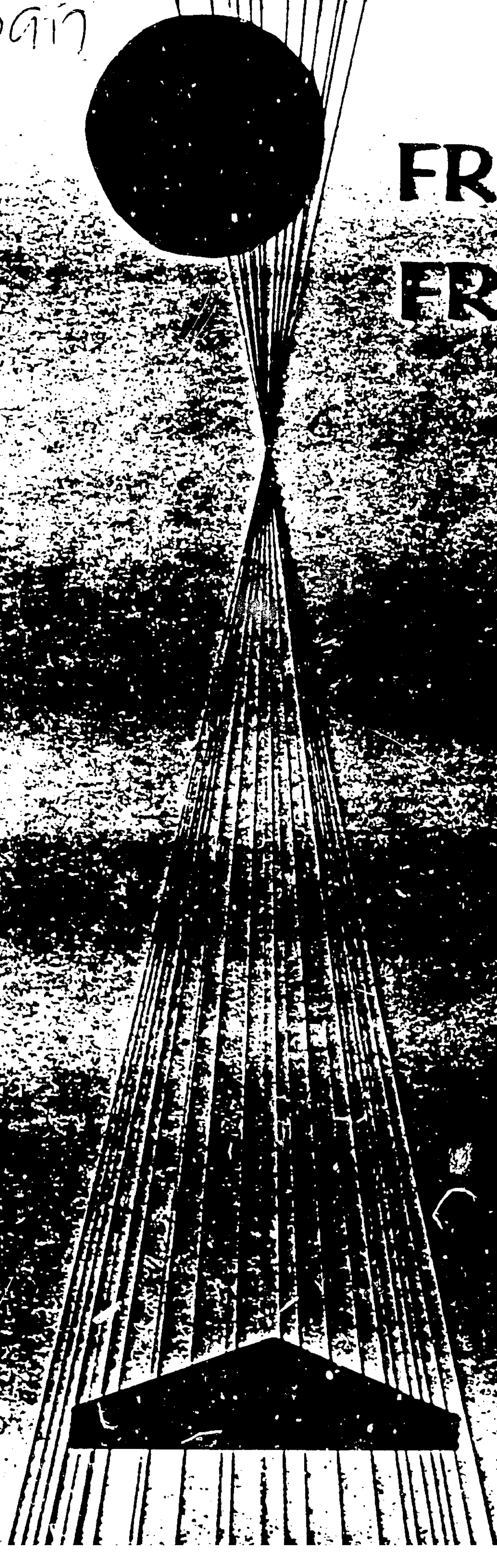

FRESH WATER FROM THE SUN

Family-sized Solar Still Technology: A Review & Analysis

by Daniel C. Dunham

Sponsored by
Office of Health
United States Agency
For International Development

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Family-Sized Solar Still Technology:

A Review and Analysis

Daniel C. Dunham

Under A.I.D. Contract
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The Office of Health
Development Support Bureau
United States Agency for International Development
U.S. Department of State
Washington, DC 20523
August 1978

TABLE OF CONTENTS

APPENDICES

PREFACE

This report was requested in order to make basic information and data on the solar distillation process conveniently available to individuals involved with the planning of water supply in developing countries. It attempts to sketch the principles, limitations, and potential of small solar still units in sufficient detail so that a perspective can be gained on their possible role as providers of pure drinking water in areas where it is in short supply.

Substantial research has been done in the field of solar distillation and many experimental installations have been made. Although the suitability of the process for small group or even family water supply in developing countries is frequently mentioned, most research investments in the U.S.A. have been made for studies relating to distillation units of larger size. One of the reasons for this may be that the background work required prior to any attempt at widespread introduction of small units is outside of the discipline of the scientists and technicians who have proposed and designed experimental installations.

The process of solar distillation is simple and easy to understand. The equipment required for it is inexpensive and easy to make. In contrast, understanding the social and economic factors which would govern its mass acceptance in developing nations requires specialized information and research, as well as a sensitivity to local priorities. These are neither easy nor simple to acquire. It may be perhaps less complicated to explain the new technology to those already experienced with the local conditions in which it is to be used than to try to explain an unfamiliar cultural environment to a distant technical researcher.

This report attempts to provide technical, practical, and economic information on solar distillation in a form that workers in the field and officials concerned with development work can utilize in decision making.

In the writing, this has frequently meant following a path on the edge of usual technological vocabulary. It has meant generalizing from data from various sources that are not completely comparable and eliminating many details, even areas of research, if they did not appear pertinent to developing country situations. No one is more aware than the author of the pitfalls that accompany this kind of effort. It is hoped that his selection of the items included and the form in which they are presented will prove useful to those working to improve the quality of life in developing countries.

ACKNOWLEDGMENTS

The author is indebted to the many researchers whose published reports provided information included in this work. Because of its nature and brevity, it has been impossible to give credit individually to many of those whose work in the field has been important.

Technical work on solar distillation before 1970 was summarized in Manual on Solar Distillation of Saline Water (see Talbert, item 83 in bibliography). This report was of inestimable value for technical information and is recommended as a basic research reference to those working with the technology. Data from research since 1970 is identified in the report, and a selected bibliography of recent published work in English is included as Appendix A.

During the preparation of the report, research institutions in the U.S. and abroad that had a history of work in solar distillation were contacted. Individuals or institutions in the United States and Canada were called. Those who indicated they were presently working on solar distillation were visited and their projects reviewed. These included:

Georgia Institute
of Technology, Office
International Programs
Atlanta, GA 30332

University of Arizona
Environmental Research
Laboratory
Tucson, Arizona 85706

University of California
Sea Water Conversion Lab.
1301 South 46th St.
Richmond, CA

Aqua-Sol, Inc.
7710 Computer Ave.
Minneapolis, MN 55435

Sunwater Co.
1488 Pioneer Way
Suite #17
El Cajon, CA 92020

University of Florida
Solar Energy
and Conversion Lab.
Gainesville, FL 32611

Brace Research Institute
Macdonald College
McGill University
Ste. Anne de Bellevue
Quebec, Canada
HOA 1CO

L'Eglise Methodiste
d'Haiti
and Brace Research Inst.
Source Phillippe
Isle de La Gonave, Haiti

Solar-Electric Lab.
Kingston, NJ 08528

The author is grateful to the directors and st of these institutions for the many courtesies they showed him during his visits.

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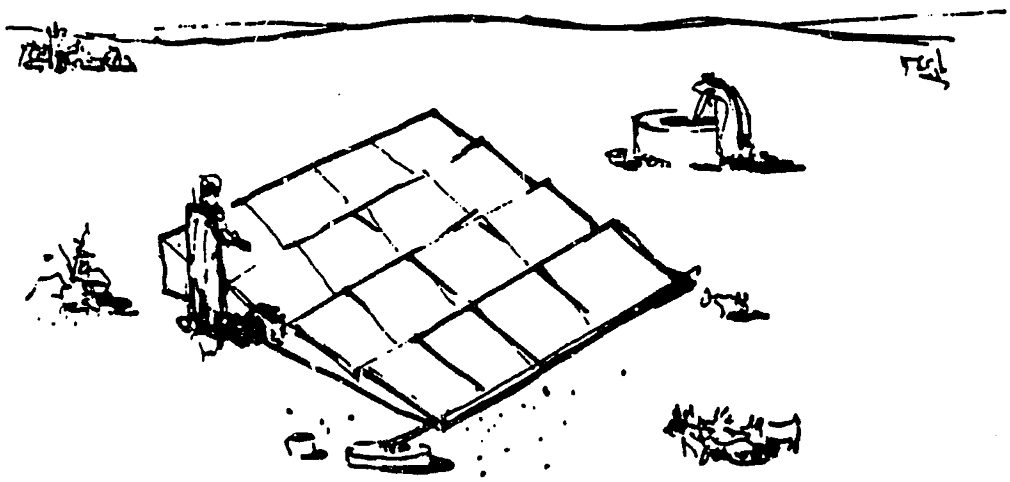

INTRODUCTION

The energy from the sun can be used to distill water. This energy arrives without cost, is widespread, inexhaustible, and non-polluting. At first hearing, this fact makes the idea of solar distillation very attractive; however, in practice many severe limitations must be faced. In fact, although solar energy is free, using it is not. In spite of the costs involved, there may now be a place in many non-industrialized countries for the technology in its present state of development. This report will concentrate on the potential role of small-scale solar still units as suppliers of pure water for family groups or other small users.

Solar distillation does not produce water where there is none; it simply purifies water supplies in areas where there is already adequate or abundant water that is unfit for human consumption or other activities. It is especially well suited to improving the quality of relatively small amounts of water in isolated areas. If there is adequate sunlight and a supply of water, a solar distillation unit can provide a safe, dependable water supply and thereby increase the scope for man's activities in the area.

<u>Benefits</u>

Solar distillation can expand areas of settlements. Certain regions of the world now sparsely inhabited could support larger populations if drinking water for them were available. These areas include marine deserts, small islands, and inland areas with saline groundwater supply. The new populations who could occupy this land would do so at an improved standard of living for themselves while removing population pressures from the areas where they originated.

Solar distillation can modify the effects of deteriorating water supplies in present settlements. In some areas already inhabited, permanent or seasonal changes in surface and groundwater conditions have made traditional water sources less acceptable to the population. The addition of solar distilled water to local drinking water supplies could permanently maintain water-quality levels.

Solar distillation makes possible the recycling of waste water. In regions where pure water is in critically short supply, used water from households and industries can be purified by distillation and added to the general water stores.

Solar distillation can improve health standards. Solar distilled water is chemically and organically pure. The removing of contaminants from questionable water supplies would have general benefits for the population's health. In specialized cases, still units could be used to supply all the pure water necessary for isolated hospitals and clinics.

Solar distillation could encourage economic activity. Animal husbandry could possibly be extended in areas where it is now limited by pure water supply. Fishing could become important on desert seacoasts where previously there were no drinking water supplies for workers. The making and installing of solar distillation units is highly labor-intensive and could in itself become a local industry.

Limitations

The spread of the technology will not be governed by the potential benefits listed above but by two strong constraints: its capital cost and its acceptability among the people who are expected to benefit from it.

Solar distillation requires large amounts of land and materials. The capital investment necessary to build the equipment for distilling water by solar energy is high but less so than other distillation methods when small volumes are needed. It is hard to grasp intuitively the large areas that are required to absorb enough energy from sunlight to perform even simple tasks. Sometimes the amount of glass, concrete, metal, or plastic necessary to trap radiant energy for most practical uses seems disproportionately high in relation to the product. A solar still unit supplying pure water to a poor family will be large in area and in some cases more expensive than the house in which they live. It will be a cost that they will seldom be able to bear unassisted.

Solar distillation may require changes in traditional life-styles. To be economic, domestic water produced by solar stills will require new water-use, work, and responsibility patterns within the household. It may come as a surprise to the user that the daily routine to which he is accustomed must change in order to use the new device, that the new water may taste different, that it must be conserved and stored, and that work patterns must change in order to produce it. Social constraints will vary widely between cultural groups, and their possible effect on the spread of the technology is yet to be investigated.

Thus far the limitations have outweighed the benefits of solar distillation where it has been considered or tried. Only in special cases will climate, resources, and needs combine to provide the conditions where the technology of simple stills can be practical and successful. An understanding of these basic factors should precede any decisions concerning solar distillation. There is considerable need for practical research and experimentation to help define those geographic regions and cultural areas for which it could be an economic and logical solution to local water supply problems.

DE DISTILLATIONIBVS.

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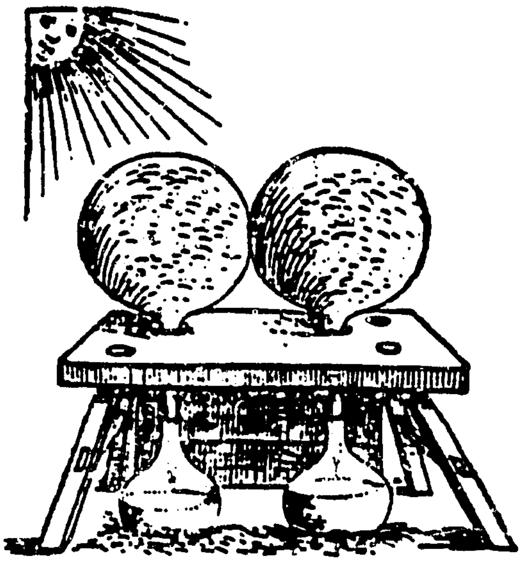


HISTORY OF RESEARCH

The dream of transforming unsuitable water, especially seawater, into fresh water for man's use recurs throughout history. Even the idea of using solar energy to distill salt water is not new. It is mentioned by the Arabs and by Italian scientists in the sixteenth century who may have actually succeeded in producing small quantities of solar distillate.

Man's early efforts to desalt seawater were frustrating; his present ones, though successful, are expensive. In recent historical times, organized research on desalination has fallen into two major categories, different in scale and objective:

1. an effort to produce fresh water from the sea with small units for sailing ships on long voyages. Research devoted to this came to an end with the invention of the steam-powered vessel that produced distilled water as a by-product of the engine;

2. schemes designed to produce large quantities of drinking water from salt water in areas where habitation was necessary because of rich resources, military installations, or growing urban populations. Research and construction continue, with a variety of distillation methods using oil, coal, or electricity to fuel the process. Many large distillation plants have been built and are currently in operation.

The modern history of solar distillation began in the second half of the nineteenth century. By that time, the industrial production of glass sheets made solar distillation a practical as well as theoretical possibility. The first major solar distillation project, and one that still holds the record for the longest period of operation, was established for the mining community in Las Salinas, Chile in 1872. It is thought to have operated until 1912; over forty years. The area had rich mineral resources, a saline water supply, extremely strong sunlight, and an absence of organic fuel. The need for a dependable water supply for men and draft animals to operate the mines demanded an innovative solution. With no known precedent, a Mr. Charles Wilson designed and constructed a huge solar still with a water surface of 48,000 square feet (4,500 square meters) turning out approximately 6,000 gallons (22,500 liters) a day. His system used water basins made of blackened wood. They were covered with glass held in wooden frames. Saline groundwater was supplied to the system and distilled water was withdrawn.

Conditions at the time it was built were certainly not more advanced than those in developing countries today. The cost of the water produced was probably substantial due to construction and maintenance expenses, but it was covered by the income of the successful mining operation. Mr. Lawand has pointed out that the productivity of this effort was roughly the same as stills recently built (item 54 in bibliography). The principles by which it operated, even the configuration of the unit, is the same as modern solar still installations.

Current general interest in solar distillation springs from problems peculiar to the twentieth century. The high cost of fossil fuels and their finite quantity have created an awareness of the possibilities for using the sun's energy directly for a variety of purposes. A spreading realization of the critical importance of adequate pure water supply is now combined with the knowledge that present sources are not infinitely expandable. The removal of many of the historical curbs on population growth has increased the pressure to expand habitable land.

New interest appeared in solar distillation after World War II. A novel element, cheap transparent plastic film, had been added to the array of materials from which stills could be made. Some researchers felt this substance might give an impetus to the technology similar to the one that had followed the introduction of cheap glass a century before.

In America, research was sponsored by the U.S. Department of the Interior, Office of Saline Water, and several of the large foundations. It was directed primarily at investigating the possible economics of solar distillation for future application to American conditions. A large installation for field-testing designs was set up in Daytona Beach, Florida, and many individual research institutions, university departments, and individuals carried on specialized studies. The results were not encouraging. The high cost of solar distilled water would inhibit its use in the U.S.A. for the foreseeable future.

By 1970, interest in the solar technology in the U.S.A. had declined. The research up to 1970 was thoroughly summarized in the report Manual on Solar Distillation of Saline Water (83), prepared for the U.S. Department of the Interior in 1970 by the staff and consultants of the Battelle Memorial Institute. The manual covers completely the history, theories, and experiments with the practical aspects of the technology in the U.S. and abroad up to that time. It remains the definitive work on the subject. Research reported since that time is generally available in the proceedings of solar energy conferences and in issues of technical journals.

Table 1, published by Mr. Lawand (54) in 1975, gives the names, locations, and sizes of major stills throughout the world. Most of these are described in the Battelle report. There is considerable doubt as to whether all those stills listed as operating in 1975 are actually operating in 1978. As most of these stills were essentially experimental in nature, there has been a tendency, as research interest and support declined, to replace solar stills with other methods of water supply as they suffer damage or breakdowns.

Table 1

Important Solar Distillation Plants (1872-1975)

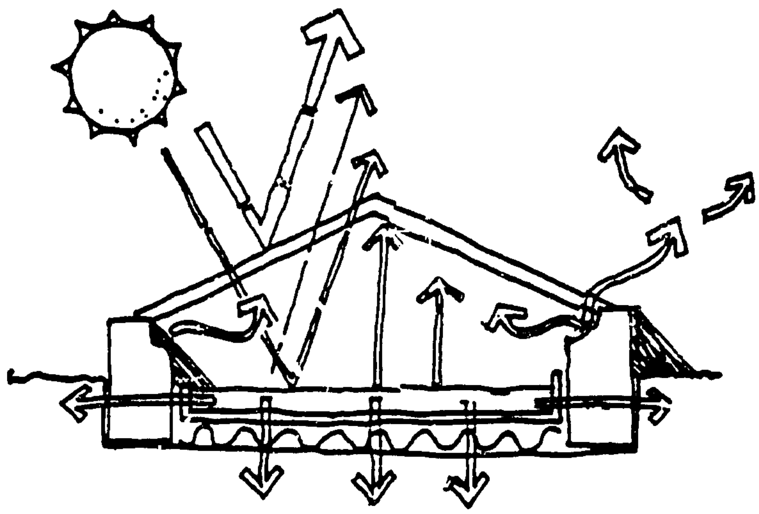
Country	Location	Year	M^2	Cover	Remarks
Australia	Muresk 1	1963	372	Glass	Rebuilt
	Muresk 11	1966	372	Glass	Operating
	Coober Pedy	1966	3160	Glass	Operating
	Caiguna	1966	372	Glass	Operating
	Hamelin Pool	1966	557	Glass	Operating
	Griffith	1967	413	Glass	Operating
Cape Verde Is.	Santa Maria	1965	743	Plastic	
	Santa Maria	1968			Abandoned
Chile	Las Salinas	1872	4460	Glass	Abandoned
	Quillagua	1968	100	Glass	Operating
Greece	Symi 1	1964	2686	Plastic	Rebuilt
	Symi 11	1968	2600	Str.Plst.	Dismantled
	Aegina 1	1965	1490	Plastic	Rebuilt
	Aegina 11	1968	1486	Str.Plst.	Abandoned
	Salamis	1965	388	Plastic	Abandoned
	Patmos	1967	8600	Glass	Operating
	Klmolos	1968	2508	Glass	Operating
	Nlsyros	1969	2005	Glass	Operating
	Plskardo	1971	2200	Glass	Operating
	Klonlon	1971	2400	Glass	Operating
	Megisti	1973	2528	Glass	Operating
India	Bhavnagar	1965	377	Glass	Operating
Mexico	Natividad Is.	1969	95	Glass	Operating
Pakistan	Gwadar 1	1969	306	Glass	Operating
	Gwadar 11	1972	9072	Glass	Operating
Tunisia	Shakmou	1967	440	Glass	Operating
	Mahdia	1968	1300	Glass	Operating
U.S.A.	Daytona Beach	1959	228	Glass	Rebuilt
	Daytona Beach	1961	246	Glass	Dismantled
	Daytona Beach	1961	216	Plastic	Dismantled
	Daytona Beach	1963	148	Plastic	Dismantled
U.S.S.R.	Bakharden	1969	600	Glass	Operating
West Indies	Petite St. Vincent	1967	1710	Plastic	Operating
	Haiti	1969	223	Glass	Operating

As part of the research in the 1950s and 1960s, many small still units were built to test principles and design factors. Certain institutions, especially the University of California, the University of Wisconsin, and Brace Research Institute in Canada, saw the potential for application of this family-sized unit in developing countries. They made a deliberate effort to design small-scale stills for developing country situations. Within these countries themselves, interest was growing even as American interest declined. Research continued abroad, including experiments with smaller units for family and small village use. The modest funds available for most research in these areas limited field testing severely.

Names and addresses of institutions in the U.S. and abroad with a history of involvement in solar distillation work are included as Appendix B. Those North American institutions that indicated they were actively involved with solar distillation at the time of this report are noted separately.

No major research projects on solar distillation are contemplated in America at the present time. There is a general consensus among those who have worked on solar distillation for many years that there will be no significant technical or economic breakthrough in the near future. Improving efficiency a few percentage points or cutting cost slightly will not bring it into a range where simple basin stills can profitably be used in America.

The question still remains large in the minds of many as to whether there are not regions where the technology of simple stills in its present state of development would be appropriate and beneficial. It has been suggested that if breakthroughs are to be made, they will be in field situations rather than in the laboratory. At least some of the effort originally devoted to developing and refining the technology might now be consigned to organized investigaiton of its application in areas outside the industrialized nations.



THE SOLAR DISTILLATION PROCESS

The broad principles involved in solar distillation are not complicated. The equipment can be simple and is easily constructed. On the technical level, solar distillation is one of the most thoroughly researched direct uses of the sun's energy.

Physical Principles

In its simplest form, a solar still is an air-tight enclosure with a transparent cover containing a shallow layer of water to be distilled. The configuration is such that the water evaporates and then condenses on the underside of the cover where it drains off and is collected. The materials and techniques involved in the fabrication of still units are similar to those used in normal building construction. Figure 1 illustrates the essential functional components of the usual "basin" or "greenhouse" still designs.

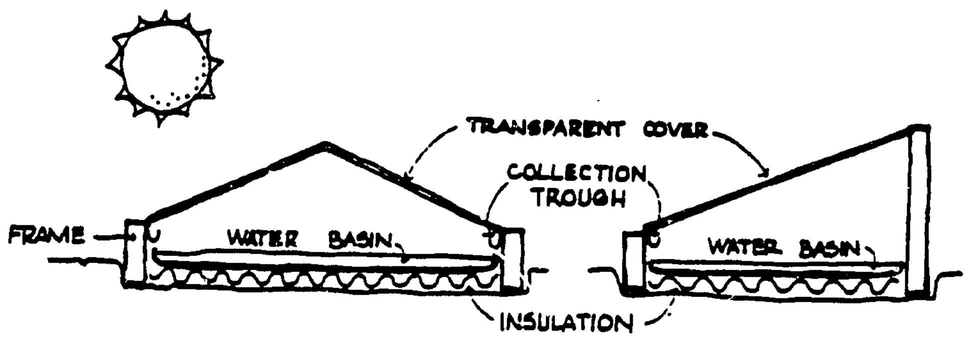


Fig. 1

The physical laws governing the process of solar distillation are simple and universal. Dr. Howe and Dr. Tleimat (item 86 in bibliography) have pointed out that simple basin-type solar stills produce pure water on a small scale in the same way that rain or snow is generated on the terrestrial level. Both processes involve four sequential steps:

1. the production of vapor from a body of water using the sun's energy for the heat of vaporization;

2. the transportation of the warm vapor upward to a

region where it is cooled;

3. the resulting condensation of vapor and its accumulation into water droplets; and

4. the descent and collection of the condensed water due to gravity.

These four steps on the global scale are represented by: the evaporation from oceans and other large bodies of water, the rising of the vapor, the formation of clouds, and the subsequent return of the water in the form of rain or snow to rivers and oceans.

In the simple basin still, the same four steps can be traced within the still enclosure (Fig. 2).

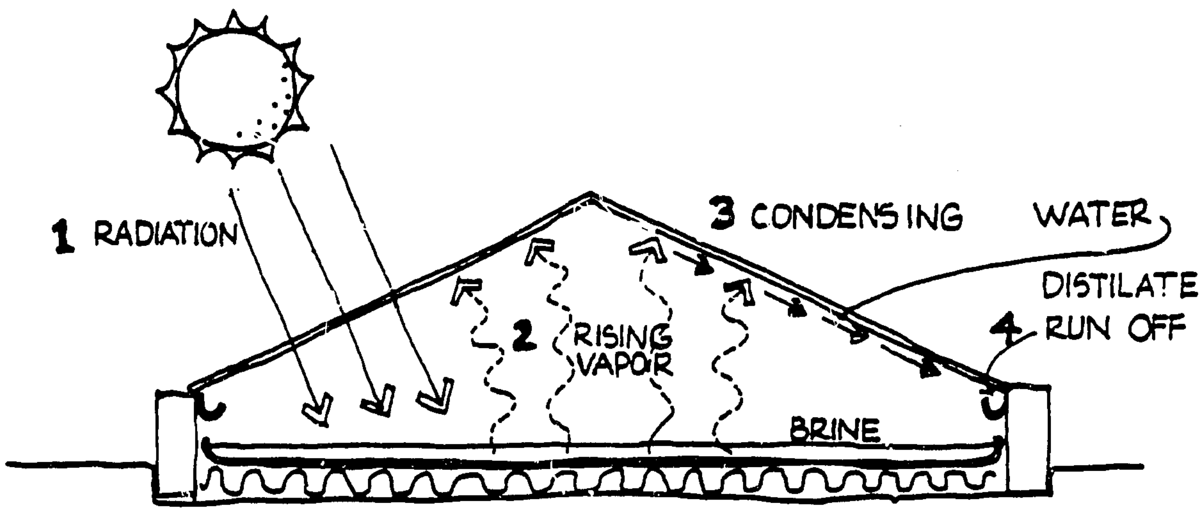


Fig. 2

1. The sun's radiation passes through a transparent cover and heats the saline water within the still enclos-

ure.

2. Water vapor is formed and carried by convective currents to the cover.

3. The vapor condenses on the cooler undersurface of the cover.

4. The condensed water collects into droplets or sheets and runs down to a trough located inside the still which leads the distillate to outside storage areas.

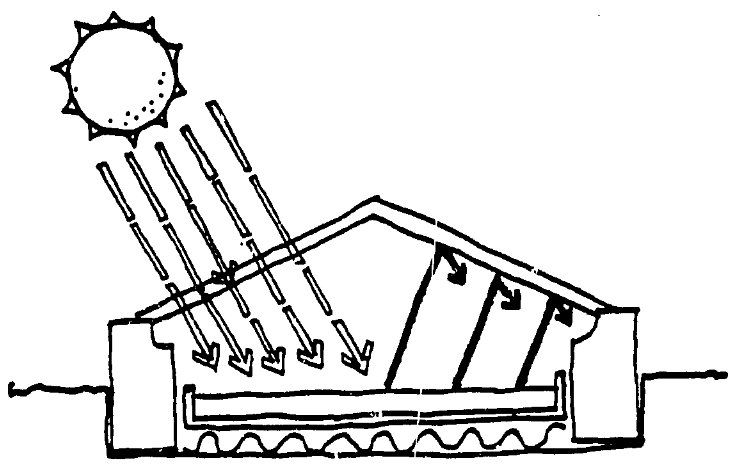


Fig. 3

Stills function because of the selective transparency of the cover material (Fig. 3). The shortwave radiation of visible light passes through glass and plastic; the longwave radiation of heat does not. Energy from the sun's light is absorbed by the water or the basin in which it is contained. Much of the heat generated there is trapped within the system because the longwave radiant heat emitted by the hot water cannot escape through the cover to the outside. The temperature within the still unit rises steadily and stabilizes when the heat losses to the outside equal the incoming radiant energy.

One method by which part of this heat is returned to the outside involves the vaporization of the water within the still and the loss of the heat of vaporization on the underside of the cover material as the vapor is cooled there and condenses.

It is this process of vaporization and condensation that leaves behind in the basin the mineral salts or other contaminants as the condensed vapor is withdrawn. The condensate formed within the still is theoretically as pure as water condensed from steam or vapor in oil-fired distillation plants. The heat of vaporization (540 kcal/liter, 8,913 BTU/gallon) absorbed from the sun's rays is delivered to the underside of the cover by the condensing vapor. The heat is carried through the cover by conduction and dispelled in the atmosphere.

If all the sun's radiation were absorbed by the water and if the vaporization-condensation sequence (distillation) were the only means by which the system could lose heat, its efficiency would be 100%. Actually, a variety of heat exchanges combine to produce a dynamic balance between the still unit and its surroundings. In attaining this balance, the vaporization and condensation of water within the unit play a large but not exclusive part. In most operating units, less than half the calories of radiant energy falling on the still are used for the heat of vaporization necessary to create the distilled water that is finally recovered. Although 60% efficiency has been reported, usual efficiency figures are not that high. Efficiency is calculated in the following manner:

$$\text{Efficiency} = \frac{\text{Energy required for the vaporization of the distillate that is recovered}}{\text{Energy in the sun's radiation that falls on the still}}$$

Much of the past research in the U.S. and elsewhere has been devoted to increasing still efficiencies by reducing the amount of non-productive heat transfers within the system. In stills that have been built, heat losses have been deliberately minimized as far as was possible. Cooper (16), Daniels (19), and Talbert (8[illegible]) have published percentage figures showing the distribution of incoming energy to various uses. Their data was obtained from records of stills operating in various areas and time periods. Average figures from these sample cases are included (in parentheses) in the following section to indicate the amount of energy used for vaporization or lost in other ways.

Vaporization (30% to 60%)

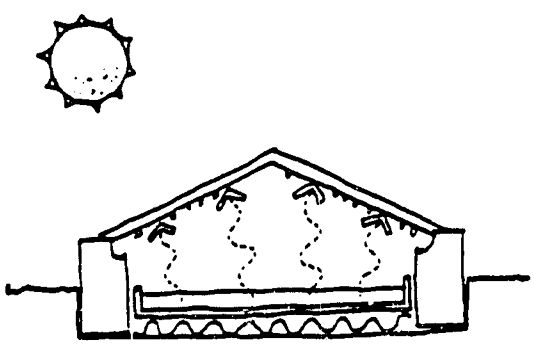


Fig. 4

Vaporization (Fig. 4) is the productive part of the heat-transfer process within the still--the use that results in distillation. The large spread in the percentage of incoming energy assigned to vaporization results from the differing data reported by researchers who are working on stills of different designs under differing climatic conditions.

Vaporization uses the largest proportion of available energy in all well-designed stills. The other heat uses described in the following sections ultimately result in losses to distillate production.

Reflection (8% to 14%)

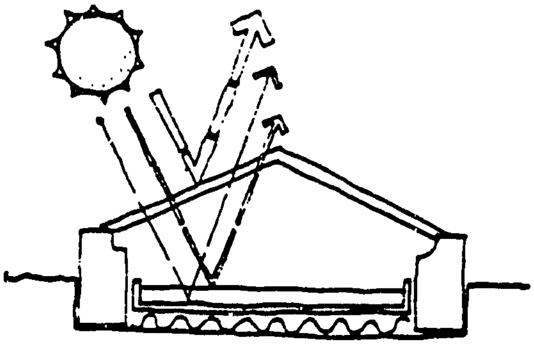


Fig. 5

Some of the incoming radiation is reflected back into space (Fig. 5). This occurs from three surfaces: the cover, the water, and the basin liner. Energy lost in this fashion does not contribute in any way to the distillation process. The greatest loss occurs in light reflected by the cover surface before it enters the still. This reflective loss diminishes as the sun's rays become more nearly perpendicular to the plane of the cover. The orientation of the still, the direction, and the angle of the cover slant are usually designed to minimize reflection at critical seasons. Reflection from the basin can be held to a minimum by ensuring that it remains dark, preferably black, in color.

Absorption (4% to 10%)

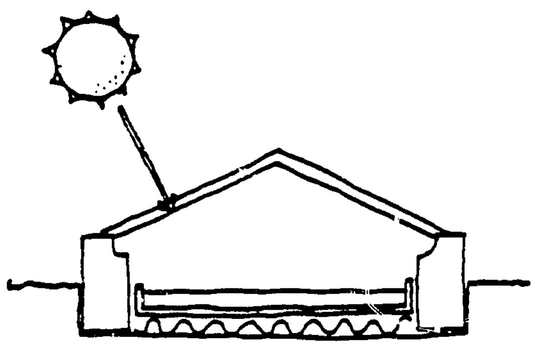


Fig. 6

Incoming solar radiation is partially absorbed by the cover itself (Fig. 6). This raises cover temperature and slows condensation. The level to which the cover absorbs heat is determined by the nature and thickness of the material of which it is made. Transmission coefficients for various energy wavelengths can be obtained from the manufacturer of the material.

Radiation (8% to 16%)

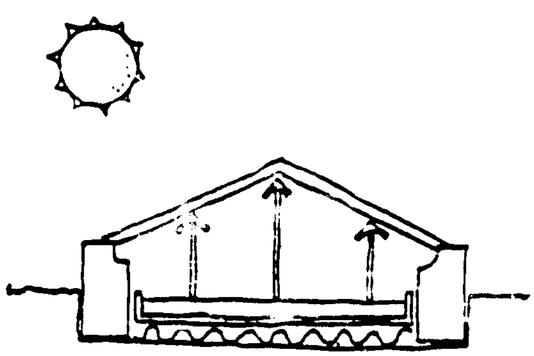


Fig. 7

Loss of heat by radiation from the surface of the water in the still can be significant (Fig. 7). The cover should be opaque to longwave radiation, and therefore will absorb most of the radiant heat emitted from the water in the still. This loss will be highest when the difference between the water and cover temperature is greatest, e.g., when the air outside the still is cold. This effect can overbalance the beneficial effect of a low-temperature condensing surface. The relative loss will vary with outside air temperature, and little can be done with simple still design to minimize it.

Convection (4% to 11%)

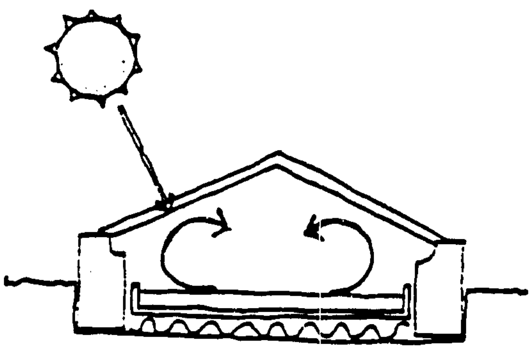


Fig. 8

The hot liquid supplies heat for convection currents set up within the still (Fig. 8). These currents account for the movement of vapor, but the heat used does not, itself, produce distillate.

Ground and Edge Loss (3% to 10%)

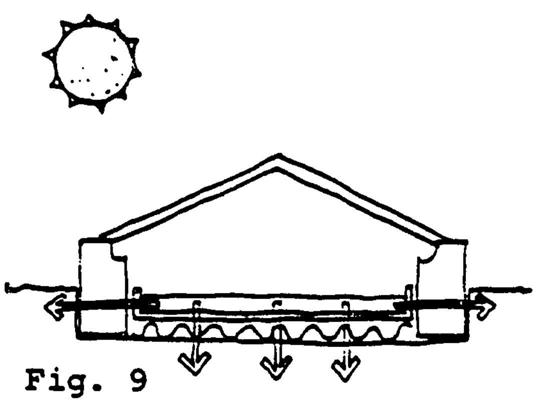


Fig. 9

The heat transmitted to the earth beneath the still and to the edges of the frame is lost to the distillation process (Fig. 9). If the base of the still is poorly insulated, losses from this broad surface can be high as water temperatures within the still rise. Most still designs include insulating layers under the still to cut down ground losses. The height of the sides of the still should be kept low to reduce the area through which heat can escape.

It should be noted here that some of the heat supplied to the system is stored in the water and utilized later, allowing the distillation process to continue after the sun has gone down (Fig. 10). The operation of stills designed with deep basins of water depends in part on this phenomenon. Even heat lost to the earth during the day is in part returned to the system at night as the unit cools while the earth below remains warm.

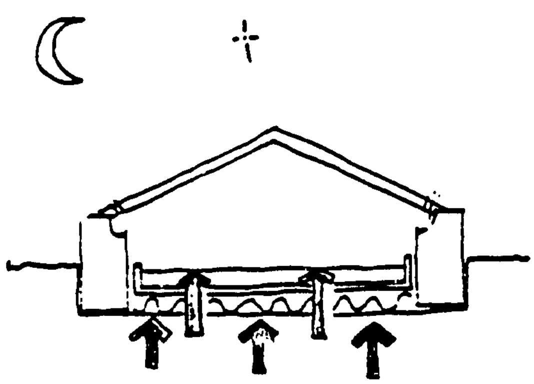


Fig. 10

Other Heat Losses (15% to 30%)

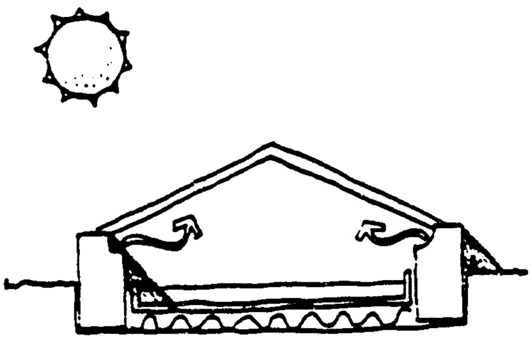


Fig. 11

The magnitude and type of other possible heat losses depend on the unit's configuration and the care taken in its construction; for example, losses resulting from the shading of the water basin (Fig. 11). The amount of sunlight not reaching the brine because it is intercepted by structural elements or end walls will depend on their size and placement. Careful design and placing of the units can minimize this effect.

Evaporation of the distillate can occur if the collection trough is not protected from reheating or if the distillate is not quickly removed from the system. Reevaporation would entail using energy to repeat the entire vaporization-condensation cycle without increasing the yield.

The energy exchanges described in the preceding sections are inherent to the technology of the system. The heat losses they cause can be reduced but never completely eliminated. Other negative heat transfers are inevitable in normal operational procedures. These include the heat carried out of the system by the warm distillate and the heat lost when warm concentrated brine is flushed out. The latter can be minimized by carefully choosing the hours for removing the unwanted brine from the unit so that it is done when the brine temperature is lowest.

A final very important cause of heat loss in operation can be the result of the unit's planning and the care taken with its construction. Large amounts of energy can escape if there are flaws in the fabric of the system which allow the loss of vapor, brine, or distillate (Fig. 12). Some leaks may occur at the time of construction. Others may develop with use and time. Any leak will adversely affect the efficiency.

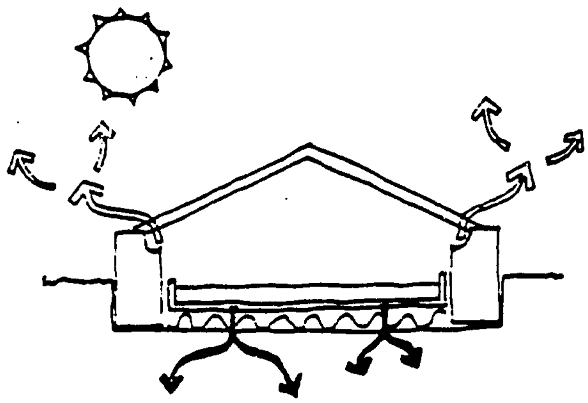


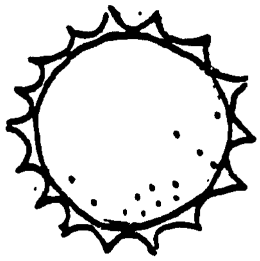
Fig. 12

Heated water leaking from the basin carries away the energy used to heat it. Even small water leaks can dampen the insulation beneath the basin and allow more heat to be lost to the ground by conduction. Vapor losses to the air remove the heat that was required for evaporation. Leaks in the distillate collecting troughs result directly in loss of the final product and all the energy that was required to produce it.

Any leakage carried to the extreme could result in a complete non-function of the system. Even minor leakage will result in a proportionate reduction in efficiency. These are losses that can be minimized by appropriate choice of materials, careful construction, and regular maintenance.

The physical laws by which the still operates are fixed. The other considerations that affect its performance can fluctuate widely. It is seldom that a still design made for one region can be copied exactly in another. Most situations, especially those of developing countries, will demand that designs be tailored specifically to the available materials and the skills of the local workers. Many variations can be made on the general theme of stable structure, sloping transparent cover, and impermeable basin. The still will function efficiently if the principles outlined in the preceding sections guide the design.

4



CLIMATIC FACTORS AND SOLAR STILL PRODUCTION

The sun provides the energy in the form of radiation which fuels the solar distillation process. However, it is not the only climatic factor involved in the still production and the cost of distillation. Other features of the climate can affect the efficiency of operation and the length of the working life of a particular still design. Although certain generalizations may be made as to the potential for solar distillation in broad climatic zones, the productivity of a particular still will be directly related to the microclimate of the area in which it is located.

Selecting appropriate general and specific sites for solar distillation units will involve compromises between (1) the needs and convenience of the users; (2) the availability of suitable land; and (3) the climatic factors that control the still's operation and efficiency.

Four features of the microclimate will have a major influence on the unit's distillation rate, total water production, and relative permanence:

1. the amount and type of solar radiation,
2. the surrounding air temperatures,
3. the amount of annual rainfall, and
4. the occurrence and force of winds.

These factors not only affect the production on a particular day, but other things being equal, will cumulatively determine the monthly and annual production of a particular unit. The climatic extremes to which the site is subject should control the choice of materials of which the still is made and its design.

Radiation

The Effect on Efficiency. The amount of solar radiation received by the solar still is the single most important factor affecting its performance. The greater the amount of energy received, the greater will be the quantity of water distilled. Still productivity is dependent on the intensity and duration of the radiation, which varies both by hour of the day and by season.

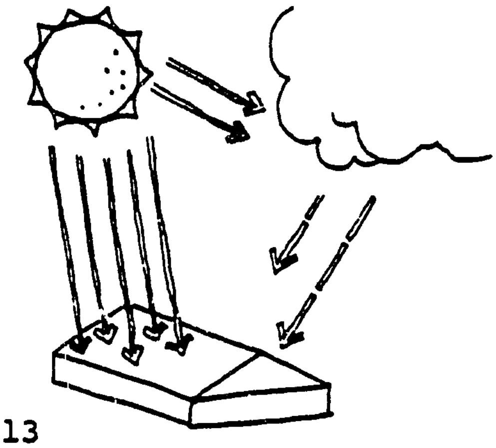
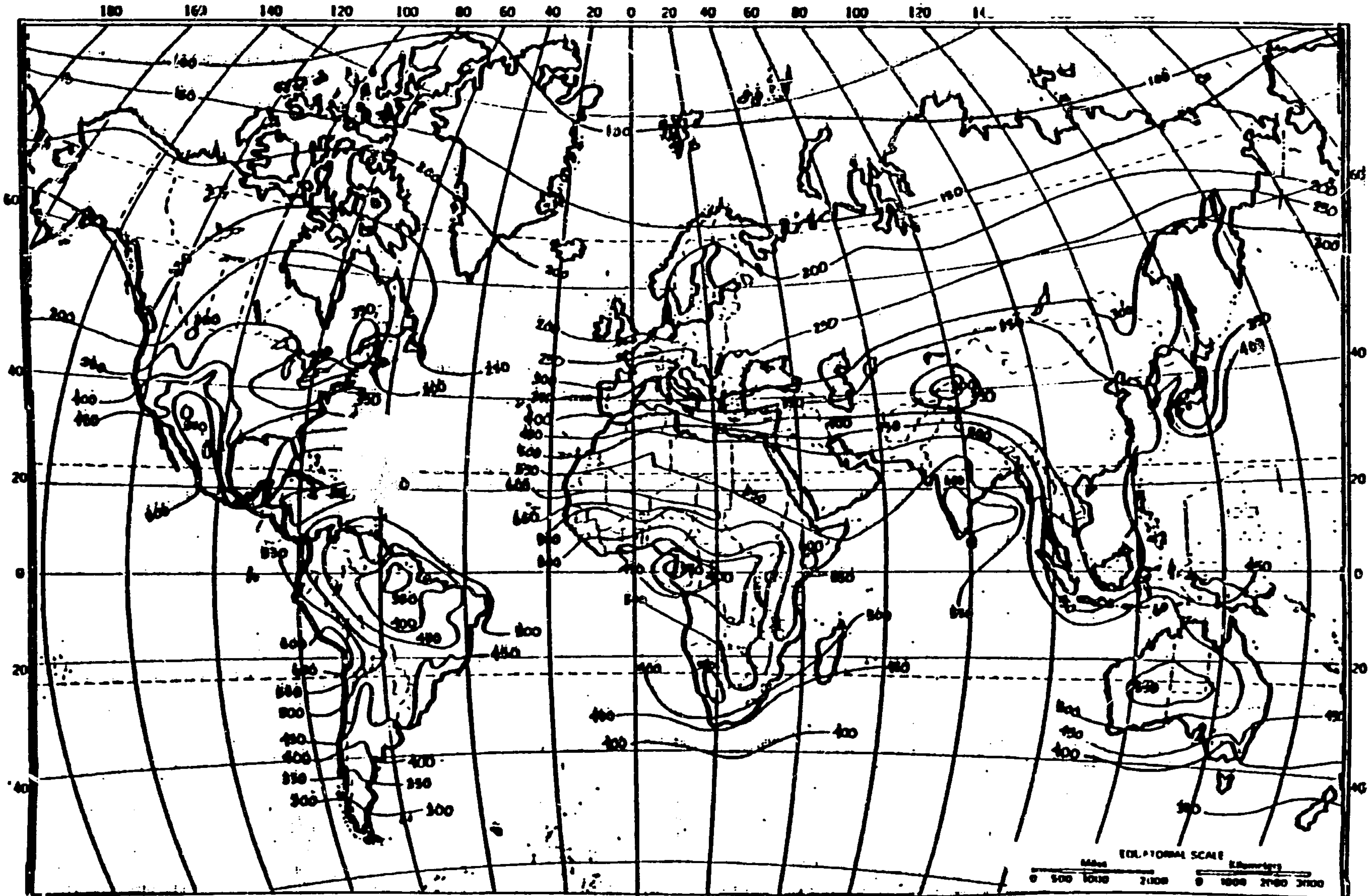


Fig. 13

The usable energy (Fig. 13) will be a combination of radiation from the rays of the sun (direct radiation), and energy originating in the sun but scattered by water or dust particles in the air (diffuse radiation). Solar technologies that require concentrating the sun's energy employ only direct radiation. Devices such as a solar still respond both to direct radiation and diffuse radiation. The latter can represent from 10% to 40% of the total energy on a mostly sunny day. Most radiation-recording instruments respond simultaneously to both types of radiation, so the data they supply can be used directly to estimate the energy available to distillation units.

Radiation records are made at a growing number of meteorological stations throughout the wrold. The following maps (Maps 1-4) indicate the levels of radiation in broad terrestrial zones for four typical months. Twelve monthly radiation maps, from which the examples are redrawn, were prepared by G. Lof and John Duffie and published by the University of Wisconsin in 1966. Solar radiation data by continent, country, or region can usually be obtained from meteorological stations in the area under consideration. These more detailed records should be consulted for feasibility studies and detailed design work.

Figures on the seasonal percentage of cloud cover are roughly the converse of total radiation figures. Data on cloudiness is usually available from local meteorological stations, even those where radiation measurements are not made. Traditionally, records of cloudiness are made by observers estimating the percentage of sky covered at certain hours. The total annual hours of direct sunlight are graphed in Map 5. It represents the total possible hours of sunlight minus those in which clouds cover the sun. Data from satellites now makes possible the computer analysis and mapping of the average percentage of cloud cover by area, hour, and season. These records are collected and published in the United States by the U. S. Department of Commerce (94).

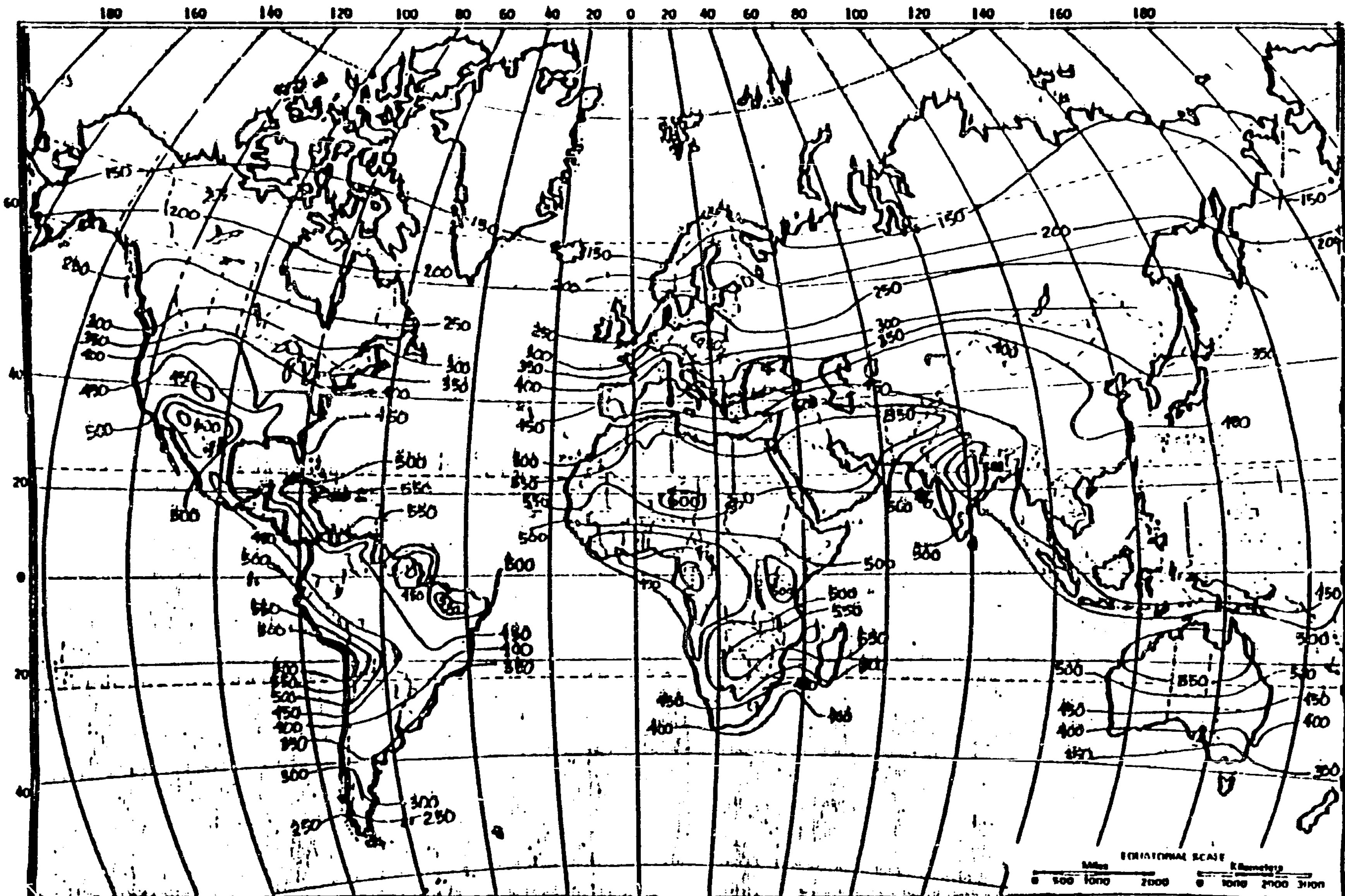


Daily Means of Total Solar Radiation (Direct + Diffuse) Incident on a Horizontal Surface, Cal/Cm^2/Day (Langleys/Da
Source: Lof,G., Duffie,J.,Smith, C., "World Distribution of Solar Energy", Univ. of Wis., 1966.

Map 1. World: Average Radiation for March (cal/cm^2/day)

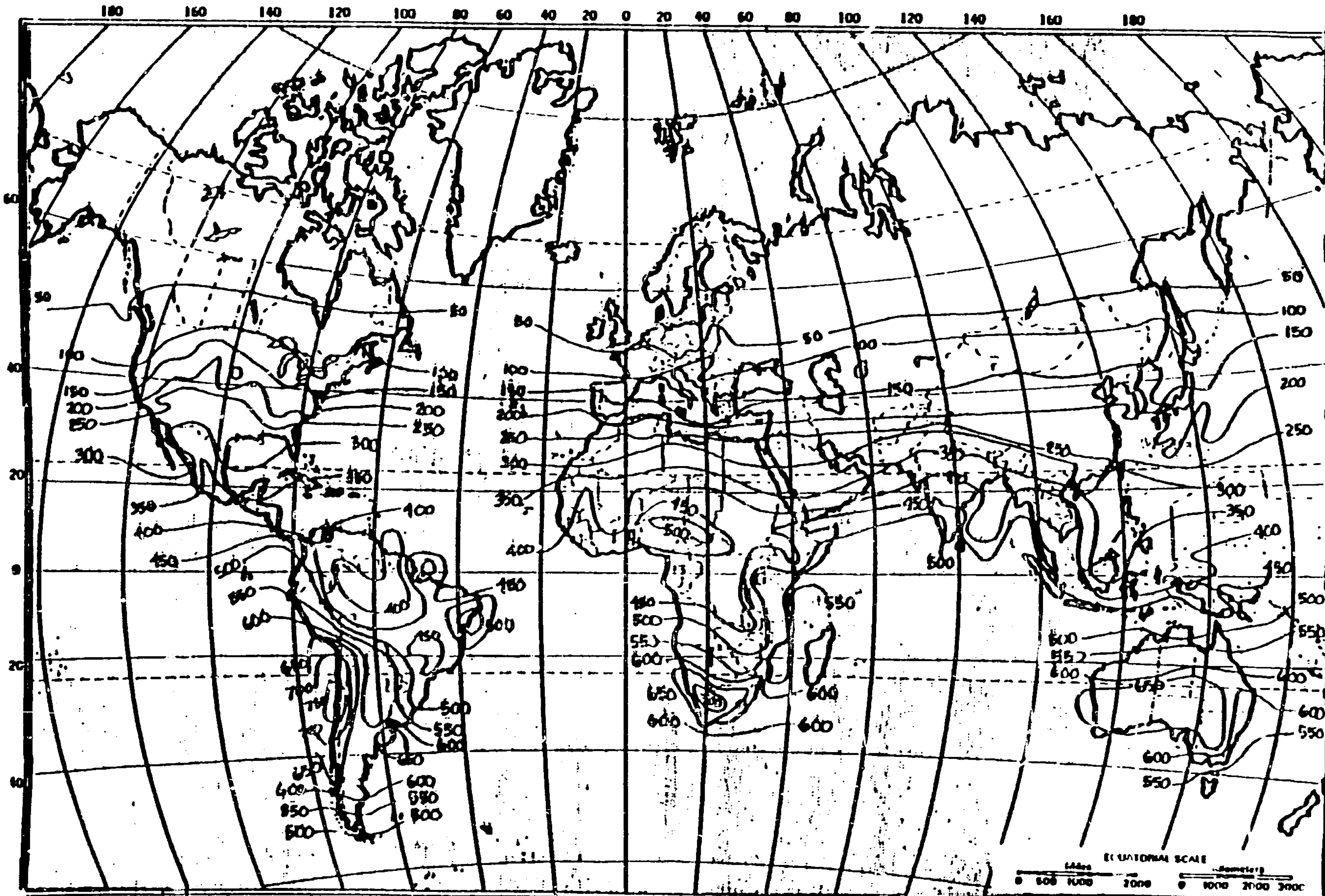
Daily Means of Total Solar Radiation (Direct + Diffuse) Incident on Horizontal Surface, Cal/Cm²/Day (Langleys/Day)
Source: Lof, G., Duffie, J. Smith, C., "World Distribution of Solar Energy" Univ. of Wis., 1966.

Map 2. World: Average Radiation for June (cal/cm^2/day)



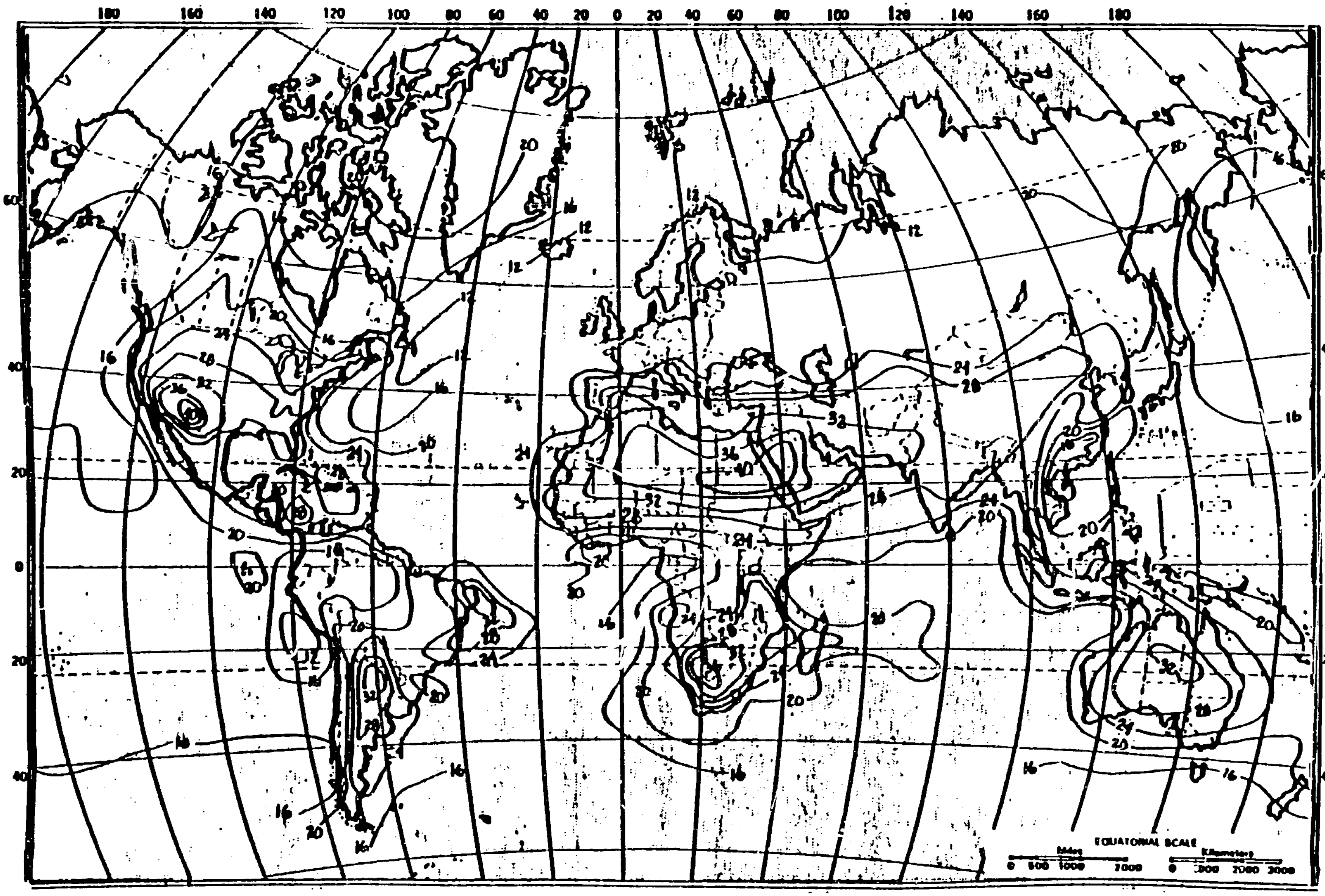
Daily Means of Total Solar Radiation (Direct + Diffuse) Incident on Horizontal Surface, Cal/Cm^2/Day (Langleys/Day)
Source: Lof, G., Duffie, J., Smith, C., "World Distribution of Solar Energy" Univ. of Wis, 1966.

Map 3. World: Average Radiation for September (cal/cm^2/day)



Daily Means of Total Solar Radiation (Direct + Diffuse) Incident on Horizontal Surface, Cal/ Cm^2/Day (Langley /Day)
Source: Lof, G., Duffie, J., Smith, C., "World Distribution of Solar Energy", Univ. of Wis., 1966

Map 4. World: Average Radiation for December (cal/cm^2/day)



Source: Daniels, F. (19)

Map 5. World: Distribution of Solar Energy (hundreds of hours per year)

The greatest part of the energy available for distillation arrives as direct radiation. The quantity of energy received on a horizontal surface depends on the angle at which the sun's rays arrive. The maximum direct radiation occurs at the hours and seasons when the sun is most nearly overhead (Fig. 14). Regions within the tropics receive the greatest amount of radiant energy annually because the sun is relatively higher in the sky throughout the year.

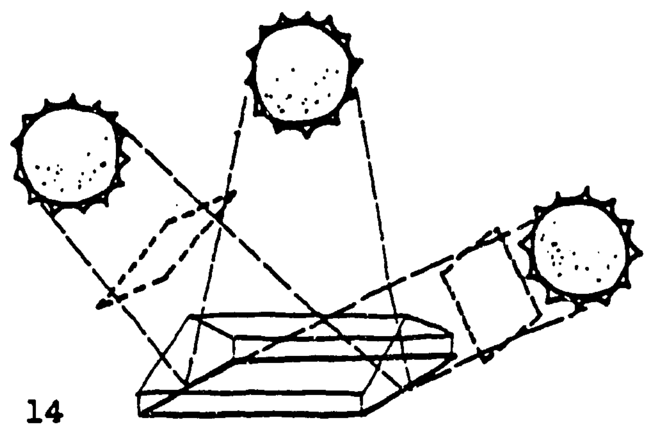


Fig. 14

In the absence of clouds, monthly solar still production will be highest in those seasons and geographical regions where elevation of the noon sun is highest. Figures 15-18 show clear-day radiation levels for representative latitudes. The maximum, minimum, and average sun angles at noon in a given latitude can be easily calculated. The noon sun elevation (90° minus the latitude) at the equinoxes in March and September is usually

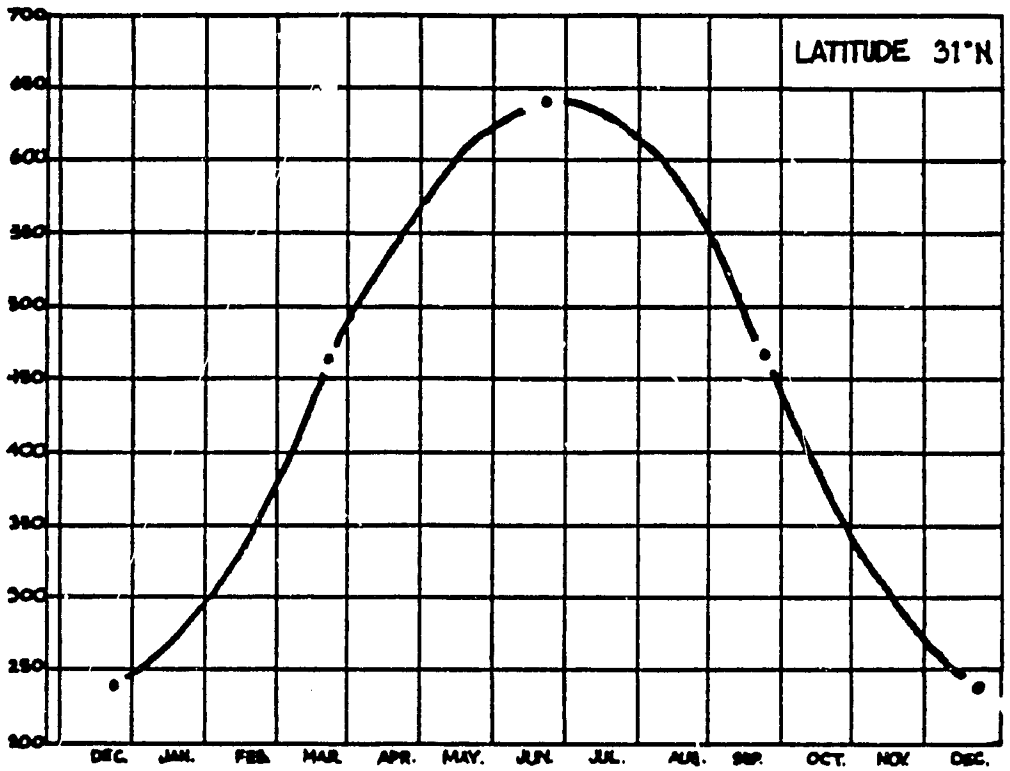


Fig. 15

Direct Solar Radiation Incident on Clear Days on a Horizontal Surface, (cal/cm²/day).

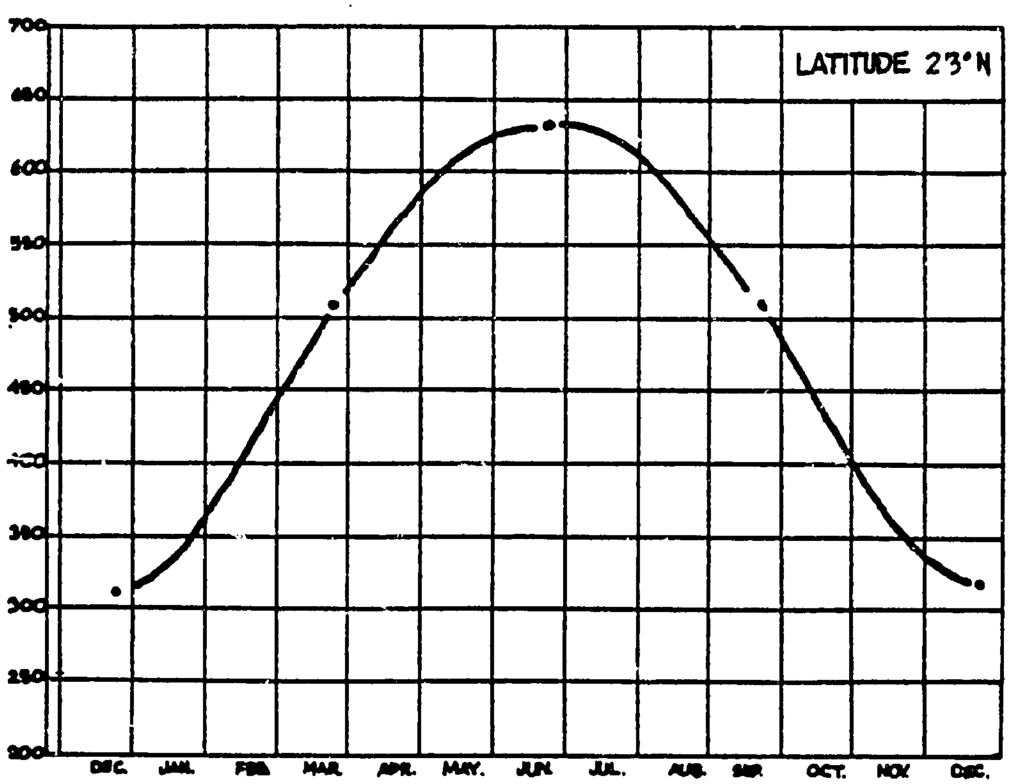


Fig. 16

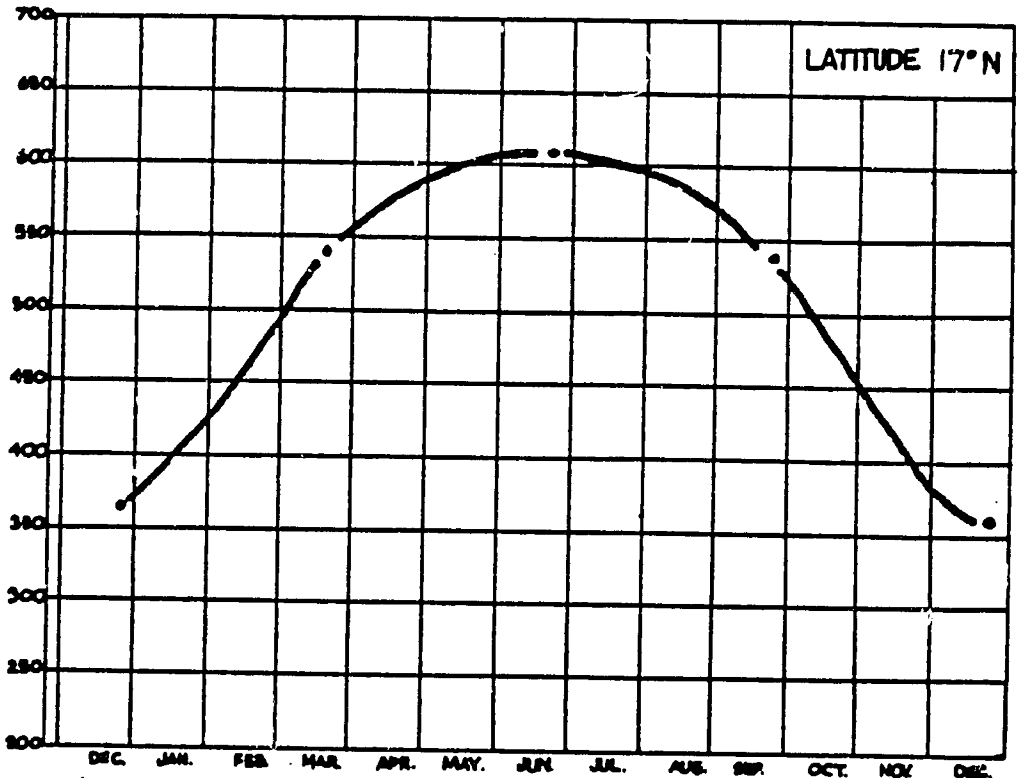


Fig. 17

Direct Solar Radiation Incident on Clear Days on a Horizontal Surface, (cal/cm^2/day).

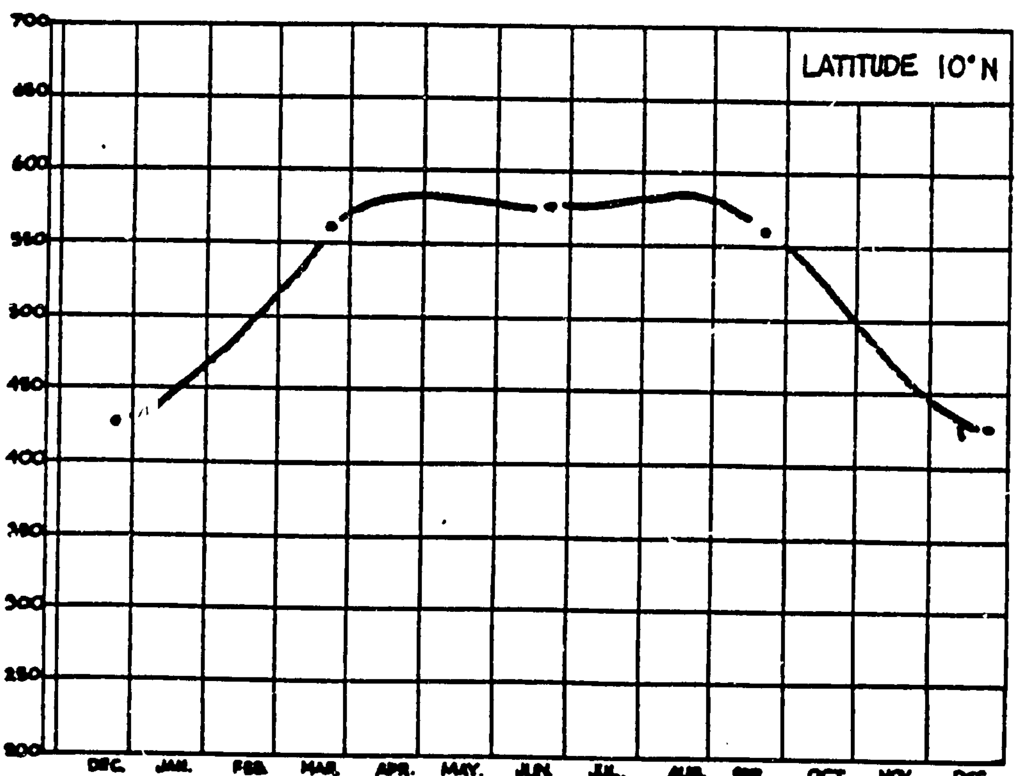


Fig. 18

used for design purposes. Sun angles for any hour of the day at any season can be found conveniently in sun angle charts or tables published for that purpose (91).

Because of the continually changing sun angles during the day, the hourly amount of direct radiant energy falling on the still will vary from a maximum at solar noon to near zero in the early morning and late afternoon hours. Solar still production will follow a similar cyclic pattern. However, proportionate production rates will lag behind the movement of the sun because of the time required to heat and cool the water within the still and the materials of which it is made.

Radiation measurements are generally reported as the amount of energy that arrives per unit area. The standard unit of measurement is one calorie per square centimeter (1 langley). One langley per minute (221 BTUs per square foot per hour) is usually taken as the average received at the earth's surface on clear sunny days. If all this heat were available to evaporate water, the heat arriving on a 10 sq. ft. horizontal area would be adequate to distill over two gallons of water per day at summer temperatures. (An area one meter square would receive enough heat to produce approximately 8.5 liters.) Actually, only about one half or less of this energy can effectively be captured for distillation by simple stills. Table 2 illustrates the amount of energy received on various surface areas and the equivalent production of distilled water by a simple still operating at 30% and 50% efficiency.

In geographic regions where an annual average of between 300 and 500 langleys arrive per day on a horizontal surface, simple solar stills should function effectively. Most solar distillation fieldwork has been done in the latitude belts between 23° and 35° N and S; there, radiation can be intense, but seasonal air temperature variations are strongly marked. Within the tropics (23° N to 23° S) high radiaiton figures are common along with more uniformly high air temperatures. Stills will be most productive in arid or semiarid areas which have clear atmosphere and relatively infrequent periods of cloud cover.

Other Considerations. Certain wavelengths in strong sunlight can speed the deterioration of plastics. Research continues to improve the weatherability of both plastic films and rigid or semi-rigid plastic sheets. Only plastics especially produced to withstand strong sunlight should be considered for permanent installations.

Strong radiation can also have a detrimental

Table 2

Quantity Of Solar Energy Received By Different Areas And Estimated Still Production When Radiation Is 1 Cal/ Cm^2/Min. (221 BTU/Ft^2/Hr)

Area	Energy			Daily Still Production At Efficiency:	
	langleys	kcal/day*	BTU/hr	30%	50%
1 m^2	10^4	5.0×10^3	2380	2.6 liters	4.3 liters
10 m^2	10^5	5.0×10^4	2.38×10^4	25.9 liters	43.1 liters
100 m^2	10^6	5.0×10^5	2.38×10^5	258.6 liters	431.0 liters
1 ft^2	929	464	221	.06 gallons	.10 gallons
10 ft^2	9290	4640	2210	.62 gallons	1.03 gallons
100 ft^2	92900	46400	22100	6.18 gallons	10.30 gallons
1 acre	4.05×10^7	2.02×10^7	9.64×10^6	2692 gallons	4487 gallons

Conversion factors: 1 kcal = 1,000 cal; 1 BTU = 0.252 kcal; 1 acre = 43,560 ft^2

Energy required for heating and evaporation: 1070 BTU's/lb. (580 c/gm)

*Assuming 500 min/day of solar radiation.

effect on sealing agents, wood, and paint. A more rigid maintenance schedule may be required for stills than is necessary for buildings whose vertical construction elements are protected for at least part of the day from strong sunlight.

Ambient Air Temperature

The Effect on Efficiency. Simple solar stills operate most effectively when surrounding air temperatures are high. This implies both a high water and a high condensing-surface temperature. In normal summer ranges, an increase of about 5% in efficiency in operation can be expected for each 10° F. (5.5° C) rise in the temperature of the surrounding air (83).

In practical production terms, this would mean that a still producing .8 gallon/10 $ft.^2$ (3 liters/square meter) on a sunny cool-season day (maximum air temperature of 70°F, 21°C) might be expected to produce nearly a gallon (3.75 liters) on an equally sunny day in the warm season (air temperature 110°F, 43°C).

Most research with still units has taken place in areas on the fringe of the temperate climatic zone, where annual average air temperatures are moderate. The efficiencies and annual production quantities reported there may be conservative when compared to possible still efficiencies in sunny tropical or semi-tropical regions where daytime temperatures are consistently higher.

Other Considerations. Although the increase in distillate production as air temperatures mount appears to follow the increase in human drinking water requirements, it falls far behind the increase necessary in regions where daytime temperatures are high. In the example mentioned above, the increase in distillate attributable to a rise in temperature from 70°F to 110°F would be only 20%. Over the same rise in temperature, the drinking water requirements of an individual might rise over 300%, depending on his occupation and degree of exposure to the air. In projecting production requirements for the purpose of still design, it is the human water consumption rate in the hot season that is critical.

High diurnal and seasonal ranges in air temperature indicate an even higher range in the microclimate near the ground. These temperatures will effect the structural materials of the still units. It is the surface of the earth or horizontal structures on it that suffer the greatest extremes, becoming hottest during the day as solar radiation passes through the air to deliver its heat to the surface it strikes.

In the evening the reverse occurs. When a surface is exposed to the night sky, nocturnal outgoing radiation can lower its temperature well below that of the night air.

The extent of expansion and contraction of the materials used in still construction will be determined by these surface extremes and not by recorded maximum and minimum air temperatures. The diurnal range of temperature of an exposed surface during clear dry-climate weather can be well over 100°F (56°C). Air temperature range will probably be less than 40°F (22°C). Records made with a thermometer sealed to a metal plate placed on the ground at the location of the proposed still will give an indication of the temperature extremes the designer should consider.

Although these extremes may be somewhat tempered by the thermal inertia of the water within the unit, the changes in dimension of materials over large temperature differences can be substantial. Even small units must be flexible enough to allow for daily dimensional changes if glass is not to crack or joints to weaken and leak vapor to the atmosphere.

Air Movement

The Effect on Efficiency. The passage of wind over the cover of a simple solar still causes a series of reactions within the still that are complicated. The effect of the wind will be a function of the shape and orientation of the still in relation to the wind direction, the temperature at which the still is operating, and the materials of which it is made. In general it can be assumed that air movement over the outside of the still will cool the condensing surface and result in an interior thermal balance different from that which would be obtained by the unit if it were operating in quiet air.

Research done on the effect of this new balance on production has produced contradictory data. Experimental results range from those which indicate that increased wind speed has a negative effect on productivity to those which record (83) a positive increase in production of 11% as wind speeds rise from 0 to 4.8 miles per hour (2.1 m/sec). Perhaps because it is most convenient, it is generally held that wind has little effect on solar still production. However, research done in Egypt reported by Soliman in 1971 (80) and by Garg in India in 1975 (28) indicates that if water temperatures inside the still are high, as they would be in most tropical areas, increasing the wind speed will increase the yield of distillate.

Other Considerations. In practice, this positive effect of wind can be more than offset by other factors. Wind can cause increased heat and vapor losses in stills that are poorly constructed or those which have developed leaks with continued use. Their production will be reduced proportionately to the amount of vapor that escapes. The positive and negative air pressures on the system set up by rapid air movement over it can add to this vapor loss dramatically. Air leaks are not always easily noticed, and their prevention requires routine maintenance and a careful inspection of the units after any unexplained fall in production.

In certain areas, wind-blown dust and sand may come to rest on the transparent cover, cutting down the radiation that must pass through it for the still to function. Some unit designs are more prone to this defect than others, especially those with V-shaped covers or those in which supporting elements are raised above the transparent surface. In regions where blowing soil is expected to be a problem, still units should be carefully designed and positioned so that the same breezes that deposit the sand or dust will later remove it.

Finally, severe windstorms or even small whirlwinds can spell disaster for lightly built units and can cause serious damage to sturdy ones if precautions are not taken immediately before the onset of high wind. Flying debris can smash glass and aerodynamic lift can remove panes or destroy supporting elements. The frequency of occurrence, force and direction of the wind, and amount of warning usually available should determine not only the location of the still and construction details of the units but in some cases the decision as to whether solar distillation should be attempted.

Rainfall

The Effect on Efficiency. The overcast skies of rainy days or seasons cut down or completely stop the production of solar-distilled water. However, if it is collected, the rainwater can frequently more than compensate for this loss. Most large basin-type stills that have been built include arrangements for the collection of the rain that falls on the sloping still covers. Researchers estimate that from 80% to 100% of the rainwater can be recovered in stills designed for that purpose They report that almost all the water that falls on the covers can be retrieved during short intermittent periods of steady rainfall. Little can be collected during very light rains. In extremely heavy downpours much of the runoff may be lost, depending on the still design and the size of piping elements.

A solar still with a basin area of 10 square feet (1 m^2) distilling an average of .8 gallons (3 liters) per day would produce an average of 292 gallons (1,095 liters) of distilled water in one year. Collecting rainfall at 80% efficiency from the same still area in a region with an annual rainfall average of 20 inches (50 cm.) would result in the recovery of 100 gallons (400 liters). This would be over one third of the amount distilled by the sun.

The general relationship between the annual rainfall and the amount that might be collected on still units is summarized in Table 3.

Table 3

Annual Rainwater Retrievable
(Assuming 80% collection efficiency)

Annual Rainfall (inches/year)	10	20	30	40	50	60
Collected Rainfall (gal/10 ft^2/year)	50	100	150	200	250	300
Annual Rainfall (cm/year)	25	50	75	100	125	150
Collected Rainfall (lit/m^2/year)	200	400	600	800	1000	1200

A comparison may be made with the annual distillate production in similar size still units at various levels of production (Table 4).

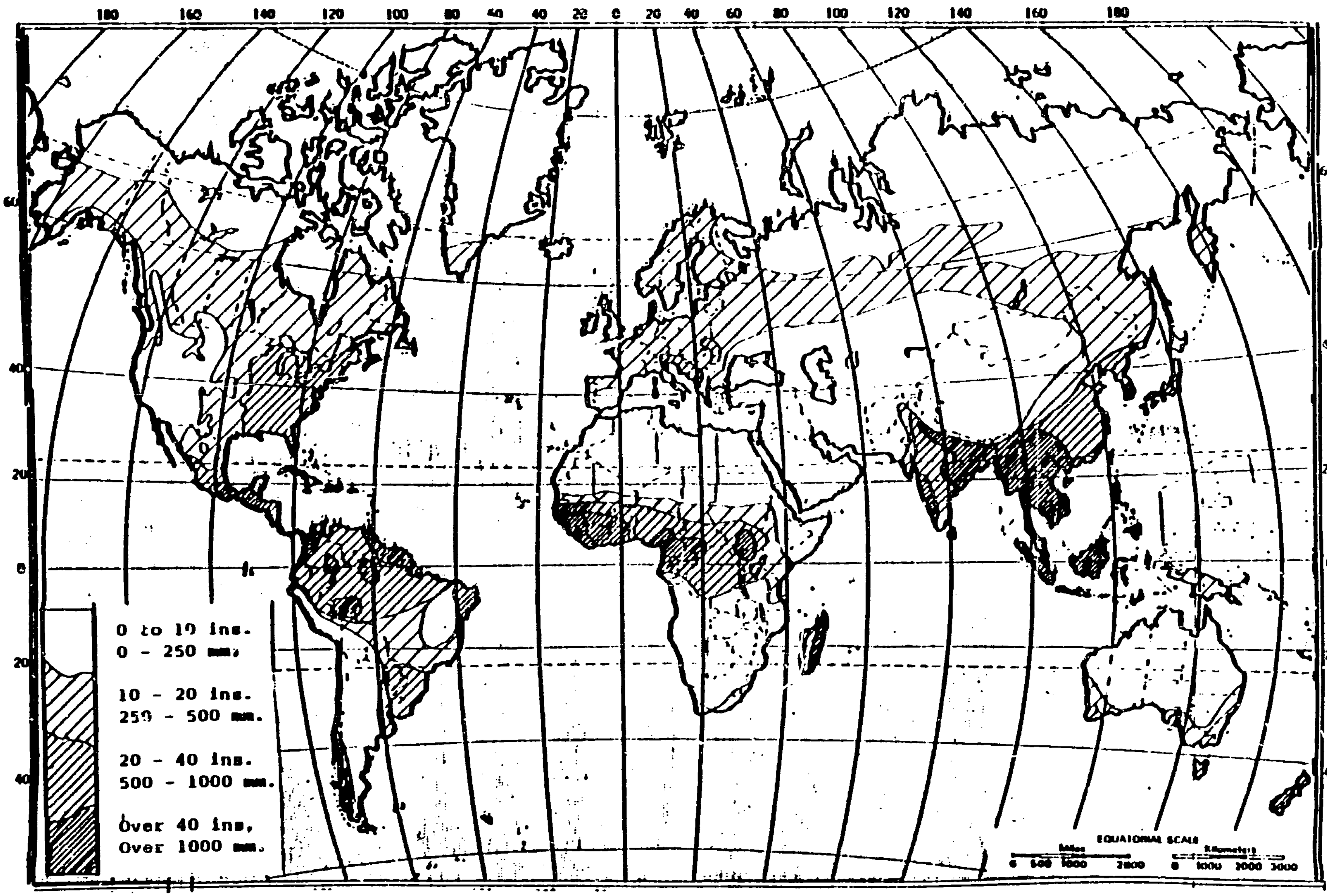
Although annual figures are helpful in preliminary estimates, in most tropical regions rainfall is concentrated in certain seasons. Semiannual rainfall figures are shown in Maps 6 and 7. Monthly figures rather than annual or semiannual ones should be used for estimating still production and rainfall amounts in critical periods. For example, if the monthly rainfall of 5 or 6 inches

Table 4

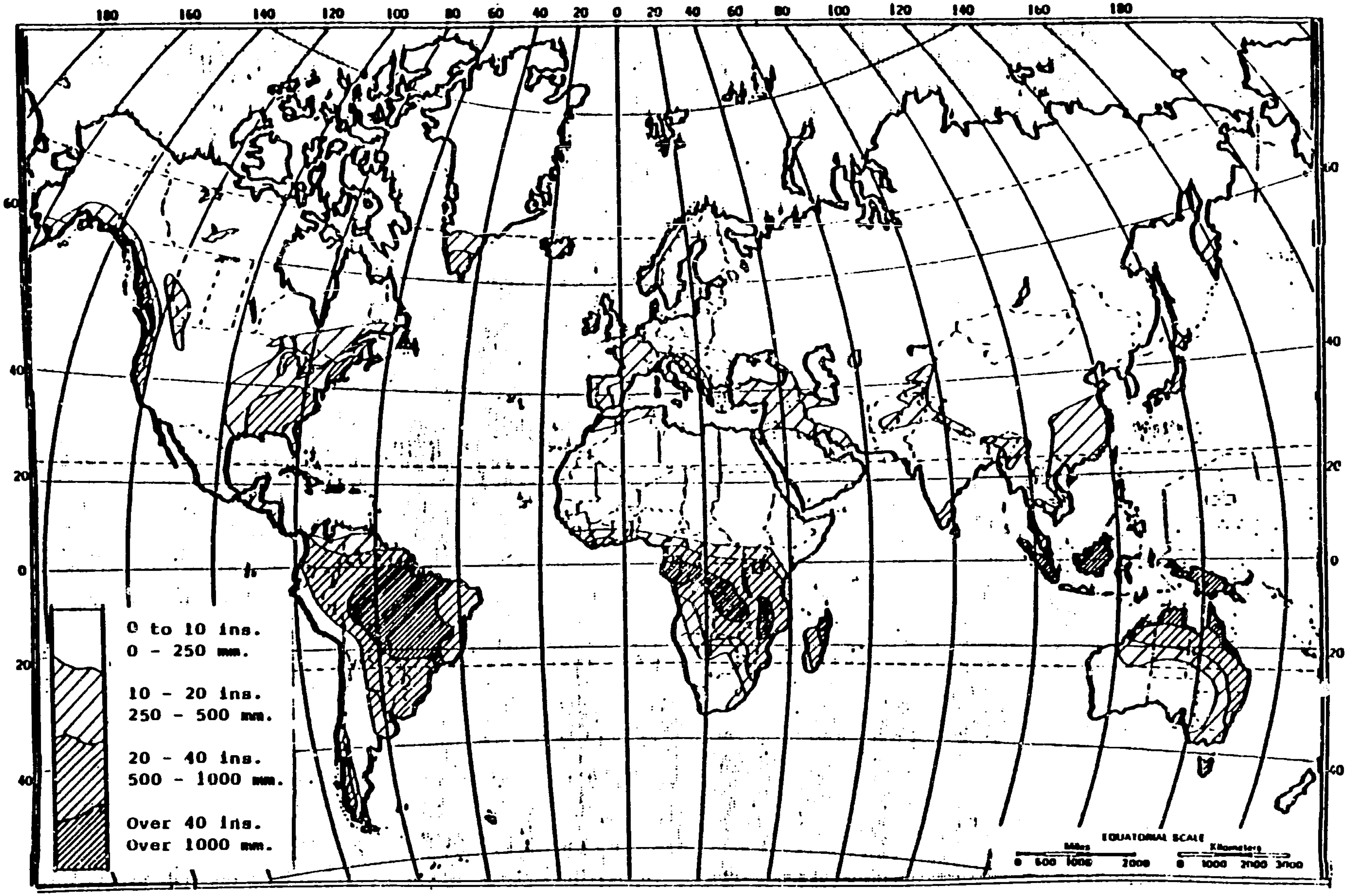
Annual Solar Distillate Production

10 Ft^2 Still Area		Meter^2 Still Area	
Still rated gal/day	Product gal/year	Still rated lit/day	Product lit/year
.5	183	1.5	548
.6	219	2.0	730
.7	255	2.5	912
.8	292	3.0	1095
.9	329	3.5	1278
1.0	365	4.0	1460

(13 to 15 cm) is collected with reasonable efficiency, it could replace completely still production during that month. Rainfall in lesser amounts may compensate for the



Map 6. World Rainfall Patterns, May through October



Map 7. World Rainfall Patterns, November through April

loss in still production that results from partially cloudy conditions or may simply be used to supplement still production.

Other Considerations. The question as to whether rainwater retrieved in this fashion is suitable for drinking purposes will depend on local conditions. Even careful collection methods will not produce water that approaches the purity of the product of the still. Various solid particles or mineral elements on the covers will be picked up along with any organic contaminants that might have settled there. In many large-scale installations, rain water is stored separately from the product of the still.

Attempting to collect rainwater from small village or family units may cause more complications than the amount collected would justify. Small-scale stills in private or village compounds are more susceptible to organic contamination than large-scale units, which are usually in more protected areas. However, even casually collected rain water will be more free of minerals than water from the sea or brackish local wells.

Rain runoff from roofs or nearby slopes is routinely collected and stored for household use in many water-short regions. In many other areas where it could be important, no attempt is made to retrieve and store it. Areas of stabilized earth, the corrugated iron, concrete, and tile roofs of houses can be used as catchment areas. If the solar still is to be used as a rain collector, it should be supplemented by rain recovered from other suitable surfaces nearby.

Separate storage and use of rainwater can be arranged. If the rainwater is for human consumption, sand filtering can eliminate solid contaminants and boiling or disinfecting can remove disease-carrying organisms.

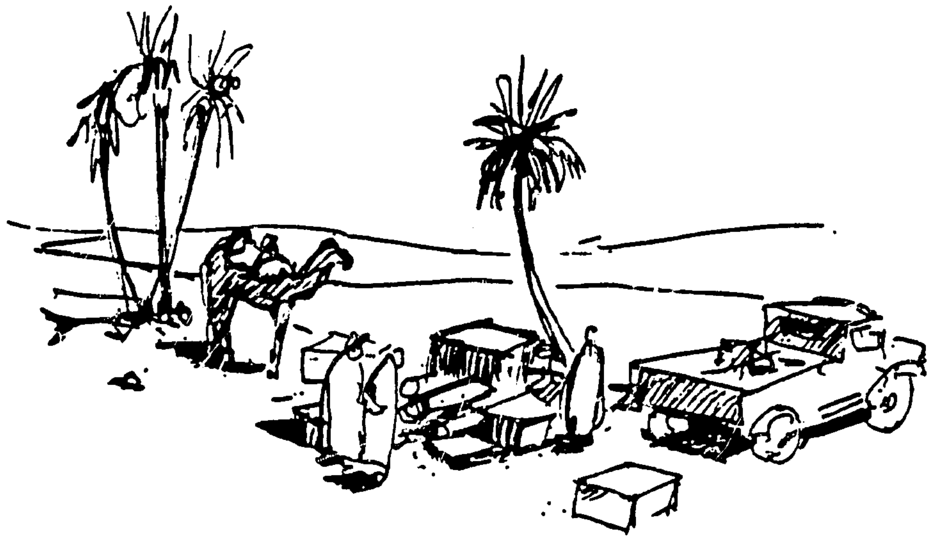
Hailstorms are a very serious potential hazard. Sizable hailstones could certainly destroy both glass and light plastic still covers. Hailstorms can come with little warning and could cause very expensive losses. Hail has not yet been reported as a cause of still destruction. In areas where it is common, special protection may be required in the season when hailstorms are likely to occur.

Climate, especially solar radiation levels, will be the determining factor in still production. To avoid disappointment, stills must be located where annual radiation levels are high. Monthly radiation levels must be especially high in those months when the most distillate will be needed. In cases where collected rainfall is to be used to supplement still production, the amounts recorded in critical months should determine the size of runoff areas and storage capacities.

If solar distillation is being considered, the collection of meteorological data will make possible estimates of solar distillate production in a specific region. On a sheet similar to Figure 19, the annual averages based on a ten-year (or longer) period should be collected. If no climatic data is available for the proposed location of the still, records from several of the nearest meteorological stations can be interpolated to provide a reasonable picture of local climatic conditions. In some instances, the people of the locality can assist in this estimating process. Radiation figures (Fig. 19, item 4) may be difficult to find. If they are unavailable at nearby stations, they can be approximated from world radiation maps or estimated by taking the possible clear-weather radiation figures based on latitude (samples are graphed in Fig. 15-18), which can be modified by local recorded figures on sunshine duration (item 5) or figures on cloud cover (item 6).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. Temperature Ave. Mo. Max.													
Ave. Mo. Min. (C° or F°)													
2. Wind Direction													
Ave. Speed (m/sec, mi/hr)													
3. Rainfall (mm or ins)													
4. Radiation, Ave. (cal/cm²/day)													
5. Sunlight (Ave. Hrs/day)													
6. Cloud Cover (% during day)													
Location:								Latitude:					

Fig. 19. Climatological Data Worksheet



5

CONSTRUCTION MATERIALS

The materials out of which stills are made are those generally used in civil engineering and architectural works. The local standards of those professions can be consulted for specifications and methods of quality control applicable to the area where the still is being built. Because of the isolated locations in which most stills will be appropriate, and because of the conditions under which they must be operated and maintained, certain special requirements should be recognized.

The following comments on the materials used in still construction and the characteristics they should display have been drawn from a variety of sources, especially works describing experience with village sized solar still units in tropical areas: (items 54 Lawand, 83 Talbert *et al.*, 37 Howe and Tleimat in bibliography).

General Considerations

1. Materials used in still construction must have a long life under exposed conditions.

2. They should be strong enough to resist high winds and slight earth movements.

3. They should be non-toxic and not emit vapors when heated.

4. Those exposed to saline water should resist corrosion caused by water-borne salts. Those carrying distillate should not contaminate it or be corroded by it.

5. They should be of a size and weight that can be conveniently packed and carried by the type of transportation that will be used to move them to the construction site.

6. They should be easily handled and used in field situations.

7. When possible, local materials convenient to the site should be employed in construction, both to lower cost and facilitate repairs should they become necessary later.

The Transparent Cover

The cover is the primary working component of the distillation process and the most exposed. It must permit the entrance of solar radiation and absorb back radiation from the hot brine. It must also be the surface on which the vapor condenses. Ideal properties of a cover material are listed below:

1. The cover material must be highly transparent (85% to 95%) to short wave solar radiation (0.3 to 3.0 microns) and nearly opaque to long wave heat radiation (over 3.0 microns).

2. At least one surface must be "wettable" so that water forms sheets on it rather than beads or droplets. It should not absorb water.

3. It must be unaffected by age or by extreme climatic conditions of sunshine, rain, high wind, etc. over long periods (10 to 20 years), or if less permanent, the material must be capable of regular replacement with ease and at equivalent cost.

4. It must withstand high temperatures (180°F, 80°C) and high humidities (100%) on one surface while the other surface is exposed to lower temperatures and humidities.

5. It should neither reflect nor absorb large amounts of incoming solar radiation.

6. It must be capable of resisting the attacks of insects and small animals, and shocks caused by wind-blown debris.

<u>Glass</u>. Glass fulfills most of the above requirements and is the most common material used for still covers.

The glass used for stills is ordinary window glass, 3/32 to 3/16 inches thick (2.5 to 3.5 mm). It is usually available in the local markets, although frequently it must be transported a considerable distance to the site where it is to be used. Horticultural glass (much cheaper than window glass but adequate for still covers) is used consistently in Australian installations.

Glass is nearly an ideal substance for still covers. For permanence and durability it is unchallenged. Its drawbacks include its cost in most places, U.S. $.30 to $.50 per square foot ($3.00 to $5.00/$m^2$), its weight and fragility which make it difficult to transport, and its susceptibility to accidental breakage once in place. Unless special containers are designed and inland transport organized, high breakage figures must be included in its expected cost.

Plastic Films. It was hoped that the use of plastic films as covers would reduce the cost and eliminate transportation difficulties. Many films were tried in the 1950s and 1960s and most exhibited defects that caused their final rejection as still cover materials.

Polyethylene and other inexpensive films had a very short life when exposed to sunlight. On them, water has a tendency to form drops rather than sheets, allowing the condensate to fall back into the basin.

During the course of research, films more particularly suited to use as still covers were developed; films that were both wettable and more resistant to ultraviolet light. Plastic films specially tested for solar still use included wettable Tedlar (DuPont), Alcar (Allied Chemical), and wettable Mylar (DuPont). The most successful of these films appears to have been wettable Tedlar. This film (.004 inches thick) supported by air pressure was used as a still cover on the island of Petite St. Vincent in the West Indies and the Greek island of Symi. In both cases it was later replaced by other materials.

A two year study comparing the performance of wettable Tedlar (.002 inches thick) with that of glass was carried out at the University of California by Dr. Howe and Dr. Tleimat (83). The total production of the plastic covered still was 82% of one covered with glass. One reason for the reduced efficiency is that the thin plastic covers are more transparent to long wave radiant heat than glass, thereby allowing more of the still's heat to escape.

Two new films, Trycite and Tyril (developed by Dow Chemical Company) were tested on a simple wooden still (basin area, 1.16 m^2) by the Office of International Programs, Georgia Institute of Technology, in the summer of 1977. The properties of the films (wettability and weatherability) may have been equal to or better than earlier films. Their physical fragility in outside weather conditions would require frequent replacement that would soon raise their cost above that of glass.

The Dow Chemical Company estimated that the plastic film used in the sample still would cost approximately U.S. $.50 and would need to be replaced two to four times a year (60). Assuming replacement three times a year over a ten year period, the total cost would be U.S. $15.00. The cost of glass to cover the same area would be approximately U.S. $4.50. This diseconomy is especially high but not uncharacteristic of the other plastic films on which research has been done.

Actually, during the Georgia evaluation, the Dow films had to be replaced several times during the month of testing because of wind and rain damage. This may have been partially the fault of the wooden still which, although ingenious in design, was lightweight and not built to withstand wind. The operational efficiencies obtained with the experimental unit (30% to 55%) were roughly those that could be expected of a glass unit of the same size at that latitude.

The results of the Georgia Institute of Technology tests are not unlike those of field experiments with plastic films in Greece, Mexico, and the South Pacific. The constant flexing and fluttering in the wind, day and night over periods of weeks or months, causes more stresses than most light plastic films can be expected to withstand. The low cost of thin films, U.S. \$.05 to \$.15 per square foot (\$.50 to \$1.50/m^2) appears to be outweighed in practice by their short lives, especially under field conditions.

In spite of the considerable research and experimentation that has gone on with plastic films, no major still on which they are used as a cover is in operation today. Although research may continue to improve the suitability of plastic film, at present it does not seem appropriate to consider it for permanent applications in developing countries.

Rigid and Semirigid Plastic Sheets. Unfortunately there are few published reports of experiments using rigid or semirigid transparent plastic sheets as still covers. Recent research in the U.S. into plastic cover elements for domestic solar air and water heaters has produced a variety of transparent panels made of acrylic, polyvinyl flouride, or fiberglass. They are designed for long life under exposed conditions. Manufacturers' claims vary, and the composition of some of the newer examples is a trade secret. Most panels are roughly the same in cost but they show significant differences in wettability, physical strength, and aging properties. The estimates of their life spans range from ten to twenty years. These figures should, however, be accepted with caution until more long-term tests have been made. In America at the present time, costs of transparent or semitransparent plastic sheets is competitive with glass if the shorter life span of plastic is not taken into consideration.

As still cover material, plastic panels display certain advantages: their weight is less than 1/4 that of glass, they can be bent into self-supporting shapes, and they have a high impact strength. Although not shatter-proof, they would withstand most wind and hail storms better than glass panes. Their drawbacks include their low thermal conductivity (a characteristic desirable in heaters but undesirable in stills), their high thermal expansion rates that make tight seals difficult, and their high cost or complete absence in developing countries.

Large-scale designs using plastic panels have been proposed, and experimental models built, by Mr. Eckstrom of Aqua-Sol Inc. (see Appendix B). Considerable experience with early plastic films and a three year search and review of current materials led to a "hard top" design of corrugated long-lasting acrylic plastic, treated to increase wettability, and shaped into self-supporting arches. The 1978 cost of the cover material used in Aqua-Sol designs is U.S. $.45 per square foot. It should be reduced to less than $.35 if the material were used in quantity. To this must be added a $.15 per square foot charge for increasing wettability by abrasion (of this, $.10 is labor cost).

If this type of plastic material were used in developing countries, where labor charges would be reduced but transport expenses increased, it might be expected to cost between U.S. $.70 and $1.00 per square foot ($7.00 to $10.00/m^2); roughly the price of imported window glass if taxes and duty charges are equivalent. The company making the material estimates a life of twenty years. Mr. Eckstrom suggests that ten years may be a more realistic estimate of its efficient working life. Although theoretically the lifespan of glass is much longer, the effective working life of glass in the field locations may well be only ten years or less due to breakage in storms, accidents, and transportation.

The Aqua-Sol design, although planned for large units, could easily be modified for small ones. It, in fact, was tested in Minnesota (latitude 45°) as a model 10 by 12 feet in size. This unit produced a maximum of 4 to 4 1/2 liters per square meter per day. The designers estimate that this would be increased to a daily maximum of 5 or 6 liters per square meter in tropical locations. The Aqua-Sol plastic cover material was used to replace the Tedlar film on the Petite St. Vincent still in 1971. There it is reported to produce a maximum of 6.2 liters per square meter per day.

In developing countries the choice of a material to be used as a still cover will be limited. If glass is manufactured in the region it will usually be the logical choice. If glass must be imported, the alternative of plastic sheets should be considered when the cost is comparable and the characteristics of the plastic match the requirements of the still. Glass covered models could certainly be used in preliminary field experiements to test the usefulness and popularity of the technology. Later models could use plastic panels if the breakage of glass and the cost of replacement is seen to be a major factor in operating costs.

Support Structures

The supporting elements of the still can be made of a variety of materials and are probably governed more by the local construction materials and techniques than any other component of the still system. Basically what must be built are a base and solid side supports for the still, and a frame for the transparent cover above the basin. The cover frame should be made of members of small thickness so that they do not excessively shade the water in the basin. Ideal characteristics of support materials follow:

1. The materials should be heavy enough to allow the still to resist the effects of high winds, or it should be securly anchored with bolts or tie wires.

2. Their rates of thermal expansion and contraction should be moderate.

3. They should be unaffected by exterior climatic extremes, and the high temperatures and humidities within the still.

4. They should resist the effects of saline water, and those elements in contact with the ground must not be affected by soil conditions, organisms, or insects.

5. They should be of a size and weight that makes their transportation to still construction sites convenient and economic.

6. They must be easily handled in the field at the time of construction, require minimum maintenance, and

should be capable of field repair if required.

Wood. The original Las Salinas still built in 1872 was completely made of wood, and wood may still be the easiest material to obtain in many areas. It is far from an ideal material. Wooden members will warp and crack making airtight seals difficult. In few developing countries is wood adequately seasoned and these defects will be exaggerated. The extreme exposure and the difference in the humidity outside and inside of the still will affect unprotected wooden members quickly. They may require frequent replacement (every two to four years under extreme conditions).

Metal. Metal members can be much smaller than wood and their use can make sealing the system easier. However, they are subject to corrosion; steel especially would require special protective coatings. Aluminum and galvanized metal sections are more resistant to corrosion but not always obtainable in suitable sizes and shapes.

Concrete and Masonry. Concrete, cement block, or brickwork can be used for the base and sides of the still and in certain designs can support the transparent cover without a frame. These materials are stable, usually inexpensive, and utilize unskilled labor in construction. Some concrete sections can be cast in place and other members could be pre-cast at central locations. Concrete supporting members are necessarily heavier in section than wood or metal, but allowances for their shading effect can be made by slightly increasing still size.

Other Materials. Extruded plastic frame members have been used for glass supports and connections in American still tests. Specially formed plastic could prove convenient and economic if needed in large enough quantities to warrant setting up the production process. Until the distillation technology had has proved popular, this original expense would not be justified.

The choice of materials of which the still structure is to be made must be determined locally on the basis of what materials are available and economic, and the final design of the still tailored to those materials. In most areas, using concrete or masonry wherever possible will prove both economic and practical.

Evaporator Basin

The basin that contains the water to be distilled must be watertight. It must absorb the solar radiation that strikes it and transmit the heat to the water. Two systems of basin construction are possible. In one, the basin is made of impervious material. In the other, the basin shape is defined by ordinary construction materials and then given a waterproof lining.

The evaporator basin should have the following properties:

1. It must be impervious to water.

2. It must have a high absorptivity of solar radiation; e.g. be made of black or dark colored materials.

3. It should not deteriorate in saline water of high temperature (200°F, 95°C).

4. It should be resistant to puncture and abrasion.

5. It should be relatively smooth and easy to clean.

Metal Basins. Metal basins are frequently used in experimental models; either galvanized iron or other metals coated with protective black paint. Metal is impervious to water and relatively permanent, however it is difficult to protect from corrosion, and in most developing regions basins of metal will be more expensive than those of other materials.

Asbestos Cement. Using the same materials and techniques as used in the manufacture of roofing sheets, basins of asbestos cement were designed by Gomella and used in Algerian stills (83). The molded shape included the trough for the distillate. Similar designs were used in Australian experiments. Basins made of this material were heavy and fragile enough to be difficult to transport, but light enough to be adversely affected by high winds at their final locations. There is now some question as to the safety of drinking water collected on asbestos surfaces.

Molded Plastics. Still basins or complete still units have been constructed experimentally out of formed plastic and fiberglass. One American firm (Sunwater Energy Products, see Appendix B) currently manufactures a plastic domestic still unit with a basin area of approximately 16 square feet. It is made of molded black fiberglass covered with a single glass sheet. The cost would be high for developing country use (U.S. $180.00). This is an extremely attractive and well designed system, and many units have been sold in the southwest area of the United States. It could be considered for use as a model to demonstrate the technology. The Sunwater fiberglass bases are made by hand, but the design could easily be reproduced by any of a variety of plastic forming methods if they were to be made in quantity. Their light weight might cause problems unless firmly anchored to the ground.

Precast Concrete. A system of making basins or entire still units of precast concrete could certainly be considered. Many developing countries have experience in small scale precast concrete work. It would be quite possible to design a basin whose main surfaces were less than one and one-half inches thick (4 cm) with distillate troughs and cover support arrangements cast into the basin. A fifteen square foot basin of this type would weigh less than 250 pounds (115 Kg). Lightweight wooden molds could be taken by a small team of workers from village to village, and individual still units could be produced at a central location in any quantity desired. They could be transported short distances and fitted manually at the final location chosen for the stills. Considering the ease and economy with which precast concrete basins could be produced for small distillation units, it is curious that they have not been tried as a basin material.

Waterproof Basin Liners. An impermiable basin can be made by lining still walls that are made of any material and the surface between them with an impermiable material. Asphalt and plastic sheets have been used in experimental models. Asphalt or other tar based products are usually available in developing countries, and applied on the base and sides they can provide a waterproof surface in the basin. Hot asphalt can be mixed with charcoal dust or other blackeners to increase absorptivity. Some researchers report that during use, stills made in this fashion develop leaks that are difficult to detect. Others report that leaks can be avoided with careful construction (33).

Each region will have its own local materials and techniques used for waterproofing roofs. Some of these systems may be suitable for making still basins or basin linings. A slight loss in efficiency that might result could be compensated for by savings in construction costs.

The second method, that of lining the basin with an impermiable plastic liner, is used in many recent still installations. The most common lining material until recently was black butyl rubber sheets 1/32 of an inch (30 mils) thick. It was used in Greek, Australian, and Caribbean installations. Currently, less butyl rubber sheeting is produced in America and the cost has risen. Other plastics that are better suited for still lining are now competitive in price.

The basin lining material recommended by manufacturers in Ethylene-Propylene-Diene (EPDM). It is more abrasion resistant and longer lasting than butyl rubber. Although slightly higher in cost per pound it is slightly less in cost per square foot in sheet form. In 1978, EPDM liner in two-ply nylon reinforced sheets sold in the U.S. for \$.52 per square foot (\$4.78/m^2) 0.03 inches thick.

It is manufactured in heavier weights but this thickness should be adequate for still lining purposes. It is produced in 54 inch, 10 foot and 20 foot widths and sold in rolls 100 feet long. The Environmental Research Laboratory at the University of Arizona is preparing designs for a large Venezuelan still installation. They have proposed this EPDM as a basin liner after comparison with other lining materials.

Even in developing regions there will be considerable scope for choice in the design of the brine basin and the materials to be used in its construction. The cost of the basin can be a large proportion of the total still cost and a special effort to use the materials and building techniques that already exist in the area may result in substantial savings in the total cost of the still. If imported materials are to be used they should be chosen when possible from materials regularly imported into the country for other uses.

Collection Troughs

In most designs the distillate that has formed on the cover is collected and withdrawn in a trough at its base. The materials of which the trough is made should have the following characteristics.

1. They should resist the high temperatures and humidities produced within the still.

2. They should not be attacked or corroded by the distillate, contaminate, or add taste to it.

3. They should be continuous within the still to avoid joints which might develop leaks.

Metal. Troughs of shaped metal have been tried in many designs. With the exception of stainless steel, which is too expensive for most applications, metals must have special protective coatings (waterproof paints, polyurethane varnishes, etc.) to prevent corrosion. In most permanent models where the original trough was aluminum, copper, or galvanized iron, the metal was later lined or replaced with plastic.

Formed Materials. If the still basin is built of formed material (asbestos, plastic, or concrete) the shape of the trough can be formed in the edge of the basin section. When a material is used that is not completely impervious, e.g. concrete, special coatings may be applied to make it waterproof.

Plastic Liners. If the basin itself is lined with plastic, the trough can be lined by extending the basin liner to cover the trough area. Both butyl rubber and

EPDM could be used as trough liners.

Sealants

The sealant will usually be required to perform three functions: to hold the glass or plastic to the cover frame, to seal the various external parts of the system so that it remains air-tight, and to absorb the difference in the expansion and contraction rates of the differing materials used in construction. Its properties should therefore include:

1. a resistance to weathering and aging while remaining flexible,
2. the ability to bond glass to glass or to other structural materials,
3. the strength adequate to resist wind pressures,
4. and ease of application under difficult field conditions.

Experimental stills have used a variety of sealing agents. Those built in developing countries have frequently chosen as sealants those products traditionally used to fit glass in windows, or other waterproofing materials that were locally available. Usually identified by their local names, these have included: ordinary window putty (chalk and linseed oil), asphalt caulking compound, "soft mastic," "tar plastic," and "black putty." Pressure sensitive tapes have also been used ranging from ordinary cotton adhesive tape to rubber tapes sealed to the glass. These local sealing materials are said to have required continuing maintenance and frequent replacement. None have been completely satisfactory.

There seems to be little doubt among those with experience in the field that silicone sealing compounds most nearly approach the ideal. They are long lasting, strong, and remain relatively flexible. However, they are seldom available in developing countries unless specifically requested, and their cost is very high compared to local sealants. Silicone sealing agents are sold in 1978 by their U.S. manufacturers for slightly less than $30.00 per gallon (e.g. Dow-Corning's Silastic #732 for glass to glass seals and #790 for glass to concrete). One gallon would seal approximately 450 linear feet (137 m). At this price, the rough cost of the sealant required to fix glass in a still module 10 feet square (1 m^2) would be roughly U.S. $1.00. In developing countries the price including transport and extras might be several times that amount; U.S. $2.00 to $3.00. A permanent supply of silicone sealant would have to be maintained in the country for repairs.

The choice between imported and local materials may be more difficult with sealants than in the case of other materials. The use of the superior but expensive imported sealant may be justified in a short time by increased efficiency and reduced maintenance problems. Silicone should be compared to local materials in early trials, and the benefits and drawbacks of its use should be carefully analyzed.

Insulating Materials

The heat losses through the bottom of the basin to the ground beneath can be cut considerably by deliberately providing an insulating layer beneath the basin. The insulating layer should have the following properties:

1. It must be strong enough to support the weight of the basin and the water.

2. It must be unaffected by the temperature at which the still operates.

3. It must resist dampness and the effects of insects or organisms found in the earth.

Many of the insulating materials used in building construction could be used beneath the basin. In practice, soil, sand, or gravel, if kept dry, can form the insulation. Although earth materials conduct several times as much heat as commercial insulation, their presence at the site and their negligible cost may justify their use, especially in isolated locations.

Auxilliary Materials

Small domestic still units will require a minimum of auxilliary materials such as piping, pumps, valves, and storage reservoirs. The filling and emptying of small stills can be accomplished manually and no pumps would be required. Short lengths of piping will be needed to introduce and remove water from the still. These pipes and any valves or plugs that are included to open or close the system should be of materials that will resist the corrosive effects of the fluids in contact with them. Local plumbing materials are usually adequate. If available, plastic pipes or tubes may help avoid joining and turning problems.

The storage reservoirs or containers can be of the type usually used for storing water in the area; masonry or concrete tanks, glass or plastic bottles, or the ubiquitous 50 gallon steel drum if it is given a waterproof coating. Under ordinary conditions, a container holding four or five times the daily production of the still will be adequate for the storage of distilled water (e.g. a 50 gallon or 200 liter container for a family of five).

If the water being distilled must be collected and stored in larger quantities to compensate for extended periods of low radiation, or if rainwater is to be collected and stored, still size, piping, and reservoir capacity will have to be adjusted proportionately.

In some countries there will be considerable scope for the innovative uses of local materials and labor in the fabrication of solar stills. In other areas, construction may depend almost entirely on materials manufactured elsewhere. For this reason, the choices of final still design and the materials of which it is to be constructed are logically made by researchers in the area where the still is to be used. Only in that region can the necessary information on climatic factors be easily obtained. Only there can the skills of local workers be judged, and the cost, quality, and availability of local products be compared with imported materials.

Experience has shown that the high cost of the distillation units limit the uses and areas in which the technology will be practical. This cost, in turn, will depend on the level to which less expensive local materials and skills can be effectively used.

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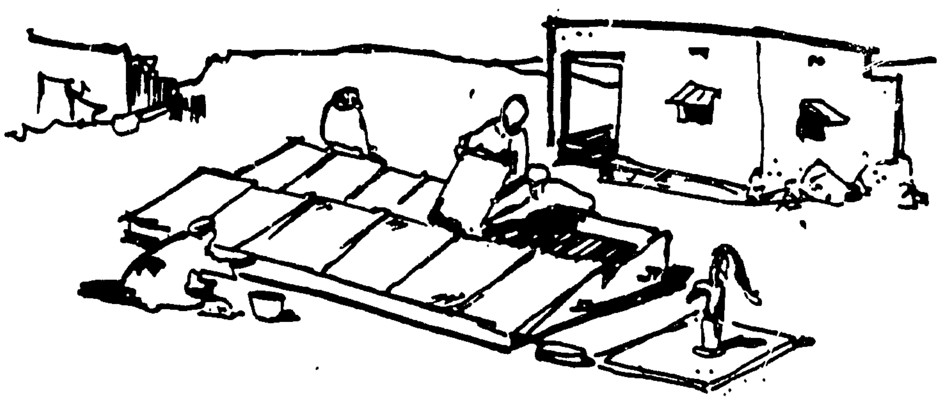


DESIGN AND OPERATION

Two decades of research have produced a variety of experimental solar still designs. Although many shapes and systems have been tried, the simple basin still of the type that was diagramed in the preceding sections of this report is generally recognized to be the most practical and economic, especially for use in developing countries.

The efficiency of simple stills is not high (30% to 50%), but attempts to increase the proportion of the sun's heat that is used in the distillation process by changing basic concepts have proved impractical. Radical change in the shape or the function has involved more expensive construction and greater difficulties in operation. These serious problems have outweighted any increased efficiencies that were obtained.

Experimental Still Designs

A complete description of the various experimental solar still designs and distillation systems that have been tried is beyond the scope of this report. However, the most common variations with their advantages and drawbacks are listed below.

Designs in which the evaporating surface is not horizontal. These designs are especially effective in high latitudes where the direct radiation arrives at lower angles. In them, the surface of the water is vertical or follows the slope of the cover. This is done by employing a "wick" to hold the brine, or using a descending series of small pans, a "cascade", through which brine flows. Problems: complicated structure, increased cost, and difficult operating procedures.

Designs using a separate condensing area. If a surface other than the cover can be used for condensing the vapor, the condensing temperature can be lower and the productivity increased. Problems: complicated fabrication and extra materials necessary resulting in higher construction costs.

Deep basin stills. Stills with basins one foot or more in depth have been built in some large installations. Deep basins held large amounts of brine, had fewer heat losses, and were easier to keep supplied with brine. Problems: lower efficiencies because of lower evaporating temperatures, and the presence of organic growths in the basins.

Stills with forced circulation. Still production can be increased by using non-solar energy (electricity or other) to circulate water or vapor mechanically through various parts of a distillation system. Problems: complexities of these processes limit their use to large scale units in areas where reliable power supplies are available.

The brief descriptions above do not do justice to the dedicated research and ingenuity that has been devoted to studying possible alternatives to the simple basin still concept. Those readers interested in a more complete discussion of alternate systems should consult the summary in the Battelle Institute report (item 83 in bibliography) and the articles listed in Appendix A that deal with other solar distillation systems.

The Simple Basin Still

The basin still remains the most practical system for small scale installations because of its simple construction and ease of operation. Those researchers who were consulted in the course of this report recommended the simple basin still for use in tropical developing countries. Glass was usually recommended as the cover material, and masonry or concrete for the structure of the still.

Basin stills have been the object of much of the practical research done on distillation. Most of the still units which have been built and operated have been of this type. Those elements of design that influence still production were studied, and principles for efficient basin still design have been determined. The comments below are based on studies of how design factors influence production. They appear generally applicable. They should, however, be modified when necessary by any special local conditions.

Cover Slope

The angle at which the transparent cover is set will govern the amount of the sun's direct radiation that is reflected back to the atmosphere. It can also affect the rate at which the distillate will run down the inner surface to the trough.

The angle will determine the area of expensive transparent material that will be required to cover a given area of basin. The amount of cover material necessary will decrease as the angle at which it is placed decreases. Reducing cover costs will have an important effect on the total cost of the still installation.

If the cover span is too great and the angle too small, cover material, even glass, may sag perceptibly. In practice, the angle chosen must be one that avoids sag and allows the distillate to run off freely. Most recent designs have used a slope of between 10° and 15° for glass covers, regardless of the latitude of the still.

No universal rule can be given about the angle at which plastic covers should be placed because their wettability will vary from one material to another. During the process of designing a plastic covered still, a few simple experiments can establish the minimum angle at which water will collect and run down its inner surface.

<u>Cover Elevation</u>

Experiments indicate that the design will be more efficient when the condensing surface of the cover is near the evaporating surface of the water. This distance should be held to a minimum, but must be great enough for the collecting trough to be raised well above the brine surface so that there is no danger of accidental mixing. The cover must be high enough to allow openings in the end walls for maintenance and cleaning. These factors combined with the angle at which the cover is set, and dimensions of the materials used to support it will determine the practical minimum distance between cover and brine.

Depth of Basin

The shallower the depth of water to be heated, the higher will be its temperature. The higher the temperature of the water being vaporized, the more efficient will be the distillation process. A depth of two inches (5 cm) is frequently used in stills. It is a depth sufficient to insure that there will be no dry overheated spots due to an uneven basin bottom. A maximum of 0.2 inches (.5 cm) per day could be expected to evaporate under favorable conditions, so fresh brine will have to be added frequently to shallow still basins.

One of the reasons for the increased efficiency of experimental "wick" stills was the relatively small amount of water that is heated at one time and its resulting higher temperature. Mrs. Stella Andrassy of Solar-Electric Laboratories reports higher efficiencies can be obtained by using peat moss in the basin of a simple still. In that case, as with "wick" stills, only a thin layer of water on the surface of the moss is heated to a high temperature. When it evaporates it is replaced through capillary action with new water from below. In developing countries, local organic materials such as shredded coconut husks or charred plant fibers could be used in a similar fashion. Their presence in the basin might increase efficiency although salt chrystallizing on their surface would add to operating problems.

Width of Bays

Solar stills are usually designed in the form of bays from two to six feet wide (.6-1.8 m) which are lengthened or duplicated to provide the quantity of distillate that is required. The dimensions of the bays do not effect the efficiency of production. Their width is chosen to utilize stock sizes of cover or basin material and to minimize waste and unnecessary cutting.

Length of Bays

The total length of the bays is determined by the basin area that is necessary to produce the quantity of distillate that is wanted. Several short bays are usually more practical than one excessively long one. Short bays require fewer joints in basin liner and troughs. They are easier to maintain and repair. Other sections of a multi-bay system will continue to operate even if one bay is temporarily out of service.

The installation will have to be fitted to the site that is available for it. In most cases a roughly square shaped site is desirable. It will be the easiest to prepare for construction and the easiest to protect after the still is completed. Covering a square site will usually involve a series of short bay units parallel to each other.

The Design of the Bays

The transverse section through the bay will be determined in large measure by the type and size of materials that are used in its construction. A variety of combinations of cover shape, basin depth, and support configurations have been tried. The following pages illustrate in diagrammatic form some of the most common configurations.

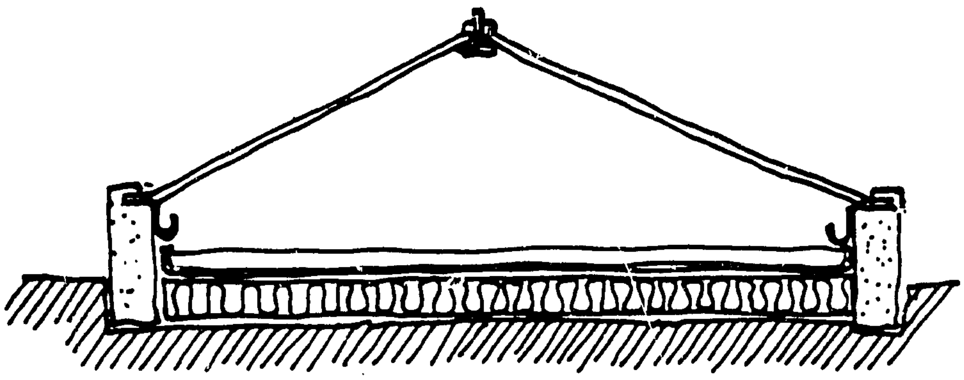


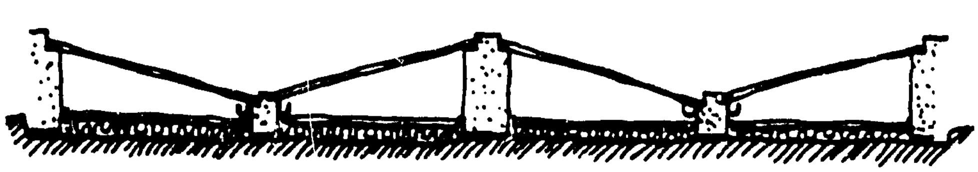
Fig. 20

Double-Sloped Covers

The most frequently used still designs use covers that slope in two directions (Fig. 20). This shape is especially efficient in areas where the sun is nearly overhead for much of the year. This design is frequently chosen because it permits the use of relatively small pieces of glass while retaining wide bay sizes.

A center ridge support is required to hold the glass, and the ridge itself usually needs internal supports if the bays are long. This support system requires extra material and complicates construction. The double slope design is best suited to fabrication in metal.

Fig. 21



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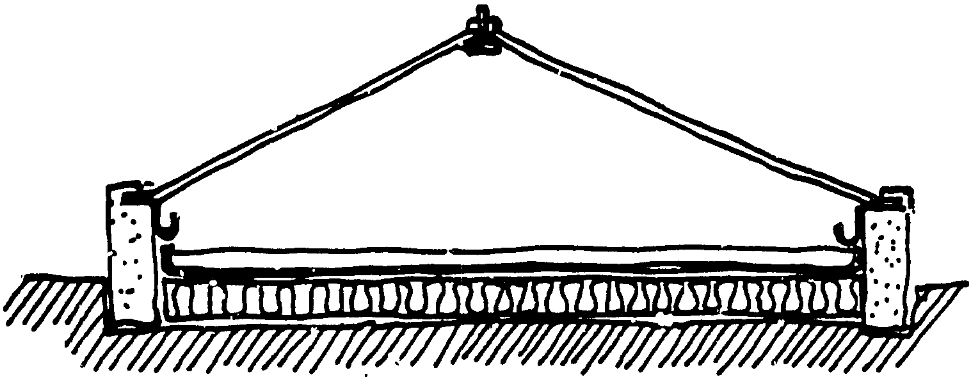

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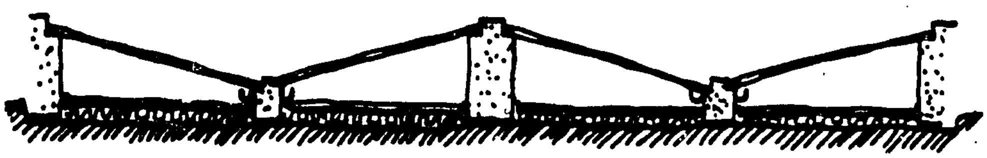


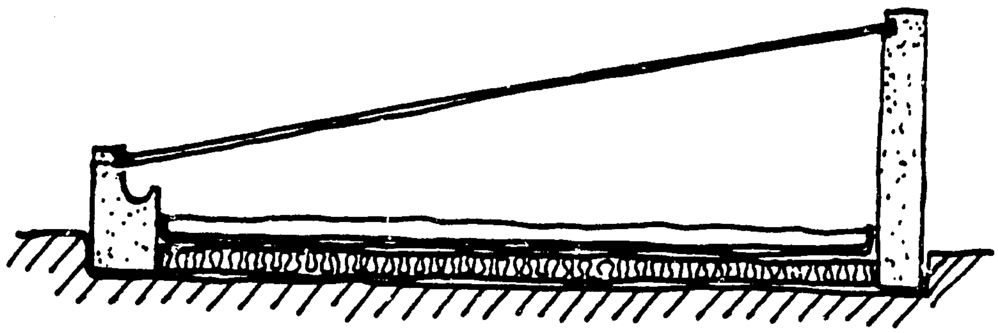


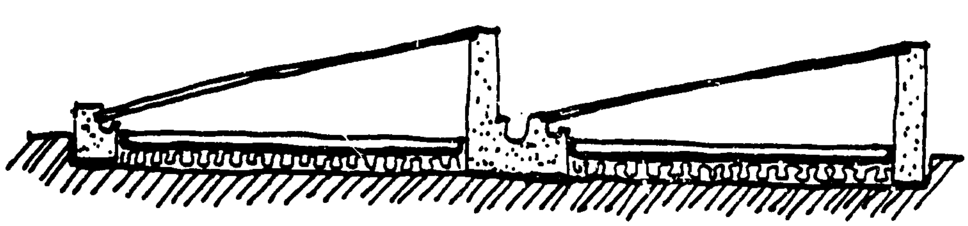
Fig. 22

Single Slope Covers

Solar stills with single slope covers are the easiest to construct and maintain (Fig. 22). They are economic and efficient if large pieces of glass can be used. No internal supporting members are necessary; the glass spans between the walls without a frame. Adjacent glass panes are sealed to each other with silicone cement, tape or other material.

The glass cover should be slanted toward the equator. Even so, within the tropics (23° N to 23° S latitude) efficiency will be reduced at certain seasons because the higher still will partially shade the basin. Still bays can be placed side by side in parallel rows to save material and collect rainfall, but bays must be spaced so that the high still walls do not shade nearby basins (Fig. 23).

Fig. 23



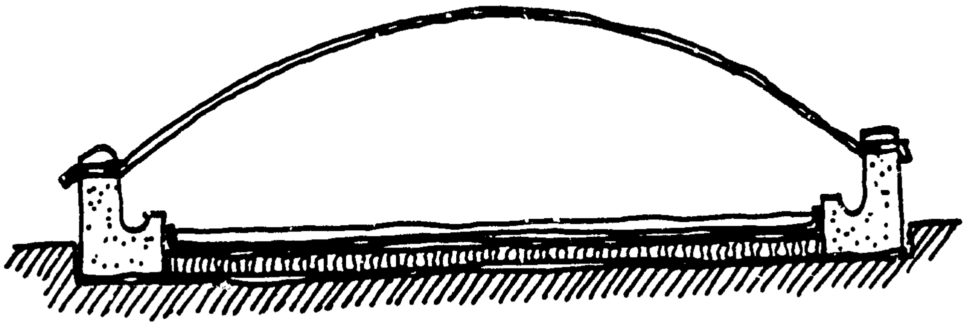


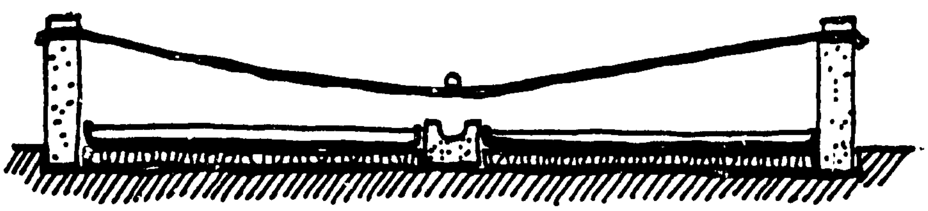
Fig. 24

Shaped Covers

Arched covers have been formed by plastic film supported by air pressure and by the bending of semirigid plastic sheets (Fig. 24). No opaque supporting elements are required over the basin. The amount of radiation reflected from the cover is not affected by seasonal changes in the sun's elevation. Film covers have proved difficult to maintain, but the thicker self-supporting plastic sheets are reported to perform well in this curved shape.

A "V" shaped cover can be made of suspended plastic film weighted in the center (Fig. 25). This design is reported to perform better than air supported models but the film has to be repaired or replaced frequently.

Fig. 25



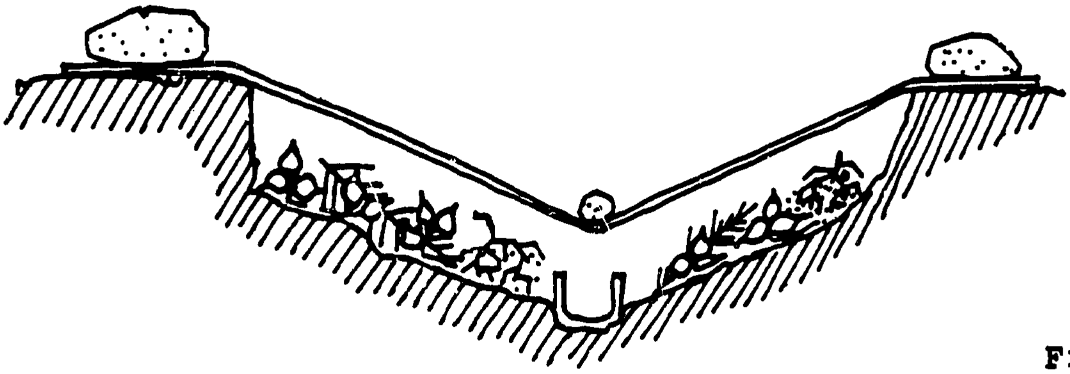


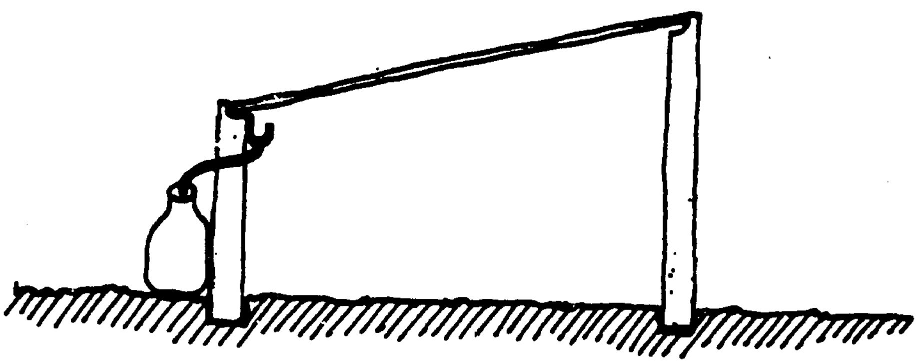
Fig. 26

Water Extracting Stills (Survival Stills)

This type of still has been designed to extract water from desert earth. A survival still (Fig. 26) suggested for use in the U.S.A. is composed of a piece of plastic film supported over a hole and weighted in the center so condensate drops into a cup. Plant materials can be added to increase the yield.

More permanent models have been operated in Japan (Fig. 27), Pakistan, and Iran, where they have succeeded in extracting small amounts of water from soils with low moisture content. For further discussion of this concept of distillation see Appendix C.

Fig. 27



The preceding section has dealt exclusively with basin stills designed to be built on the ground. Although this type would be logical for general water supply in poor areas, two other construction systems are possible for special water needs.

<u>Portable Stills</u>. These stills are built in a central location and carried to the site for installation. Many types have been designed. They are light, usually small units that are self-contained. Built of metal and glass in developing countries, they are frequently made of plastic or formed materials in industrialized nations.

Units made in the U.S. designed by Sunwater Co. were described in the section on materials (page 71). The University of California Sea Water Conversion Laboratory also produces a small plastic still. It has a basin area of slightly less than four square feet (.35 m^2), walls of expanded polystyrene, a glass cover, and uses black pebbles in the basin to increase absorption. The unit is efficient and inexpensive. Small units can be joined in parallel to produce more distillate.

<u>"Built-in" Stills</u>. Provision could be made for solar distillation units on the roofs of certain buildings at the time of construction. This concept is both logical and economic but as yet appears not to

have been tried. Still basins could be cast easily into concrete roofs at very little extra cost. The distillate provided could be valuable for medical or scientific use, or even as a pure drinking water in private homes. Construction practices are slow to change. The benefits of solar distillation would have to be explained to the potential client and the process would have to be made clear to the architect or engineer.

Many sketches, working drawings and photographs of different basin still designs have been included in publications on distillation. The Manual on Solar Distillation (83) has diagramatic sections and photographs of over 100 experimental stills (a sample is included in Appendix C). The publications listed below contain detailed working drawings and material specifications. Although it is doubtful if they can or should be copied exactly in developing countries, they can be a useful reference for still designers.

Brace Research Institute (McGill University)

- L. 1. "How to Make a Solar Still (Plastic Covered)," Jan. 1965, revised 1973.
- T. 17. "Simple Solar Still for the Production of Distilled Water," Oct. 1965, revised 1967.
- T. 58. "Plans for a Glass and Concrete Still," Dec. 1968, revised 1972.
- T. 65. "Specifications for a Prefabricated Solar Saline Water Distillation Unit," Sept. 1970.

Commonwealth Scientific and Industrial Organization, Melborne, Australia

Report E.D.9, "A Solar Still for Water Desalinization," Sept. 1965.

Sea Water Conversion Laboratory, University of California

Report 67-2, "Solar Distillation," 1967.

"How to Build a Solar Still (no date).

"Glass-Covered Solar Still," 1967. (Included in Appendix C of this report.)

Operation

Operating a still designed to produce water for a small family or small group would not be complicated or time consuming. The work could become part of the regular household routine. In most areas for which small solar distillation units would be considered domestic water is normally transported manually. Distillation would represent an intermediate stop between the source and the home.

The regular duties required in the distillation process would include:

1. Supplying the still with saline water. In shallow basin stills this would be done two or three times a week. About fifty per cent more water should be supplied than is withdrawn in the form of distillate. The extra would be used to flush out concentrated brine before crystals can form. New water should be added to the still and

the brine withdrawn at a time when the water in the still is cool (e.g. early morning hours) to reduce heat losses.

2. Collecting the distilled water that has accumulated. This should be done daily. Distillate should be carried and stored in closed containers to prevent evaporation.

3. Wiping dirt or dust from the covers before it can collect in large amounts.

The unit should not be allowed to run dry. Without water in the basin high temperature can build up rapidly and cause permanent damage to basin liners and sealing agents. A still cannot be left unattended even if the family leaves for short periods.

Brine flushed out from the still should be channelled or carried to an area where it will not damage vegetation. It can be returned to the sea or left in an open evaporating area which has been especially prepared for that purpose. Once or twice a year the still may have to be drained completely and cleaned; this should be done during a cool cloudy period.

A strong fence should be considered part of the distillation system. The still must be protected from damage by animals and children. Wire fencing is best, but a fence made of local material (thorn bushes, woven palm, etc.) can be used if it is strong and well maintained. The destruction of the still would be much more serious than the destruction of a vegetable crop the fencing usually guards. Once damaged, stills tend not to be repaired. Marauding cows, fighting dogs, or rock throwing boys seem to be the most common causes for abandonment of experimental family stills.

Maintenance and Repair

The materials of which the still is constructed dictate the level and type of maintenance that will be required. Most stills have been designed and constructed to minimize maintenance. Paradoxically, in the effort to make the still maintenance free, some designers have made the still maintenance proof. If leaks occur, or accidents happen, they cannot be repaired without destroying other elements of the still in the process.

The still should be designed to permit the annual or semiannual cleaning which may be necessary. Silt and/or organic growths that are light in color may gradually collect in the basin. Although theoretically they could reduce the amount of radiation absorbed at the bottom, they have not been reported as a cause of reduced efficiency.

There appears to be little agreement on the possibility of algae growth in stills or its effect on efficiency. Most researchers state that it should not be a problem in shallow basin stills in tropical areas. In these stills, where the temperature of the water in the basin is above the pasturization level much of the day, algae should not multiply. Algae is most frequently encountered in stills located outside the tropics. Algicides have been used in some major installations with varying degrees of success. Their use should not be encouraged among unsophisticated small still users because of the chance of poisoning accidents.

In some areas, glass will be an unfamiliar material to the people. They will understand its fragility only after the first accidents. If glass is used in these regions, allowance should be made for replacement during this period of practical education.

Stills made of materials not regularly available in the country may be difficult or impossible to repair after those responsible for their construction have left. Several bays of the Haitian still visited by the author were out of use because the silicone sealant which had been imported for the original construction could not be obtained to replace glass that was broken later.

If the maintenance and repairs can be done within the family or the village, the amount of labor per unit area could be higher than would be accepted in large scale or commercial stills. The people in many developing areas are accustomed to on-going maintenance and regular repair of the structures in which they live, their store-houses, or their boats. If the still is useful to them, and the work to be done is within their capability, their time would be gladly given. If repairs cost more than they can afford, or if materials are unavailable, the unit will be abandoned after its first breakdown.

Many factors will influence the specific type of still design chosen for a particular region. In most areas it will not be a choice between models developed elsewhere, but a design process in which a model appropriate to the specific needs and conditions of the area is created. Adaptation of existing models must be supplemented with innovation if the design is to be economic, efficient, and popular.

The design concept must include awareness of the long time spans through which a still must operate to be economic. Even if the still is made of "permanent" materials, its operation can be "temporary" unless the need for maintenance and repair is anticipated and provided for.

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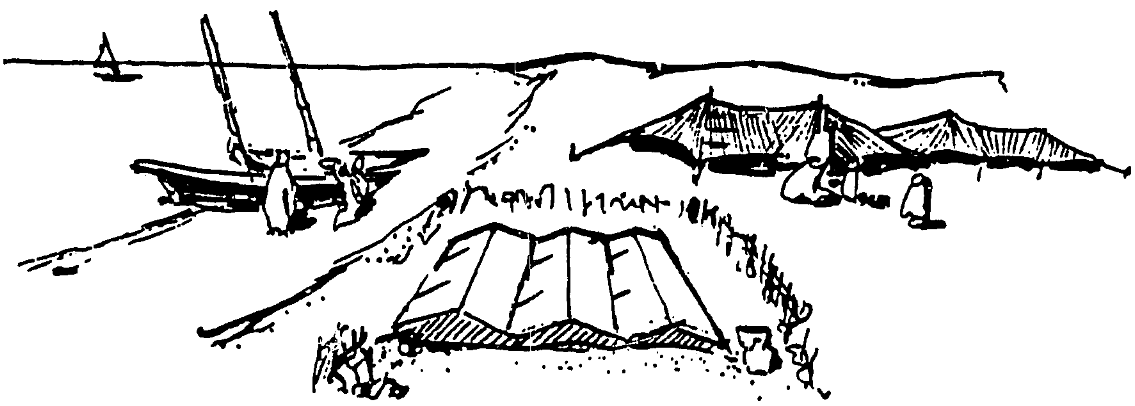


DISTILLATION COSTS

The cost of constructing solar distillation units will be the major determinant of the final cost of the water that is produced. In the case of family stills, operation can be considered virtually costless. In still designs appropriate for the developing areas, the anticipated maintenance and repair costs should have been held to the absolute minimum.

Construction Costs

It is impossible in a report of this nature to give even a general indication of the price of the construction materials needed for still construction in developing countries. These prices could, however, be easily obtained in the locality where the stills are to be used. Current U.S. manufacturers' prices for items that might be imported have been quoted in the preceding section. However, actual local market charges for these materials including transport duty, taxes, and importers' profits can be several times the manufacturer's price.

The 1977 West African glass prices will serve as an extreme example of this. In Dakar, Senegal, prices of common construction materials are listed by the Commission d'Officialisation de Prix de Gros Materiaux de Construction. Such official lists are available in many countries. West African prices inland from the coast can range from 20% to 15% higher than those listed for Dakar.

The prices in Dakar, Senegal and Nouakchott, Mauritania to the north for glass panes that would be used in stills are noted below:

Dakar - (2.9 mm) = $11.62/m^2$ (approx. U.S. $1.08 ft^2$)

Nouakchott - $14.20/m^2$ (U.S. $1.32 ft^2$).

According to the Pittsburgh Plate Glass Co., West Africa desk, export prices for 3 mm float glass (a superior quality window glass; cheaper qualities are no longer made in the U.S.A.) range from \$.30 to \$.35 per ft^2 (\$3.23 to \$3.77/m^2) in quantity. To this, \$.08 to \$.17 per ft^2 (\$.86 to \$1.83/m^2) should be added for shipping costs to West Africa. This brings landed costs for American glass to between \$.38 and \$.52 per ft^2 (\$4.09 to \$5.60/m^2). The difference between this figure and the selling price of glass in West Africa represents "in-country costs" that raise glass into the category of a luxury item.

Glass of the quality noted above is not needed for still applications. The glass known as "horticultural glass" (green-house glass) is adequate and much cheaper. That used in Australian stills in the 1960's cost \$.10 per ft^2 (\$1.08/m^2) at that time. The distortions and flaws in it do not affect its thermal effectiveness. No longer made in America, this type of glass is available from several European suppliers (e.g., Graverbel, Brussels, Belgium). Its landed cost would probably be well below the costs quoted above. Manufacture of this ordinary glass is not difficult if raw materials are available. Glass is frequently fabricated in developing countries themselves when large-scale use results in the establishment of manufacturing plants nearer the market.

Unit prices of glass used in some recent still construction in representative regions and its proportion of the total still cost is noted below:

Country	m^2	ft^2	% of Cost	Ref.
Pakistan (1972)	$2.58	$.24	18%	(72,73)
Chile (1973)	$3.25	$.30	33%	(25)
Dakar (1977)	$11.62	$1.08	14%	(23)
Australia (1978)	$1.08	$.10	7%	(90)

The cost of American materials described in earlier sections that would be required for a sample still module area of 10 ft^2 (1 m^2) are roughly estimated below (allowances have been made for cutting, fitting, and some waste).

Material per 12 ft^2, 1.1 m^2	U.S. Price	Est. Developing Country Price
Plastic or glass	$5.00	$7.00 - $12.00
Plastic basin liner	$6.25	$8.00 - $11.00
Silicone sealant	$1.00	$2.00 - $ 3.00
TOTAL	$13.25	$17.00 - $26.00

These three items alone in America would cost U.S. $1.33 per square foot ($14.31/m^2) and in developing countries would probably range between $1.50 and $2.60 per ft^2 ($18.00 and $28.00/$m^2$). To these costs must be added the cost of preparing the site, the structural elements of the still, the auxilliary piping, labor, and financing charges. In America at the present time, the cost of a simple basin still would probably range between $3.00 and $5.00 per square foot ($30.00 and $50.00/m^2) according to those working in the field.

In developing countries, prices might be expected to run between $15.00 and $50.00 per 10 ft^2 ($16.00 to $54.00 m^2) except in exceptional cases. In those countries where locally manufactured materials can be used, prices will be lowest. Even assuming indigenous materials are used to the greatest extent possible, in many areas efficient prototypes will depend on certain, often simple, components not now manufactured in the country. This will be reflected in higher unit prices. Examples of recent unit costs reported from developing areas include: Philippine Islands (1977), $35.56 per 10 ft^2 ($38.28 m^2); India (1975) $13.90 per 10 ft^2 ($15.00 m^2); Pakistan (1973) $13.70 per 10 ft^2 ($14.74 m^2); Niger (portable metal unit, 1977) $63.00 per 10 ft^2 ($68.00 m^2).

The spread in the figures above gives some indication of the large variations that can occur in construction costs depending on the region and the materials used. Although labor is comparatively cheap in developing countries, it can only partially counter-balance the generally higher cost of materials. The Indian and Pakistani construction costs, approximately $1.50 per ft^2 ($14.00/m^2), would appear to be the minimum that can be expected at the present time. In most developing countries, the costs of a simple basin still would range rapidly upward from that amount.

A realistic estimate of local costs per ft^2 or m^2 can be obtained from building contractors in the area if they are provided with simple diagrammatic sketches of the unit desired using the various possible construction materials. In areas where actual construction costs are known, those figures can be used to estimate the cost of family water supply. In this report, for use in the estimates that follow, a figure of $2.50 per 1 ft^2 or $25.00 per 10 ft^2 (1 m^2) will be assumed as the cost of a simple basin still emphasizing local materials

Water Requirements

Estimates of water requirements will have to be made before the still size can be determined. For some uses (industrial, medical, etc.) requirements will be fixed. Human requirements can vary widely. Stills have been designed to provide from two to five gallons a day per person.

A study should be made locally of the quantities of water customarily used in households, but this quantity should not be accepted for design purposes if it appears to be overly high. A high use figure will indicate that adjustments must be made by the family if solar distillation is to be economic. Distillate must be reserved for drinking and cooking; other household water should be drawn from other sources.

A dependable supply of two and one-half gallons a day would appear to be adequate in most regions if reasonable care is taken with its use. This figure will be used for the estimates that follow.

In actual field conditions, the entire two and one-half gallons need not be solar distillate. The water produced by the still can be supplemented with rainwater or mixed with local water supplies if conditions permit.

Still Efficiencies

The efficiencies of well designed solar stills range between 30% and 60% depending on the climate in which they are operating, their design, and their construction details. Theoretical and empirical formulas have been derived that relate still production to differing climate and design features (83, 16). Actually, sample units constructed and operated in the region where solar distillation is proposed will give the most realistic indication of the efficiencies that can be expected with a particular unit in a particular place. Designs can be modified if efficiencies appear to be unrealistically low.

A 40% efficiency would appear to be a modest aim for a locally constructed still in a sunny tropical area. If radiation figures average 500 langleys per day, a still module 10 ft^2 (1 m^2) in size operating at 40% efficiency would produce .82 gallons per day (3.4 liters per day). Considering the variations that will occur even in ideal climates, a rounded estimate of 250 gallons per year from 10 ft^2 (1,000 liters/m^2/year) is usually assumed for preliminary design purposes.

Sample Calculations

A family of five requiring 2.5 gallons (10 liters) of water each per day would need approximately 4,600 gallons per year (18,250 liters/year). At the efficiency suggested in the preceding section, this would require a still basin area of approximately 185 ft^2

(18 m^2). The cost of an installation of this size at \$2.50 per ft^2 would be roughly \$462.00; \$500.00 would allow the extra that might be required for repairs or storage facilities. If it is assumed that the distillate could be mixed with local water in the proportion of four to one, or if an equivalent amount of rainfall was used, the cost of a smaller family still would equal about \$400.00.

In many areas, this figure would more than equal the average annual per capita income in the country. It should be pointed out here that in virtually none of the experiments that have been tried have the users been asked to bear the cost of construction. In most cases, the still unit has been a gift or has been heavily subsidized by a sponsoring authority. Even if the cost of the still is spread out over a ten or twenty year period, the interest charges that will be required would raise the cost of the unit beyond that which most simple families could afford.

Ignoring interest charges, capital cost and maintenance expenses apportioned over a 10 year period might equal between \$40.00 and \$50.00 a year. In regions where per capita income is less than \$300.00, this would represent an expense that few families could bear. The exception would be those cases where the still's operation made possible a new or increased income for the family; for example, allowed fishing from a previously uninhabited stretch of coastal water, or farming and herding in an area with no potable water supply.

The unit costs of water in the case of the $500.00 still mentioned above, if operated 10 years, would be equivalent to $.01 per gallon (approximately 4 liters) or $10.00 per 1,000 gallons (approx. $2.50 per 1,000 liters). Although this cost appears extraordinarily high when compared to usual drinking water costs in most areas, there are regions where privately sold water approaches these figures. In Aleg, a city 150 miles inland from the Mauritanian coast, local residents reported in 1971 that well water was sold there by the government for $12.00 per 1,000 gallons ($3.20 per 1,000 liters) (23). Families in Aleg must purchase beyond that which is necessary for drinking and cooking to provide water for washing and cleaning.

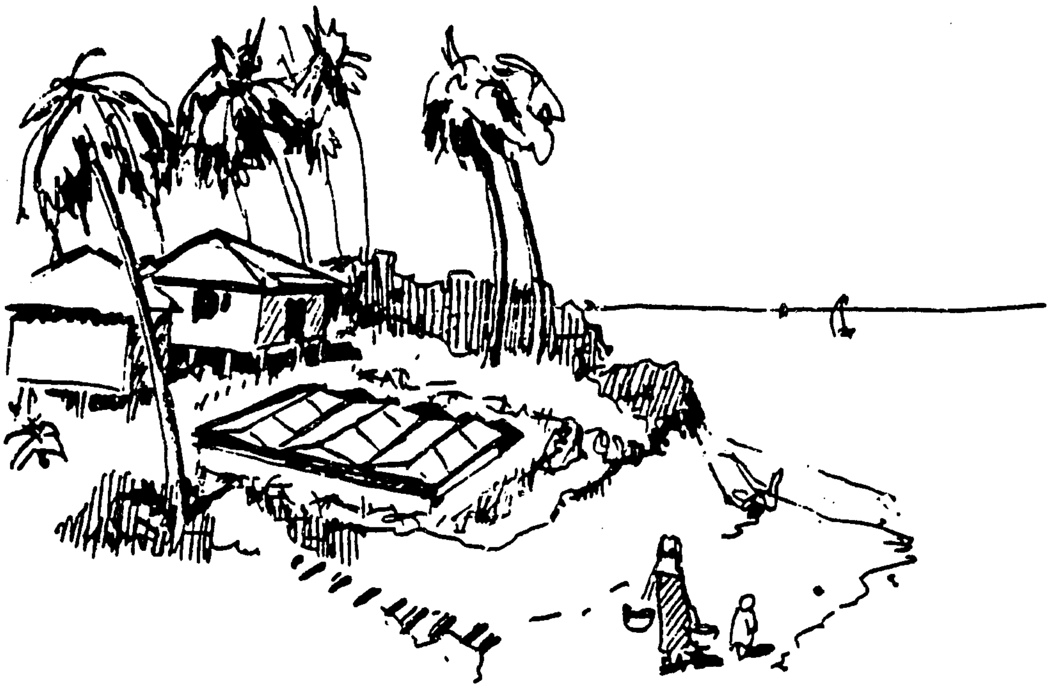
A new settlement on the desert seacoast of this same country could use solar distilled water for drinking, and seawater for other purposes. If still costs were as estimated in the example, even bearing some interest charges for the solar distillation unit, a seacoast family's water costs would be less than those of an inland city family.

The calculations above are meant to give a rough indication of the type of costs that may be involved in family sized solar distillation units. Once climate, construction costs, and needs have been studied in a given area, this type of calculation will permit a preliminary, more realistic, appraisal of the role the technology might play in water supply.

At the present time, solar distillation can compete with water prices primarily in those areas to which fresh water is transported by truck or boat. It has been estimated in India that solar distillation is economic if water must be transported more than 25 km from its source.

Recent inflation in the prices of materials has pushed the cost of solar distillation beyond that reported in much of the research literature. A minimal cost of $5.00 per 1,000 gallons ($1.25/1,000 liters) is probably the best that can be expected in most developing countries at this time. In most areas costs will be higher.

The expense of solar distillation will continue to limit its widespread acceptance except in cases where the technology directly replaces other high costs such as transportation, or where it can be responsible for new income producing activities.



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SOCIAL CONSIDERATIONS

The research that has been devoted to solar distillation over the last few decades has had two main objectives: to increase the efficiency of the process through new or better designs and construction techniques, and to reduce the capital costs of the still units primarily through the investigation of new materials. Even the solar energy research that was carried on at universities and research institutions in the developing countries themselves followed the patterns set by western institutions. They have, however, given more emphasis to the applications that might be specifically applicable to their situations.

Model stills made in "family size" have been made and reported on as being workable, practical, and potentially popular.

A report of success with a single unit that has been tried in a family should be approached with guarded optimism. A single model placed in a simple household and checked frequently by "impressive" outsiders may operate well during the trial period on which the report is based. More units with less supervision over longer periods might have produced results somewhat less reassuring.

During a cooperative effort between the University of California and the South Pacific Commission in the 1960s, about twelve small stills were placed with island families. Glass-covered "saw-tooth" designs (see Appendix C) proved to be the most suitable and were in use for several years (37). With the exception of this demonstration project, no large or even moderate-sized field tests involving many family-sized still units seem to have been tried in developing countries.

The Technology and Tradition

Technical researchers are reluctant to include in their publications the anecdotes and personal frustrations that have accompanied their contacts with potential users. This is unfortunate, for these experiences frequently hint at the fundamental conflicts between the technology and local tradition. Some of these conflicts can be avoided if they are understood.

Reluctance to publish anecdotal material does not always extend to informal discussion of it. The comments below have been drawn from such discussions, from the author's interviews with people using stills, and from his own experiences in the field.

Field Testing. In the field test situation, the design of the unit itself and the process by which it is introduced can unwittingly create conditions of stress that will influence the test results and shape the attitudes of potential users.

The status of a family using the still can easily be affected by the way in which neighbors and friends view the innovation. If first introduced among low-income families, people at higher income levels may be reluctant to be associated with it. In some societies, obtaining field test data can involve invasions of a family's privacy that may be resented unless handled with the ultimate of tact.

If early experimental still models are awkward to operate or difficult to maintain, their poor performance may unjustifiably color reactions towards the solar technology as a whole. Such early judgments are often premature, but they are frequently permanent. They can strongly affect the course of field experiments and, ultimately, final attitudes towards acceptance. It is therefore critically important that the design of the still unit and the field test procedures be carefully tailored to the particular society before full-scale field investigations begin.

Cooperation. Most still installations have been constructed for village use. Such stills involve a degree of community cooperation and support that would be new to some cultural groups. In areas where water is valuable, accidental errors in its allocation have become a source of strife. At the site of a community still visited by the author, a user stated that he would prefer a small still of his own. His wife would, he said, go to the sea and get salt water, and all the fresh water he could make would belong to him.

Although this attitude may not be universal, it may be more common than many researchers realize. It may account for some of the success reported with family units. Using the family rather than the village as the unit to which water is to be supplied does not necessarily restrict the designer to small stills. Family groups, or extended family groups in certain areas, will approach the population of small villages. The family, however, usually represents a social unit in which cooperation is traditional, and basing the size of the solar still design on it may be both logical and practical.

<u>Size of the Unit</u>. A solar still will be large, and few modifications are possible in its dimensions. As has been pointed out earlier, the amount of water obtained will be directly proportionate to the area of radiation intercepted by the still. Consequently, it will have fixed minimum size if it is to provide adequate water for the family. In many of the areas where its use is suggested, it may approach the size of the family's dwelling. Fortunately, land in arid areas is not as valuable as in some regions, but space near the house or near a well may already be intensively used. It may be necessary to place the distillation unit outside the dwelling compound or at considerable distance from the source. This may increase the problems of transporting water and protecting the still.

<u>The Taste of the Water</u>. The taste of solar distillate, or perhaps its lack of taste, has been mentioned by researchers as a reason for local disappointment with the technology. Those investigators who have

made an effort to solve this problem seem to have done so without difficulty. Distillate mixed with local water, with seawater, or filtered through charcoal has made it acceptable to various local tastes. The solution to this problem will have to be made experimentally in each location.

The problem of taste should be attacked early in the investigation, for an unfamiliar taste in water worries even sophisticated drinkers. During his course of research, Dr. Kobayashi of Japan submitted samples of solar distillate to the country's leading authority on tea making for his approval. Although the usual chemical analyses were also made, Dr. Kobayashi realized that the ultimate decision would have to be a cultural rather than chemical one.

Domestic Patterns. As the still is a new, valuable, and somewhat mechanical looking device, in some societies there may be confusion as to whether its operation is the responsibility of the man or the woman of the household. Domestic reputations and family peace may be in jeopardy if water supply failures occur that can be attributed to the still.

To have its water supply in part dependent on the weather will require novel adjustment for many households, and one that will be met with varying degrees of good will. In this respect, solar produced distillate resembles rain. Those who are used to collecting and storing rainwater will understand better that solar water is only partially predictable and the extra benefits of good days must be conserved and stored for use in periods of cloudy weather.

<u>Auxilliary Water Supply</u>. If solar distilled water is to be the sole source of drinking water for a family, production and storage capacities must be adequate to carry the users through normal periods of adverse weather. In addition, another dependable water supply should be available at a reasonable distance. A still destroyed in a storm after several sunless, therefore waterless, days might place a family in a hot arid area in great jeopardy. In extremely isolated regions, an emergency supply should be maintained capable of sustaining the family until water could be ordered and obtained from outside. The amount in the emergency supply should be determined by the transportation time (walking, sailing, or other) to an area where good water is permanently available.

Resistance to Change

Some field test reports mention "resistance to change" on the part of local people as one of the major reasons for the technology's lack of acceptance. In many cases, this catch-all category can be broken down into user attitudes towards specific characteristics of the technology such as those this paper has touched on. In effect, the "resistance" is a series of interrelated judgments made by the user, many of which are quite understandable when approached from his viewpoint.

Paradoxically, "resistance to change" may not indicate an out-of-hand rejection of a particular new innovation, but may actually lead to its acceptance. Unplanned changes in traditional life-styles are occurring inevitably in many developing regions. They result from external changes, often deterioration, in economic, environmental, or population conditions. To cope with these new factors, affected families are forced to change certain aspects of their life-style in order not to change other aspects that they consider more important.

Certain practical devices, such as the still, appropriately designed and introduced at the proper time, can assist a people in their efffort to "resist change," that is, to continue those aspects of their tradition on which they place a high priority. A technology such as solar distillation will be widely accepted in such regions and at such times as it is seen by the users to be a positive factor in this struggle, that is, when it helps them support those aspects of their life style they consider important.

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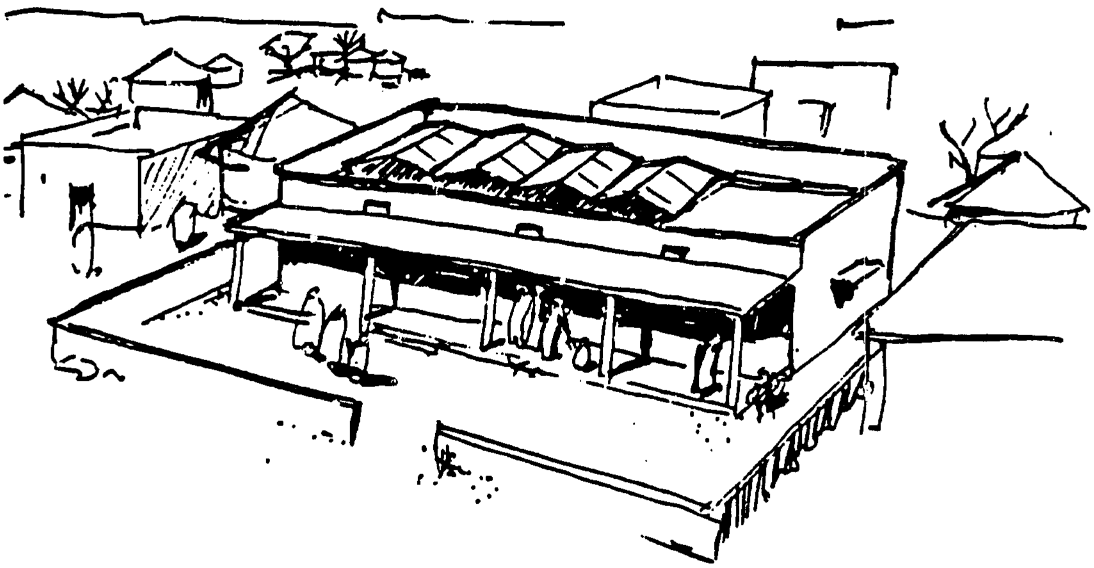

SUMMARY AND RECOMMENDATIONS

A well designed and constructed solar still is a device that can be used with confidence. The technology is well understood; the cost and benefits can be predicted with reasonable accuracy before major investments need be made The less quantifiable aspects of social acceptance remain to be investigated. They may be significant when large numbers of small family units are planned.

General Considerations

In a particular region, the potential role of solar distillation can be assessed in general terms after certain preliminary data has been obtained.

Climate. In areas with high average radiation levels (about 500 langleys/day) and high air temperatures, efficient distillation should be possible. Large seasonal variation in radiation or temperature will result in corresponding changes in production levels. Solar distillate can be supplemented by rainfall if local conditions permit. This additional water supply will reduce still areas and storage volumes that are required.

Design. Stills can be made of a variety of materials and in several configurations. Each region and use for which the technology is proposed will have a design-materials combination that is best suited to it. The economics of the technology are dictated by the cost of still construction. Still units should be planned for both short and long-term economy.

Costs. The cost of supplying water to match a particular requirement will be governed by the cost of the still, its efficiency of operation, and the quantity of water required. Production estimates can be made once climate and design factors have been established. They will determine the size of the still necessary and unit costs of production. In developing countries these costs presently appear to range upward from $6.00 per 1,000 gallons in stills built to last ten years, from $4.00 per 1,000 if a twenty year life span is assumed.

Social Factors. The production and use of solar distillate may touch on fundamental aspects of the user's lifestyle. It will be accepted most easily in those regions where it is not in conflict with local traditions, and where the level of need is high in the groups expected to benefit from it.

Special Applications of the Technology

The solar distillation technology will be readily accepted for those uses that are economic. It is, in fact, already being used to supply pure water to areas with special needs where suitable water would otherwise have to be purchased at a higher price.

Automotive Uses. Perhaps the most popular use of small scale units at the present time is providing distilled water for automobile service stations in isolated areas. The solar water is used to replenish batteries and to fill radiators in regions where ordinary saline ground water would cause excessive scale formation. One of the reasons for its success in this application is the mechanical aptitude and tools available to the garage operators that allow them to build and maintain the units with ease.

Luxury Uses. Solar distillation has proved successful in supplying drinking water to tourist facilities and vacation homes on otherwise waterless islands. These "luxury" uses of solar distilled water can be expected to continue at locations where it is economic without deliberate incentives from outside.

In many upperclass houses in tropical areas, drinking water is filtered and boiled to assure its purity. Solar stills could be integrated into these buildings, thereby eliminating both these operations with consequent savings in time and fuel.

Governmental Supported Uses. Solar distillation is being used to provide water for extremely isolated areas which must be inhabited in the national interest. In India, solar stills supply drinking water to lighthouse keepers in locations that are otherwise extremely difficult to service. A major still is being designed for a military installation on an island off the South American coast. In cases such as these, the cost of providing the distillation unit is absorbed in the general cost of the operation. This type of use might be expanded if the characteristics of the technology were more generally known.

Medical Related Uses. Although theoretical literature on solar stills makes reference to the possibility of their use by medical facilities, little research has been done which directly relates solar still capabilities to the quantitative or qualitative water levels that are required in practice by clinics or small hospitals. Nor have specific still designs been proposed that might meet their special requirements.

The prospect of producing solar distillate in developing areas for medical facilities is especially attractive. Distilled water costs that loom large when considered for household use, seem more reasonable when they are considered for uses where high quality is important and relatively small quantities are required. Costs of solar distillation would compare favorably with costs required for purifying or transporting pure water to medical units in areas where it is not now available or is difficult to obtain.

A still installed beside a clinic or on a flat roof (a common design feature of "modern" medical facilities in tropical areas) could occupy an area that is protected and/or otherwise unused. The level of skill required to build and operate a superior still apparatus is less than that required for most medical equipment. The usual social constraints involved with producing or using the water would be absent.

Medical Uses Related to Solar Still Capabilities

Type	Solar Distillate
1. General housekeeping water: cleaning, mopping, etc.	not required
2. High purity water: drinking, nutritional mixes, etc.	appropriate
3. Chemical level distilled water: laboratory, pharmacy, surgical equipment cleaning, etc.	probably appropriate
4. Fluids for infusion	theoretically possible but hard to achieve in field situations

Uses numbers two and three appear to be well within the capacity of the solar technology. Water to these levels of purity is obtainable with fairly simple equipment if the required attention is given to design and operating procedures. Designs and materials of fabrication might vary for varying uses.

In theory, no chemical or pathogenic substance could transfer across the vapor bridge. The purity of the final product would, in practice, depend on the design of the unit, materials used for collection and storage, and the care taken to avoid mechanical contamination.

The theoretical capabilities, convenience, and economy of producing solar distilled water for certain medical uses would appear to justify an investigation into the practical difficulties that may be involved.

Drinking Water

The most significant contribution that the solar distillation technology could make in developing areas would be the provision of a drinking water supply to areas which now have none, or the improvement of existing water supplies which are inadequate, of poor quality, or deteriorating. Much of this report has dealt indirectly or directly with this possible application of the technology.

Costs. The limiting factor has been, and will remain for some time, the cost involved in the construction of the distillation apparatus. In industrialized countries, research on new materials will continue with the object of reducing costs. In developing countries, research with the same goal should be encouraged. This should involve a continuing search for appropriate materials that are easily available and inexpensive.

At the same time, the reasons for excessively high local costs of imported materials should be analyzed. Frequently the market prices of materials produced elsewhere such as glass, plastic, and metal sections are illogically high. The local prices of imported materials are sensitive to government policies. The cost of those items needed for applications of proved popularity and practicality can be controlled if required to meet development or ecological goals. For this reason, initial experiments and demonstrations should be conducted in spite of their apparent ineconomies based on current material prices.

After the technology has proved itself, once its benefits are understood by local officials, and the scale of projects blocked out, the factors affecting the prices of necessary materials can be more effectively influenced.

Design. In spite of the best efforts of designers outside the developing world to provide still designs appropriate to conditions there, the division of costs between labor and materials, with which the foreign designers are most familiar, unconsciously guides many features of the designs they produce. In developing countries, this labor-materials cost ratio can be radically different. The common practice there is to attempt to modify foreign designs to reflect the new cost relationships.

This attempted modification may be less productive than would be a complete redesign based intuitively on experience with costs and conditions in the area where the design is to be implemented. The local designer would need to understand the physical laws that govern the distillation process and be aware of the water supply problems it might help to meet.

Design and refinement of construction details need not be a completely formal process. An appropriate design concept will allow the users themselves to suggest or make modifications that will increase the unit's efficiency, economy, or ease of operation. Although the resourcefulness of local people is generally recognized, their possible contributions to the design process are usually underestimated. The talents they have must be deliberately given scope and encouragement if they are to be effectively used.

Recommended Investigations

The solar distillation research which would be most useful is practical rather than technical. It should take place within those countries or regions where the technology appears appropriate. To be successful there, it will entail the involvement of local authorities, the talents of various disciplines, and international cooperation.

The areas in which research and testing might be most productive may, in some cases, be those areas least equipped to organize experiments or mount field tests. If requested, initial assistance should be supplied by institutions outside the country. It should be available to provide sample still designs, to assist fabrication of local models, and to help in organizing experiments and analyzing their results.

A logical research program within a developing country would divide itself into three phases:

Analysis of Suitability. This phase will involve the gathering and analyzing of data to determine those geographic regions and uses for which the technology of the simple basin still will be appropriate.

The fundamental climatic data should be obtained for the region. It will allow a rough prediction of the efficiencies that may be expected with the usual still designs.

Simultaneously, data should be gathered which applies to the uses of the still. This will include the analysis of population data and traditional water-use and work patterns which may support or conflict with the technology.

This essentially theoretical investigation can be carried out by a university department or by a special office established for the purpose. Appendix B contains a list of institutions that have past involvement with solar distillation. If they are near the region under consideration they should be consulted and involved. Reference works should be gathered. The list below includes recently published volumes which can serve as basic reference resources. They are available through the publishers.

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United Nations, Solar Distillation as a Means of Meeting Small-Scale Water Demands, ST/ECA/121, Sales No. E.70.II.B.1, United Nations, New York, NY, U.S.A. U.S.$6.00.

Solar Energy. Reprints from specific articles on solar distillation are available from Pergamon Press, Inc. Maxwell House, Fairview Park, Elmsford, NY, U.S.A., 10523.

Brace Research Institute. Publications on solar distillation are available for a small charge from Brace Research Institute, Macdonald College of McGill University, Ste. Anne de Bellevue, PQ., Canada HOA 100.

Design and Demonstration. A still unit appropriate to the region should be designed in collaboration with individuals who have experience in the construction industry, and with those who are acquainted with local building practices in the area where the still is to be used.

The advantages and costs of imported materials should be compared to those locally available. The final design should be the result of a thorough cost analysis, tempered by the knowledge of problems that may develop during operation over long periods in the field.

It is suggested that an efficient control model be built or imported (for example, the small plastic still manufactured by the University of California, Sea Water Conversion Laboratory is inexpensive, light, and dependable). Locally produced models can be compared against a control model or against theoretical calculations to determine their efficiencies.

An efficient demonstration model that has been manufactured locally should be available for public and official inspection. Its potential should be explained and suggestions for possible uses sought.

Introduction and Support. Solar distillation can be tried in any region where need and appropriate climate coincide. If however, resources for experimentation are limited, both theoretical and practical objectives will be best served if early investigation is made of those uses that appear economically justifiable. Simultaneously, investigation can be carried out into application where need rather than economics is the overriding criterion.

Although the costs and efficiencies of solar distillation units have been the object of much research, the methods of insuring the successful introduction of small units on a large scale are ill defined and thus far unstudied.

The selection of field test areas should not be arbitrary, nor should it be based on the presence of a single positive aspect such as maximum sunlight or severe need. It should not be overly influenced by the desire of local authorities to have it tried in a particular area. In most regions, sufficient information is available, or could be easily gathered, to allow a preliminary estimate of the costs and the conflicts that are likely to be encountered. In many respects, the maximum potential of the solar distillation technology is fixed permanently by a region's climate, the efficiency of the still unit, and the level of need before the test begins. Field tests can, at best, only study the ways in which this potential can be approached.

As the design of the still unit must be specially tailored to a particular region where it is to be used, so must the process of its introduction. The above mentioned phases of feasibility and design have required neither large amounts of time nor financial resources. Competent field testing may require both. The continuity that is required suggests that it be included in ongoing programs such as rural development or health planning, so that the results can be studied over a sizable time-span.

Premature optimism has been responsible for many of the disappointments that have accompanied the results of past solar distilllation research. Even in regions where the technology can be shown to be a logical and appropriate solution to special local water supply problems, its acceptance will not be automatic among those it is designed to help. Its introduction must be carefully pre-planned to avoid the technical, economic, and social hurdles. An innovation such as the solar still which touches family economic, lifestyle, and preference patterns will face formidable obstacles. The problems that may accompany efforts to introduce it must be approached with humility, ingenuity, and patience.

APPENDIX A

BIBLIOGRAPHY

SELECTED PUBLICATIONS ON SOLAR DISTILLATION

1970 - MARCH 1978

A bibliography of 493 works was included in the Manual on Solar Distillation (83) prepared by the Battelle Memorial Institute for the U.S. Dept. of the Interior in 1970. This list should be consulted for works published before that time. The following list was drawn from works published in English since 1970 that appeared to be relevant to small scale solar distillation.

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APPENDIX B

INSTITUTIONS INVOLVED WITH SOLAR DISTILLATION RESEARCH

Note: The names of institutions and individuals which follows was drawn from recent publications on solar distillation. As research changes emphasis frequently, the list should not be considered a definitive one. The errors or omissions it may contain are unintentional.

ARGENTINA

Observatorio Nacional de Fisica Cosmica
Comision Nacional de Estudios Geoheliofisicos
Departamento de Radiacion Solar
Programa de Helioenergetica
Av. Mitre 3100, San Miguel, Pcia. de Buenos Aires,
Argentina.
J. Guerrero.

Universidad Nacional de La Pampa
Instituto de Estudios Regionales
Mansilla 178, Santa Rosa, La Pampa, Argentina.
J. Zabala.

Universidad Nacional de San Luis
Departamento de Fisica y Quimica
Chacabuco y Pedernera
San Luis, Argentina.
M. Diaz.

AUSTRALIA

Commonwealth Scientific and Industrial
Research Organization (CSIRO)
Solar Energy Studies
P.O. Box 89, East Melbourne, Victoria 3002, Australia.
R. Morse.

International Solar Energy Society
Australian and New Zealand Section
c/o CSIRO
P.O. Box 26, Highett, Victoria 3190, Australia.
R. Dunkle.

C.S.I.R.O.
Mechanical Engineering Division
P.O. Box 26, Highett, Victoria 3190, Australia.
R. Dunkle, P. Cooper.

Sola-Ray Appliances
P.O. Box 75
Tuart Hill
Western Australia 6060, Australia.
(still manufacturer)

EGYPT

Ain Shams University
Heliopolis, Cairo, Egypt.
M. Elnesr, N. Sarakat.

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I. Ahmed.

FRANCE

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M. Vergnet.

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R. Bonhomme.

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Postfach 1360, 7990 Friedrichshafen,
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Nuclear Research Center "Demokritos"
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Hellenic Industrial Development Bank
Amalias Ave. 20, Athens 118, Greece.
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Institut des Etudes Avancees Sur Les Energies Solaires et Eoliennes
Athens, Greece.
A. Spanides.

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BURMA

Central Research Organization
Rangoon, Burma.
U. Maung.

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CANADA

Brace Research Institute
Macdonald College, McGill University
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Design and operation: village sized still units in developing countries.
T. Lawand.

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Universidad Tecnica Federico Santa Maria
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J. Hirschmann, B. Seifert.

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Government College of Science
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M. Tarnekar.

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G. Sootha.

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A. Moumouni.

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Department of Physics
Ile-Ife, Nigeria.
M. Karim.

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Lahore, Pakistan.
M. Saif-ur-Rehman.

PHILIPPINES

University of the Philippines
Quezon City, Philippines.
L. Abis.

SAUDI ARABIA

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College of Engineering
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J. Sabbagh.

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South Africa Council for Science and Industry Research
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SPAIN

La Commission National des Energies Speciales
Madrid, Spain.
P. Blanco.

SUDAN

Institute of Solar Energy and Related Environmental Research
National Council for Research
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Y. Hamid.

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Asian Institute of Technology
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Division of Environmental Engineering
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R. Exell, M. Htun.

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University of the West Indies
Faculty of Natural Science
Faculty of Engineering
St. Augustin, Trinidad.
O. Headley, S. Satcunanathan.

153

UNION OF SOVIET SOCIALIST REPUBLICS

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Ashkhabad, Turkmen SSR, Union of Soviet Socialist Republics.
A. Khanberdiyev.

UNITED KINGDOM

Intermediate Technology Development Group Ltd.
Parnell House
25 Wilton Road, London SWIV 1JS, United Kingdom.
G. McRobie, S. Watt.

UNITED STATES

The following organizations in the United States were actively engaged in some aspect of solar distillation technology at the time of this report, 1978.

University of Arizona
Environmental Research Laboratory
Tucson, AZ 85706
Design and installation: distillation plant for South American military installation.
C.N. Hodges.

Battelle-Columbus Laboratories
505 King Avenue, Columbus, Ohio 43201
Evaluations: materials and economics of solar distillation.
J.A. Eibling, S. Talbert.

University of California
Sea Water Conversion Laboratory
1301 South 46th St., Richmond, CA 94804
Research and experimental operation: small scale still units.
A. Laird, B. Tleimat, D. Howe.

Columbia University
Department of Architecture and Urban Planning
New York, N.Y. 10027
Investigation: feasibility of medical uses in developing countries.
D. Dunham.

University of Florida
Solar Energy and Energy Conversion Laboratory
Gainesville, FL 32611
Research: the effect on efficiency of using dye in solar distillation.
E.A. Farber.

Georgia Institute of Technology
Engineering Experiment Station, Atlanta, GA 30332
Research: evaluation of plastic film cover material.
R.W. Hammond.

Aqua-Sol, Inc.
7710 Computer Ave, Minneapolis, MN 55435
Design and consulting: still units using semi-rigid covers.
R.M. Eckstrom, A.A. Mikhail.

Sunwater Co.
1488 Pioneer Way, Suite #17, El Cajon, CA. 92020.
Manufacturer: small scale domestic units.
W. Groh.

Volunteers in Technical Assistance (VITA)
3706 Rhode Island Ave., Mt. Rainier, MD 20822.
Technical service: literature, booklets, assistance on request.
T. Fox.

The following United States organizations and individuals have a history of interest in solar distillation.

Battelle Memorial Institute, Columbus, Ohio 43201 (S. Talbert, J. Eibling).

University of Wisconsin, Solar Energy Laboratory, Madison, Wisconsin 53706 (J. Duffie).

Franklin Institute, Philadelphia, Pennsylvania.

Department of the Interior, Office of Water Research and Technology, Washington, D.C.

Colorado State University, Fort Collins, Colorado 80532 (G. Lof).

University of Delaware, Institute of Energy Conversion, Newark, Delaware 19711.

Solar Sunstill, Inc., Setauket, L.I., New York 11785.

Solar-Electric Laboratories, Kingston, New Jersey 08528 (S. Andrassy).

Harold Hay, 945 Wilshire Blvd., Los Angeles, California 90000.

Maria Telkes, Solar Energy, Box 1416, Killeen, Texas 76541.

PROFESSIONAL ORGANIZATIONS

International Solar Energy Society
P.O. Box 26, Highett, Victoria 3190, Australia.

Cooperation Mediterraneene pour l'Energie Solaire
Siege Social: Palais de la Bourse
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United States Section
International Solar Energy Society, Inc.
American Technological University
P.O. Box 1416
Killeen, Texas 76541.

APPENDIX C

SAMPLE STILL DESIGNS AND WORKING DRAWINGS

Contents:

REVISED
JULY 1967

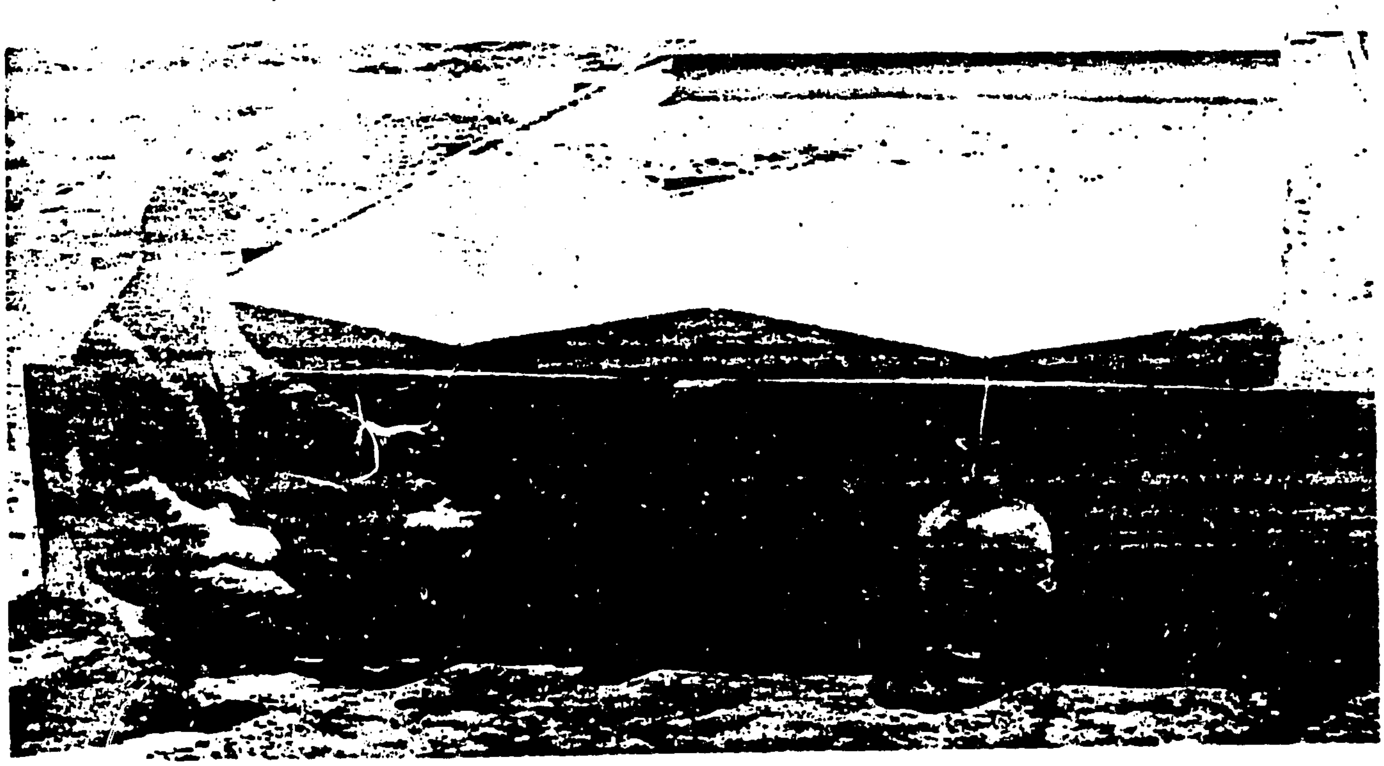
UNIVERSITY OF CALIFORNIA
SEA WATER CONVERSION LABORATORY
1301 SOUTH 46th STREET
RICHMOND, CALIFORNIA

GLASS-COVERED SOLAR STILL

The attached drawings give the details of a glass-covered solar still intended for assembly on the ground. Designed by Mr. B. W. Tleimat, of this Laboratory, this still can be assembled from materials generally available, with the possible exceprion of the aluminum Tee-section glass supports. This particular design, using wooden side pieces, is intended for demonstration and evaluation purposes. For more permanent use, the wooden sides should be replaced with precast concrete members, which would involve minor dimensional alterations in other components. Those desiring to build the more permanent form may obtain further information from the Laboratory.

The unit should be mounted as nearly level as possible, with final adjustment by means of the sand bed inside of the wooden frame. The height of this sand bed above the bottom edge of the frame will depend upon the depth of water to be placed in the plastic basin. The depth of water will, in turn, depend on the frequency with which the basin is to be refilled--the estimated maximum production rate being capable of lowering the water level by nearly 1/2 inch per day. Thus, if the unit is to be serviced every three days, the depth of the water should be about 1-1/2 inch, which would reserve 1/2 inch for possible unevenness of the bottom and delays in filling. A further limit is imposed by the requirement that the distillate collection troughs must be definitely above the saline water in the basin.

On Drawing No. 5D968 Item 7, the black polyethylene plastic bottom is an 8-foot by 10-foot sheet of Type 65 Griffolyn, made by Griffolyn Fabric Films, 6815 Dixie Drive, Houston Texas. Additional copies of this brochure may be obtained from the Laboratory.



DEMONSTRATION GLASS-COVERED SOLAR STILL (6 FEET BY 8 FEET)
LOCATED AT SEA WATER CONVERSION LABORATORY, RICHMOND, CALIFORNIA

STEPS IN ASSEMBLING A 6-FOOT BY 8-FOOT SOLAR STILL

1. Assemble a kit of parts containing all of the items listed on Drawing No. 5D968. In addition to the kit, the following items will be needed:

   a. Fence wire, 50 feet long and three feet high, and supporting posts (usually 9 posts are required).

   b. A 20-gallon tank for sea water, which should be painted with bitumen or other coating to prevent rusting. This tank should have an outlet in one side about 4 to 6 inches above the bottom, preferably fitted with a shut-off valve and suitable for connection to the 1/2 inch O.D. feed tube (Part No. 3).

   c. Plastic containers for fresh water. These should have a capacity of three gallons, and may be used containers from chlorox, detergents, etc., which have been thoroughly cleaned.

   d. Four wooden stakes, approximately 2 inches by 2 inches by 18 inches in size.

2. Nail the frame together, being careful to match up the bottom of the boards at the corners. Turn the frame upside down, and nail the sheet metal corner braces to the end boards. Measure the diagonals to the outside corners of the wooden pieces, and adjust the frame until these are equal, within 1/16 inch. Nail the metal corner braces to the side members of the frame.

3. Clean off the site, which should be about 11 feet by 13 feet, and free from shadows. Pull out all grass and weed roots, and rough grade to level condition.

4. Place the frame in position right side up, and check for level. Drive two of the stakes against the outside of the frame on the higher end, with the stakes about four feet apart. Fasten the end of the frame to the stakes with one nail each, making sure that the end board is level when the second nail is driven. Drive the other two stakes against the outside of the frame at the opposite end, level the frame longitudinally, and fasten it to the stakes with one nail in each stake.

5. Place clean sand inside of the frame, and smooth the surface of the sand even with the lower edges of the frame.

6. Place the black plastic basin liner over the frame, and pour in a few pails of water. Work out the wrinkles from the plastic, and check the depths of water in the various areas of the basin. If these are unequal, roll the plastic part-way back and add or take away sand to make the water depth equal throughout the basin. Cut a hole in the plastic for the clean-out block on the inlet end, and place the outlet level-control and drain fittings in place at the opposite end. (See Sections EE and FF on Drawing No. 5D968 for details.)

   Place the elbows (Items Nos. 9 & 12) under the plastic bottom (Item No. 7) in the desired position and press the short plastic pipes (Items Nos. 8 & 11) over the elbow as shown in Sections EE and FF. Cut out the plastic to clear the holes in the elbows. Make certain that the top of Item No. 9 is flush with the level of the bottom cover for thorough cleaning.

   Add enough water to bring the level to the top of the outlet fitting. The depth of water should be 1-1/4 to 1-1/2 inch. If necessary to adjust the height of the outlet fitting, this may be done by adding or removing sand beneath it. The drain tube of the outlet level control (Section FF) should be attached to the elbow on one end and should drain into a hole filled with stones on the other end. The wooden cleaning slot cover should be faced with plastic cut from a corner of the basin liner, assembled with the copper feed tube, and bolted into place.

7. Assemble the two product troughs with two of the aluminum Tee-bars, using a wire hanger at the center. Place the rubber drain tubes in the holes at the larger ends of the product troughs, locking the rubber tubes in place with short pieces of plastic tube, as in Section CC of Drawing No. 5D968.

8. Place the Tee-bars into position, passing rubber drain tubes through the holes in the frame and corresponding holes in the plastic basin liner. Blow through the rubber tubes to be sure that they are clear and not pinched. Screw the Tee-bars to the frame, making certain that the ends of the Tee-bars are just even with the outer surfaces of the wooden sides and that the tabs at the ends of the product trough are in proper position under the Tee-bars.

9. Spread Dap mastic along the upper side of the flanges on the middle Tee-bar. (See Sections GG and HH of Drawing No. 5D968 for details.)

10. Wash one side of each pane of glass and be sure it is dry before applying it. Place one pane in an end position. Place the next pane of glass with its lower edge against the Tee-bar and opposite to the first pane. Place the next pane in the end position beside the first pane. Apply the black vinyl tape over the glass-to-glass joint, making sure that the surface of the glass is dry before the tape is applied. The tape will not adhere to the glass if the latter is wet. Put the fourth pane of glass into place and close the glass-to-glass joint with the black vinyl tape, thus completing this half of the still.

    Place the other half of the glass in the same order, beginning with a pane in an end position When all the glass is in place and black vinyl tape applied, use Dap mastic to seal the outer edges of the glass to the plastic along the wooden frame.

11. Smooth the exposed sheet plastic against the outside of the wooden frame, and tack it in place to keep it from blowing in the wind.

12. Place the fence around the still, to keep out small animals, etc., which might damage the glass.

13. Dig holes for the distillate containers under the ends of the rubber tubes. If the soil is sandy and likely to cave in, the holes may be lined with old metal drums large enough to hold the distillate containers.

14. Place the water supply tank near the inlet and attach it to the inlet connection. Put about 20 gallons of sea water in the tank for use in the first flushing period.

OPERATION OF A 6-FOOT BY 8-FOOT SOLAR STILL

1. This unit should produce about five gallons of distilled water on a clear sunny day, and somewhat less on cloudy days.

   The vulnerable parts of this still are the glass cover and the plastic basin liner, and suitable precautions should be taken to avoid damage to both of these. The plastic basin liner should never be permitted to run dry because, if it does run dry, the interior of the distiller enclosure will become overheated and the plastic may be burned.

2. The distillate containers should be emptied each day, preferably in the morning. When records of production rate are being kept, the distillate should be measured at very nearly the same time each day.

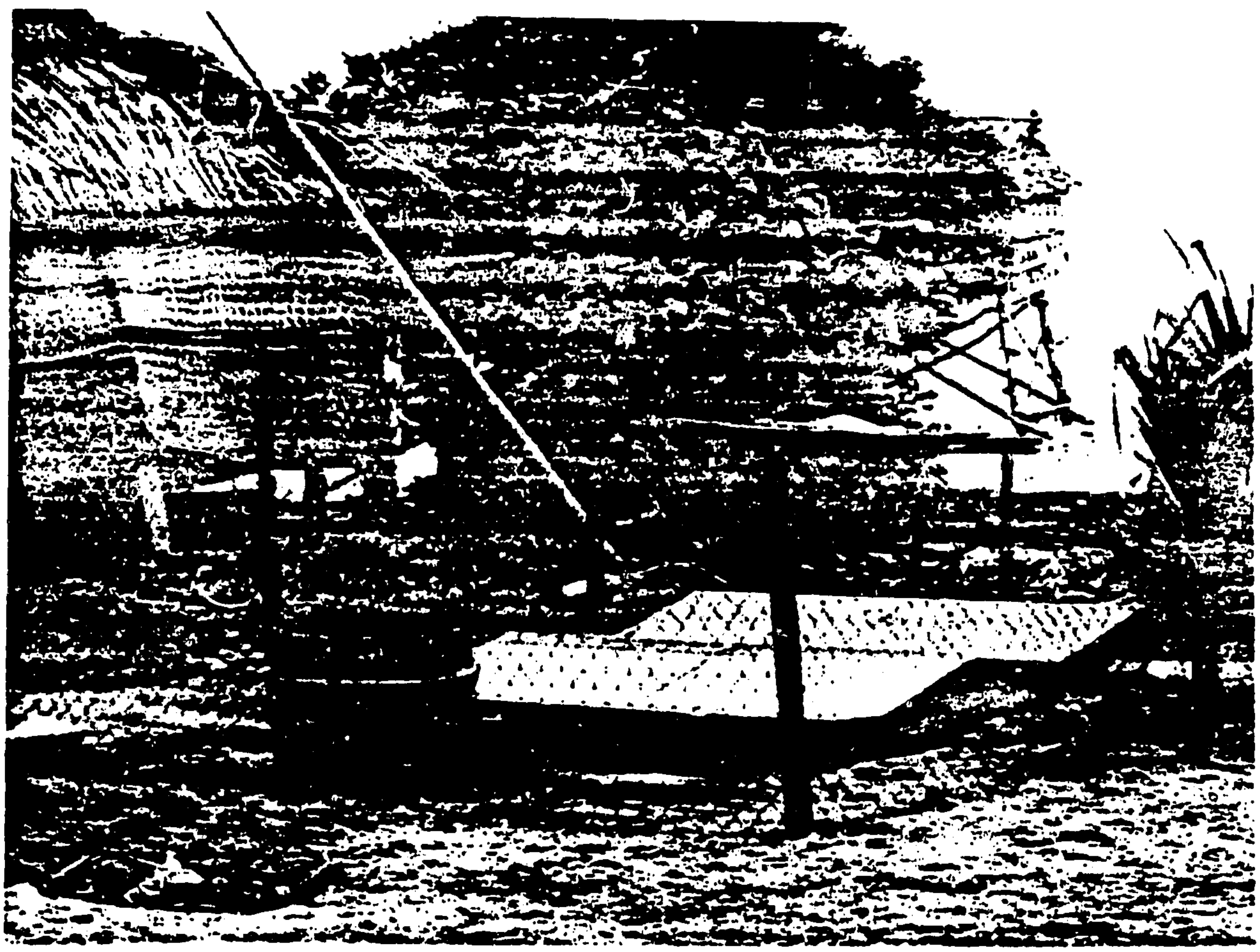
3. Flushing by the addition of fresh sea water should be done twice each week, for example, on Mondays and Thursdays. The amount of sea water or brackish water used in each flushing should be about one-half of a barrel, or 20 gallons.

4. The condition of the still should be noted, and any vapor or air leaks should be stopped with black tape or Dap mastic. Broken glass panes should be replaced at once. If the plastic basin liner should become punctured, the breaks in it can be patched by gluing over them pieces cut from the excess around the outside of the still. The adhesive used may be any available glue or mastic Dap, preferably one which does not become brittle after setting.

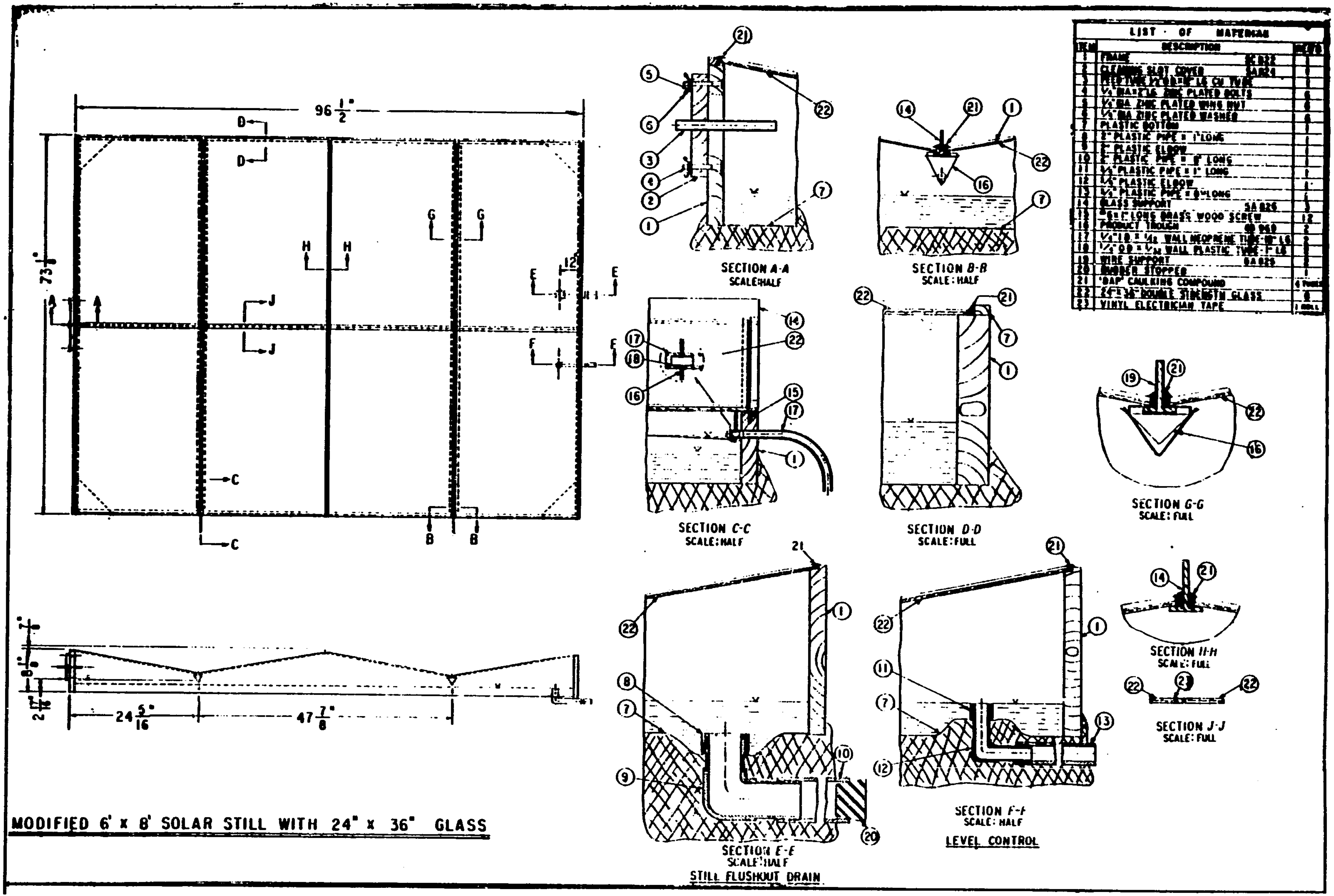
5. The glass panes should be wiped off occasionally with a damp cloth if they become dusty. Materials floating on the surface may be removed through the clean-out hole on the inlet end.

6. The flushing operation in (3) above is intended to limit the salinity in the still basin. For a more complete flushing and major clean-out of the basin, the rubber plug can be removed from the large drain pipe to drain out all of the water. The clean-out closure at the inlet end of the wooden frame can also be removed to facilitate the cleaning operation. This major clean-up should be required very infrequently--say, once in six months.

7. If the taste of the water seems objectionable for potable purposes, the water should be passed through a chamber filled with charcoal or activated carbon.



SAWTOOTH-TYPE SOLAR STILL, TARAWA ATOLL, GILBERT ISLANDS
(6-foot x 8-foot Demonsrration unit, maximum production 5 gpd)



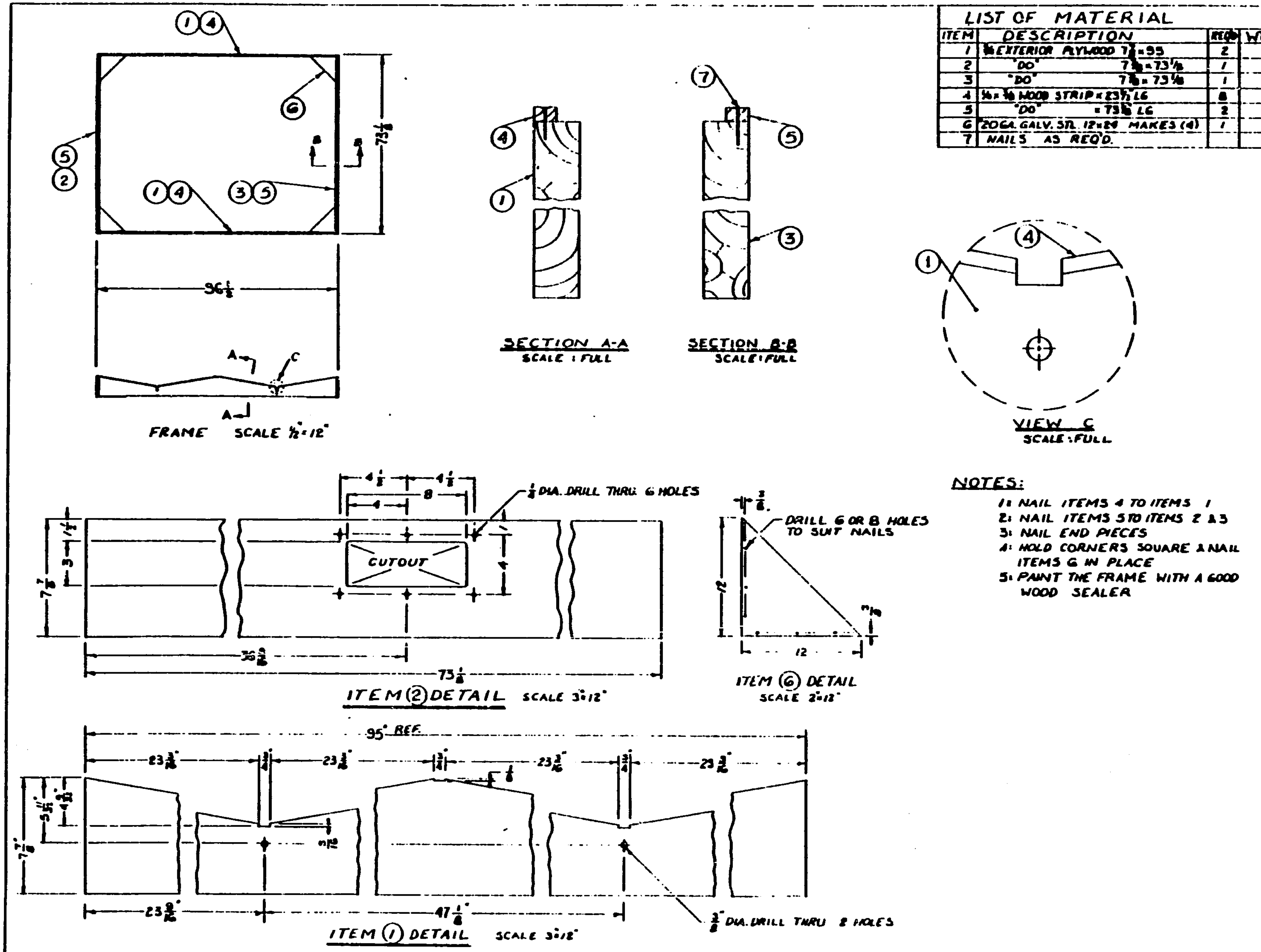
LIST OF MATERIAL

ITEM	DESCRIPTION		REQ'D
1	FRAME	5C 822	1
2	CLEANING SLOT COVER	5A 824	1
3	FEED TUBE 1/2" OD x 8" LG CU TUBE		1
4	1/4" DIA x 2" LG ZINC PLATED BOLTS		6
5	1/4" DIA ZINC PLATED WING NUT		6
6	1/4" DIA ZINC PLATED WASHER		6
7	PLASTIC BOTTOM		1
8	2" PLASTIC PIPE x 1" LONG		1
9	2" PLASTIC ELBOW		1
10	2" PLASTIC PIPE x 8" LONG		1
11	1/2" PLASTIC PIPE x 1" LONG		1
12	1/2" PLASTIC ELBOW		1
13	1/2" PLASTIC PIPE x 8" LONG		1
14	GLASS SUPPORT	5A 826	3
15	#6 x 1" LONG BRASS WOOD SCREW		12
16	PRODUCT TROUGH	6D 950	2
17	1/4" ID x 1/16 WALL NEOPRENE TUBE-[illegible]" LG		2
18	1/4" OD x 1/32 WALL PLASTIC TUBE-1" LG		2
19	WIRE SUPPORT	5A 825	2
20	RUBBER STOPPER		1
21	'DAP' CAULKING COMPOUND		4 TUBES
22	24" x 36" DOUBLE STRENGTH GLASS		8
23	VINYL ELECTRICIAN TAPE		1 ROLL

MODIFIED 6' x 8' SOLAR STILL WITH 24" x 36" GLASS

DRAWING NO. 5D868 — 6 FOOT BY 8 FOOT SOLAR STILL WITH 24 INCH BY 36 INCH GLASS

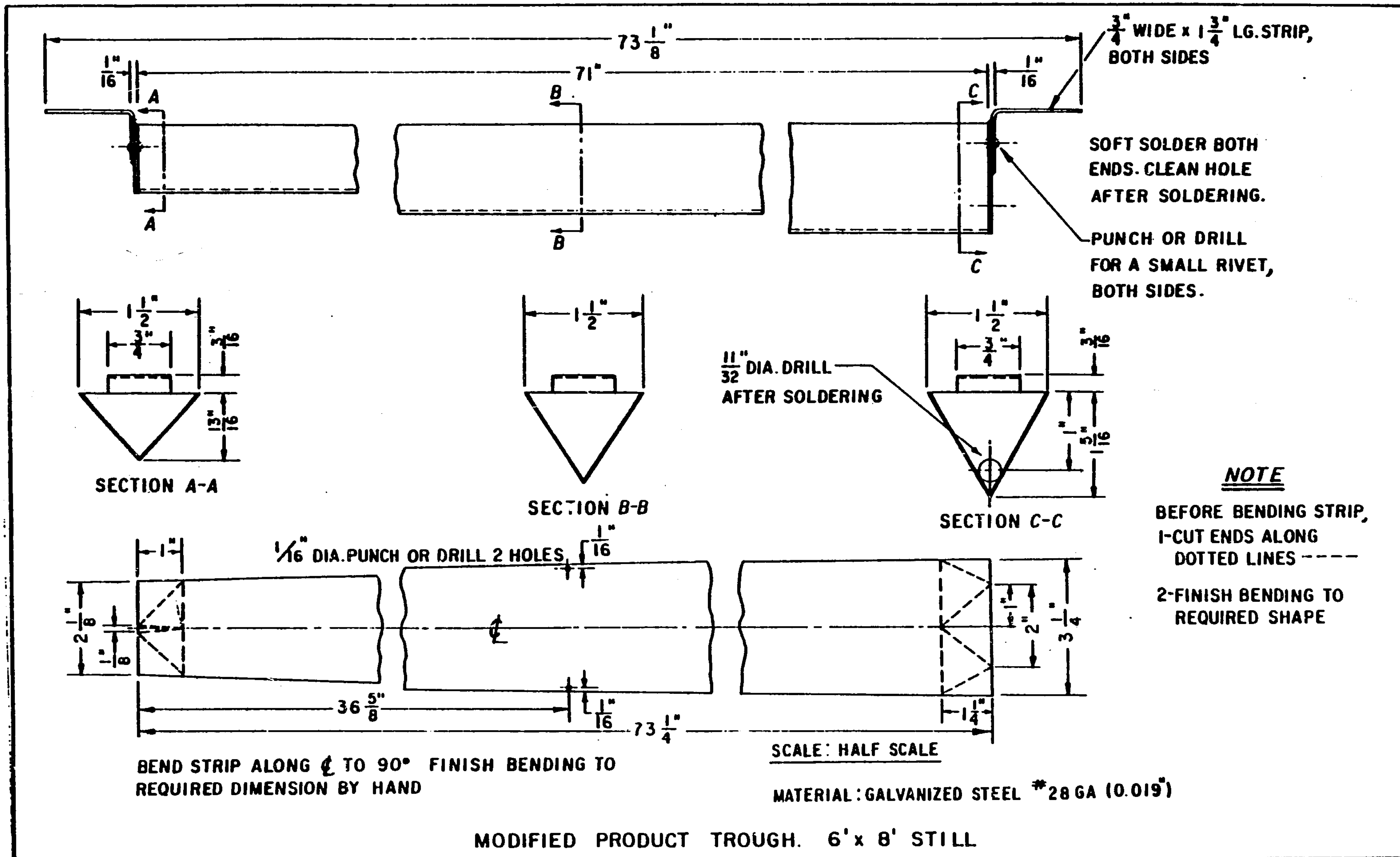
C-6



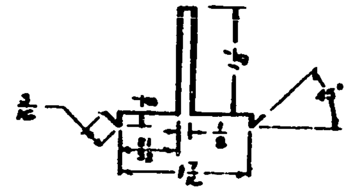
LIST OF MATERIAL

ITEM	DESCRIPTION	REQD	WT
1	[illegible] EXTERIOR PLYWOOD 7[illegible] x 95	2	
2	"DO" 7[illegible] x 73⅛	1	
3	"DO" 7[illegible] x 73⅛	1	
4	½ x [illegible] WOOD STRIP x 23½ LG	8	
5	"DO" x 73[illegible] LG	2	
6	20 GA. GALV. STL. 12 x 24 MAKES (4)	1	
7	NAILS AS REQ'D.		

DRAWING NO. 5C822. FRAME OF 6-FT X 8-FT SOLAR STILL WITH 24-IN. X 36-IN. GLASS

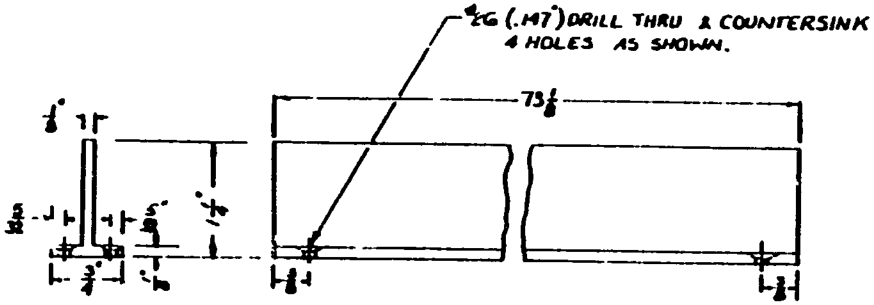


DRAWING NO. 5B969. MODIFIED PRODUCT TROUGH FOR 6-FOOT WIDE SOLAR STILL



Material: .035" dia. type 304 spring temper stainless steel wire x 4-5/16 lg.

Drawing No. 5A825. Product Trough Support for 6-ft wide Still with 24-in. x 36-in. Glass & T Section Glass Support.

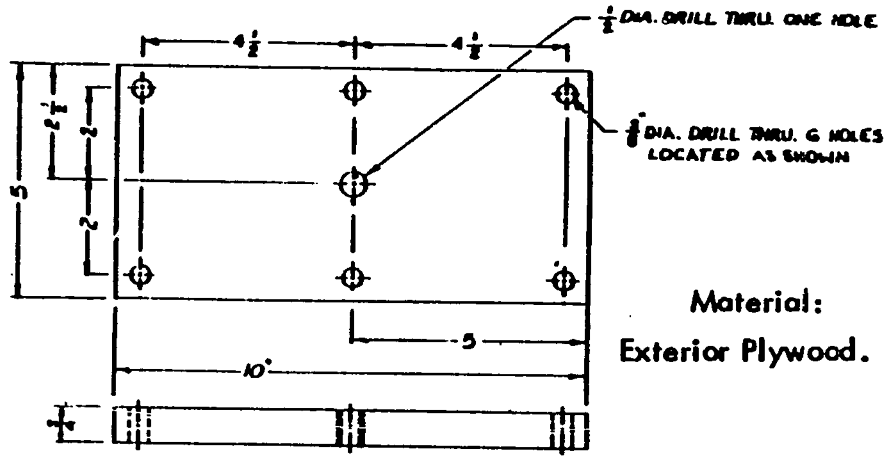


Material:

Aluminum Alloy 6063-T5 Tee Alcoa Section No. 4716 x 73-1/8 in. lg.

Drawing No. 5A826.

Glass Support for 6-ft wide Still with 24-in. x 36-in. Glass & T Support.

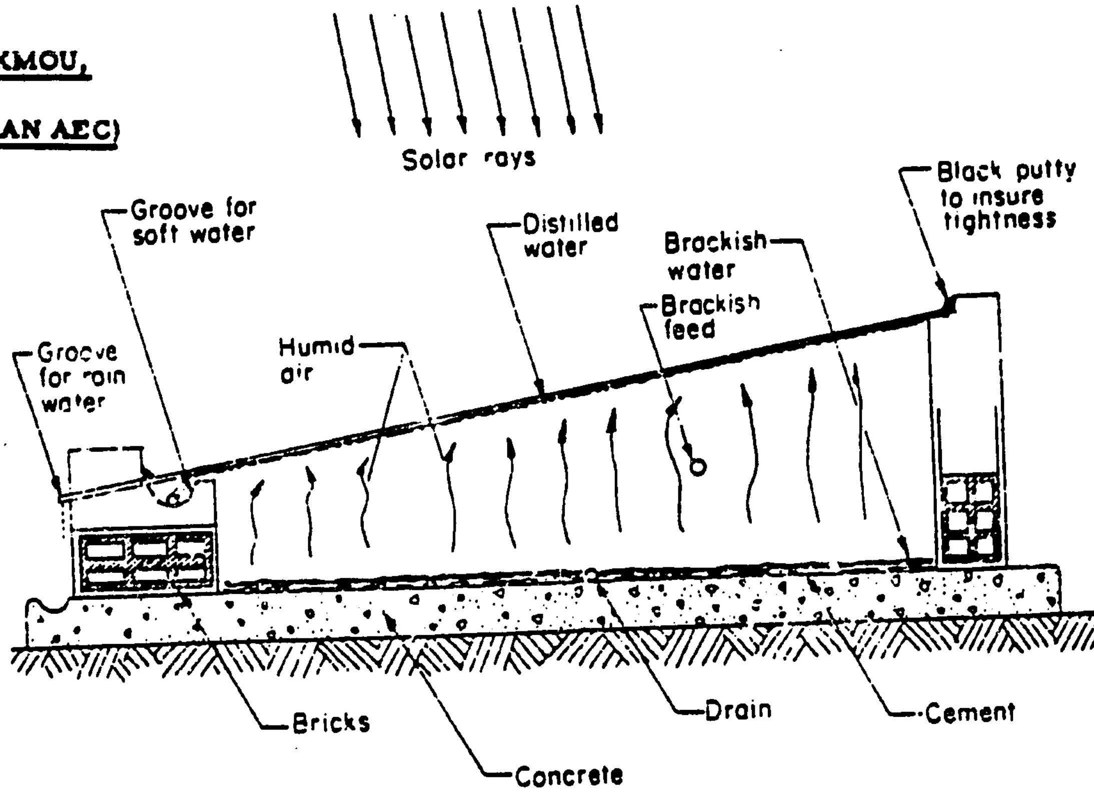


Material:

Exterior Plywood.

Drawing No. 5A824. Cleaning Slot Cover for 6-ft x 8-ft Still

STILL AT CHAKMOU, TUNISIA (TUNISIAN AEC)



Internal size:	Approximately 50 bays, 4,730-ft^2 total evaporating area.
External size:	6,450-ft^2 overall area.
Brine depth:	Approximately 1 in.
Cover:	Glass, 10-degree slope facing southward.
Vapor seals:	Rubber strips, plaster, and mastic.
Distillate troughs:	Moulded concrete curb.
Basin liner:	Concrete bottom, asphalt coated.
Walls and curbs:	Bricks and concrete.
Other features:	Provides drinking water for 500 persons, rainwater collected off still's concrete platform, brackish feedwater has 6 g/ℓ of salt, two parts of distilled water mixed with one part brackish water for drinking, 1/2 hr maintenance daily.
Productivity:	Varies between 53 and 210 gal/day (about 0.01 to 0.04 gal/ft^2-day).
Problems:	Cracks in base and walls leak brine and vapor (performance should be tripled after repairs are made), clogging of feedwater pipes, dust must be cleaned from glass after dust storms, every 2 weeks calcium sulfate deposits and a floating carbonate film must be cleaned from bays.

Sample Still Diagram from Manual on Solar Distillation, Batelle Memorial Institute, item 83 in bibliography.

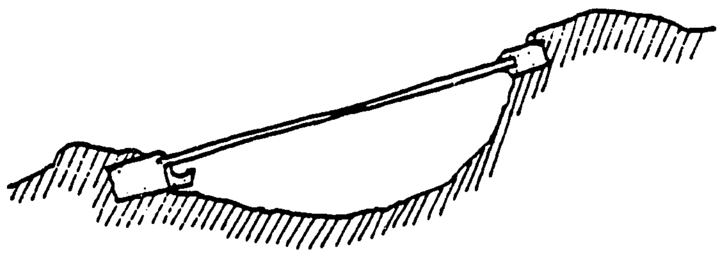


Diagram 1

Basinless Stills

The concept embodied in the "survival" or "earth" still design deserves more consideration than it has apparently been given. Only two researchers have published quantitative material on it: Masatusugu Kobayashi ("A Method of Obtaining Water in Arid Lands," Solar Energy, Vol. 7, No. 3, pp. 93-99, 1963) and J. Ahmadzadey ("Solar Earth-Water Stills," Solar Energy, Vol. 20, pp. 387-391, 1978). Both were attempting to extract water from dry or desert soils. The amount of water retrieved was never very high - about 1 liter per square meter per day - one-fourth the amount that might be expected of a regular basin still. Their production was highest when the stills were first placed on the ground. Production fell rapidly after water near the surface had been vaporized. Much of the distillate was produced at night.

It would not be difficult to design basinless stills of shaped mud or sand to which water would be deliberately added. Keeping the soil constantly moist would increase production dramatically. The efficiency of the still would depend on the type of soil, its particle size, its color, and its capillarity.

Unsatisfactory soils could be modified in various simple ways to make them perform better.

In principle, such a still would use the earth itself as a basin or a "wick." A still designed to capitalize on this would eliminate completely the cost of building and maintaining the usual impervious basin. The still sketched in the accompanying diagrams (1 and 2) represents the reduction of the formal still components to the transparent cover and the distillate trough. Water would be added directly to the still or through a channel nearby. The unit would probably operate both during the day and at night as some of the heat lost to the ground returns to the system.

Efficiency might be lower than the usual basin still, but eliminating the cost of the impervious basin (one-half or more of the total cost) might result in a cost-efficiency higher than that of the usual basin still.

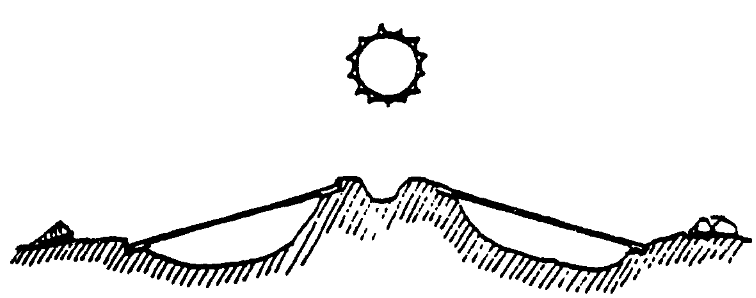


Diagram 2

A basinless still would appear to lend itself well to those areas where there is a tradition of working in mud or earth, or to those coastal areas where saline water is normally near the earth's surface (tidal or mud flats). The sealing agent around the cover frame would be mud, sand, or earth. It could be molded, removed, or replaced as necessary by those using the still. When the crystallization of salt reduced efficiency below an acceptable level, the cover could be moved to a new area.

The cover would have to be strong and light enough to be moved periodically without breaking. Several small independent units (1 m^2) rather than large ones would be easier to handle. Framed or formed rigid plastic (diagram 3) would be lighter and more shatter-resistant than glass.

A large part of the usual capital cost of a solar still would not be needed for a basinless still; this part of the cost would be replaced by continuous but simple maintenance.

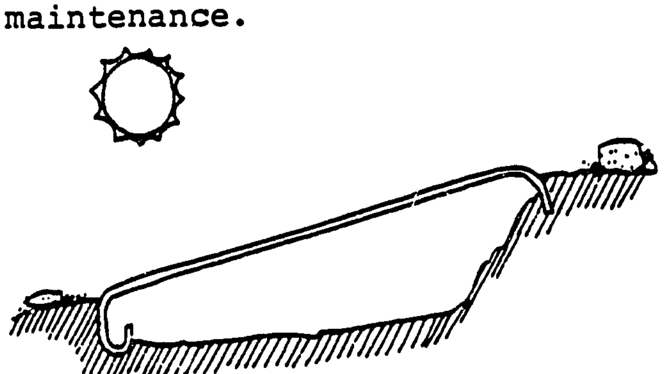


Diagram 3