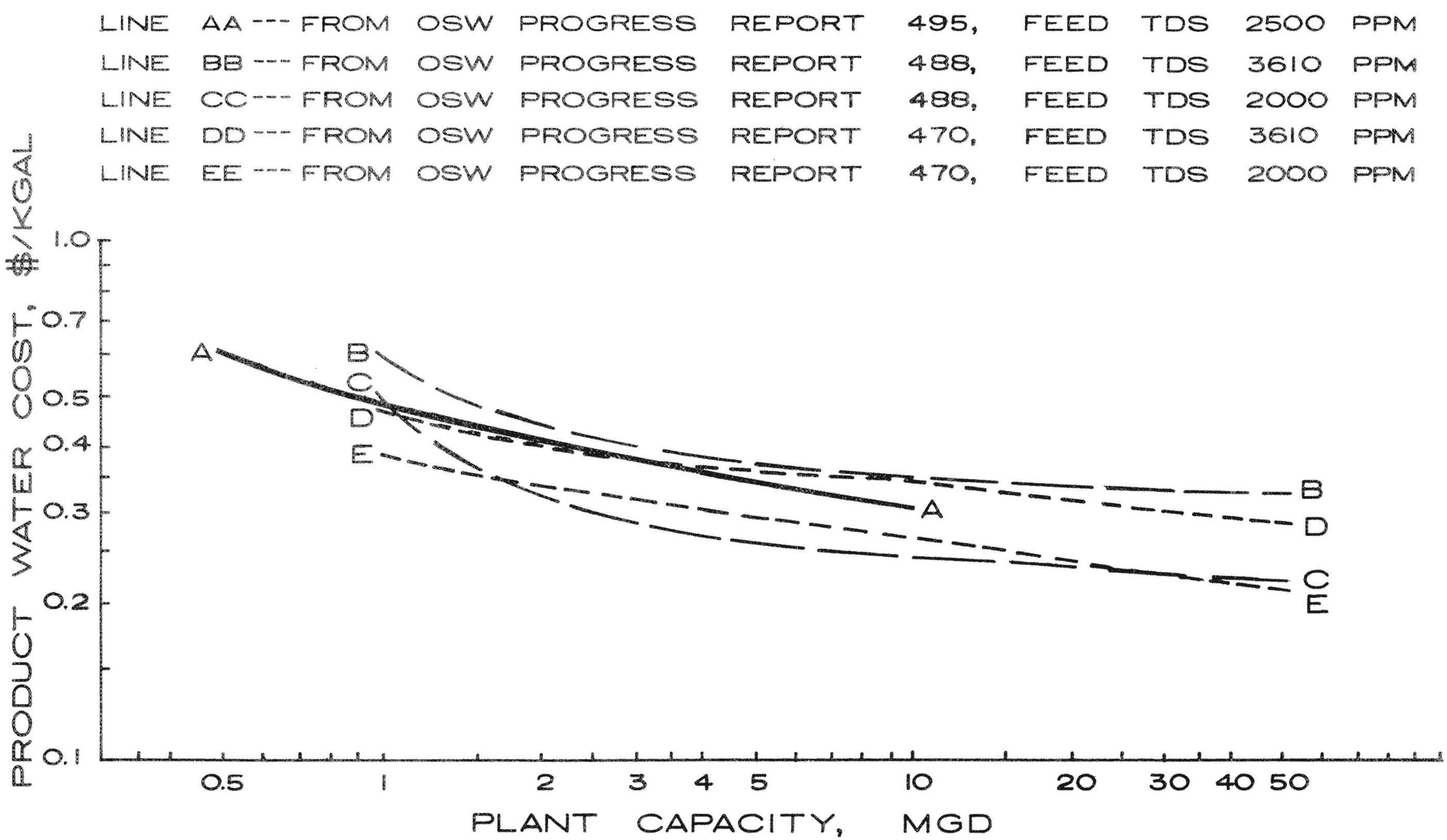


FIGURE 4. ESTIMATE OF PRODUCT WATER COST OF LARGE PLANT.

energy charge and demand charge. In general, the unit cost is much higher than 7 mills per kwh. Based on the assumption of 6 percent interest rate and 2 cents per kwh of power, the product water costs will be about 38 percent higher than those shown in Figure 4.

The investment cost in dollars per 1,000 gallons of product water increases with the decrease in unit size. The equipment amortization is the principal item of the water conversion cost for units smaller than 10,000 gpd, and the power cost is comparatively minor. Sufficient information is not available to warrant a reasonable estimate of the product water cost for small units as there are no reliable data on the service lives of equipment.

CONCLUSIONS

1. Brackish ground-water sources in Hawaii are identifiable, numerous, renewable, and requires a low pumping lift.

2. The brackish ground water in both the basalt aquifer and the reef limestone aquifer can be upgraded by electrodialysis from a non-potable to potable quality which can satisfy the U. S. Public Health Service Drinking Water Standards with respect to the chemical content.

3. The production rate of the testing unit was on the order of 420 gpd and the rejection rate was also 420 gpd. The performance is sustainable.

4. No pretreatment besides filtration was found to be necessary. The caprock water at the HIC site appears to contain organic matter although analysis was not made for organic content.

5. The costs of producing potable water by electrodialysis are largely dependent upon the size of the plant, the quality of feed water, the interest rate on capital investment, and the power cost. Studies done on large plants by others show that the electrodialysis process can compete in costs with other methods of desalting brackish water. Although the need for desalting water on a large scale appears not to be immediate in Hawaii, the small electrodialysis units could be feasible for upgrading brackish water to meet the drinking water needs in some locations in consideration of their compactness, accessibility and reliability.

ACKNOWLEDGMENTS

This study represents the joint efforts of several agencies. The Water Resources Research Center provided the research personnel, the necessary facilities, and services. The Department of Mechanical Engineering provided research personnel and shop service. The Board of Water Supply, City and County of Honolulu provided professional advice and various services. The Ionics Corporation donated the electrodialysis unit, personnel, and other services. Excellent cooperation was given at the test sites by Mr. Vincent Esposito, Director, Honolulu International Center, City and County of Honolulu and Mr. Richard J. C. Loo, Manager of Production, Honolulu Gas Co. Ltd.

REFERENCES

Christodoulou, A. P., F. R. Olsson, and J. Monnik. 1969. *Parametric economic and engineering evaluation study of the electrodialysis process for water desalination.* Research and Development Progress Report No. 488. Booz-Allen Applied Research Inc., Office of Saline Water.

Clark, C. F. 1969. *Cost analysis of six water desalting processes.* Progress Report No. 495. Stanford Research Institute, Office of Saline Water.

Cox, D. C. 1955. " Current research on the fresh-salt interfaces at the base of Ghyben-Herzberg lenses in Hawaii." *Geological Society of American Bulletin.* 66(12) Pt. 2. 1647 p.

Cox, D. C. and C. Lao. 1967. *Development of deep monitoring stations in the Pearl Harbor ground water area on Oahu.* Technical Report No. 4. Water Resources Research Center. University of Hawaii. 34 p.

El-Ramly, N. 1970. A paper in preparation. College of Business Administration. University of Hawaii.

HBWS. Annual Report 1968.

Katz, W. E. 1968. *Electrodialytic saline water conversion for municipal and governmental use.* Proceedings of Western Water and Power Symposium.

Lau, L. S. 1962. *Water development of Kalauao basal springs - hydraulic model studies.* Board of Water Supply. 109 p.

Lau, L. S. 1967. *Dynamic and Static Studies of Seawater Intrusion.* Technical Report No. 3. Water Resources Research Center. University of Hawaii. 31 p.

Lau, L. S. 1967. *Seawater encroachment in Hawaiian Ghyben-Herzberg systems.* Proceedings National Symposium on Ground Water Hydrology, American Water Resources Association. p. 259-271.

Lee, Y. F, 1967. Private Memorandum of the Honolulu Board of Water Supply. 4 p.

Macdonald, G. A., D. A. Davis, and D. C. Cox. 1954. "Kauai, an ancient Hawaiian volcano. *Volcano Letter.* No. 526. p. 1-3

Mink, J. F. 1961. *Some geochemical aspects of sea water intrusion in an island aquifer.* International Association Science Hydrology Committee on Subterranean Waters. Pub. 52. p. 424-439.

Mink, J. F. 1962. "Excessive irrigation and the soils and ground water of Oahu, Hawaii." *Science.* p. 672-673.

Mintz, M. S. 1963. "Electrodialysis-principle of process design." *Industrial and Engineering Chemistry*. 55(6). 19 p.

Porter, J. W. and S. Cherney. 1969. *An economic and engineering analysis of the electrodialysis process*. Research and Development Progress Report No. 470. Office of Saline Water.

Stearns, H. T. 1940. *Geology and ground-water resources of the islands of Lanai and Kahoolawe, Hawaii*. Bulletin No. 6. Hawaii Division of Hydrography. 177 p.

Stearns, H. T. and K. N. Vaksvik. 1935. *Geology and ground-water resources of the island of Oahu, Hawaii*. Bulletin No. 1. Hawaii Division of Hydrography. 479 p.

Stearns, H. T. and K. N. Vaksvik. 1938. *Records of the drilled wells of Oahu, Hawaii*. Bulletin No. 4. Hawaii Division of Hydrography. 213 p.

Stearns, H. T. and G. A. Macdonald. 1942. *Geology and ground-water resources of the island of Maui, Hawaii*. Bulletin No. 7. Hawaii Division of Hydrography. 344 p.

Stearns, H. T. and G. A. Macdonald. 1946. *Geology and ground-water resources of the island of Hawaii*. Bulletin No. 9. Hawaii Division of Hydrography. 363 p.

Tenorio, P. A. 1970. Oral communication.

Tenorio, P. A., R. H. F. Young, and H. C. Whitehead. 1969. *Identification of return irrigation water in the subsurface: water quality*. Technical Report No. 33. Water Resources Research Center. University of Hawaii. 90 p.

U. S. Office of Saline Water. 1968. Saline Water Conversion Report. 347 p.

U. S. Water Resources Council. 1968. *The Nation's Water Resources*. (Hawaii Region). p. 6-19-1 to 6-19-9.