Sun At Work

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Solar Experiment Station of the Technical University, Island of Symi

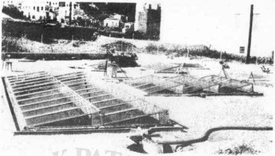

Fig. 1—Prototype solar stills at the Experiment Station in Symi.

Solar Distillation Developments in Greece

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WHEN the era of saline water conversion started, about 12 years ago, sea-water distillation by means of solar energy appeared to be one of the promising processes. An energy source at no charge is an attractive factor to cut operation cost.

Physical limitations in solar radiation, economic limitations in investment cost, and natural limitations in the design of solar stills were reasons that promoted the development of other processes for application in large-size desalination plants. Nevertheless, solar distillation remained the best process for family-size units and for small community plants, for two reasons: low investment cost and low operating cost.

Two individual programs to supply small communities with fresh water, using solar radiation as the energy source have been developed in Greece in the recent past. The first program, sponsored by Church World Service, is related exclusively with Tedlar-covered solar stills. The inflated type with air-supported cover, as devolepd by Frank Edlin,[1] was used in Symi[2,3,4]. In Perdika, on the island of Aegina, a still with a V-shaped cover was used[5]. This paper deals with the second program, sponsored by the Greek Ministry of Industry.

Glass or Plastic Stills?

When the Greek Government decided to finance a large program of erecting solar stills on arid islands, a decision had to be made about the type of still to be selected. Whereas in the United States both plastic and glass stills have been extensively tested, in other countries, like Algier, India, Spain, Australia, etc., glass-covered stills have mainly been used. After long deliberation the Greek Ministry of Industry decided in favor of glass. The reasons can be summarized as follows.

• **Lower investment cost.** In a preliminary evaluation it was found that the cost of Tedlar-film, including the unavoidable delustering to make it wettable, is higher than the cost of glass.

• **Local availability of materials.** It was considered important that materials of construction should be locally available, as far as possible, not only with regard to investment cost, but primarily for ease of maintenance and replacement.

• **Weather-proof construction.** Experience has shown that the inflated plastic stills are sensitive to weather. The V-type plastic cover seems to be less sensitive, but it is still to be proved if it might withstand strong winds without damage. On the contrary, properly designed glass stills are wind and storm proof.

•**Electrostatic properties of plastic films.** Dust is collected and tightly adheres to the outside surface, due to the electrostatic properties of the plastic films. This affects considerably the penetration of the solar radiation and reduces still productivity. Frequent washing of the film covers becomes necessary, a procedure that involves the extra cost in labor and wastes precious distillate.

• **Total productivity.** Even if it is claimed that Tedlar-film shows a penetration for solar radiation better than glass and therefore higher production figures are expected, the total productivity remains far behind glass, because of the waste of water for washing.

• **Average productivity per year.** Rain catchment is important for the economics of solar stills. The average productivity per year is considerably increased when all the rain falling on the still surface is collected. The rigid cover of the glass still is more suitable to collect rain, even in violent storms.

• **Need for repairs.** Experience has shown that glass stills need less repairs than plastic stills.

• **Durability.** Experience is in favor of higher durability for glass stills and therefore of longer life without important replacements.

A design of glass still, developed at the Technical University of Athens, was adopted by the Ministry of Industry for all stills to be erected in its program. About fifteen different models were constructed and tested on laboratory scale, before decision was made for the final construction form. Two prototypes of the final design were tested for a period of over a year at the University's Solar Experiment Station in Symi. The net evaporating area of the two prototype stills is 13.4 and 24.3 square meters respectively. The Solar Experiment Station of the Technical University at the island of Symi is shown on the cover of this issue.

The Design

The adopted design seems to be simple and easy to assemble, strong in construction, and not expensive in capital cost. It permits prefabrication and is promising for a long life of operation with minor labor and insignificant maintenance cost. Long life was an important factor to be considered in devising the still.

Generally speaking, it is a shed type of two or three bays having a shallow basin. A frame of concrete walls of about 10 by 10 cm forms the basin, which is levelled first with earth or sand. Final levelling is made with pumice sand, when available at a low price from nearby volcanic islands, to ensure a bottom insulation. An overflow at one end of the basin allows a maximum sea water depth of about 15 mm (⅝ inch). Standard inside dimensions of the basin are 3.09 by 39.86 meters. The basin is lined with 1/32 inch thick butyl-rubber sheeting.

The glass cover is supported by a strong, hard-aluminum structure. The condensate collecting gutters are used as the main frame, which rests on the concrete walls, forming the basin. This aluminum does not come in direct contact with sea water. The supporting structures (tees), factory precut and predrilled, are rivetted on the main frame at the erection site.

Special profiles of the aluminum gutters at the two ends have been devised, to permit easy rivetting of the glass-supporting tees and to secure safe fitting of the glass sheeting in case of strong winds and storm. The upper edges of the glass are secured by an aluminum corner, screwed to the main frame.

To minimize labor, standard outside dimensions of 3.23 by 40.00 meters were defined for the frame of one still unit of two bays. Thus one frame consists of eight prefabricated elements of five meters each. Such elements are assembled and rivetted close to the erection site, using a standard mold as model. The prefabricated elements are placed on the basin's concrete walls and the gutters are rivetted together to form the 40-meter still unit. The structure is then ready to receive the glass cover, which is made airtight with putty.

The general layout of the still is shown in Fig. 1, representing one of the prototype stills at the Experiment Station in Symi.

In previous papers [2,8,9] we reported on an attempt to increase the distillate yield of solar stills by introducing internal condensers. Sea water was used as cooling water in the condensers. Distillate condensed on both the glass covers and the condensers. By this method part of the heat of condensation could be reused. The preheated water, coming from the condensers with a temperature of 50 to 55 deg C at noon, was then introduced and stored in the basin. The cooling and water storing operation was extended during the warm hours of the day only. Consequently, the shallow basin of the early morning became progressively a deep basin in the afternoon and still operation could be extended during the night hours.

The distillate output was considerably increased, but not enough data are available to determine if the additional investment is justified. Nevertheless in the design as described, additional inside condensers can easily be added any time, if further research proves such operation to be profitable.

Field Evaluation of the Glass Still

The prototype stills were tested for more than a year and continue in operation at the Experiment Station in Symi. The field evaluation of these stills permits the following conclusions:

• **Investment cost.** The total cost per unit of evaporating area is estimated to be about ten dollars per square meter or slightly less than one dollar per square foot. The cost of plastic stills is not exactly known, but it is believed to be considerably higher.

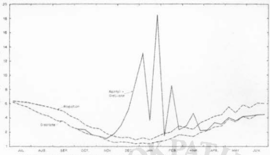

Fig. 2—Radiation, distillate output, and rain catchment as daily average of ten days.

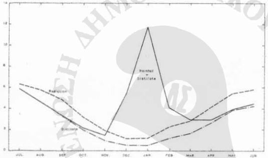

Fig. 3—Radiation, distillate output, and rain catchment as daily average of the months of July, 1965, to June, 1966.

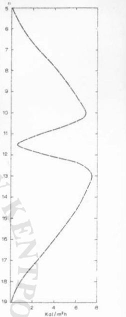

Fig. 4—Radiation record during the nearly complete eclipse of May 20, 1966.

• **Local availability of materials of construction.** All materials of construction, except the butyl rubber sheeting, are manufactured in Greece.

• **Weather-proof construction.** The prototype stills in Symi, as well as other small units, were exposed last winter to strong winds and storms. They withstood all atmospheric conditions without damage. Not one day of operation was lost due to weather.

• **Productivity.** Distillate production in the prototype stills varied from a high of 6.2 kg per square meter a day in July 1965 to about 0.5 kg in December 1965-January 1966. Data collected from July 1965 to June 1966 are summarized in Table I. The obtained data in radiation, distillate collection, and rain catchment as daily average of ten days are shown in Fig. 2 The importance of rain collection to augment the annual average is obvious. In one day, on January 27, about 62.5 kg of rain per square meter were collected, exactly 10 times the maximum average distillate production in a summer period. It was a day of storm and a hard test for the stills. The glass stills were not affected in any way.

To get a clearer picture of the importance of rain collection in a glass still, the daily production is computed as the daily average of the respective month, from July 1965 up to the end of June 1966. As shown in Table 2 and Fig. 3, the distillate production was increased by about 68 percent from 2.62 kg to about 4.40 kg per day and square meter of evaporating area, as the year's average.

• **Scale formation.** To increase absorption of radiation a black body of orlon butting was at first used at the bottom of the basin. Table 1 shows that high figures of productivity were obtained during the first months

TABLE 1–OPERATING DATA OF THE SYMI PROTOTYPE GLASS STILLS

1965-1966	Daily Average Radiation, kcal/m² day	Distillate kg/m² day	Rain, kg/m² day	Total, kg/m² day
Jul 1-10	6370	6.20		6.20
11-20	6298	5.86		5.86
21-31	6200	5.55		5.55
Aug 1-10	5958	5.02		5.02
11-20	5750	4.55		4.55
21-31	5517	4.24		4.24
Sep 1-10	5245	3.68		3.68
11-20	4967	3.53		3.53
21-30	4276	2.80		2.80
Oct 1-10	3843	2.44		2.44
11-20	3084	1.96	0.39	2.35
21-31	2643	1.62		1.62
Nov 1-10	2512	1.41		1.41
11-20	1811	0.92	0.23	1.15
21-30	1470	0.60	1.15	1.75
Dec 1-10	1268	0.65	2.32	2.97
11-20	1336	0.60	4.57	5.17
21-31	966	0.38	7.51	7.89
Jan 1-10	1229	0.47	12.61	13.08
11-20	997	0.42	3.22	3.64
21-31	1394	0.65	17.79	18.44
Feb 1-10	1841	0.80	0.67	1.47
11-20	2073	1.15	7.35	8.50
21-28	2903	1.65	0.70	2.35
Mar 1-10	2705	1.56	0.30	1.86
11-20	2433	1.40	3.24	4.64
21-30	3331	1.98	0.29	2.27
Apr 1-10	3771	2.24	0.05	2.29
11-20	4265	2.76	0.61	3.37
21-30	4452	2.89	0.24	3.13
May 1-10	5597	3.87	0.16	4.03
11-20	4790	3.47	0.13	3.60
21-31	5880	4.21	—	4.21
Jun 1-10	5432	3.91	0.41	4.32
11-20	6078	4.43	—	4.43
21-30	6045	4.46	—	4.46

of operation (July-August 1965). As time progressed, the distillate yield was diminished. After a year of operation the stills were opened for overhaul. Large crystals of calcium sulfate were found on the orlon butting. Its use was consequently abandoned.

A new technique for feeding the stills with sea water was introduced to prevent scale formation. Instead of having a constant overflow inside the still basin and flash the brine by displacement, a movable overflow was adapted outside the stills. The brine is completely evacuated every day in summer and every two or three days in winter time. Fresh sea water is then introduced to the stills up to the desired level. The still performance was considerably ameliorated, as shown by the figures that represent the daily average of eight days immediately before and after the elimination of the black orlon butting, as follows:

	Before	After
Radiation, kcal/m²day	6007	5775
Distillate output, kg/m²day	4.46	4.48

As a matter of interest, we are reproducing on Fig. 4 the radiation record at the Symi Station during the nearly complete sun eclipse of May 20, 1966.

Projected Solar Distillation Plants

The Ministry of Industry has transferred the erection of solar stills, as well as any desalination activity in Greece, to the Hellenic Industrial Development Bank.

The still on the islands of Patmos (Dodecanese) and Kimolos (Cyclades) are the first to be erected. The people of both islands depend almost exclusively on rain for their water supply. Rain is collected either in individual house cisterns, as in Kimolos, or in both house cisterns and large community reservoirs, as in Patmos.

Special provision has been made in the general layout for good accessibility to all parts of the still. Instead of devising large basins with several sheds on top, which would be less expensive in construction, individual basins for each two sheds were adopted, as already mentioned. The paved sidewalks serve also as conveyors of the rain water.

The Kimolos still is composed of 14 distilling units of 30 meters and 12 units 35 meters long. Insufficient width of the available terrain made it necessary to reduce the standard design to respectively either 6 or 7 elements of 5 meters each. The total evaporating area is 2584 square meters and the total rain catchment area 4160 square meters, having a ratio of 1 to 1.6.

Taking into consideration the mentioned average of 4.4 kg per square meter and day, the Kimolos still might produce as an average 11.4 cubic meters per day and provide the 1412 inhabitants of the village with an additional 8 liters per capita per day, approximately.

In the Patmos still 68 units of 40 meters each are gathered in 9 groups. The net evaporating area of each unit is 123.2 square meters, forming a total net evaporating area of about 8380 square meters or about 90,000 square feet. The rain catchment area is 11,800 square meters having a ratio of 1 to 1.4.

TABLE 2–DAILY OUTPUT OF THE SYMI GLASS STILLS

1965-1966	Radiation kcal/² day	Daily Average Distillate kg/m² day	Rain kg/m² day	Total kg/m² day
July	6289	5.87		5.87
August	5742	4.60		4.60
September	4829	3.34		3.34
October	3190	2.01	0.13	2.14
November	1931	0.98	0.46	1.44
December	1190	0.54	4.80	5.34
January	1207	0.51	11.21	11.72
February	2272	1.20	2.91	4.11
March	2823	1.65	1.28	2.93
April	4163	2.63	0.30	2.93
May	5422	3.85	0.10	3.95
June	5852	4.27	0.14	4.41
12 Months	3743	2.62	1.78	4.40

The Patmos still, when in operation in summer 1967, will be the largest solar distillation plant in the world. It will be a valuable experiment for determining and evaluating the economics of large solar stills. After completion, the still will be turned over to the community of Patmos for commercial exploitation. Nevertheless, the Technical University will supervise for some time the operation and collect performance figures and other data that might be of interest for projecting other solar-distillation plants.

In both plants, Kimolos and Patmos, provision is made either for daily flushing of the brine or for continuous feeding from a sea-water reservoir.

Two fresh-water reservoirs to control the daily output will be built in each plant, with a capacity for anticipated fresh-water production of two days in summer, as well as one day's probable rain collection. In cases of heavy rain both reservoirs, connected with an overflow, will be used. From here the fresh water will be pumped to the community's main reservoir distribution.

Using the average of 4.4 liters for the Patmos still, as calculated for Symi, it might be expected that about 37 cubic meters will be produced per day, distillate and rain catchment, as the year's average. This will provide the 2092 inhabitants of Patmos with an additional 18 liters per capita per day.

The existing program calls for the next solar distillation plant to be erected on the island of Nissyros. Erection of stills on several smaller islands of Akri, Agathonisi, Megisti, and on some villages of Crete is being considered.

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Comparative Costs of Distilling Small Amounts of Sea Water with Fuel and with Solar Heat

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IN A REPORT to the Pacific Science Board of the National Academy of Sciences National Research Council in 1961, a preliminary study was made on the feasibility of small, plastic, sea-water stills for drinking water on Rangiroa, an island in the South Pacific near Tahiti. The costs were compared with the costs of distilling water in small fuel-operated stills. The study was financed by a grant from the Rockefeller Foundation. These costs may have changed during the past five years, but the general comparisons are believed to be currently valid.

For distilling a few gallons to a few hundred or a thousand gallons, solar distillation is cheaper than other methods because in these small capacities the capital investment and operating costs are lower. In large fuel-fired stills the heat of condensation of the water can be reused in multiple stills, thus giving greater efficiencies and lower costs. The present studies apply to just a few gallons per day and to the smallest-sized standard equipment that could be easily located on the American market. The capacities, costs, operating data and fuel or electricity consumption are those supplied by the manufacturers of each still. The data are summarized in Table 1.

These costs of distilling sea water on a small scale with fuel or electricity can be compared with the costs of solar distillation as given in Table 2, assuming 500 langleys of solar radiation per day and not counting labor costs for operation.

Small plastic stills of 30 square feet, to be reported later, costing less than 50 cents per square foot for materials of construction have been developed for low-investment family stills. At 30 to 40 percent efficiency and 500 langleys per day they give a cost of 0.8 to 0.6 cent per gallon for a three year (1000 day) life. For capacities larger than 2 or 3 gallons per day several small plastic solar stills are operated separately and the total cost is directly proportional to the number of gallons distilled per day.

In all these estimates of distillation interest charges are not included. If the interest is 5 percent, the capital investment plus interest would be 25 percent greater than the capital costs given here for ten years of operation. The labor cost of operation for both the solar stills and the fuel-fired stills is excluded. Only the cost of fuel or electricity is included in the operating costs.