EARLY WORK ON SOLAR DISTILLATION IN ITALY, 1953-1970

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ABSTRACT

The present paper describes the early experiments carried in the University of Bari, Italy, on solar distillation of sea and saline waters and on solar and unconventional sources of energy and water, in the years 1953-1970.
The work on solar desalination has been carried having in mind the production of drinking water for the arid and poor areas, and the solar stills have been designed to be built with simple and local materials in such areas. The paper describes the problems encountered with material corrosion, maintenance of the stills, cleaning of the trays, improving the taste and palatability of the distilled water, and disposal of residual salts. Other solar work has been carried on the use of biomass as a source of energy, expecially on the use of ethanol as a fuel.

1. FRESH WATER FROM SALINE WATER WITH SOLAR ENERGY.

In the University of Bari --- where the author has taught Natural Resources in the Faculty of Economics from 1952 to 1995 --- a research program has been carried for the study of solar distillation and of solar energy.

In the years from 1953 to 1970 ten different models of solar stills have been built, in about 105 units, using different designs and materials. The operation of solar stills has been tested in Bologna, in Bari and in the Mediterranean islands Tremiti and Pantelleria (latitude 45 to 35°N). The results have been presented at various international conferences, are described in many papers (a detailed list is contained in <www.gses.it/bib-nebbia>) and in two books (1)(2).

Most of the experimental work has been carried in Bari (latitude 41°N), an harbor in South-Eastern Italy, with clear skies for many months of the year and an intensity of solar radiation that in the summer days reaches 24 MJ/(m^2)(day), with an average of 4.000 MJ/(m^2)(year)

The research and development program carried in the years 1953-1970 was devoted at the following main fields:
--- solar distillation,
--- condensation of fresh water from the atmosphere,
--- use of volcanic steam as a source of fresh water,
--- history of solar desalination and solar energy.
Other researches dealt with the economics of solar collectors and of sea water desalination, the physical properties of seawater and salt solutions, the membrane properties and their use in desalination.

The work on solar distillation was stimulated by the papers appeared in the early 50's of the past century in the literature (3)(4)(5), and was devoted at the building and testing of solar stills in order to identify the construction materials, design and systems for the control of scale and corrosion, best suited for the manufacture of simpe and durable solar stills, to provide fresh water to isolated houses and small villages in the arid areas, in particular in arid islands of Southern Italy, along the seashore or in locations in which the only water source is underground brackish water.

The first solar still was built in 1953; it was a small still, 0,18 m^2 tray area, with a plexiglas tray and plexiglas cover; in this model is was experienced the inconvenience of the drop condensation of distillad water on the inner surface of the plastic cover, a fact that suggested of preferring glass plates for the cover of the stills. Another model, presented at the Trade Fair of Bari, in september 1953, had a plexiglas tray, 0,25 m^2, and glass cover.
The next solar still had a wood tray, 2 m^2, and a glass cover, with cork insulation at the bottom of the tray; the operation experienced water losses because of bad insulation and the results helped to build a better model.

In 1954 three solar stills were built and tested; they had iron plate trays, 1,5 and 3 m^2 area, and glass covers, all with cork insulation of the tray bottom. A water production of 3 liters/(m^2)(day) was obtained in the summer months.

In 1955 a solar stills having a 10 m^2 concrete tray and glass cover in an iron frame, was built on the roof of a University building. The tray was placed on perforated bricks that offered some sort of thermal insulation. The test gave indications on how a still can be integrated in a building, expecially in the southern areas where buildings have flat roofs. The glass cover may be utilized as a collector of rain water, so increasing the yearly water production of the roof unit (6).

The interest for solar desalination was increasing in the world as a consequence of the spreading of the results of the 1954 Phoenix and Tucson conferences on solar energy organized by the Association for Applied Solar Energy (later Solar Energy Society, and now International Solar Energy Society), and of the creation, within the U.S. Department of the Interior, of a special Saline Water Conversion Program. The Research and Development Progress Reports No. 4, authored by G.O.G. Löf (5), and No. 13, authored by Maria Telkes (7), were dedicated at the solar desalination, with extensive reviews of the previous work.

Always within the Bari research work, in 1957 a plexiglas tubular still was built. The tray, (0,33 m^2), was made of anodized aluminum suspended in the middle of a romboidal tube of plexiglas. The upper surface transmitted the solar energy and the bottom acted as condensing surface. So suspended between air warmed by solar energy and bottom air cooled by surrounding external air, the tray did not require any insulation (8). This was a stationary extension of the floating still devised by Telkes for rafts (3).

In 1958 a vertical solar still was designed and built for operation in temperate zones. This still had a vertical structure with four trays, placed one above the other, in a glass greenhouse; the total area of the trays was 1 m^2 and the ground area occupied by the still was 0,3 m^2. The trays did not need thermal insulation being surrounded by still air. During the test it was possible to obtain appreciable amounts of distilled water also in the months in which the elevation of the Sun was low. The results were presented in 1958 at the Teheran Conference on arid zones (9).

A review of the above work was presented at the United Nations Conference on New Sources of Energy held in Rome in 1961 (10) and in the following Conference on solar and aeolian energies held in Sounion (Greece), in the same summer (11).

In 1962 a new model of solar still was designed and tested; this was a stepped inclined still, in which the trays were obtained dividing the sheet of blackened anodized aluminum by baffles to retain the saline water; the glass cover had an inclination of about 20° and the bottom of the sheet contaning the saline water was insulated with 5 cm of expanded polystyrene plastics. The tray area of the tested units varied between 1,5 and 3 m^2. The model was very simple and efficient and high water production per unit area was obtained. The saline water was charged in the night, in the first upper tray and trickled down in the lower trays until they were all filled. The excess saline water was discharged from the lower tray, through the same tube used to discharge the distilled fresh water during the day. The glass cover could be easily removed for the cleaning of the trays (1)(2).
Many dozens of these stills were built and tested in arid islands such as Pantelleria (in the Mediterranean Sea, midway between Sicily and Tunisia), and Tremiti (Apulia), and in other coastal locations.

In 1964 another unit of a vertical solar stills, placed in a greenhouse, was built with five water trays of anodized aluminum, one above the other, each having 2 m^2 area, with a total tray area of 10 m^2. The area of the transmitting and condensing glass walls was 12 m^2. The distilled water condensed on the vertical glass panes and was collected at the bottom of the greenhouse. A water production of 20 liters/day was observed during the summer months.

2. EXPERIMENTAL RESULTS

The results of the twenty years of experimental work on solar stills in Bari may be summarized as follows (12).

---- The solar stills that gave the most satisfactory results were of the tilted tray design; they gave the highest yields of fresh water per unit area and per unit solar radiation intensity, and were of the easiest maintenance; solar stills with a vertical disposition of salt water trays have given also rather good results, since they utilize the solar radiation in areas and seasons in which the Sun has a low inclination.

---- In the best stills the water production in the summer days, with a solar radiation intensity of 20 MJ/(m^2)(day), reached 4-5 liters/(m^2)(day), with an annual average of about 700-1.000 liters/m^2, according the design.

---- The distillation of water begins when the intensity of the solar radiation exceeds the value of the thermal capacity of the still; such value was about 3 to 4 MJ/m^2, in all the various models of tested stills; the distillation continues for some time after sunset, until exists a difference of temperature between the saline water and the external air.

---- In order to avoid corrosion, the tray containing the saline water should be made of metals (anodized black aluminum revealed itself satisfactory), or plastics. The wood revealed itself not satisfactory since it requires treatments to avoid rotting.

---- The high absorption of solar radiation by part of the saline water requires a black collecting body; a blackening of the tray is best obtained by surface anodic treatment of the tray metal; the blackening with paints causes the release of bad odors to the distilled water and should be avoided; to increase the "blackening" of the saline water body, such water may be added with special green organic dyes, a solution sometimes adopted in solar salt pans to increase the solar radiation absoprtion.

---- The basin of the still should be watertight and the entire still should be airtight, except for the saline water inlets and the distilled water outlets.

---- The fresh water, condensed on the inner surface of the transparent cover, should be collected in a trough in the lower part of the still; the troughs should be inclined, about 1 %, to assure the flow of fresh water to distilled water outlets and external collectors.

---- The taste of distilled water may be bad and, for drinking purpose, the distilled water should be filtered through a small layer of marble or limestone pieces (that release some calcium salts to the water) and of active carbon powder to eliminate organic taste and odors.

---- The bottom of the trays contaning the saline water should be insulated to avoid thermal losses since the saline water, heated by the Sun, may reach temperatures as high as 70°-80°C; cork insulation resulted not satisfactory; better results have been obtained with layers of expanded plastics, a material that is generally available almost anywhere.

---- For small stills an expanded plastics box, such as those used for fish, food and goods packaging and transportation, may be adapted as a solar stills, with a glass or plastic cover and a small inclination; the box itself is the container of the saline water; care should be taken to create a trough for the collection of distilled water; a fresh water production of about 1 liter/day may be obtained with a box having an area of about 0,3-0,5 m^2.

---- The transparent cover (glass or plastics) assures the inlet of solar radiation within the stills, its internal surface acts as condenser for the distilled water; it should be inclined of about 20° and should be airtight; silicone sealants revealed themselves satisfactory; the cover should however be easily removable for periodical tray cleanings.

---- Saline water should be charged in the still tray, if horizontal, or in the upper tray in a stepped inclined still; saline water should flow into the still from a container at a level higher than that of the still; in general saline water should be elevated to such container by hand or with pumps.

---- During evaporation the salt concentration of the saline water increases; when the salt concentration is twice the original value, begins the deposition of whitish salts (mainly calcium sulphate and carbonate) in the trays and this causes a decrease of the solar radiation absorption by the saline water; new saline water should therefore be charged in the trays before the evaporation of half of the original water content.

---- The draining of brine from the trays and the recharge of saline water is a delicate optimization problem of design; in fact an higher water yield is obtained when the saline water content of the trays is small and the water level is low; in the same time, the water evaporation leaves a brine that must be diluted before salt deposition takes place in the trays.
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---- The success of the solar stills depends on a good maintenance, care in the charging of saline water and draining of the brine before appreciable salt deposition; this sometimes is difficult by part of the populations that most need fresh water; in the same time the design and the choose of materials should be done giving priority to the materials and structure available where live populations that most need fresh water.

3. OTHER SOLAR WORK

Always in the field of solar energy, an analysis has been carried on the competition between high temperature and low temperature collection system; the Sun's energy collected at higher temperatures has, obviously, an higher exergy value but requires concentration systems that are more technically complicated, more costly and utilize only the direct radiation; the low temperature systems offer energy with a lower exergy value but utilize both the direct and diffuse radiation, i.e. a larger fraction of the total solar energy, and are more simple, require less maintenance and are less costly.
The thermoeconomic analysis indicates that the most economic solar collection requires devices without concentration, with which it is possible to obtain heat at 80-100 °C (13).

After the year 1970 the work on solar energy in the University of Bari has been devoted at theproblems related at the use of ethanol, obtained from "solar" biomass products and byproducts, as a substitute of gasoline (14).

4. OTHER RESEARCHES ON UNCONVENTIONAL WATER SUPPLY

Although not directly related at the solar energy, other researches have been carried in the University of Bari on the production of fresh water for arid zones.(15)
In 1960 a series of experiments was made to obtain fresh water from air humidity condensation obtained with a mechanical dehumifier operated with eletric power; the amount of condensed water was measured in relation at the energy consumption in various humidity conditions.

The experiments indicated that it is possible to obtain 2 liters/day of condensed water using a 100 watt dehumifier and that the electricity consumpion may be as low as 3 MJ(el) per liter of condensed water when the air humidity is high. One mechanical dehumifier has been tested in Pantelleria where high air humidity values are generally recorded (16)(17).

Furthermore, in 1962, during the survey of the water needs of the island of Pantelleria and of the availability of geothermal energy to be used as a heat source for desalination processes, volcanic steam (called fumarole, vulcarole, favare) was located in an internal valley of the Montagna Grande; to condense the steam a net of air cooled cement pipes was built with a final receiver of the fresh water (18)(19).

The condensation of just a part of the available steam gave, continously, all the year round, 1 m^3/day of fresh water. It was estimated that the condensation of all the available steam might give between 3.000 and 5.000 m^3 of fresh water per year, an amount enough to supply drinking water to a fraction of the inhabitants and tourists. Volcanic steam is available in other Italian islands and volcanic areas which lack of fresh water, and may be considered as a source of drinking water after condensation with relatively simple devices.

At integration of the experimental work, various papers have been published on the history of solar energy and of sea water desalination (20)(21).

In a short paper (22) the author has suggested a method to recover fresh water exploiting the high pressure of the sea water at dephts greater than 300 m, where the pressures are greater than the osmotic pressure of sea water, 25 bar (2,5 megapascal) (2). Immersing a pipe, with the lower extremity closed by a semipermeable membrane, or by a bundle of semipermeable hollow fibers, at such depths, fresh water flows inside the pipe and may be pumped to the sea surface, with an energy cost little greater than the minimum theoretical energy requirement for the separation of fresh water from an infinite amount of sea water (2,5 MJ/m^3). As a matter of fact the high saline concentration of sea water has been generated by the Sun !

After the 70's of the past century the author's interests have mainlybeen dedicated at the environment and natural resources and his activities in solar energy have been limited at teaching and lecturing, to stress the importance of renewable energies --- direct use of solar energy, and derived energies such as wind and wave power, solar ponds, vegetal biomass, hydro power --- expecially at the service of human development.

5. A SOLAR ARCHIVE

When the author retired (as an emeritus professor) from his teaching in the University of Bari in 1995, all his private archive, that includes papers, manuscripts, research notebooks, photographs, books, and designs, has been donated at the Fondazione Luigi Micheletti --- Library and Archive for the Study of Technics, Industry and Contemporary Society, Via Cairoli 9, 25122 Brescia, Italy --- as a "Giorgio and Gabriella Nebbia" fund.

The solar section extends for about 25 meters and contains, among others, the Proceedings of the Tucson and Phoenix Conferences of 1954, the Proceedings of the Rome Conference on New Sources of Energy (1961) and of the Sounion Conference on solar and eolian energy (1961), a large collection of early solar energy journals (Solar Energy from the first issue, Sun at Work, Comples Bulletin, Rassegna Italiana di Eliotecnica, and others), covering mainly the years 1950-1980's. It contains also about 700 Research and Development Progress Reports of the Saline Water Conversion program of the U.S. Department of the Interior, published from 1954 to 1979.

Furthermore in the author's archive are collected copies of articles and reports of early pioneers of solar energy such as the Italians Giovan Battista Della Porta (1535-1615), Antonio Pacinotti (1841-1912) and Giacomo Ciamician (1857-1922), and correspondence with, and papers of, Farrington Daniels (1889-1972), Harry Tabor, Maria Telkes (1900-1995), Marcel Perrot, Vittorio Storelli, the Somor Company of Lecco (Italy), Giovanni Francia (1911-1980), Gino Bozza (1899-1967), John Yellott (1908-1986), Everett D. Howe (1903-1989), Valentine Baum, Anthony Delyannis, Carl Hodges, and many others.

The archive includes also documents on the early history of AFASE, Association for Applied Solar Energy, then Solar Energy Society (now ISES), in which the author served as a member of the board of Directors from 1967 to 1970; and on the history of the Cooperation Méditerranéenne pour l'Energie Solaire (Comples), that the author cofounded with Marcel Perrot and three others in 1961.

An inventory of the archive section on solar energy and the photographs of historical interest, will be published shortly in the Internet site: <www.fondazionemicheletti.it>. The whole archive, that contains many documents rare and not generally available, is being opened to the public at the end of 2005.

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