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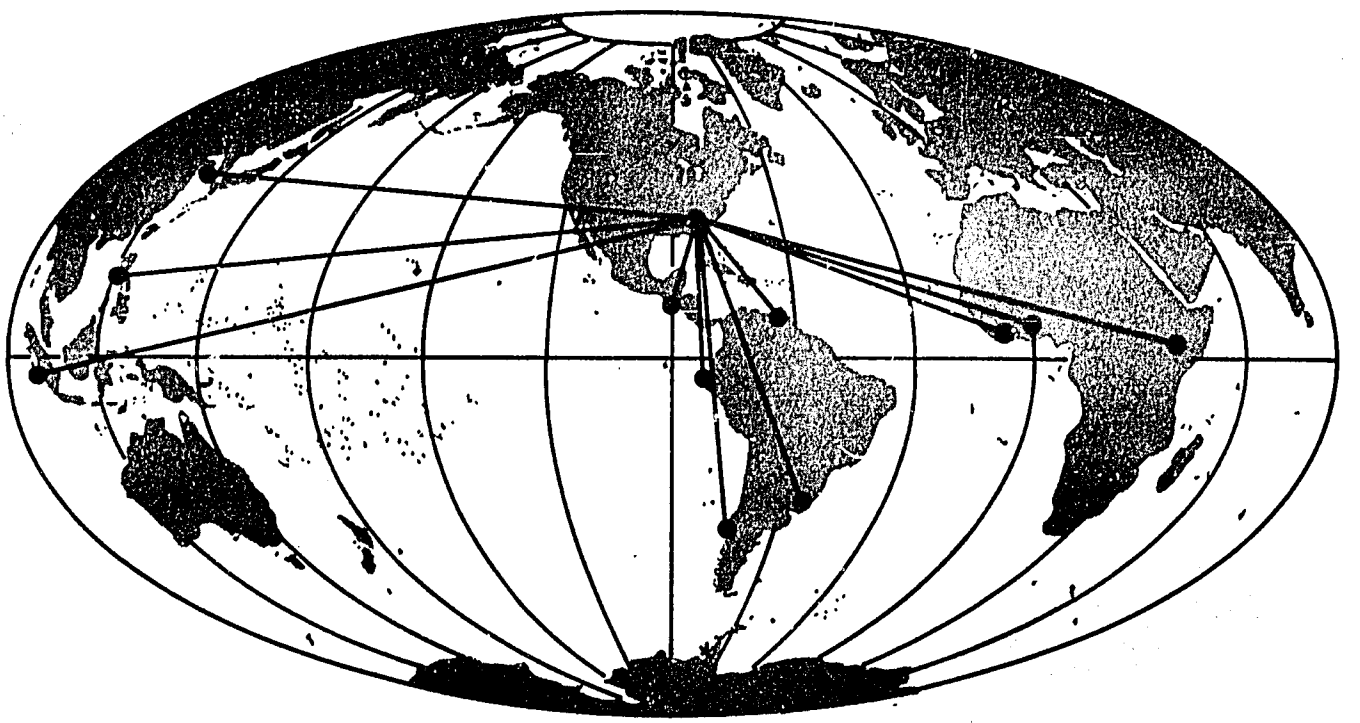

TESTING AND EVALUATION OF DOW CHEMICAL'S SOLAR STILLS

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TESTING AND EVALUATION OF DOW CHEMICAL'S SOLAR STILLS

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Summary

In July 1977, the Office of International Programs, Georgia Institute of Technology, began to monitor the operation of two solar stills which had been constructed by Dow Chemical, U.S.A.

The purpose of this monitoring was to determine the performance of both the still and the plastic films supplied by Dow Chemical.

Four different types of plastic films were tested -- two from Dow Chemical and two from other companies. It was found that the Tyril by Dow Chemical produced the highest quantities of water but was extremely brittle. As a result, it was vulnerable to heavy rains and moderate to heavy winds.

The solar stills require some modification in design but are suited for local manufacture in LDCs.

Chemical and bacteriological tests were performed on the water going into and coming out from the stills. It was found that highly polluted water was put into the stills, and although the stills did not produce completely pure water, they did produce safe, drinkable water.

It is Georgia Tech's understanding that Dow Chemical is presently developing a film which produces the amount of water that Tyril does and yet is as flexible as a polyethylene film.

When developed, Georgia Tech would like to have the opportunity to test it along with a modified solar still. If successful, a demonstration project could be set up in one of OIP's counterpart organizations which are located in Africa, Latin America, and the Far East.

INTRODUCTION

In July 1977, the Office of International Programs (OIP), Georgia Institute of Technology, began to monitor the operation of two solar stills which had been constructed by Dow Chemical, U.S.A.

The purpose of this monitoring was to determine the performance of both the still and the plastic films supplied by Dow Chemical. In doing so, the stills were tested so as to determine how long they could remain in operation without requiring an operator's attention. Four different types of plastic films were tested: two from Dow Chemical, one from the Starrtex Co., and one from Union Carbide.

Monitoring of these stills was terminated October 7, 1977. During the time in which they were in operation, water output from each still was measured and the interior and ambient temperatures from each unit were recorded. Chemical and bacteriological tests were conducted on water going into and that coming out from the stills.

In order to manufacture the stills, Dow Chemical claimed that each solar still required from $12 to $15 of locally available material, $0.50 of U.S.-made solar plastic wettable film, and one to two man-days of local labor.[1/]

The plastic films which Dow Chemical manufactured for these stills are covered by issued patents, while a patent on the still itself is pending. If Dow should obtain patent rights for this particular type of still, it intends to make the rights available at reasonable cost so as to encourage local enterprise to manufacture them.[1/]

1/ Letter dated July 15, 1977, from W. E. Walles of Dow Chemical to R. W. Hammond, OIP, Georgia Tech.

DOW CHEMICAL'S ANALYSIS OF THE PERFORMANCE OF ITS SOLAR STILLS

Before the Georgia Institute of Technology became formally involved in the monitoring of Dow Chemical's solar stills, Dow had already performed tests of its own.

From these tests, it postulated that in Australia, with a December insolation of 6,500 Kcal/m^2/day (7,560 W hr/m^2/day), a still with a surface area of 1.16 m^2 would produce 7.0 liters (28 cups) of distilled drinking water per day. At this production level, one still was expected to serve about four people, depending upon what other food they consumed. It was also found that the temperature inside the stills reached and maintained pasteurization temperatures. Storms, winds, and other natural forces were expected to cause the need for two to four film changes per year.[1/]

In conclusion, Dow stated that good quality drinking water could be made from sea water, contaminated well water and/or bacterially polluted water.[1/]

1/ Letter dated July 15, 1977, from W. E. Walles of Dow Chemical to R. W. Hammond, OIP, Georgia Tech.

DESCRIPTION OF APPARATUS

The solar stills which Georgia Tech monitored for Dow Chemical were of the dimensions 1.45 m x 1.00 m. The roof of the stills sloped in two opposite directions at an angle of approximately 23 degrees. Total surface area of the roof was 1.47 m^2 (1.47 m x 1.00 m). Therefore, the total amount of plastic film required per still was 1.83 m^2 (1.83 m x 1.00 m, allowing for the quantity needed to clamp the plastic on the still). There were 14 pans which made up the basin on each still. These pans were painted a dull black and held the water being put into the still. A door was on each side of the still which facilitated the replenishing of water to each pan.

When in proper operation, water from the basins would evaporate, condense onto the plastic film, and flow down into an aluminum trough which fed into a plastic tube. This tube extended out from the still and emptied its contents into a storage container. There was a container on either side of the still.

A temperature-compensated dial scale made by the Metro Equipment Corporation was used to weigh the distillate. Thermometers were used to record the interior temperature of each still and the ambient temperature.

Four different types of plastic films were tested. They were Trycite and Tyril, both plastics having a wettable surface and made by Dow Chemical; polyethylene, a plastic with no wettable surface from the Starrtex Co.; and clear, flexible vinyl which has a wettable surface and is made by Union Carbide.

PROCEDURE AND SET-UP

Upon receipt of the two solar stills from Dow Chemical, personnel from Georgia Tech and Dow set up these units on the roof of one of Georgia Tech's office buildings.

The stills faced south so that the maximum amount of sunlight would fall on them. They were supported by 4x4's and were about 30 cm off the ground so as to allow the distillate to be easily collected. As the roof of this office building was 21 stories high, some rather strong winds were expected. As a result, the stills were protected by a windbreak.

From July 12 through August 9, only the water output from each still was monitored. This was done to determine whether further testing of the stills was justifiable. Upon determining that further testing was necessary, the interior temperature of each still and the ambient temperature were recorded for the duration of the tests. When possible, all monitoring of the stills was done on a daily basis. However, they were not monitored during periods of rain, during the time when there was damage to the stills, or on some weekends. All monitoring took place at approximately 13:00 hours.

During this test period, the Solar Energy Lab at Georgia Tech recorded the total daily insolation readings. These readings were later compared with the daily water output from each still to obtain correlations between water output and total daily insolation.

Brackish water was used as input for the stills. The only exception occurred when bacteriological and chemical tests were conducted on water going in and coming out from each still. For these tests, the filthiest, most polluted nearby source of water was used as input for the units.

When measured, each still had the same surface area and, therefore, both required the same amount of plastic film. In order to test the different films, the following schedule was used:

July 12 - August 8:	Trycite (Dow Chemical) used on both stills.
August 9 - September 1:	Trycite used on Still A; clear, flexible vinyl (Union Carbide) on Still B.
September 2 - September 9:	Clear, flexible vinyl on Still A; Tyril (Dow Chemical) on Still B.

September 10 - September 18:	Polyethylene (Starrtex Co.) on Still A; Tyril on Still B.
September 19 - October 7:	Clear, flexible vinyl on Still A; Tyril on Still B.

RESULTS

All the data obtained from the two solar stills have been tabulated in Tables 1-5.

In Table 1, Trycite was tested on both stills. This plastic film was one of the earlier ones manufactured by Dow Chemical. It contained streaks in its structure which were not water wettable, and, as a result, water output was impaired. An average of 7.6 pounds of water (15.2 cups) was produced daily, with the high being 10 pounds of water (20 cups) when the total daily insolation was approximately 7,400 W hr/m^2. The film was rather brittle and required frequent changes during periods of heavy rains and/or moderate to heavy winds.

In Table 2, Trycite was tested on Still A, and clear, flexible vinyl on Still B. During the days in which the stills were in operation, the still with the vinyl covering had an average daily output of 4.8 pounds (9.6 cups) of water to Trycite's 3.9 pounds (7.8 cups), almost a one pound difference in output. During most of the test period, temperatures in both stills reached and maintained the pasteurization temperature (140°F or 60°C) and on several days even exceeded it. (This occurred with all the plastic films tested.)

The brittleness of the Trycite continued to be a major problem, causing several film changes. Dow Chemical was informed of this as well as the non-wettable streaks in the film. As a result, another plastic film (Tyril) was received from this company for testing.

Table 3 compares polyethylene to Tyril. The Tyril appeared to perform well, with an average daily output of 5.0 pounds (10 cups) of water. The maximum amount of water produced in one day was 7.1 pounds (14.2 cups) and this occurred when the total daily insolation was approximately 6,000 W hr/m^2. However, for all practical purposes, the polyethylene film on the other still produced no water at all. The water in the still would evaporate, condense onto the film and fall back into the basin. Thus, after eight days of testing, this film was removed and the vinyl from Union Carbide was reinstalled.

Table 4 shows the results of the flexible vinyl when compared to Tyril. Tyril produced a significantly greater amount of water than the vinyl did. Its high was 9.9 pounds (19.8 cups) of water versus the vinyl's 4.8 pounds (9.6 cups) of water. This occurred when the total daily insolation was

approximately 6,500 W hr/m^2. The daily average of the clear, flexible vinyl and the Tyril was 4.5 pounds (9 cups) and 7.7 pounds (15.4 cups), respectively. However, Tyril continued to have the same problem that Trycite had; that is, it was easily damaged by the forces of nature. From September 18 to October 7, the Tyril was replaced four times, while the vinyl was never replaced.

In Table 5, the results of the chemical and bacteriological tests are shown. Result #5 is the outcome of tests performed on a sample of the water being put into the stills. Results #1 and #2 are samples of water which were distilled by Still A, while results #3 and #4 are samples of the type of water which Still B distilled.

In summary, Table 5 shows that highly polluted water was put into the stills, and although the stills did not produce completely pure water, they did produce safe, drinkable water. The stills killed all the coliform that was in the feedwater, drastically reduced the amount of bacteria, and reduced the amount of dissolved solids in the water by at least 4.5 times. Turbidity and the color in the water were reduced, thus giving the distillate a clearer and more transparent appearance.

Table 1

WATER OUTPUT FROM STILLS USING TRYCITE

Date	Time	Water Output* (lbs.) Still A	Still B	Comments
7/11	13:50			Start tests
7/12	13:20	6	6	
7/13	13:15	9	10	
7/20	13:15	12	15	Output from 7/18, 13:20 hrs.
7/22	13:15	8	7	Output from 7/21, 13:20 hrs.
7/27	13:00	4	5	Output from 7/26, 13:25 hrs.
8/2	13:15	4	5	Output from 8/1, 14:00 hrs.

* Output measured to nearest pound.

Table 2

DATA FROM STILLS
TRYCITE ON STILL A, CLEAR FLEXIBLE VINYL ON STILL B

Date	Time	Water Output (lbs.) Still A	Water Output (lbs.) Still B	Temperatures (°C) Interior Still A	Temperatures (°C) Interior Still B	Temperatures (°C) Ambient	Comments
8/9	14:15	2.9	-				Clear, flexible vinyl installed on B.
8/10	13:40	3.8	4.8	66	66	32	
8/11	13:09	5.2	6.6	66	66	32	
8/12	13:28	4.6	6.0	54	66	32	
8/15	13:45	10.0	12.9	49	44	30	Output from 8/12 (3 days accumulation)
8/16	13:04	3.1	3.9	49	52	29	
8/17	13:17	3.0	3.5	54	60	31	
8/19	13:10	2.3	2.8	49	49	27	Output from 8/18, 13:37 hrs.
8/22	13:26	8.4	11.4	60	66	31	Output from 8/19 (3 days accumulation)
8/23	13:25	3.9	5.3	60	66	32	
8/24	13:07	3.5	4.8	54	57	31	
8/25	13:31	4.3	5.2	43	46	29	
8/26	13:57	2.9	4.2	38	38	27	
8/29	13:20	16.4	17.2	60	63	30	Output from 8/26 (3 days accumulation)
8/30	12:54	3.8	4.4	63	63	30	
8/31	13:22	5.8	6.8	60	63	31	
9/1	13:45	4.9	5.5	63	63	31	

Table 3

DATA FROM STILLS
POLYETHYLENE ON STILL A, TYRIL ON STILL B

Date	Time	Water Output (lbs.)		Temperatures (°C)			Comments
				Interior			
		Still A	Still B	Still A	Still B	Ambient	
9/11	9:50	0.7	7.1	32	33	22	
9/12	15:04	0.4	-	51	65	28	One collecting bottle blew over.
9/13	11:38	0.4	2.8	33	35	25	
9/14	13:09	-	4.1	48	57	29	One collecting bottle blew over.
9/15	13:21	-	6.1	54	63	30	One collecting bottle blew over.

Table 4

DATA FROM STILLS
CLEAR FLEXIBLE VINYL ON STILL A, TYRIL ON STILL B

Date	Time	Water Output (lbs.)		Temperatures (°C)			Comments
				Interior			
		Still A	Still B	Still A	Still B	Ambient	
9/22	13:08	5.0	9.0	66	67	27	
9/23	13:16	5.4	9.2	61	63	28	
9/27	13:10	2.4	3.5	54	57	28	Output from 9/26, 13:10 hrs.
10/4	13:05	-	6.4	60	66	22	Output from 10/3, 13:15 hrs. One collecting bottle blew over.
10/5	13:00	4.8	9.9	54	60	23	
10/6	13:00	4.5	8.3	54	54	24	
10/7	13:20	4.8	-	49	-	23	Plastic on B blown off.

Table 5

BACTERIOLOGICAL AND CHEMICAL RESULTS

	Still A (Output)		Still B (Output)		Input to Stills
	No. 1 9/21/77	No. 2 9/21/77	No. 3 9/21/77	No. 4 9/21/77	No. 5 9/20/77
Total Aerobic Plate Count (No./ml)	310	3,000	650	17	3,800,000
Total Coliform (MPN/100ml)	0	0	0	0	15,000
Color (Color Units)	5	5	5	5	10
Conductance (MMHOS/cm)	20	16	18	21	90
Turbidity (NTU)	0.7	0.8	0.9	0.7	7.6

Source: Letter from Southeast Laboratories, Inc. dated September 27, 1977.

CONCLUSIONS AND RECOMMENDATIONS

The principle of solar distillation is a good one. Using this "free" energy to produce drinkable water is something that people all over the world require.

What Dow Chemical has manufactured is a still made out of locally available material and of very simple construction. However, some changes in the still design are required. One large pan should be used as the basin for the still instead of 14 small ones. This basin would contain baffles so as to reduce water disturbance within the still. Filling of the still should be very simple. Instead of reaching inside the still and filling each pan, a plastic or rubber tube which runs inside the unit could be connected to a container of water which is slightly higher than the still. The water level within the unit could be controlled manually by use of a clamp on the tube or automatically by using a simple metering device within the still to turn a valve on or off. For best results, automatic control of the water is recommended. This would reduce the probability of the still running dry (unless the outside container runs out of water) and also could keep the water at an optimum level. (Studies have indicated that a greater amount of water is distilled if relatively shallow depths of water are kept within a basin.)

The most important part of the solar still is the plastic film. Past tests have shown that without the right type of film, there would be no water output from the still. What is ideally required is a film which holds up to the forces of nature, does not deteriorate with time, and which absorbs the most infrared rays from the sun so as to produce a maximum amount of distillate. In the films that were tested, Union Carbide's vinyl was extremely durable but produced only about half of the distillate that Dow Chemical's Tyril did. However, Tyril is an extremely brittle film and is highly susceptible to wind and rain damage.

In conclusion, modifications are required on the stills before they can be introduced into a consumer market. No plastic film which was tested was suitable for use on a solar still. Either the water output was too low, or the film was easily damaged by the forces of nature. This does not imply that a film suitable for a solar still is not available. It simply means that such a film was not tested. Some films which might be of future interest for testing

are Du Pont's Weatherable Mylar, Tedlar, and Aclar. It is also Georgia Tech's understanding that Dow Chemical is presently developing a film which produces the amount of water that Tyril does and yet is as flexible as a polyethylene film.

If this type of film is developed, Georgia Tech would like to have the opportunity to test it. If successful, this film and a modified solar still could be used as a demonstration project in one of OIP's counterpart organizations which are located in Africa, Latin America, and the Far East.

APPENDIX

HISTORY OF SOLAR DISTILLATION[1/]

In order to obtain a perspective view of solar distillation, a brief history of its development is presented.

Over the centuries, man has used solar energy in distillation processes which have included the extraction of perfumes and medicines from flowers, herbs, grasses, etc. However, the earliest, most significant solar distillation plant on record was constructed in Las Salinas, Chile, in 1872. It was designed by Mr. Charles Wilson and was of the greenhouse type, i.e., it contained a shallow rectangular pool of salt water beneath a transparent glass cover which sloped downward in two directions. The still contained 64 separate water basins that were constructed of wood planking and had a framework made from timber with sloping glass covers. The total glass area was 51,200 ft^2 and the total water surface area was about 48,000 ft^2. When new, the still was reported to have produced approximately 6,000 gallons of fresh water daily, which was used primarily for the watering of mules. With the coming of the railroad, the purpose of the still was eliminated and, as a result, it no longer exists today.

No further significant work was noted until the years 1926-1930, when it was reported that studies were being conducted on simple glass-covered solar stills.

In 1952, with the creation of the Office of Saline Water (OSW), a great deal of interest was stimulated in the need to plan for future desalination. Several institutions and foreign nations became involved in this challenge.

One of the foremost people in the area of solar distillation has been Dr. Maria Telkes. She began her work at MIT in late 1942, and during World War II invented a small, inflatable solar still for use on life rafts. Eventually, more than 200,000 units were produced as standard equipment for life rafts on aircraft and ships. After World War II, Dr. Telkes continued her

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1/ Summarized from J. A. Eibling and S. G. Talbert, Manual on Solar Distillation of Saline Water (Washington, D.C.: U.S. Government Printing Office, April 1970) and Department of Economic and Social Affairs, Solar Distillation as a Means of Meeting Small-Scale Water Demands (New York, N. Y.: United Nations, 1970).

research on small glass-covered solar stills and eventually proposed two different designs -- one for the tropics and another for the temperate zones. The tropic design had a symmetrical roof with glass sides which were sloped at 45 degrees. In the temperate design for the northern hemisphere, the side facing the south was made of glass and the north side of the roof was made of a thin reflecting material which was tilted to best reflect the sun's rays into the basin. From the studies done on these stills, Dr. Telkes concluded that:

1. An insulated base was beneficial.
2. The efficiency increases with ambient air temperature.
3. Wind velocity does not have an appreciable influence on still productivity.
4. Shallow water layers in the basin were most desirable (less than 1/2 inch recommended).
5. Large solar distillers may use a continuous feed of seawater.
6. The glass surface could be used to catch rainwater.

She also had experimented with tilted wick stills sponsored by the OSW. The still had a black fabric surface saturated with saline water. Plastic or glass was used to cover this fabric and the whole still was tilted at a fixed angle to best intercept the solar energy.

Many other people, institutions, and nations deserve to be mentioned, due to the work that has been accomplished. A list of names and locations, followed by brief explanations of what they accomplished, is presented below.

Virgin Islands

During 1948-1949, a small solar still was constructed in order to test water output. This still was supposed to be a forerunner of a much larger 1,000-gallon-per-day (gpd) still. However, the proposed still was never built. The smaller still was similar in design to some of those designed by Dr. Telkes and, indeed, was constructed with her assistance.

University of California

Experimentation with solar stills has been going on since 1952. Major emphasis has been placed on a small still which would provide enough water for one family. However, some work also has been done on the tilted tray still and has been continued by Horace McCracken.

University of Wisconsin

Research work on solar stills was begun in 1952. At first, research was done on a solar still made up of two horizontal eccentric tubes. The outer tube was inflated to reduce heat losses. The inner tube was nearly filled with saline water which was dyed black. Air was blown over this water so that the water vapor was carried to a condenser.

Later work involved designing several plastic-covered solar stills for the South Pacific islands and elsewhere. A typical still had a 12-foot-long by 2- to 5-foot-wide basin lined with butyl rubber, wooden or concrete distillate troughs, and a wooden framework covered with weatherable Mylar or Tedlar which was held in place with long plastic sandbags.

A study of the worldwide distribution of solar energy also was published by this university.

Battelle-Columbus

The Battelle Memorial Institute, Columbus, Ohio, has been involved in solar still research since 1953. They initiated their study by first conducting an investigation for the OSW concerning the multiple-effect evaporation of saline waters, using solar energy to generate steam. Then, in 1958, they operated a solar distillation research station at Daytona Beach, Florida, for the Office of Saline Water. This was the first station where different types of stills could be tested and their performance predicted. The station was in operation for seven years and during this time period tested 40 different types of plastic films. The most durable films lasted for four years and were Tedlar, weatherable Mylar, and Aclar. However, the exposure conditions were considered less severe than those of an actual solar still because of lower operating temperatures and lower-velocity winds.

After all these tests, the research station concluded that glass-covered basin stills were the most satisfactory of all those evaluated, taking into consideration every factor, i.e., construction methods, first cost, performance, and maintenance.

In 1967, Battelle conducted a brief study to determine if plastics costing less than one cent per square foot could produce water more cheaply than glass-covered stills. It was found that just the opposite was true.

In 1968, Battelle compiled a manual concerning the state of the art of solar distillation and it was published in April 1970.

George O. G. Löf

Dr. Löf began his work with solar stills in 1953. He served as a consultant to OSW and investigated several different methods for solar distillation. Among these were survival stills, basin-type stills, tilted-type stills, solar evaporators with external condensors, multiple-effect stills with membranes or plates, and focusing-type solar collectors for steam generation. He also designed a 12-inch-deep, basin-type solar still with interconnected bays which covered a total area of about 5,000 ft^2. It was originally designed for a site near San Diego, California, but was never built. However, a smaller scale of this still (2,450 ft^2) was built at Battelle's Daytona Beach facility under OSW sponsorship. At a radiation level of 2,000 Btu/ft^2-day, the average productivity was approximately 0.08 gal./ft^2-day or 200 gpd for the whole unit.

Dr. Löf played a major role in evaluating solar desalting research and proposals in Spain, and in 1965 assisted the OSW in a cooperative program for building a solar still at Las Marinas, Spain. The design was similar to the one built at Daytona Beach and covered an area of 9,500 ft^2. A shallow basin was used (a depth of approximately 4 inches of salt water), but water output remained essentially the same.

Australia

In 1953, the Commonwealth Scientific and Industrial Research Organization (CSIRO) began to investigate solar stills as a way in which brackish water could be purified in remote areas. At first, tests were made of small 5 ft^2 Telkes-type stills. Emphasis was later placed on large, low-cost units. These units consisted of an asbestos-cement (Transite) tray measuring about 4 x 6 feet with a glass cover at a 10-degree angle to the horizontal and insulated on the bottom.

In 1963, CSIRO developed a bay-type, glass-covered solar still with each bay being 3.5 feet wide by 128 feet long. The bottom was lined with black polyethylene sheet with a thickness of 8 mils. Table 6 gives the locations where these stills were built.

Table 6

SOLAR STILLS IN AUSTRALIA[1/]

Location	Date Built	Basin Evaporating Area, ft^2	Projected Glass Area, ft^2
Muresk 1	Dec. 1963	4,000	4,500
Northam	Dec. 1964	4,000	4,500
Perth	Dec. 1966	?	5,400
Muresk II	Nov. 1966	4,000	4,500
Coober Pedy	Nov. 1966	34,000	38,000
Caiguna	Dec. 1966	4,000	4,000
Hamelin Pool	Dec. 1966	6,000	6,800
Griffith	Aug. 1967	4,450	5,000

1/ J. A. Eibling and S. G. Talbert, Manual on Solar Distillation of Saline Water (Washington, D. C.: U.S. Government Printing Office, April 1970)

Algeria

In 1953, Cyril Gomella began developing several types of tray-type stills in Algeria. Eventually, 20 stills of 10 different designs were tested around the country. From these tests, a small unit consisting of a molded asbestos-cement tray, set on insulation and covered with glass, was put to wide use. The tray area was 33 ft^2, and the still was unique due to the fact that the glass covers were inclined only 10 degrees to the horizontal.

Italy

Under the direction of Dr. Giorgio Nelbia, the University of Bari in Italy initiated development work on solar stills in 1953. Most of the stills were of the small shallow-basin, tray-type design with a 45-degree roof. At first acrylic plastic (plexiglas) was used to make the entire still. Later, glass covers with wood, concrete, and other materials were used to make the stills. In 1958, a "vertical" solar still was built. It had four horizontal trays (one above the other) and was enclosed in glass. All the glass walls acted as condensing surfaces, thus giving a high water yield per unit of ground area.

Bjorksten Laboratories

In 1954, Bjorksten Laboratories built several types of large plastic-covered stills for the OSW. The intention was to develop a still which would be applicable to large-scale distillation plants. Tubular designs were also constructed and tested. Later a vertical-wick solar still was developed and evaluated at Battelle's Daytona Beach facility. Unfortunately, no useful data were obtained, due to wind damage and poor wettability of the wick material.

South Africa

As of 1954, South Africa has reported working on solar stills. There is much interest in the development of solar stills on farms and in small communities. Also, small-scale pilot plants have been constructed to evaluate existing designs.

Cyprus

During the summers of 1954 and 1955, several experiments were conducted on the north of Cyprus with small solar stills. These stills were of the shallow-basin type with 45-degree glass covers. Productivity in each unit was increased by completely sealing the stills to prevent vapor leaks and by using a reflector to concentrate the sun's rays.

Chile

Since 1955, research work at the Universidad Tecnica Federico Santa Maria in Valparaiso, Chile, has been conducted on solar energy. The idea was to use solar energy to both generate electric power and distill water. Solar ponds with concentration gradients were to be used to produce heated saline water for the system. The heated water would pass through a vacuum evaporator and the resultant steam would drive a turbine to produce electricity. The steam would then be condensed and distilled water would be produced. Further work on this system will depend on the availability of funds.

U.S.S.R.

During 1956, the Solar Energy Laboratory at the Krzhizhanovsky Power Institute in Moscow began to investigate the use of solar stills for supplying water to arid and semiarid lands. In doing so, it was found that only the

boundary layers within the stills circulated and contributed to the process of heat and mass transfer. The remaining volume remained relatively stagnant.

From 1961 to 1965, five experimental stills were tested at the experimental station of the Physics and Engineering Institute of Turkemenian S.S.R. Academy of Sciences to determine the optimum design for solar stills. From these results, a 25,800 ft^2 still was designed and construction was begun in 1969 at Ashkabad, Turkemia. When completed, this unit will distill water and collect rainwater. It will also be supplemented by well water which will use a pump run on solar energy. The sun's energy will be collected through the use of photovoltaic cells. Thus, this watering system for karakul sheep will be a total solar energy unit.

France

In 1956, the Laboratory of Solar Energy, National Commission for Scientific Research, Montlouis, France, combined the functions of a solar still with that of a hothouse to provide water and the appropriate climate for the growing of plants. A much larger unit was planned for the Sahara, but it is not known if it ever was constructed.

Senegal, West Africa

In 1956, experiments were conducted in Senegal on a small solar still being mass-produced by the Radiosol Company.

However, during the early 1960's, work at the University of Dakar, Dakar, Senegal, shifted from simpl. solar stills to solar energy systems producing electric power and fresh water. The vapor-generating plants used solar energy to heat water which, in turn, vaporized another heat-transfer fluid that drove a turbogenerator. The power generated was used to drive a pump which produced fresh water. The overall efficiency of this sytem was below one percent.

India

Work on tray-type solar stills began in 1957 at the National Physical Laboratory, New Delhi, India. Five different still designs were tested to determine the performance of various materials and the glass covers. A design was formulated for a 4,000 ft^2 still to be installed in a remote Rajasthan village, using wood frames, glass covers, and stabilized soil for the basin, but funds have not become available.

Iran

In 1957, three small glass-covered, basin-type solar stills were tested in Tehran, Iran. Double- and single-sloped glass covers were used, and one design had a cemented glass cover over the east, south, and west sides. Water-cooled copper coils were installed on two of the units to serve as the condensing surface.

Georgia Institute of Technology

From 1958 to 1961, the Georgia Institute of Technology, under contract with the OSW, studied both natural and forced convection solar still designs. Depending on the design and operating conditions, the productivities of the forced-convection stills were approximately double those of the standard, natural-convection stills. Several different ideas were tried so as to increase the rate of evaporation. Among these were: Orlon wicks, brine-spray nozzles, elevated brine trays, double covers, storage of the condenser cooling water for use at night in the basin, and multiple-depth trays within a single unit.

Spain

In 1958, two 20 ft^2 tray-type solar stills were constructed in Spain. In 1960, the testing of the stills was expanded to 10 different types. It was found that a conventional glass-covered still and a low-inclination cover was the most efficient design. In November 1963, Las Marinas was chosen as the first large-scale solar distillation plant in Spain. This installation was designed to provide water to 300 people. The 9,350 ft^2 still was completed in March 1966. Maximum distillate output approached 1,000 gpd, and rainwater also was collected. The water was sterilized and slightly mineralized before being drunk.

Franklin Institute

In 1958, work was begun for the OSW to determine a means of producing permanently hyrophylic surfaces on plastic films for use as solar still covers. A continuous dip-coating technique was developed for applying a titanium dioxide coating, and samples were run with cellulose acetate, Mylar, and Tedlar.

Sunwater Company

In the late part of 1959, Horace McCracken began selling solar stills commercially. These step-inclined-tray stills used a porcelain-enameled steel tray and a glass cover. The available sizes ranged from 1/2 to 3 gpd. Currently, portable, residential, and commercial types are available which range in size from 1/2 gpd to 100 gpd and which have been installed at various locations in the southwestern United States, Mexico, and the Caribbean.

Egypt

In 1960, several small stills were tested by the National Research Centre, Cairo, Egypt. The first still was of wooden construction with a single glass pane as a cover. Later, stills had concrete basins for durability, with the largest one being 215 ft^2 in area.

Richard Hummel

In 1960, a design for a large-scale still producing 10 million gpd of fresh water was presented by Hummel and Rudd. The design consisted of two layers of wire-reinforced plastic covers. The lower covers were air inflated and covered bays 50 to 100 feet wide by one mile long. The elevated upper cover was stretched flat and covered an area of one square mile. Drainage of rainwater and high winds appeared to be some of the problems facing this design.

University of Arizona

In the spring of 1961, the University of Arizona, Tucson, Arizona, began developing a distillation system using solar energy to preheat the saline water for a humidification-dehumidification cycle. In this system, the heating of the saline water, the evaporating of a portion of it, and the condensing of the vapors were performed in three separate components. This was not an ordinary solar still, as solar energy was used to warm the saline water to a final temperature of 150°F before it was circulated through an evaporation chamber. The total area of the solar absorbers was 10,400 ft^2, and when tested in Mexico, they produced over 5,000 gpd.

McGill University

In 1961, the Brace Research Institute (BRI) of McGill University began to develop solar stills on several West Indies islands. Most of these stills were of the small tray type.

Taiwan

In 1961, Taiwan Normal University reported that research was being done on several small tray-type stills. The units were used on surrounding islands by troops and fisherman and had roof-type glass covers.

Japan

In 1961, an "earth-water collector" was developed in Japan. This unit was essentially a solar still without a brine basin. Water vapor was extracted from the soil and condensed on the cover. Tests were conducted at Tokyo, Mt. Mihara, Mt. Fuji, and on a desert in Pakistan to study productivity of various types of soils. It was found that at night distillation continued, but at a reduced rate. The average productivity of this type of still in Tokyo was one-fifth that of a conventional solar still.

Tunisia

Since 1962, the Solar Energy Group of the Tunisian Atomic Energy has been actively studying solar distillation. Stills ranging from very small (for use by two people) to large (14,000 ft^2 for the use of 2,000 people) have been constructed.

Tunisia hopes that by providing fresh water to the people, the people will, in turn, become more vigorous. The usually available drinking water is high in salt content (6,000 ppm or more) and it is felt that the energy required by the liver and kidneys to remove the salt greatly reduces the strength of an individual.

Aqua-Sol Inc.

Currently, Aqua-Sol Inc. is developing a small, portable solar still to produce 3 to 5 gpd. A new semirigid type of material has been developed for the cover.

Greece

In 1964, several solar stills were constructed on the island of Symi. Since that time, large solar stills have been constructed on the islands of Aegina (16,000 ft^2), Salamis (4,200 ft^2), Patmos (93,000 ft^2), Kimolos (27,000 ft^2), and Nisiros (22,000 ft^2). Plastic covers for stills of this

size do not seem to last for any length of time. As a result, glass covers have been widely used and the stills with plastic covers were either replaced with glass or abandoned.

Cape Verde Islands

In 1965, an inflated, plastic-covered still was built on the island of Santa Maria do Sal in the Cape Verde Islands. Reynold Eckstrom of Aqua Sol, Inc. built the still to supply water to a hotel. Recent reports concerning this still state that it is operating well and the blowers for inflating the still need to be actuated each evening for only a few minutes.

Ethiopia

A 1965 report describes the design of a small solar still developed in Ethiopia at the Haile Selassi I University. The glass cover was single-sloped at 12 degrees and mounted over an insulated metal tray painted a dull black.

U.S. Water Conservation Laboratory

The U.S. Water Conservation Laboratory in Phoenix, Arizona, developed a simple desert-survival still in 1965. The still uses solar energy to distill water from soils and plants. The still is made by digging a shallow hole in the ground about 3 feet in diameter and covering it with a plastic film weighted in the center to form a conical shape. A container is placed below the center weight to catch the condensate water dripping from the plastic film to increase the amount of water from the soil.

Harold R. Hay

In 1961, Harold Hay developed the use of weighted V-covers for plastic-covered stills. In this design, some of the problems of the inflated plastic cover can be overcome. However, the valleys of the V-covers tend to collect rainwater and debris, and the plastic may be damaged by the movement of the pipes that are used as weights.

Mr. Hay also obtained a patent on an elaborate solar still concept. This still comprised a plastic cover draped over ridge beams and weighted in the valleys, movable and stationary brine trays, and a distillate reservoir built beneath the brine trays.

Pakistan

Since 1967, the Atomic Energy Commission has been investigating the feasibility of using solar stills to provide water for the arid Makran coastal regions. When funds become available, the proposed still will be similar to the one on Patmos, Greece, with a capacity of 18,000 gpd.

Solar Sunstill Inc.

In 1969, a plastic-covered solar still was marketed commercially by Solar Sunstill Inc., Setauket, Long Island, New York. The unit was of pyramid shape with a plastic cover and a square basin with a total surface area of 64 ft^2.

In summary, solar stills are presently going through a development phase and have yet to be accepted as established technology.