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THE EXPERIMENTAL WORK ON THE SOLAR STILLS
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In the study of solar stills two large roads of scientific interest meet: the one regarding the possibility of obtaining fresh water for the arid zones and the other regarding the possibility of using the solar energy.

The solar stills are among the most effective and promising ways for the utilization of the sun's energy because they require no energy storage system and the solar energy is utilized as it becomes available and is received by the still. A high percentage of the available solar heat is used in the best designed units.

The solar stills also play an important role when little amounts of fresh water are needed in emergency conditions and other sources of energy are unavailable.

The general principle of operation of the solar stills is well known: the salt water is placed in a room or box tightly closed by a roof transparent to the solar radiation. The solar energy is so trapped and causes the water to evaporate; in a short time the air at the interior of the box becomes saturated and water condenses on the internal face of the transparent roof.

A very great number of modifications of this general scheme have been constructed and tested; in few of these models the condensation takes place in a separate condenser but anyway the most promising units are those related to the most simple scheme.

The solar stills have the great advantage that they do not require any orientation of the collectors and require very little maintenance.

The solar stills, used for the first time in Chile at the end of the last century in the only large-scale plant so far built, received a renewed interest around 1930 but became a subject of systematic studies only during the Second World War in the United States by Doctor Telkes.

Dr. Telkes studied the fundamental elements of the thermodynamics of the process. This gave a scientific basis for her own and for the next developments.

After 1950 the studies on solar stills spread greatly in various countries and this was undoubtedly due also to the publicity given by the Office of Saline Water of the U.S. Department of the Interior to the general problems of the demineralization of saline waters.

The results of many workers have been published through the Annual

Reports and the Research and Development Progress Reports of the Office of Saline Water; such Office has also organized a Symposium in Washington, D.C., U.S.A., in November 1957. The results have been published at the National Academy of Sciences — National Research Council Publication No. 568 in 1958.

The writer became interested in the field in 1953: the experimental work was carried out in the Universities of Bologna and Bari, Italy.

During the spring and summer 1953 three units were assembled; each was a greenhouse model of a solar still built using different construction materials.

The main characteristics of these stills and of those built in the following years are collected in Table 1. Figure 1 shows photographs of the same stills.

The first model (Fig.1, No.1) was an all-plexiglas box, with a tray surface of 0.16 sq.meters, uninsulated, and distilled some hundred ml of water per day. With this unit the first difficulties in assembling the plexiglas plates were encountered and also the drop condensation on the plastic surface of the condensing area was met.

The model No. 2 was glass and wood, appeared heavy and of low efficiency; better results were obtained with the model No. 3 which combined the easy assembly of plexiglas with a glass-wettable condensing surface, mounted in a plexiglas frame.

In the next months, between 1953 and 1954, an investigation was conducted on the fresh-water needs in many sites in Southern Italy and in a few sites abroad and very interesting information was collected. It is the opinion of the writer that a world-wide investigation of the market for solar stills— and, in general, for the equipment using the solar energy— is not still available and should be very useful.

In 1954 a new series of solar stills was built according to a new model (No.4) with iron tray and frame and glass roof. The three units so prepared were very simple to manufacture and assemble and rather efficient but very heavy.

The next No.5 model was developed in 1955 in order to study the possibility of adapting the solar stills on the roofs of houses. Such a unit, with a 10-sq.meter tray, gave a rather low yield of fresh water. This result was caused by an insufficient insulation of the bottom of the water tray and by a re-evaporation of the distilled water in the collecting channel which had an insufficient inclination.

All the above models presented a roof inclination of about 45°. The experience of other workers, and especially of Gomella, has shown that better results are obtained when such inclination is lowered up to 10°.

In 1957 a plexiglas tubular solar still (Model No.6) was tested. It was similar to the other stills tested by Howe and Fitzmaurice and gave very satisfactory results. This solution seems one of the best for simplicity and efficiency.

In 1958 the last model (No.7) of this series was built. It was a vertical structure still designed for temperate zones with a high water yield per surface unit of occupied ground and a very good insulation of the four trays placed one above the other in a glass cage. As in the Model No. 6 all the external surfaces are condensing ones. The original idea of such a model is due to Dr. Wilson from Australia.

The results obtained with this unit were very interesting and showed that it was possible to obtain appreciable amounts of water also in the months in which the inclination of the sun is low, recovering very high percentages of the low intensity solar energy available in such months.

At present, the experimental work is developing in the field of multiple-effect plastic-framed solar stills.

The experimental work in the solar stills is now carried on in at least twenty different laboratories in many countries of the world. The great amount of material and knowledge so far collected suggests few considerations on the present status of the development and on the future of the solar stills.

A review of the present knowledge shows that the present models, although very ingenious, all suffer from the same drawback, due to the source of energy on which they depend: the amount of water produced is little and relevant amounts of water are obtained only with very large, complicated and expensive units.

The amount of distilled water practically varies in the range from 2 to 5 liters/sq.meters per day, in the clear days in the simple-effect stills, up to perhaps 10 to 15 liters/sq.meters per day, in the multiple-effect stills of best design, which must still be developed and thoroughly tested.

At present the best models require at least about 200 sq.meters of tray surface to give one cubic meter of fresh water per day.

The cost of the solar stills (not considering the cost of the ground) per surface unit is still high even in the cheapest models. Such cost is hardly lower than U.S $20 per sq.meter of tray area. The solar stills present, however, the advantage that the operation and maintenance costs are very low and that the only large expense concerns the building of the unit.

The present experience shows that, although the solar stills cannot solve the problem of obtaining fresh water on a large scale, for instance for the needs of a town, they can solve various very important individual problems in arid zones and they remain one of the most interesting, easy and efficient systems for the utilization of the solar energy.

With this picture in mind one may consider the possibility also of a mass production of little solar stills to be installed in deserts or in arid zones in order to give fresh water to one or very few persons in emergency conditions.

Along this line is the very interesting work performed in Algeria by Gomella, who has developed solar still units with the cement tray and with a low inclination glass cover.

The problem of the knowledge of solar stills is surely by no means closed. Many developments of the present models have been reported and presently the work of the various groups proceeds along few common lines:

a) The testing of solar stills of the roof-type model, varying the details of design and the construction materials both for the water tray and the rigid roof; usually in these models the tray contains a thin layer of saline water and the bottom of the tray is insulated.

b) The development and testing of plastic film stills, especially of inflatable type, using newly developed plastic materials (films of Mylar, Teflon, Teslar, etc.) which are rendered wettable with various processes.

c) The development of tilted flat stills, both with rigid glass cover and with plastic glass cover; in such stills the water is absorbed by a black porous evaporator which allows keeping the water layer perpendicular to the solar radiation; the amount of solar heat which reaches the water is thus a maximum.

d) The development of deep basin solar stills proposed by Löf. In such stills a great amount of water (a layer of 30 cm and more) is heated by solar energy within a roof-type solar still placed in the ground; the water heats the surrounding ground until it reaches a rather constant temperature greater than the external one, and begins and continues the distillation, day and night.

Some improvements may be expected by a more extensive testing of multiple-effect solar stills, which so far have been tested only on a limited scale by a few workers. It has been reported that a three-effect unit may give an amount of water twice that of the single-effect unit.

Other arrangements of the collector and the condenser have been suggested but they seem mechanically more complicated.

The knowledge gained in the experiments carried on the past ten years on solar stills permits, in conclusion, considering the maturity of the development and the practical applicability of the most simple models, with the limitations outlined above, namely for giving limited amounts of fresh water, up to 100 or few hundreds liters per day, to isolated groups of persons.

According to the opinion of the writer the solar stills may be best used as structural elements of the buildings in arid zones. I suggest that solar stills of the conventional greenhouse type, with low-inclination glass covers, be placed on the flat roofs of the houses.

The concrete solar stills developed by the writer in 1955 (model No.5) were designed for this purpose and the operation has suggested various improvements.

The saline water in such projected units is pumped or carried in the trays every two or three days and the fresh water flows by gravity in a tank inside the house.

Our present knowledge of construction materials and of stills design is mature enough to suggest that home constructors add such elements in the country houses; the inhabitants will so have a limited but very useful amount of fresh water with a minimum of maintenance and with a relatively low additional cost of building.

Photographs of the seven models of solar stills developed and tested in the Universities of Bologna and Bari, Italy, starting from 1953.

TABLE 1

Characteristics of the seven models of solar stills developed and tested in the Universities of Bologna and Bari, Italy, after 1953

Model No.	Construction material: Water tray	Construction material: Transparent roof	Insulation	Tray surface sq.meters	Maximum water production liters (sq.meters)(day)	Approximate cost of the experimental unit in U.S. dollars per sq. meters.
1 1953	plexiglas	plexiglas	none	0.16	-	-
2 1953	wood	glass	cork	2.5	3	60
3 1953	plexiglas	glass	cork	0.25	4	50
4 1954 3 units	iron plate	glass	compressed cellulose fibers	1.5 and 3	3	50
5 1957	concrete	glass	pumice	10	2.5	50
6 1957	aluminum plate	plexiglas tubular	inner hot air	0.33	4 (a)	40
7 1958	aluminum plate	glass	inner hot air	1.08 (b)	3.5 (c)	40

(a) The data on the amount of distilled water have been correlated with solar energy measurements and an efficiency of about 40% was recorded.

(b) Four trays 0.27 sq.meters each, assembled one above the other within a glass cage.

(c) The data on the amount of distilled water have been correlated with solar energy measurements and an efficiency varying between 25 and 45% was recorded, according to the inclination of the sun.

D I S C U S S I O N

Prof. F. D a n i e l s (Chairman): Thank you Prof. Nebbia. We have five minutes for discussion now and what we don't finish now, we'll carry over until tomorrow morning first thing. Who has any comments or suggestions on either of the two papers? Dr. Khanna, will you come to the microphone please?

Dr. M.L. Khanna: Two friends have given their papers on the solar stills, namely low roof type and multiple-effect stills. I would like to ask Dr. Telkes if, after working for sometime, some salts get deposited on to the fabric or the material they are removed by allowing this water to flow along and, secondly, whether the material is dyed a black colour or if the black colour is especially incorporated into the fabric of the material which holds that water. I would highly appreciate having light thrown on these points, because blackening of the surface of the low roof type still is a problem. At least we haven't been able to find a paint or a treatment of the surface that would give permanent black surfaces. This is a problem which may also be faced by so many other workers in this field of solar water distillation. I would like to have more information on these points.

Dr. M. Telkes: Dr. Khanna has pointed out the most important problem of the solar stills, i.e., to maintain the basin absorbent permanently black. I have already mentioned this requirement for the horizontal solar stills, but now I realize I forgot to mention the most important point in the tilted still. Actually, this is a new material. It is a synthetic fabric which uses carbon black, which is also known as finely divided carbon, which is incorporated into the synthetic material before this is extruded into filaments. These filaments are then permanently black, because the black is not on the surface of the filaments; it is in the material of the filaments. The material is generally a polyester type material and it is available under the name of dacron or orlon. Woven fabrics exist of this material and our experiments in some stills have been carried out with woven material. However, this at the present time is still quite expensive and other material is being developed by the Dupont Company in the U.S. This uses non-woven filaments of the same type, the so-called non-woven fabric, which is sufficiently coherent for this purpose. This fabric has been obtained in small pieces. We have tested it and it is very suitable. It is, however, not available as yet in large sizes (in wide sheets) as would be necessary for the flat tilted stills. Not having this material, although it has been promised to us, we have to use ordinary dyed cotton fabric, which, of course, as it is well known, will bleach under the influence of the sun. However, we expect that rather soon some of the synthetic material will be available, as a felt non-woven fabric, at a cost which is even lower than that of cotton fabric, and so we believe that this problem can be easily solved into the near future.

T. S. Laszlo: Several years ago I worked on the problem of producing a fabric which would withstand very high temperatures. As a solution to this problem, a process was developed consisting of the carbonization of a fabric made of conventional fibers (cotton, rayon, wool, synthetics) by conventional methods of weaving or knitting. Under the conditions of the carbonization used, the organic compounds of the fiber undergo pyrolytic decomposition and the residue becomes very high in carbon content. During this process the fabric loses somewhat in mechanical strength but it maintains its shape and coherence. The carbon content can be as high as 80-90% and, accordingly, the fabric is completely black. Since the black color is not the result of a dye, it will not fade under any condition of use, including continuous exposure to sunshine. It occurred to me that a fabric with a high effective surface area (e.g., terry cloth) could be carbonized until it becomes completely black, but is still strong enough to preserve its shape and structure. Such a cloth could then be used as the evaporator in a solar still. It could be fastened by the same techniques as ordinary fabric and would not fade or otherwise deteriorate even after very long usage.

Mr. E. Golding : I am no expert at all on solar energy, but, listening to these two interesting papers, I was wondering what is the main factor in making these stills less costly. What have you got to aim at, if you are going to reduce the cost? Is it the blackened base, is is the cover, or what? Because one hears that they are too expensive for this purpose or another and I would like to know what you have to aim at in cost reduction.

Dr. M. Telkes: I can answer that very briefly, referring to the flat tilted still for which I remember all the figures. Now, the base of the still is two or three— perhaps even four—millimeters thick in composition and it costs 50 cents a square meter. The insulation, which can be fiber-glass or glass wool or whatever name you call it, is also not more than 50 cents (that's American money) per square meter. So far we have one dollar. Now, this is followed in the best model that we have built by a layer of 1/10mm thick, the so-called weatherable mylar. This, at least in the U.S. is available for $1 per square meter. It can thus be seen that so far we have two dollars. This mylar is essentially a polyester material without fibers of glass in it and it is very very thin. Now, the black evaporator absorber is so much more expensive (probably slightly over $1 per square meter). That makes $3 per square meter. And finally the glass cover is available in the United States for $3 a square meter. I understand in Europe it is somewhat lower. So the material cost, added up, comes to about five to six dollars per square meter. The still has a frame; the frame can be made of wood or composition (reinforced, impregnated) and its over-all extent, i.e., frame serving several square meters — adds barely another dollar to the cost. Then legs and holders and feeders add probably another dollar or two, as does the stand or attachment, and the result is that the total material of the still is probably not more than $10 per square meter. Add the labor, which must be very low, because after all is just a matter of putting a few layers together into a frame, and add the other necessary costs and the probable ultimate cost is not more than $20 per square meter. Obviously, this is still a little too high, because one square meter will produce on the average, for the tilted stills, five, six, seven or possibly eight liters per day in the arid tropical countries. So, therefore, the yield one liter per day would cost about $4 and this, according to some estimates, is already on the border of being economically satisfactory. Naturally a simplification would be to make all the base, absorber, reinforcement, and frame in one piece, by some sort of molding technique, which could be put in mass production. This would be the only solution of the problem and this is the direction in which future developments should be aimed.