First International Symposium on Water Desalination

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THE WORK ON DESALINATION IN THE UNIVERSITY OF BARI

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ITALY

In 1953 in the Istituto di Merceologia, Università di Bari, Bari, Italy, a research and development program has been undertaken in the following main fields:

(a) solar distillation;
(b) condensation of fresh water from the atmosphere;
(c) use of volcanic steam as a source of fresh water;
(d) economics of sea water desalination;
(e) physical properties of sea water and salt solutions;
(f) membrane properties and use in desalination.

In the present report a review of the experimental and research activities and results is presented.

Solar distillation

The work on solar distillation has been carried with the purpose of building and testing solar stills in order to identify the construction materials, the design and the systems for the control of scale and corrosion to be preferred for the manufacture of cheap, simple and durable solar still to provide fresh water to isolated houses and small villages in arid areas and, in particular, in arid islands of Southern Italy.

In 1953 the first solar stills have been built.

Model No. 1 was a little still, 0.18 sq.m. (2 sq.ft.) tray area, with a plexiglas tray and plexiglas cover. The low water production was due in part to the drop condensation of the water vapor on the plastic inner surface.

Model No. 2 had a wood tray, 2 sq.m. (22 sq.ft.) area, and glass cover, with cork insulation; the unit presented low efficiency and water and vapor losses.

Better results were obtained with the Model No. 3, having plexiglas tray, 0.25 sq.m. (2.7 sq.ft.) area, and glass cover (1)(2)(3).

In 1954 three solar stills have been built and tested according a new Model No. 4; they had an iron plate tray, 1.5 and 3 sq.m. (16 and 32 sq.ft.) area, and glass covers. A water production of 3 liters/(sq.m.)(day) [0.07 gallons/(sq.ft.)(day)] has been obtained in the summer months (2)(4).

In 1955 solar still Model No. 5, having a 10 sq.m. (110 sq.ft.) concrete tray and glass cover, was built on the roof of a building. The experience obtained with this unit has led to recommend the use of solar stills placed on the flat roof of the houses, as a construction element of the buildings(5)(6).

In 1957 a plexiglas tubular solar still, Model No. 6, 0.33 sq.m. (3.5 sq.ft.) of tray area, has been tested and a production of 4 liters/(sq.m.)(day) [0.1 gallons/(sq.ft.)(day)] has been recorded (7)(8).

In 1958 a vertical solar still, Model No. 7, has been built and tested. This still has a vertical structure, designed for operation in temperate zones, with four trays, placed one above the other, in a glass cage. The total area of the trays was 1 sq.m. (11 sq.ft.); the ground area occupied by the still was 0.3 sq.m. (3.5 sq.ft.). During this test it was possible to obtain appreciable amounts of water also in the months in which the inclination of the sun is low (9)(10).

A review of the above work has been presented at the United Nations Conference on New Sources of Energy, held in Rome in 1961 (11)(12).

In 1962 researches have been carried with various units of Model No. 8 solar still; this was an inclined tray still, with horizontal baffles to keep the saline water, and glass cover. The tray area was 1.5 sq.m. (16 sq.ft.). The model was very simple and efficient and high water productions per unit area have been recorded (13)(14)(15).

In 1964 another unit, assembled according the vertical solar still Model No. 7, has been built. This unit has five trays, each having a 2 sq.m. (21 sq.ft.) area, with a total tray area of 10 sq.m. (110 sq.ft.). The area of the transmitting and condensing glass walls is 12 sq.m. (130 sq.ft.). A water production of 20 liters/day (5 gallons/day) has been observed during the summer.

The cost of the various stills did never result less than 20,000 It.Lire/sq.m. (3 U.S.dollars/sq.ft.) and this high investment cost is one of the disadvantages of the solar stills at the present stage of development.

In order to test the practical possibilities of application of solar stills in arid areas, ten solar stills have been distributed in arid islands of Southern Italy (Isole Tremiti and Pantelleria island). In Pantelleria inclined tray, Model No. 8 solar stills have been provided to the homes of fishermen near the sea, placed on the roofs, and to the Hospital. It has been observed that people, after some time, did not care to recharge and clean the stills, although this did not cause but little trouble, and in some cases the stills have been abandoned.

This suggests that more simple models must be devised and care must be paid to the simplicity of maintenance.

The present status of development and the perspectives of the solar stills in relation to the fresh water supply in arid countries has been dealt with in a recent italian book on the solar energy (16) and in another italian book on the water problem and saline water desalination (17).

Condensation of fresh water from the atmosphere.

Although not directly related to saline water conversion, in the present and in the following paragraph the results of work on dew condensation and volcanic steam condensation as sources of fresh water are reported.

Dew is a potential source of fresh water in arid countries, although no practical and large scale system has so far been devised for recovering such water. In 1960 a series of experiments has been made using a mechanical dehumidifier, operated with electric power, in order to measure the amount of condensed water vs. energy consumption, in various humidity conditions.

The experiments have shown that it is possible to obtain 2 liters/day (0.55 gallons/day) of condensed water using a 100 watt unit and that the energy consumption may be 800 kcal(electr.)/liter [0.25 kWh(electr.)/gallon] of condensed water, when the air humidity is high (18)(19)(20).

One mechanical dehumidifier has been under test in Pantelleria, an island where high humidities are generally recorded.

Use of volcanic steam as a source of fresh water

In 1962, during a survey of the water needs of the island of Pantelleria and of the availability of geothermal energy to be used as energy source for desalination processes, volcanic steam has been located in a valley of the island and a device has been built to condense such steam.

The condensation of just a part of the available steam gives 1 cu.m./day (265 gallons/day) of fresh water; it is expected that the condensation of all the available steam might give between 3,000 and 5,000 cu.m./year (0.8 and 2 million gallons/year) of fresh water, an amount sufficient to supply the water needs of at least a part of the 10,000 inhabitants of the island. The fresh water supply is now being carried from Sicily with tank ships at a cost of more than 10,000 It.Lire/cu.m. (60 U.S.dollars/1,000 gallons).

Volcanic steam is available in other Italian islands, lacking of fresh water, and may be considered as a source of fresh water, after condensation with relatively simple devices.

Economics of saline water desalination

A survey of the water needs of little islands and arid areas of Southern Italy, lacking of fresh water, has been made since 1953-1954; this investigation has indicated that sea water desalination, possibly also through solar distillation, is a convenient system to relief the hard living conditions of the inhabitants (2)(4).

The role and increasing importance of sea water desalination for Italy has been stressed in various publications (17)(21)(22)(22a).

However until recent years the interest for desalination in Italy has been limited. Such interest is now growing after the recent success of many plants in various countries and after the significant decrease of the cost of desalinated water.

In 1963 an economic study was undertaken on the different desalination processes in relation to the possibilities of obtaining fresh water on a large regional scale in the arid southern parts of Italy.

In 1964 in Milano the Federazione delle Associazioni Scientifiche e Tecniche (FAST) has organized a conference on the present status of desalination research and development in different countries (23)(24). During such conference the status of saline water desalination activities in Italy has been reviewed by the Author (25)(26).

During the years 1964 and 1965 various conferences have been held in Italy in order to evaluate where - and at which extent - desalination may contribute to the development of arid regions of Italy. Reports have been presented at such conferences in Brindisi (27), Cagliari (28), Palermo (29), Rome (30).

A general analysis of the desalination processes, their economics and their effect on the development of arid areas has been the subject of a recent book (17).

Presently an investigation is being carried on the cost and prices of fresh water obtained from conventional sources in the various parts of Italy, in order to evaluate in which areas the water obtained from the sea may be competitive with the water from conventional sources.

The investigations have shown that the desalination may have an important role not only in the areas in which presently water is carried by tank ships, with costs greater than 1,000 It.Lire/cu.m. (6 U.S.dollars/1,000 gallons), but also that many continental areas are facing an increasing scarcity of fresh water and that in such areas desalination, eventually using dual-purpose nuclear plants, may give a definite contribution to maintain and develop the present industrial and life level.

In fact in some continental region, such as Puglia, with 3,000,000 inhabitants, the fresh water for domestic and industrial uses is presently paid 90 It.Lire/cu.m. (0.55 U.S.dollars/1,000 gallons), because it is carried with aqueducts from 200 miles, through the mountains; such water is now insufficient for the present and near future needs and the region must face a choice between new and expensive aqueducts or desalination plants.

Physical properties of sea water and salt solutions

In order to have better informations on the thermodynamic properties of sea water and saline solutions for the study of the economics of desalination processes, a critical analysis has been made of the available data, and a new series of figures has been calculated for (a) densities, (b) vapor pressures, (c) osmotic pressures, and (d) boiling point elevations of standard average sea water (3.52 % total dissolved salts) and concentrated sea water, at temperatures between 0° and 100°C.

Table I (17)(31) contains the properties of sea water which best fit the experimental values reported in the literature (32).

On the basis of such figures the theoretical minimum work for obtaining pure water from an infinitely large amount of sea water has been calculated and values of 0.55 - 0.58 kcal/kg. (0.64 - 0.68 kWh/cu.m., or 2.4 - 2.55 kWh/1,000 gallons) have been obtained; such figures are somewhat less than those generally reported in the literature (33).

The optical dispersion properties of sea water and saline solutions are now being studied; a new device has been developed to measure the refractive index in the visible and ultraviolet (220 - 800 nm)(34). Presently dispersion curves of NaCl solutions are under investigation .

Membrane properties and use in desalination

New researches are presently being carried in the field of membrane desalination. The objectives are (a) to develop and test membranes which are permeable to water vapor, but not to liquid water and salts, and which might be used in improved solar stills, and (b) to develop new membranes for reverse osmosis.

In order to find membranes suitable for a liquid permeation membrane still a survey of plastic and cellulosic commercial films is under way; for each film the transport properties of water vapor, liquid vapor and salts are tested at various temperatures. For each film the infrared spectra are also being measured.

A still has been developed and is now under test; in such still one compartment contains the warm saline water, separated by a membrane from the air chamber in which diffusion and condensation of the water vapor takes place.

Using a commercial coated-cellophane membrane, 35 μm. thick, and operating with saline water (3.5 % dissolved salts) at 60°C and with a condensing surface at 25°C, a water vapor flux of 250 - 280 gr/(sq.m.)(hour) [0.0065 gallons/(sq.ft.)(hour)] has been observed; the condensed water

Table I

Properties of average sea water (3.52 % total dissolved solids), recalculated from the data available in the literature.

Temperature, °C	Density, gr/ml	Partial molal volume, $\frac{\text{litres}}{\text{mole}}$ (*)	Water vapor pressure, po mm.Hg.	Sea water vapor pressure, p mm.Hg. (*)	$\log_{10} \frac{p}{p_o}$ (*)	Osmotic pressure, atm. (*)	Boiling point elevation °C (*)
0	1.0276	0.0180	4.579	4.50	- 0.0076	22.0	0.28
5	1.0273	0.0180	6.543	6.43	- 0.0075	22.1	0.28
10	1.0267	0.0180	9.209	9.05	- 0.0074	22.3	0.29
15	1.0259	0.0180	12.788	12.57	- 0.0074	22.4	0.30
20	1.0249	0.0181	17.535	17.24	- 0.0073	22.5	0.30
25	1.0238	0.0181	23.756	23.36	- 0.0072	22.6	0.31
30	1.0223	0.0181	31.824	31.30	- 0.0071	22.7	0.31
35	1.0205	0.0181	42.175	41.48	- 0.0071	22.8	0.32
40	1.0185	0.0181	55.324	54.4	- 0.0070	22.9	0.33
45	1.0163	0.0182	71.88	70.7	- 0.0069	23.0	0.33
50	1.0141	0.0182	92.51	91.0	- 0.0069	23.1	0.34
55	1.0117	0.0182	118.04	116.2	- 0.0068	23.2	0.34
60	1.0091	0.0183	149.38	147.1	- 0.0068	23.3	0.35
65	1.0065	0.0183	187.54	184.7	- 0.0067	23.4	0.35
70	1.0036	0.0184	233.7	230.2	- 0.0066	23.5	0.35
75	1.0006	0.0184	289.1	284.4	- 0.0066	23.6	0.36
80	0.9975	0.0185	355.1	349.9	- 0.0065	23.6	0.36
85	0.9945	0.0185	433.6	427.3	- 0.0064	23.7	0.37
90	0.9913	0.0186	525.76	518.2	- 0.0063	23.7	0.37
95	0.9881	0.0186	633.9	624.8	- 0.0062	23.8	0.37
100	0.9849	0.0187	760.00	749.5	- 0.0061	23.8	0.38

Freezing temperature: - 1.90°C.

(*) The figures are interpolated from the series of data which best fit the experimental values reported in the literature (32).

contained less than 300 p.p.m. of dissolved salts, independently of the position of the distiller, during a test run of more than 100 hours; the permeability of the film decreased after this period.

The still seems suitable for development as a portable solar still.

In the project for the study of membranes for reverse osmosis, new membranes are being prepared using amylose as a starting material; amylose triacetate membranes have been prepared and their transport properties are under investigation.

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SWD /120 (Abstract)

THE WORK ON DESALINATION IN THE UNIVERSITY OF BARI

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A research program on desalination started in the University of Bari in 1953.

Investigations have been carried on the development of solar stills, using and comparing different design and materials and testing the efficiency of eight different models of solar stills. The purpose of the program has been the development of simple and durable solar stills to be used in arid areas, and, in particular, in arid islands of Southern Italy.

Investigations have also been carried on the condensation of water vapor from the air and of water vapor from volcanic steam in Pantelleria.

An economic analysis is being developed on the possibilities of sea water desalination in Southern Italy and on the position of large scale desalination in relation to conventional water supply systems.

Physical properties of sea water and salt solutions are being reinvestigated and vapor pressures, osmotic pressures and boiling point elevations have been recalculated and are presented in a Table. Dispersion of sea water and salt solutions in the visible and ultraviolet are being measured with a specially designed device.

A research is also being carried on the investigation of membranes properties and their use in desalination. Membranes are studied in connection with the development of an improved solar still in which water vapor is permeated from warm saline solutions though membranes. New membranes, to be investigated as possible materials for reverse osmosis, are being prepared using amylose as a starting material.

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