100b

A Publication of
N.A.T.O. Institute of Advanced Studies in Solar and Aeolian Energy
Athens, Greece

SOLAR AND AEOLIAN ENERGY

PROCEEDINGS
of the
International Seminar on Solar and Aeolian Energy
Held at Sounion, Greece
September 4-15, 1961

Foreword by
Admiral A.G. SPANIDES

President of the Greek Atomic Energy Commission
Director of the Advanced Studies Institute in Solar and Aeolian Energy

Edited by
Admiral A.G. SPANIDES

and Rapporteur of the Seminar
ATHAN. D. HATZIKAKIDIS

Head of the Solar Energy Department of the Greek Atomic Energy Commission
General Secretary of the Hellenic Scientific Society of Solar and Aeolian Energy

Distributed by

PLENUM PRESS
NEW YORK

THE PROBLEM OF OBTAINING WATER FROM THE AIR

G. NEBBIA
Istituto di Merceologia
Università di Bari
Italy

A great number of studies have been reported on the demineralization of saline water, which is often available even in the arid zones.

The main processes for the demineralization of saline water are the following (1):

(a) Distillation. The energy consumption varies from 600 to about 50 kcal/kg of fresh water for the various processes (simple or multiple-effect, thermocompression, flash distillation, and so on); for distillation the sun energy may be used, generally in simple effect units (utilizing for the distillation a maximum of about 50% of the available energy); conventional fuels are, however, generally the source of energy for the distillation plants. The efficiency of the distillation plants becomes greater with an increase in the size of the plant; namely, when the fresh water is produced in amounts larger than many cubic meters per day; the solar stills now produce fresh water in amounts less than one cubic meter per day.

(b) Freezing. The energy consumption to obtain 1 kg of ice low in salts from salt water is about 80 kfrigories. Since it is possible to operate well designed compression refrigerators working with a "figure of merit" of 5 to 1, in that it is possible to obtain 5 kcal of heat shifted by the engine per 1 kcal of mechanical energy, the total energy consumption may become as low as 16 kcal/kg of water partially demineralized, which seems very attractive. At the present, however, systems are lacking to separate the ice from the surrounding concentrated salt water in a simple and efficient way and the process cannot be considered really feasible on a large scale.

(c) Electrodialysis. The energy consumption depends on the amount of dissolved salts in the treated water and on the amount of salts allowed in the demineralized water, on the characteristics of the plant and of the membranes, and on the water output. The data obtained with the existing plants show an energy consumption of about 5 kcal of electrical energy per kg of water demineralized from 5000 to 500 ppm, and for a water output of 10-60 cubic meters per day.

The above listed processes differ both for the amount of energy and for the type of energy used in the demineralization process.

In the distillation plant thermal energy is used; in the freezing process mechanical energy is used (or thermal energy if an absorption cycle is used); in the electrodialysis electrical energy is necessary, produced by either mechanical or thermal energy.

In all the processes salt water is necessary and severe scale and corrosion problems are encountered.

In the present report a solution is suggested to the problem of obtaining fresh water from a practically endless source of water— that of the atmosphere, in which water is present as a gas in varying amounts, ranging at saturation point for temperatures between 15°C and 40°C from between 11 and 50 gr/kg of dry air, or from between 12 and 55 gr/cubic meters of air.

The water in the air covering one sq. meter of ground may reach the value of hundreds of kgs. and is many times the amount of water reaching the same surface as rain during one year.

The presence of water in the atmosphere accounts for dew, which appears when a lowering of the temperature takes place with resulting decrease of the solubility of the water vapor in the air. The dew is observed in many arid zones where strong variations of temperature are observed from the day to the night (2).

The extraction of fresh water from the atmosphere may be made following two different processes:

(a) by cooling the air— lowering its temperature below the dew point;

(b) by absorption of the water on a solid absorbent or over a hygroscopic solution and subsequent heating of these substances in order to evaporate the water.

The water separated in this way from the air is saltless and during the separation no scale and corrosion is observed as we have in the demineralization of saline water.

Very little experimental work has been done thus far in this field (3); this prompted us in Bari to begin in 1959 a study on this problem and I present here the first results.

The process of extraction of the water from the air by absorption on solid absorbents or in hygroscopic solutions presents undoubtedly a great interest. It consists in bringing the moist air in contact with solid bodies (for instance silica gel) or hygroscopic solutions (glycol or water solutions of lithium bromide or chloride, etc.) which absorb the moisture.

The absorbent, saturated by water, is regenerated by heating; the absorbed water is carried away by a stream of air and is discharged in the surrounding atmosphere (4), (5).

It appears that the energy consumption is given, at the limit, by the heat necessary to evaporate the water from the absorbent—which is, practically, by the latent heat of vaporization of water, and the process is therefore similar to the distillation. The solar energy may be used as a source of energy.

Many plants have been commercially built which use liquid absorbents and also solid absorbents to absorb moisture from the air, but the purpose is not to obtain the water but to decrease the moisture in the rooms for comfort and in the warehouses for storage. With some modifications these plants may be used also for recovering water from the atmosphere if water is condensed during the regeneration of the absorbent.

Although the process may be of interest, especially in connection with solar energy heating, nevertheless it is mechanically complicated and the work here described has been done by using a mechanical refrigerating machine for obtaining water from the atmosphere.

The essential elements of the unit are shown in Figure 1. (1) indicates the evaporator coil of the unit and (2) indicates the condenser coil, placed downstream of the cooling coil (1). The air is aspired by the fan (3) and comes in contact with the cooling coil (1); its temperature is lowered and, if it becomes lower than the dew point, a portion of the water contained in the air condenses on this cooling coil.

The cool air comes in contact with the condenser coil (2) and cools it; the air emerges in D at about the same dry-bulb temperature as at the inlet A but with a lower moisture content.

The energy consumption is given by the difference of enthalpy between the states A and D; and such difference, at the limit, is given by the latent heat of the condensed water (equals 600 kcal/kg of condensed water).

It is necessary for this to have a good recovery of the sensible heat, and this may be obtained with a very good heat exchange between the cool air C and the condenser coil.

Assuming use of a refrigerating machine operated by a mechanical compressor and assuming a "figure of merit" as favourable as 5 to 1 for this machine, the energy consumption of the process would be about $\frac{600}{5} = 120$ kcal/kg of separated water.

If the compressor were driven by a Diesel engine using a fuel with a calorific value of 10,500 kcal/kg. and with a yield of 33%, a 1 hp refrigerating machine would require $\frac{640}{0.33 \times 10,500} = 0.180$ kg of fuel per hour to obtain 5.3 kg. of water.

In other words 1 kg. of fuel would give about 30 liters of water; if the fuel were burnt directly in a thermally actuated refrigerant machine the yield might be a little greater.

The energy balance seems attractive and we have therefore studied conditions under which, in practice, water may be separated from the atmosphere, and in particular the amount of water separated from the air while at different physical conditions and the amount of energy that this separation requires.

Experimentation

For the present research one commercial Frigidaire mechanical dehumidifier, type BO-1, has been used. The power of the unit is 1/8 hp (about 95 watts) and the cooling unit is arranged according to Fig.1. The evaporator and the condenser are two parallel coils, about 5 cm apart; the section of the air duct is 24 cm x 20 cm.

The air entering the unit flows on the elements of the cooling system; the water condensing on the evaporator coil is collected in a measuring flask and measured.

The consumed electrical energy is measured at 0.01 kwh; the conditions of the inlet air have been measured with a couple of dry-bulb and wet-bulb thermometers and, for a second time, with a recording thermo-hygrometer.

The measurements had been recorded on a roof in Bari at about 100 meters from the seashore and the observations were made 3 to 6 times a day.

Results

Table 1 gives the order of magnitude of the water obtained and of the energy consumption in the various months of the year.

A weekly production from 6 to 20 liters per week has been observed with energy consumption practically constant between 15 and 20 kwh/week.

The specific energy consumption per weight unit of water in the various weeks varies in general between 1000 and 1500 kcal/kg of separated water (the latent heat of vaporization of water being about 600 kcal/kg. and the ideal minimum, assuming a figure of merit of 5 to 1, being therefore 120 kcal/kg).

During 18 months, considering the effective specific energy consumption only when condensation took place, we have observed energy consumptions as low as 780-860 kcal/kg, when the relative humidity was high and this especially during the night.

In Figures 2 to 5, relative to four weeks in June and July 1961, we show, in the order from the top, the relative humidity, the dry-bulb temperature of the air, the hourly water production in cc, the daily water production in liters and the daily energy consumption in kwh.

The results so far obtained may be summarized as follows:

(a) With the present particular experimental arrangement the energy consumption was, obviously, constant around 110 ± 10 watt-hours/hour independently by the amount of separated water.

(b) The amount of water separated from the air depends on the physical conditions of the air itself.

(c) With the present particular experimental arrangement, water condensation is observed when the relative humidity is more than 50%, independent of the dry-bulb air temperature.

(d) The energy consumption per weight unit of separated water has been, under best conditions, somewhat greater than the latent heat of vaporization of water and several times greater than the theoretical energy consumption assuming a "figure of merit" of 5 to 1 (in this case the minimum energy consumption, due to the latent heat only, would be about 0.14 kwh/kg of water). The higher energy consumption is due to the poor heat exchange between the cooled air, at the outlet of the evaporator coil, and the surface of the condenser coil of the refrigerant machine. In the little dehumidifiers (1/8 to 1 hp), in fact, the air speed is rather high, of the order of 200-400 cubic meters per hour; such speeds do not allow a good heat exchange.

(e) When the dry-bulb temperature of the inlet air is lower than 10°C ice formation is observed on the surface of the evaporator coil.

The above data show that it is possible to obtain appreciable amounts of water from the atmosphere and that such amounts depend on the air conditions.

A unit for extracting water from the air would best be operated only when the air conditions are such to assure that condensation takes place. It is necessary to design any unit in such a way as to have a very good heat exchange between the air and both the evaporator coil and the condenser coil, though keeping the friction low.

Keeping well in mind that under best conditions a compressor system may give about 7 kg of water per kwh, I suggest the possibility of operating the compressor using the wind energy and this would permit a direct use of the mechanical energy of the wind.

The evaporator and condenser coils might perhaps be arranged downstream of the blades so that the wind itself brings the air inside the refrigerating machine.

Owing to the modest space requirements of the unit the dehumidifier might use the excess power of a car, or of a fuel engine, and so on, thus giving fresh water through the recovery of waste mechanical energy when available.

If heat is available, for instance solar energy, an absorption refrigerating machine may be satisfactorily operated.

The amount of water obtained with little power units is obviously low and at present suitable for emergency cases only, but the method seems rather promising and suggests further developments.

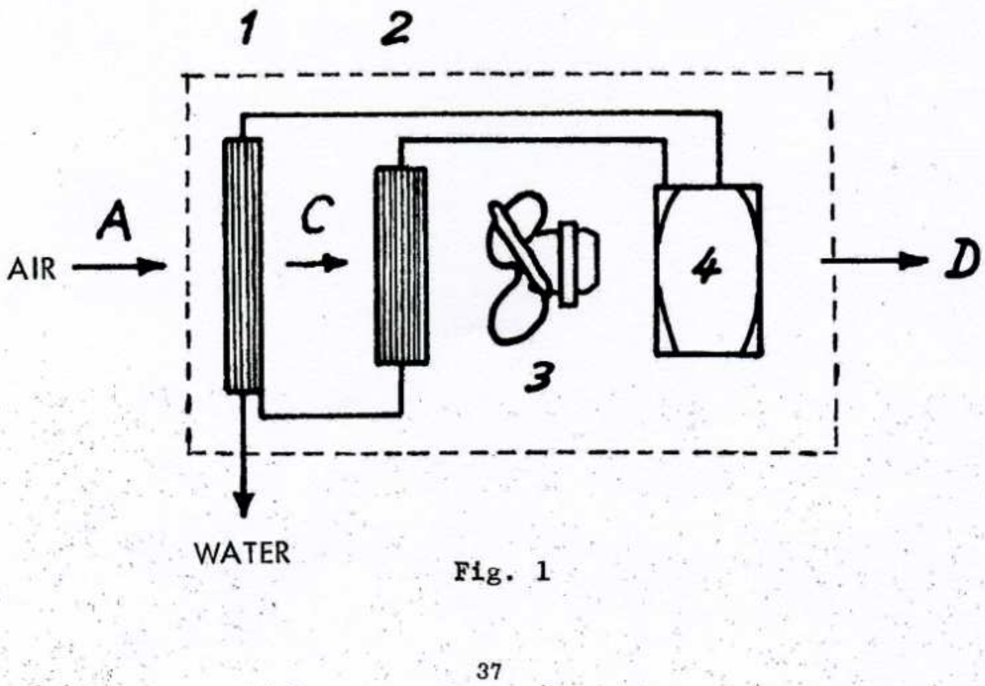

Fig. 1

TABLE I

Water production and energy consumption in various weeks of operation of the dehumidifier

Week* From	to	Energy consumption kwh	Amount of separated water kg	lbs	Specific Energy consumption kwh/kg	kcal/kg	Btu/lb
22-2-60	29-2-60	17.86	6.60	14.5	2.69	2300	4280
29-2	7-3	16.89	4.27	9.1	3.95	3400	6150
7-3	14-3	16.22	10.99	24.0	1.47	1270	2290
14-3	21-3	17.89	8.01	17.6	2.23	1920	3470
21-3	28-3	17.17	10.47	23.0	1.65	1420	2560
28-3	4-4	15.72	6.31	13.9	2.50	2150	3890
4-4	11-4	19.09	5.27	11.6	3.61	3120	5630
2-5	9-5	16.27	13.28	28.2	1.22	1050	1900
9-5	16-5	20.21	4.35	9.6	4.63	4000	7200
16-5	23-5	18.53	5.74	12.6	3.23	2800	5030
30-5	6-6	20.07	5.28	11.6	3.82	3300	5930
6-6	13-6	19.68	14.01	31.0	1.40	1200	2180
13-6	20-6	20.06	13.05	28.7	1.54	1330	2400
20-6	27-6	19.43	9.63	21.2	2.00	1720	3110
27-6	4-7	20.52	15.08	33.0	1.36	1170	2120
4-7	11-7	20.23	9.49	21.0	2.13	1830	3310
11-7	18-7	20.32	12.26	27.0	1.65	1420	2560
18-7	25-7	20.85	5.38	11.8	3.89	3320	6020
25-7	1-8	20.16	9.51	20.9	2.12	1830	3300
1-8	8-8	21.36	9.57	21.1	2.23	1920	3480
22-8	29-8	20.78	7.52	16.5	2.76	2360	4600
29-8	5-9	21.16	15.12	33.2	1.39	1200	2160
5-9	12-9	19.42	12.68	28.0	1.52	1310	2360
12-9	19-9	20.70	16.11	35.5	1.28	1100	2000
19-9	26-9	19.26	16.96	37.2	1.21	1050	1890
26-9	3-10	19.76	17.35	38.0	1.14	980	1760
3-10	10-10	19.60	22.31	49.0	0.88	760	1370
10-10	17-10	18.29	14.39	31.5	1.27	1090	1980
17-10	24-10	17.99	14.49	31.6	1.24	1060	1930
24-10	31-10	19.35	19.62	43.2	0.98	840	1520
31-10	7-11	18.45	16.34	36.0	1.12	960	1740
7-11	14-11	17.40	15.45	34.0	1.13	970	1760
14-11	21-11	16.55	11.55	25.5	1.43	1230	2230
21-11	28-11	16.63	14.64	32.2	1.14	980	1770
17-4-61 (only six days)	24-4-61	13.02	11.91	26.2	1.10	945	1710
24-4 1-5	1-5 8-5	28.75	25.56	58.4	1.12	960	1740
8-5	15-5	14.33	10.45	23.0	1.36	1170	2110
15-5	22-5	14.68	9.08	19.9	1.61	1390	2500
22-5	29-5	15.38	13.63	30.2	1.11	950	2730
29-5	5-6	17.07	11.20	24.6	1.50	1290	2330
5-6	12-6	15.04	17.98	39.2	0.84	720	1310
12-6	19-6	16.79	18.14	40.0	0.92	790	1430
19-6	26-6	17.62	21.12	46.2	0.84	720	1310
3-7	10-7	17.72	17.08	37.5	1.03	890	1610
10-7	17-7	18.30	11.83	26.2	1.34	1150	2090
17-7	24-7	17.67	17.12	37.5	1.03	890	1610

* The weekly periods extend from the morning of one Monday to the morning of the next Monday.

REFERENCES:

(1) "Symposium on Saline Water", National Academy of Sciences, National Research Council Publication No. 568, 1958. G. Nebbia, "La transformazione delle acqua salmastre in acqua dolce", Boll.Sci.Fac. Chim.Ind.Bologna, 16, 47-66 (1958). For an analysis of the various demineralization systems and their energy consumption, see: K.C.D. Hickman, "The water conversion problem", Ind.Eng.Chem., 48, 7A, April 1958. More recent data on the demineralization processes can be found in: "Saline Water Conversion Report for 1960", U.S. Department of the Interior, Office of Saline Water, Washington, D.C., January 1961.

(2) H. Masson, "La rosée et les possibilités de son utilisation", Institut Hautes Etudes, Ecole Sup. Dakar, 1, 45-88 (1954).

(3) G. Lejeune and J. Savornin, "Recovering water vapor from the atmosphere", Trans. Conf. Use of Solar Energy, University of Arizona, Vol.III, Part II, 138 (1955); A. Bocchi Bianchi and A. Petroni, "Procedimento e dispositivo per la estrazione dell'acqua dall'aria atmosferica", Brevetto Italiano 462.809, Depos. 13 Luglio 1949.

(4) W.L. Ross, "Dehumidification by solid absorbents", Symposium Session on Dehumidification, Am.Soc.Heating Air-Conditioning Engrs., New York, 1957, 10-13.

(5) E.W. Gifford, "Dehumidification by liquid sorbents", Symposium Session on Dehumidification, Am.Soc.Heating Air-Conditioning Engrs., New York, 1957, 13-16.

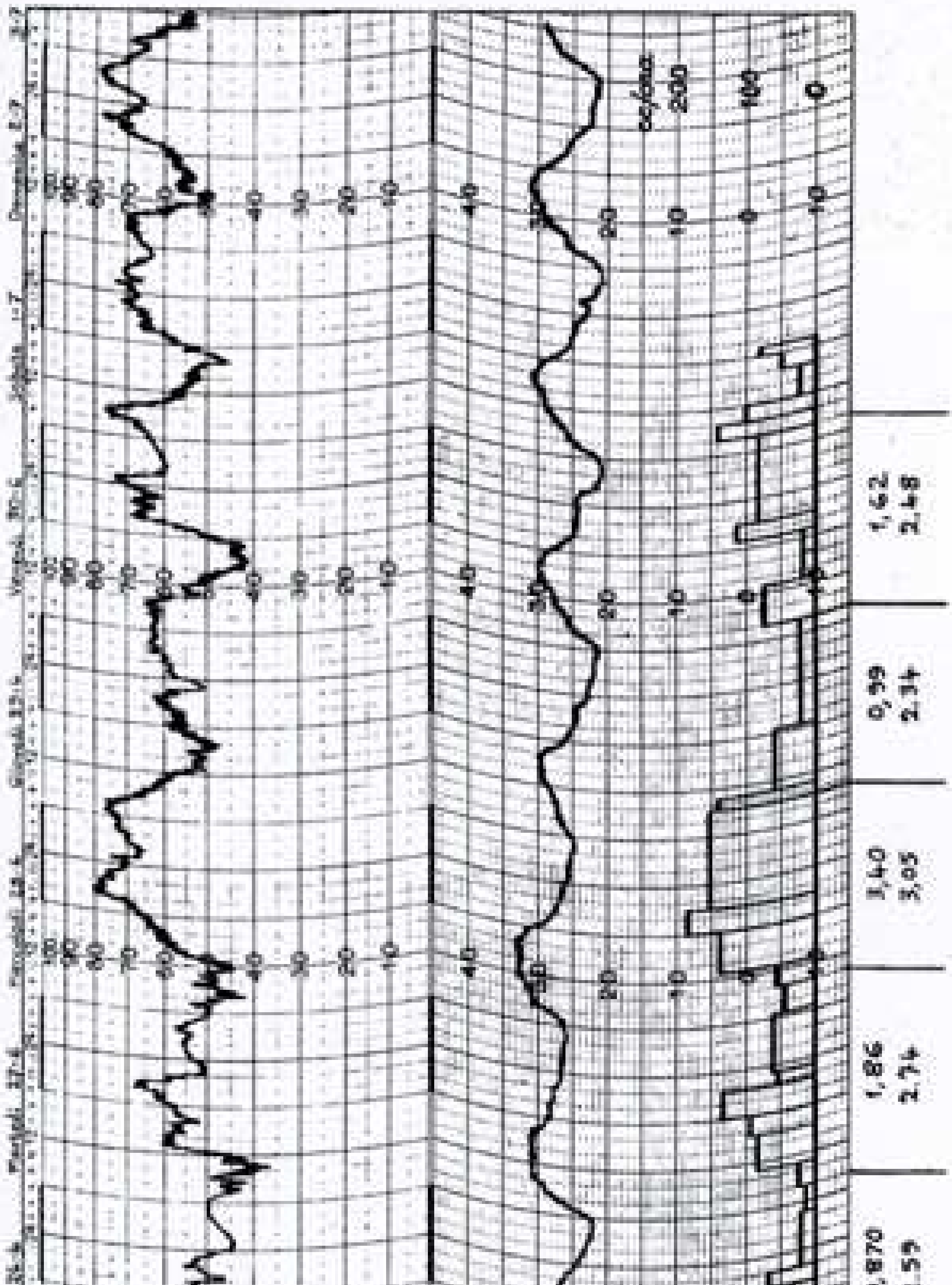

Fig. 2.

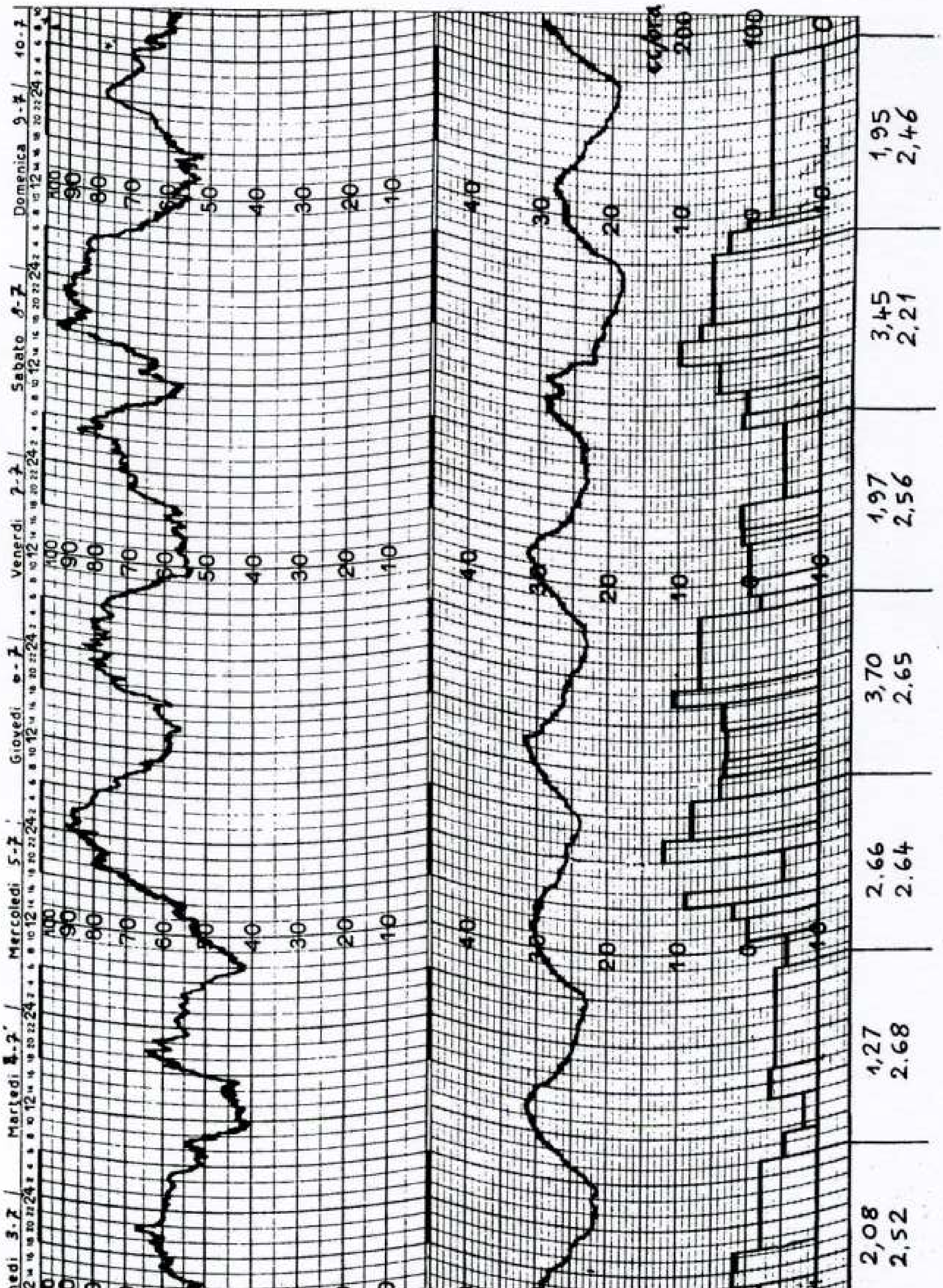
Lunedi
Martedi
Mercoledi
Giovedi
Venerdi
Sabato
Domenica
2,08
2,52
1,27
2.68
2.66
2.64
3,70
2,65
1,97
2,56
3,45
2,21
1,95
2,46

Fig. 3.

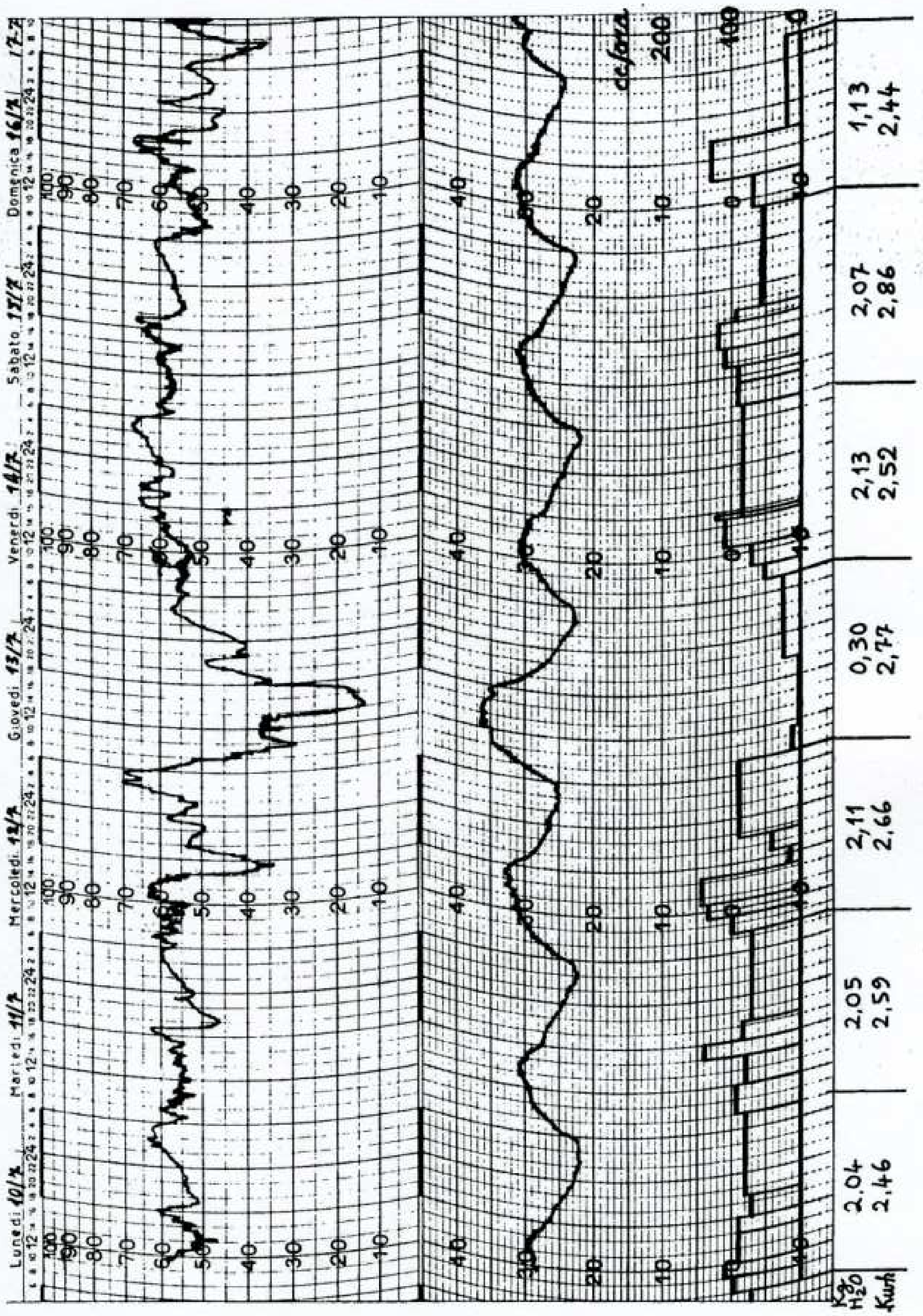
Lunedì 10/7
Martedì 11/7
Mercoledì 12/7
Giovedì 13/7
Venerdì 14/7
Sabato 15/7
Domenica 16/7
17/7
2,04
2,46
2,05
2,59
2,11
2,66
0,30
2,77
2,13
2,52
2,07
2,86
1,13
2,44
Kg H_2O
Kwh

Fig. 4.

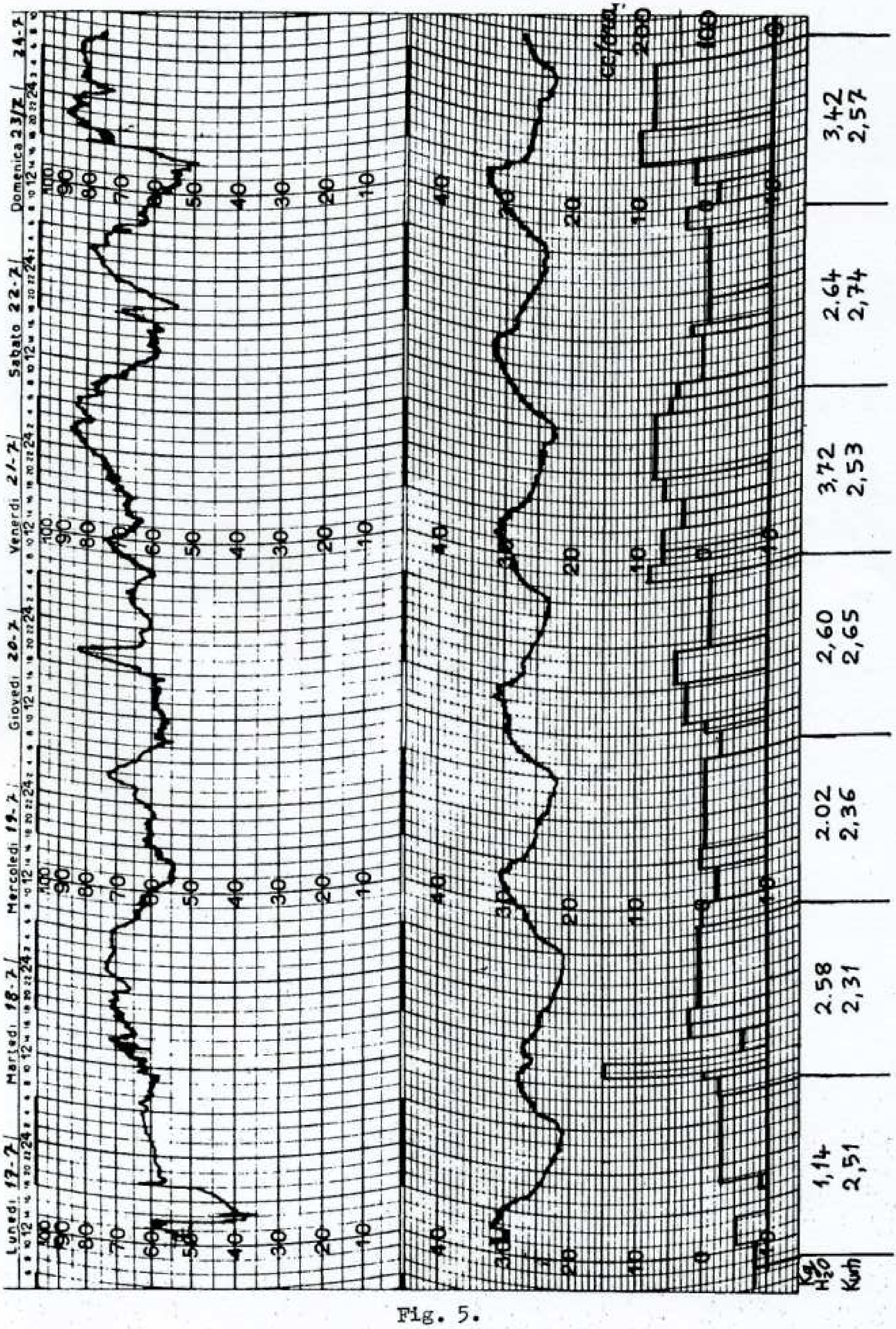
Lunedì 17-7
Martedì 18-7
Mercoledì 19-7
Giovedì 20-7
Venerdì 21-7
Sabato 22-7
Domenica 23/7
24-7
cc/ora
Kg H2O
Kwh
1,14
2,51
2.58
2,31
2.02
2,36
2,60
2,65
3,72
2,53
2.64
2,74
3,42
2,57

Fig. 5.

D I S C U S S I O N

Prof.M. Anastassiades: The suggestion of Prof. Nebbia is really a very important one and indeed these first experiments about getting water from the air may be a good way to get water; but I would like to suggest that the old Greek method about getting water from the air might be developed by Mr. Krispis, who is the promoter of this question,and I think that Mr. Krispis can give us some details about this old method.

Mr. C.F. Krispis: J'ai déjà dit que les anciens grecs ont trouvé une solution tout à fait simple de ce problème. On a trouvé avant 35 années à Criméa, près de la ville de Théodossia, sur une colline, 13 cônes d'un diamètre de 50 m. et d'une hauteur de 15 m. qui sont formés de cailloux, de fleuves tout à fait rondes et lisses. Le terrain était en mortier d'une forme concave (Voir Fig.A) et le problème était: si pendant la nuit l'air passe par les éspaces qui sont formées de cailloux et comme vous comprenez, à cause de la grande surface, de très grandes quantités d'air passent et alors les cailloux prennent la température de la nuit, et parce-que la masse de cailloux est très grande, le soleil ne peut pas augmenter la température de cette masse pendant le matin. Alors, la température reste à peu près la même avec la température moyenne de plusieurs jours. Les matins, quand il y a de soleil, la température de l'air est augmentée, et aussi l'humidité absolue. L'air passe par les mêmes éspaces et là il y a une condensation, dont on prend de l'eau. Avant 35 ans, à peu près, en France, à l'Académie de l'Agriculture, un Ingénieur Russe a fait une communication. Il a calculé la quantité de l'eau qu'on peut prendre de chaque cône par jour de 50 mètres cubes, mais je crois que c'est trop. Après on a fait plusieurs experiences, comme par example un ingénieur Belge, en France, en Province, mais il a fait une autre construction. Il a construit un cône de béton armé (Fig.B) qu'il a nommé puits aérien mais il n'avait pas de bons résultats, parce que le béton armé n'avait pas une masse suffisante, et la circulation de l'air était très faible. Après je ne sais pas qu'est ce qu'on a fait.

Prof. G. Nebbia: Mr. Chairman, there are at least two important papers on the historical aspect of this problem. One from Prof. Maçon,"La rosée et les possibilités de son utilisation" published in 1954 by the Institute of Hautes Etudes, Ecole Supérieure de Dakar, perhaps under the auspices of UNESCO, if I remember well, and the second one is by Prof. Lejeune and Prof. Savornin: "Recovering water vapour from the atmosphere"in the transactions of the conference on solar energy in Arizona, in 1955. Also there are a lot of records of ancient buildings; the Theodossian one is one of the best known. I have heard about similar buildings in Libya and Prof. Blanco has also told me that something similar is in Spanish Morocco. If it is possible, I would like to hear from Prof. Lejeune and Prof. Blanco about such ancient and such possible systems of recovering air. The system I have discussed is an artificial mechanical system but perhaps we have lost much of the art of some empirical solutions which ancient people did use, and perhaps our studies may be properly directed toward the objective of repeating what such primitive people or such ancient people did.

Prof. P. Blanco: Monsieur le Président: Je veux aussi mentionner un autre exemple de captation d'eau de l'atmosphère. Il a lieu à l'île de Lanzarote (Canarias) dans laquelle les agriculteurs font la culture des tomates mettant au dessus de la terre végétale une couche de sable fin noir, d'origine volcanique. Pendant la nuit cette sable se refroidit beaucoup par radiation et condense l'humidité de l'air qui par convection se met, à tour de rôle, en contact avec lui. Cet eau, par gravité coule, à travers de la couche de sable, jusqu'à la terre végétale où se trouvent les racines des plantes. Il y a déjà beaucoup de temps qu'on profite à Lanzarote de l'eau de l'air de cette façon.

Prof. M. Anastassiades: Il me semble qu'au point de vue physique le projet que M. Krispis a dévéloppé tout à l'heure vraiment c'est très bon. D'ailleurs c'est une solution qui vraiment n'a pas beaucoup de dépenses à faire. Alors, bien entendu l'equipement qui a été décrit par M. Nebbia, est une solution partielle d'un problème. C'est un problème qui peut être renforcé un peu, enfin c'est une reproduction si vous voulez d'un ancien problème. Je regrette infiniment que notre collègue M.Kyriazopoulos ne se trouve pas ici, qui s'est spécialisé un peu sur la question arrosé, mais enfin je pense que c'est pour nous les autres au point de vue d'irrigation que la question d'arrosé c'est une question très grande vraiment en Grèce et même qu'il y a une très grande partie de notre délégation, qui est basée sur la rosée. Je pense que si nous avons déjà cette expérience-là certainement ça vaut la peine de faire des experiences suivant le système de pyramide en cailloux, parce que justement les cailloux présentent une surface plus grande et alors comme-ça il arrive d'avoir une différence de température entre l'intérieur et l'extérieur, et de cette façon là, je pense que ça vaut la peine peut être que le Comité de l'Energie Atomique dépanse quelques centennes de drachmes pour voir si cette ancienne expérience est encore valable, parce que vraiment ça vaut la peine.

Mr. E. Golding: You remember, Dr. Daniels, when we were together— I think you were there— in Israel, they had, in the ancient times apparently heaps of stones round the base of the trees in the desert plantations. We came across, in the very dry area, the remains of an orchard and the stones were still there from possibly hundreds of years ago, I suppose. The explanation was that they were there to catch the moisture from the atmosphere for the benefit of the fruit trees. That is one thing, but what I really wanted to do was to try to respond to Prof. Nebbia's suggestions that we might use wind for this particular object of extracting the moisture from the air. Now, there is, as probably some of you know, one form of windmill which has hollow blades. It is a somewhat complicated machine, but the propeller is hollow and there is a hollow down tube so that the wind drives the propeller round, and air is flung out centrifugally from the tips of the blades. Now, the whole machine is air-tight and at the base of the supporting tube is an opening. Immediately above the opening there is an air turbine and this has a vertical shaft and drives an alternator. The air comes in through the air turbine and is flung out from the tips of the blades. The intention of this machine is that it should be used for electricity generation and the advantage is that all the equipment— the alternator and the air turbine and so on— are housed nearly at ground level. But it seems to me that Prof. Nebbia might use this kind of windmill for his process because you are, in fact, drawing in air and you might have his equipment situated somewhere in the base of the machine.

Dr. S. Papagianakis: Je crois que c'est le Professeur Chaptal en France qui a fait tout d'abord des experiments sur ces "Puits artificiels", comme on les appelle en France; cette disposition était semblable à la disposition de Théodossia. J'ai eu l'occasion, en 1956 en visitant Montpellier de voir de petits copies de cette disposition de Théodossia et le premier modèle de Chaptal qui avait un rendement, un petit rendement. En 1956 j'ai vu des "modèles amelliorés", comme on disait, mais leur rendement était nul. En 1956 j'ai écrit une lettre à un ami à Montpellier et j'ai eu une réponse que le rendement était encore nul avec les modèles amélliorés. Peut-être nos collègues de la France présents ici ont plus d'information sur ce point.

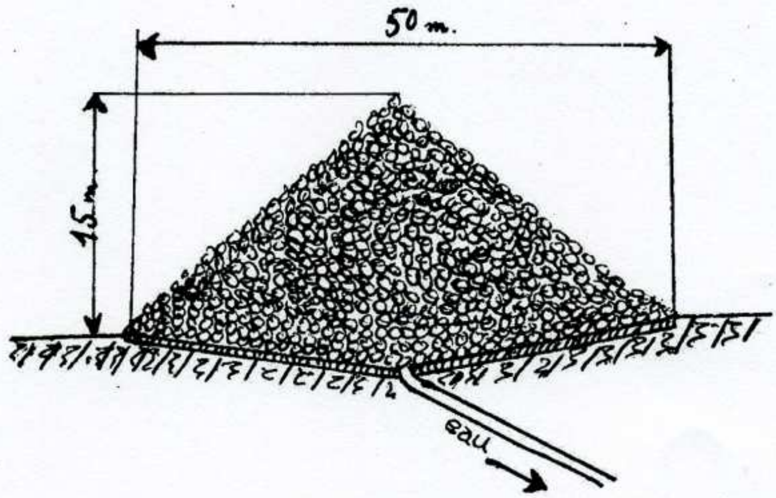

Fig. A. - Cône de cailloux à Théodossia

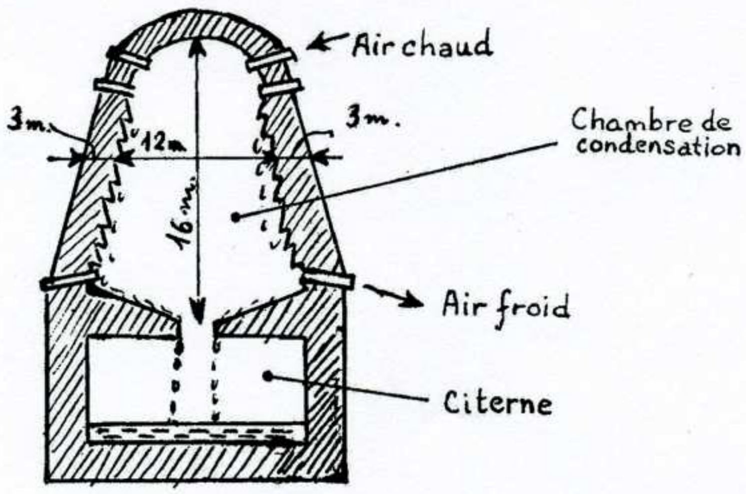

Fig. B. - Puits aérien.