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THE DEVELOPMENT OF SOLAR ENERGY UTILIZATION IN DEVELOPING COUNTRIES[1]

by

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TABLE OF CONTENTS

INTRODUCTION

History shows that solar energy has already been utilized for a long time, but it is only since the 19th century that improved equipment has come into being, such as boilers fitted with mirrors, steam engines, hot air engines and cookers. The intensive development of thermal and electrical engines as well as the extremely low cost of energy, especially that imported from the Third World, have to some extent discouraged research in the field of solar energy. Now that the cost of energy is in the process of reaching a normal level and that the discovery of new oil resources is becoming rare, industrialised countries are launching important research programmes to domesticate solar energy For example, the ERDA (Energy and Research Development Administration) in the USA had a budget of $115 million for the fiscal year 1976. Solar energy has reached a stage where in some fields it has started to compete economically with conventional sources of energy. Due to the fact that developing countries are often situated in very sunny regions, it is in their own interest that they should develop the utilization of solar energy, which is free, inexhaustible, omnipresent (no transport or distribution problems) and non-polluting. This energy could be converted into mechanical, electrical or chemical energy to be used in various fields; such as the production of electricity, the desalination of water, irrigation, cooking, food preservation by means of refrigeration, drying of fishery products, fruit and vegetables, space heating and air conditioning.

AIMS AND SCOPE OF THE STUDY

The purpose of this study is to give an account of the development of research on solar energy and its utilization from the techno-economic point of view. It aims mainly to throw light on the principal issues related to the utilization of solar energy by developing countries, and it is hoped that it could serve as a first guideline for technicians, economists and policy makers in these countries.

A proliferation of commercial companies in the field of solar energy has emerged; some of them often failed to propose realistic performances or lifetimes of equipment, and have also asked for prohibitive prices for the transfer of solar technology to the developing countries. The majority of these countries need a first tool permitting them to improve their position to negotiate the transfer of solar technology for Research and Development purposes. This study is a first attempt at providing such a tool. For more details concerning one aspect or another of the study, more specialised references should be consulted. A summarised list of important sources of information (institutions and bibliography) will be supplied in the annex of this study.

Attention has been focused on the short and medium term perspectives because it is felt that this is most important for the moment, and because available data does not allow a valid long term projection. However, due to the accelerated change in technology, it is also felt that a study of this nature should be repeated periodically and that the specific field of utilization of solar energy in developing countries should be discussed periodically in specialised expert group meetings.

This study is neither a manual nor an extensive and detailed survey of all aspects related to solar energy utilization. Its chapters are not balanced; in general more importance has been given to fields which have not yet been popularised.

The study will deal with:

1. Development and State of the Art

This section will describe the general applications of existing technology, and will include the findings of the visits paid by the author to Research and Development Centres, and of discussions and participation in international meetings. Comments on and extracts from the findings of international, regional and national meetings, sruveys and inquiries will be reported.

2. Techno-economic evaluation of solar equipment

In this chapter, some general techno-economic comparisons will be made to show which solar equipment could be economically utilised in the short and medium term in developing countries. Equations will be outlined with parameters to be quantified according to prevailing conditions in each country. An elaborated example will be given in the paragraph "Techno-economic Comparison between Solar Engines and Internal Combustion Engines". It is very difficult to go into detail as this would produce a very narrow case study, which is not the intention of this report. Nevertheless, it is hoped that this chapter will permit a first evaluation of the kind of equipment that could be envisaged.

3. Possibility of solar energy utilization in developing countries

The author has visited some important centres of solar and wind energy research in developed countries (France, Netherlands, FRG, Canada and the USA) and developing countries (Greece, India, Mexico and Trinidad). Some findings of these visits, as well as an evaluation of the existing experience, will be reported. Problems and possible solutions, and the general trend for co-operation between developing and developed countries and among developing countries, will be discussed. The role of UNIDO in the field of solar energy will also be discussed.

4. Annexes

Important current programmes of R and D on solar energy, extracts from information systems in solar energy and from the enquiry undertaken by the Austrian Solar and Space Agency on small solar power systems, and addresses of important centres in developed and developing countries, will be included in the annexes.

A bibliography of practical manuals, books and publications utilised in the study will also be included.

Unfortunately no adequate information is available to the author about the important activities undertaken in countries such as USSR and Japan in the field of solar energy.

It has not always been possible to use the metric system when giving quotations.

Except for the original work and the personal appraisals, the author does not claim credit for the information included in this study. Such information is based on available technical literature, brochures and/or statements by manufacturers and direct contacts and discussions held in specialised institutions.

CHAPTER I - DEVELOPMENT AND STATE OF THE ART

1. CONVERSION OF SOLAR ENERGY INTO MECHANICAL ENERGY

General considerations

The term "solar engine" designates an engine operated by solar energy. Steam or vapour is obtained by heating the working fluid with solar radiation. This vapour or steam expands in a reciprocating or rotative engine. From the engine it flows to a heat exchanger (condensor) in which it condenses, and from there it is reinjected by a pump (usually operated by the solar engine itself) to a heat exchanger (evaporator) in which it evaporates. The cycle is then closed. The Rankine cycle is most often used. The efficiency of the system depends firstly on the Carnot efficiency:

$$e_c = \frac{T_1 - T_2}{T_1}$$

T_1 - the absolute temperature of the hot source

T_2 - the absolute temperature of the cold source

It appears from this equation that, from the thermal point of view, it is more economical to use a very high temperature for the hot source and a very low temperature for the cold source. In a practical sense, T_1 is limited by the performance of the solar collectors and by the high pressure, which implies the use of special materials and special techniques, for example, the pressure of freon 22 is 20 bars at 50°C. T_2 is limited by the cooling source: water or air with natural or forced convection.

No standards yet exist defining the range of low, medium and high temperatures.

In this study, low temperature solar engines refer to temperatures below 100°C. This means that flat plate solar collectors, capturing direct and diffuse solar radiation, are used. Medium and high temperature solar engines refer to temperatures above 100°C; in this case, focusing solar collectors, which track the sun and use only direct solar radiation, are used.

Air could be heated to a relatively high temperature by solar energy and used to operate solar engines. Two cycles could be used:

- Closed cycle system (Stirling): the air is compressed in a cold space, then it is put into contact with a hot source, where its pressure increases and expands in a power cylinder. From there it flows to the cold space and the cycle is closed.

- Open cycle system (Ericson): compressed air is introduced into a hot space. It then expands and exhausts into the atmosphere.

1.1 Low temperature solar engine

The low temperature solar engine system refers practically to temperatures lower than 80°C. It consists of flat plate solar collectors which convert solar energy into heat. A working fluid (freon 22, freon 12, freon 11, freon 114, butane . . .) is evaporated directly in solar collectors or by hot water obtained from solar collectors circulating in a heat exchanger (evaporator). The working fluid in its gaseous phase flows to and expands into a reciprocating or rotative engine. From the engine it flows to a condensor, air or water cooled. From the condensor, the working fluid in its liquid phase is reinjected into the evaporator by a pump operated by the solar engine. In some applications, when hot water is used to evaporate the working fluid, a circulating pump also operated by the solar engine could be used to accelerate the circulation of the hot water in order to improve the heat transfer in the evaporator. In this case, manual starting is necessary.

The solution of evaporating the working fluid directly in the solar collectors could be economical in small installations but it seems that it would be very difficult to adapt such a solution in the case of large solar collectors, since the circulation of the working fluid may present great difficulty and the tightness of the system would be very difficult to obtain.

1.1.1 SOFRETES, the Société Française d'Etudes Thermiques et d'Energie Solaire, has already installed or is installing about 50 solar pumps. The majority of them has about 1 kw.

The technology, however, has evolved too far. They have tried butane and many kinds of freon, especially freon 12 and 11, and now it seems that they are changing to freon 114. They have also changed their technology in the matter of heat exchangers.

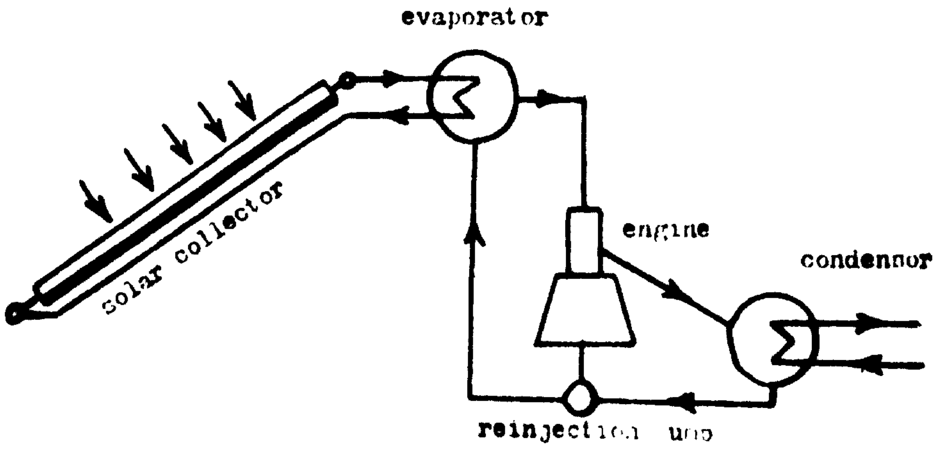
They began with shell and tube condensors and evaporators. Afterwards they used tube in tube (coaxial) condensors and now it seems that they are changing to plate heat exchangers similar to those used in the food industry. In one of the 1 kw solar pump installations using butane as the working fluid and 60 m^2 flat plate solar collectors, the following approximative data has been obtained. The water outlet temperature of the solar collectors is about 70°C. The temperature in the outlet of the evaporator and in the entrance of the solar reciprocating engine is about 67°C and the outlet temperature of the engine is about 50°C. The condensing temperature in the condensor, cooled by the pumped water, is about 30°C. In a good solar radiation regime, such an engine could function about 6 hours a day without solar storage, but it would not give full power all this time.

In another 1 kw solar pump installation, the following data has been obtained:

entrance temperature in the engine	55°C
outlet temperature from the engine	40°C
outlet temperature from the condensor	30°C

The same company, in collaboration with the Mexican Government, has installed a 25 kw solar power plant in San Luis de la Paz. The electric generator is operated by a turbine of 7,200 rpm operated by the evaporated freon 11 at a pressure of about 3 [illegible]s,, working fluid entrance temperature of 57°C and outlet temperature about 30°C. This turbine is fed by freon 11 evaporated in an aluminium evaporator with an exchange surface of about 350 m^2 and 415,000 kcal/hour with water entrance temperature 62°C and water exit temperature 58°C.

The evaporator is fed with hot water coming from 1200 m^2 net effective surface solar collectors. The gas is condensed in a stainless steel condensor of 380,000 kcal per hour with about 100 m^2 exchange surface. The condensed freon is reinjected into the evaporator by a 3 kw reinjection pump driven by electric energy delivered by the electric generator.



Principle of low temperature solar engine with working fluid evaporating in the evaporator heated with hot water which is heated by solar energy.

The installation has been in operation for about one year and does not present serious technological problems, but the control of the system is very sophisticated.

1.1.2 A V-2 solar vapour engine has been developed by Farber of the Solar Energy and Energy Conversion Laboratory of the University of Florida. The system uses freon evaporating directly in the solar collectors. It consists of two cylinders, each having an inside diameter of 51 mm. The two cylinders are oriented at 90° to each other. The piston in each cylinder has a stroke of 39 mm. Slide valves control the vapour flow in and out of the cylinders admitting vapour for 90° of the flywheel rotation and exhausting it for 140°. The 25 cm tall, 35 cm wide and 23 cm deep engine is mounted in housing 40 cm in diameter and 25 cm deep. The total displacement of the engine for one revolution is 305 cc.

The vapour is fed to the engine through the housing. The vapour after it has produced work, is exhausted into the housing surrounding the engine. In this manner any leaks which may be present are not critical since the housing catches all exhausted and escaping vapours. From the housing, the vapour flows to the condensor.

The engine is speed-controlled by a centrifugal flywheel governor which regulates the vapour flow to the engine and can be adjusted to give the speed desired for operation.

The water-cooled condenser used in connection with this engine is a cylinder 76 cm in diameter and 61 cm long. In this cylindrical container are 7 coils of 2.5 cm diameter pipe giving a total length of 13.5 m. The vapour is condensed in this pipe.

The operating conditions and an ideal system T-S diagram is shown in Fig. 1. 1-2 indicates the expansion of vapour through the engine which converts some of the energy into mechanical work. 2-3 indicates the state changes which occur in the fluid when it is moving through the condensor. 3-4 is an indication of the pump action, raising the pressure to that of the solar vapour generators. 4-1 completes the cycle of the system and presents the changes which occur in the evaporator. This same cycle is presented for a freon 11 as working fluid in Fig. 2. Conservative operating conditions were selected which can readily be obtained by such systems. 72°C vapour is

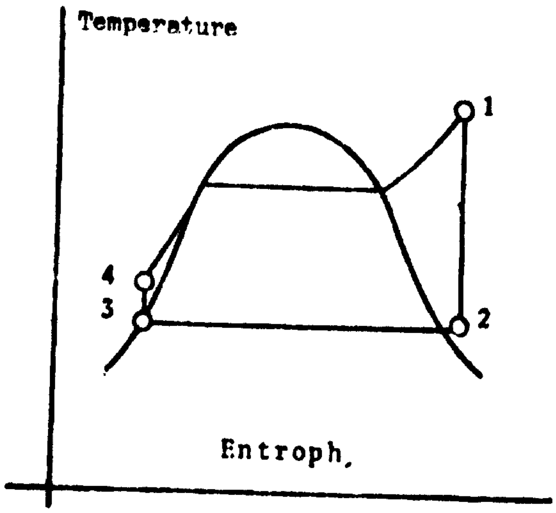

Temperature
1
2
3
4
Entroph.

Fig. 1

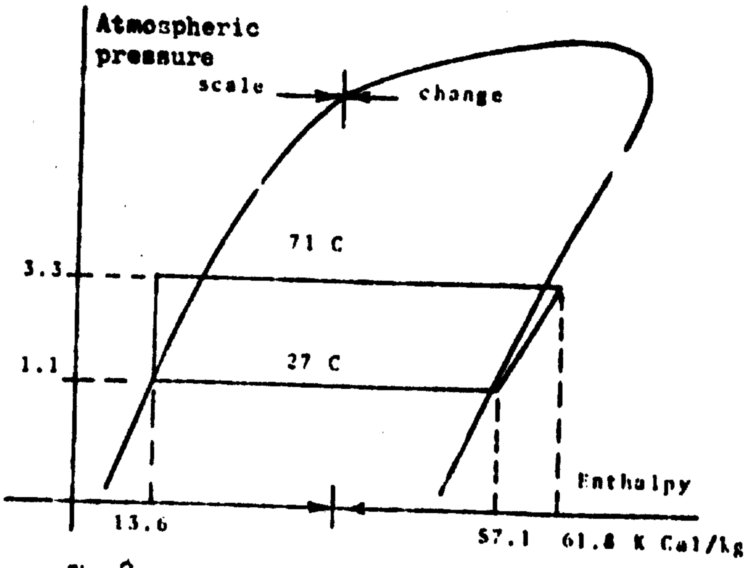

Atmospheric pressure
scale
change
71 C
27 C
3.3
1.1
Enthalpy
13.6
57.1
61.8 K Cal/kg

Fig. 2

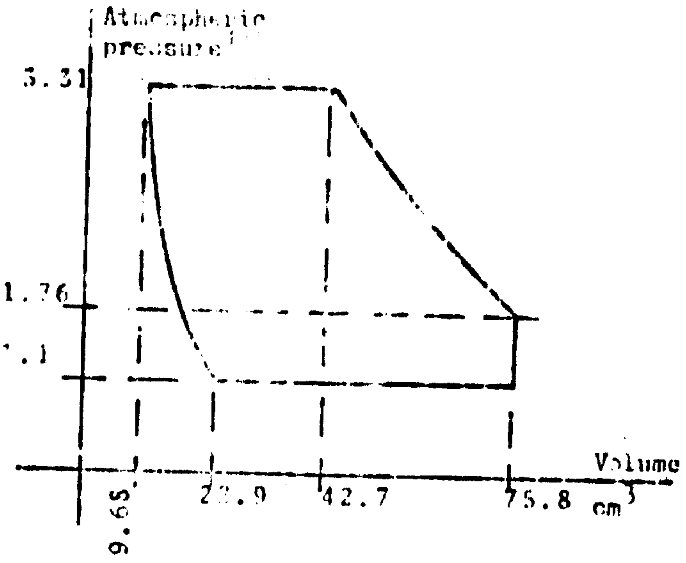

Atmospheric pressure
3.31
1.76
1.1
9.65
22.9
42.7
75.8
Volume
cm³

Fig. 3

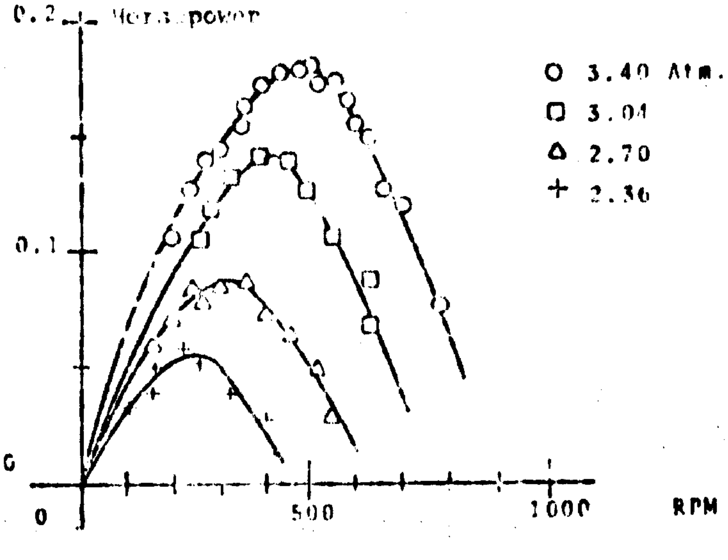

0.2
Horsepower
0.1
0
0
500
1000
RPM
○ 3.40 Atm.
□ 3.04
△ 2.70
+ 2.36

Fig. 4

is delivered by the flat plate solar collectors and 28°C liquid by the water cooled condensor. The pressures corresponding to these temperatures are moderate, not requiring special designs.

Idealised conditions inside the engine cylinders, on one side of the piston are indicated in a diagram pressure-volume air Fig. 3, and the corners are not rounded as they are in the real case.

Fig. 4 presents the actual performance of the engine with supply pressures held constant at 2.36, 2.70, 3.04 and 3.40 atmospheres, pressures which correspond to R-11 at temperatures of 51, 56, 60 and 65°C respectively.

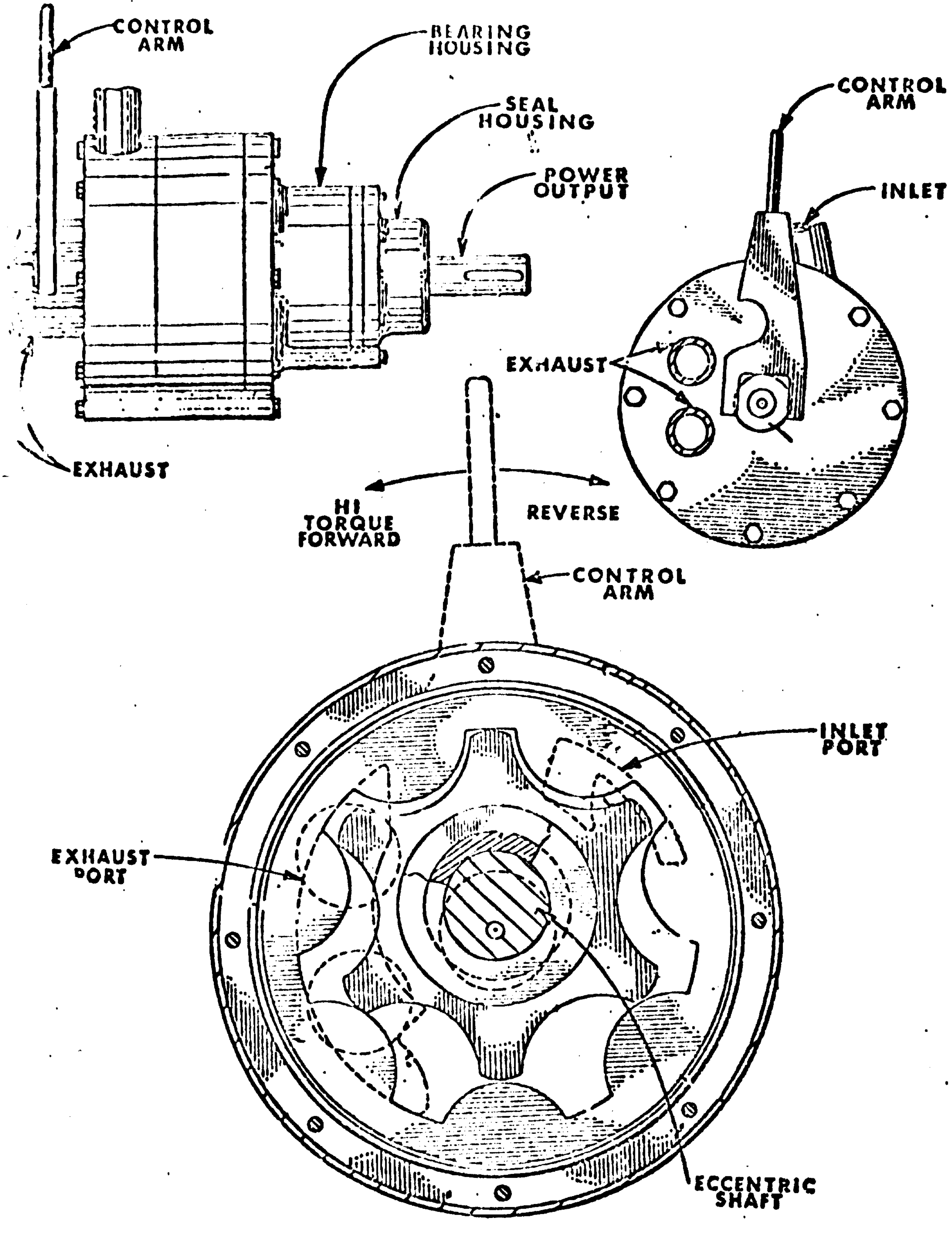
The curves are typical of engine performance. Maximum speed is reached at no load and as the load is increased the speed drops. If the power output is plotted against revolutions per minute a maximum power point is shown on each curve.

Curves for temperatures and pressures higher than those presented could be obtained, but only during a very short part of the dayl

The combination of two cylinders in a compact V arrangement makes this engine self-starting, which is a distinct advantage when intermittent clouds cover the sky.

1.1.3 Sun Power Systems: This company has developed a rotative engine mainly destined to use industrial waste energy. However the working fluid, namely freon, could be evaporated by hot water obtained from flat plate solar collectors. The engine is based on the Rankine cycle. A 10 kw power generation plant was visited by the Special Technical Adviser in October 1976, which was ready for shipment to Albuquerque in the USA, for testing by a team of consultants working for the United Nations Environment Programme before being sent to a project executed by this agency in Sri Lanka. According to a letter from the manufacturer to UNIDO dated 15 November 1976, this unit is now operating at 10 kw power with 12 m^3/hour of water entering the freon evaporator at 90°C and it is expected that 276 m^2 net effective surface of solar colleotors could ensure the energy necessary to heat the water. In this plant two standard heat exchangers manufactured by Carrier, the refrigeration and air conditioning firm, are used.

KINETICS ROTARY ENGINE



An 09RH-43 model with 23 m^2 heat exchange surface is used as evaporator and an 09RH-70 model with 35.2 m^2 heat exchange surface is used as condensor. The engine has 1800 rpm and its weight is about80 kg. It operates an electric generator 1800 rpm, 60 Hz. The engine, including the heat exchangers, the reinjection pump and the electric generator is rather compact.

The 10 kw power is for a 55°C difference between the evaporating and the condensing temperatures, but in practice such a difference could not be obtained with a flat plate solar collector and only a difference of about 40°C could be expected with the usual flat plate solar collectors. The maximum expected power will then be about 7 kw. As in the case of the SOFRETES engines, the lubrication is ensured by lubricant dissolved in the freon. The actual surface of the evaporator seems to be insufficient, particularly when the temperature of the hot water entering the evaporator is about 70°C. According to the manufacturer, one of his small prototypes has been tested for 10,000 hours without significant problems. However the test was undertaken in the proximity of the factory and not in the field.

1.1.4 Gironnet-ENSAM engine

A fractional kw prototype reciprocating low speed engine has been developed by the Ecole National Supérieure des Arts et Métiers. The School is now negotiating the manufacture of a 2 kw prototype with an industrial firm. The only technical difficulty which has not yet been resolved is the lubrication. They can use the same system of lubrication as that used by the SOFRETES engine or the Sun Power Systems engine and this solution does not present any difficulties for them, but they are trying to develop a dry lubricating system, which they believe would be a better solution.

The cost of construction of the next 2 kw prototype is estimated at $4000 not including the solar collectors of which the required surface is estimated at 50 - 60 m^2 in a favourable solar radiation regime.

The first prototype is being tested with compressed air, but this does not permit a valid evaluating. However, its design is simple and its expected cost is relatively low.

1.5.5. Messerschmidt-Bölkow-Blohm

M.B.B. Ottobrun is working on a 10 kw solar thermal plant. This plant shall be an independent power station for remote rural communities. Besides the required peak power of 10 KW_E, a power reserve for night operation is planned which has been specified to 12 KWh_E for a power of 1 KW_E. This requirement implies an energy storage system to be optimised. The flat-plate collectors used by MBB for solar space heating in a pre-development phase of about two years, will be used as solar collectors. According to the given peak power a total collector surface of approximately 700 m^2 is required (According to the meeting held between Dr. Hoffmann of MBB and the Special Technical Adviser on 2 December 1976, MBB is expecting the possibility of reduction of the net effective surface of solar collectors to about 350 m^2). However, the definite specification of the required surface highly depends on the local climatic and consumer-oriented operating conditions and demands a careful harmonisation of required storage capacity with 24 hour working cycles taking into consideration the partial-load behaviour of all respective plant components. A screw motor developed by the LINDE company with R114 as working fluid will be used. A possible advantage of this type of machine for the low power class required could be an expected high efficiency behaviour of the displacement machine also in the partial-load range. Low specific (kg per kw) weight, small bulkiness and no valves should be mentioned.

The MBB flat-plate collector is a two-glass collector of modular design. The outer dimensions of the absorption surface of each module are 60 cm x 180 cm = 1 m^2. The absorber is made of roll-bond aluminum, and it is protected against corrosion by an inhibitor. The outer absorber layer is a thermal point with a high absorbability value (0.96). This paint had been developed for space applications.

The rear heat insulation consists of a protected polyurethane-foam cover. Fig. shows the typical efficiency of the flat-plate collector as a function of the collector temperature. It is expected that the temperature of the hot water could be 95°C.

Evaluation:

MBB has already assembled its prototype which has been tested several times for short durations with hot water supplied by electric boiler. Some modifications are now under consideration. The engine itself is very compact and is used in the air conditioning of trains. It has been modified to be included in this plant: Obtaining 10 kw with 95°C. Evaporating temperature of freon 114 could be possible but it seems that obtaining this temperature is very difficult with the conventional flat-plate solar collectors. Sophisticated technology including the use of selective surfaces in the collectors should be used. It has not yet been proved that such collectors could easily be manufactured and with reasonable costs. However, the firm MBB is open-minded about all possible changes regarding used temperatures or the necessary modifications in the design of the plant.

A further study in the summer of 1977 is recommended, when the experiment which is necessary for a valid evaluation will be necessary.

1.2 Medium and high temperature solar engine

To obtain steam or vapour is the main problem with this type of system. Conventional steam engines have successfully been used in the early years of this century. Steam turbines are reliable but a small size does not exist on the market.

The Carnot efficiency is relatively high but other efficiencies should be taken into consideration: in the case of heliostat, for example, the global efficiency is:

$$e_g = e_c \cdot e_d \cdot e_r \cdot e_s \cdot e_a \cdot e_l \cdot e_h \cdot e_t \cdot e_m$$

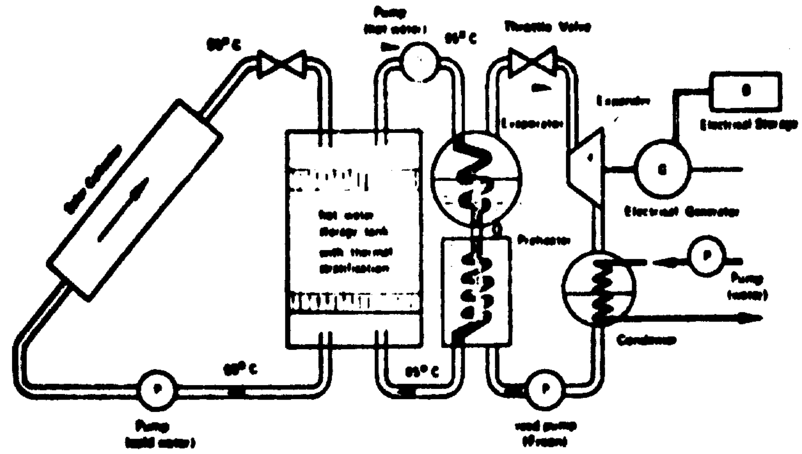
The indexes designate the following and could have the following order of magnitude:

g	-	global	
c	-	Carnot, depending on the used temperatures	
d	-	Diffuse-direct solar radiation	0.80
r	-	reflectivity of mirror	0.80
s	-	Sunset - sunrise	0.70
a	-	focal absorption - geometrical losses	0.70
l	-	heat losses	0.70
h	-	clouds transient	0.80
t	-	heliostat spacing factor	0.6
m	-	engine	0.5 - 0.8

Then the global efficiency could be about 5 - 8% of that of the Carnot efficiency. For example, if the steam temperature is 200°C and the condensing temperature is 30°C, the Carnot efficiency is about 30% and the global efficiency of the system will be about 1.5 - 2.4%. This means that in a favourable solar radiation regime about 40m^2 of heliostat will be needed per average kw of solar engine during the daytime. Some firms aim to obtain 1 kw per 10-15m^2 but this generally refers to peak kw (this term designates the power delivered by the engine when solar radiation is maximal).

Many institutes are working on very large thermal power plants, among them the following could be mentioned:

The Centre National de la Recherche Scientifique in France, in collaboration with Electricité de France, is working on a high temperature power station of 10 MW in which the pressure could reach



SOLAR POWER PLANT WITH THERMAL AND ELECTRICAL POWER STORAGE SYSTEMS

PERFORMANCE	● 10 kW_E peak-load – 1 kW_E night service
SOLAR COLLECTOR	● MBB flat-plate collector with coated Al-absorber Module size : 60 cm x 160 cm (1 m^2) Total collector surface : 700 m^2 (peak-load)
POWER CONVERTER	● LINDE screw expansion prime mover: 16,5 KW Working fluid R 114 AC (or DC) generator : 10 KW_E Integrated power control equipment : 220V, 50 Hz
ENERGY STORAGE	● Thermal energy storage at ambient pressure : 30 m^3 Battery set : 24 KWh (supply of recirculation pumps during starting procedure: 220V =)

MAIN DATA OF 10 KW_E SOLAR POWER STATION

Figure 1

80 bars. In early 1977, a 100 kw boiler, which is being developed jointly by the CNRS, Babcock Wilcox, Heurtey, St. Gobain and Renault (SERI) and using heliostats, will begin operation at Odeillo.

USA Initiation of the construction of a 5 MW_{th} solar thermal test facility for testing and evaluating components and advanced conceptual designs is planned for 1976. Assessment of solar thermal systems and their economic viability will be continued. Studies of the environmental and social impact of solar thermal systems will be pursued. The design of a 10 MWe pilot plant will be initiated; and preliminary cost estimates for this facility will be obtained.

Among the firms which have already realised a prototype of a small steam engine, M.A.N., in the FRG, should be mentioned.

M.A.N. in collaboration with the research institute DFVLR, Stuttgart (FRG) are constructing a plant which consists of 12 collector rows (N-S mounting tracking the sun in one direction and E-O in 2 directions) with 6 parabolic trough collectors (concentrating factor 30) in each row. The length of a collector is 2.5 m, the aperture 1m. The collectors are arranged on a platform which is inclined at an angle corresponding to the latitude. The total effective mirror area of the prototype is about 180 m^2, the working temperature 200°C and the mean thermal energy output per day is about 700 kWh (working time from 7 a.m. to 5 p.m.). With a steam motor and electric generator (10 kW_e peak), the electric power output is about 70 kWh/d (overall efficiency about 6%). The condensed water has a temperature of 95°C and it is planned to use it for hot water supply and/or space heating and air conditioning. To increase the electrical output while decreasing the effective collector surface, higher working temperatures are envisaged. The following table shows the planning data of different stages of solar power plants.

		Prototype	Improved Type	Optimised series type
Effective Area	m^2	180	130	100
Working Temperature	°C	200	250	300
Thermal Capacity	kWh/d	700	480	390
Electricital Capacity	kWh/d	70	69	68
Efficiencies	%			

	Prototype	Improved Type	Optimised series type
Collector	58	54	59
Cycle	20	24	28
Motor/Generator	50	60	63
Overall	6	8	10

According to the design, this plant could be extended in modular construction to larger plants up to several hundreds kW_e.

M.A.N. is also working on a screw mover, and it is planned that this unit will work with superheated vapour of freon 114. This firm believes that

> "the chance of success with a low temperature solar engine is very small. Contrary to concentrating collectors conventional flat plate collectors utilise partly the diffuse radiation. This part however, is on the average lower than 10 per cent for the regions considered (1) and plays therefore a minor role. Flat plate collectors have the crucial disadvantage of strongly decreasing efficiency with increasing collector temperature. Furthermore the insolation on fix tilted collectors is smaller in the morning and afternoon. Thus the value of efficiency decreases still more. An additional disadvantage is that a low boiling working fluid such as Freon must be used. This demands expensive heat exchangers.
>
> The thermal efficiency increases correspondingly for higher collector temperatures. However, sufficiently high efficiencies can be achieved only if envelopes reflecting the infrared radiation are used (-which are expensive) or selective coatings are applied (-which show degradation).
>
> Focusing collectors consist for instance of a parabolic trough or a Fresnel lens concentrating the direct solar radiation on an absorber pipe mounted in the focus line. These collectors have very high efficiencies - about 50 per cent - already for low concentrating factors between 20 and 30.
>
> Focusing collectors must track the sun. Thus the high efficiency remains nearly constant in the morning and afternoon. A further crucial advantage - contrary to flat plate collectors - is that conventional, available steam engines can be used because of the higher working temperatures."

The prototype steam engine, when visited by the Special Technical Adviser at the beginning of December, was being fixed on the ground, the solar collectors were ready and a refrigerating absorption machine was integrated in the installation. It is expected that tests will begin within one month at the latest. The prototype with the screw expander was assembled and it was expected that tests will begin soon.

The steam engine utilised in this plant is one of the series which has been manufactured in the 60th. Its power is greater than that which could be given by the available set of solar collectors.

The expected break-down of the cost of the 10 **kW** steam engine is:

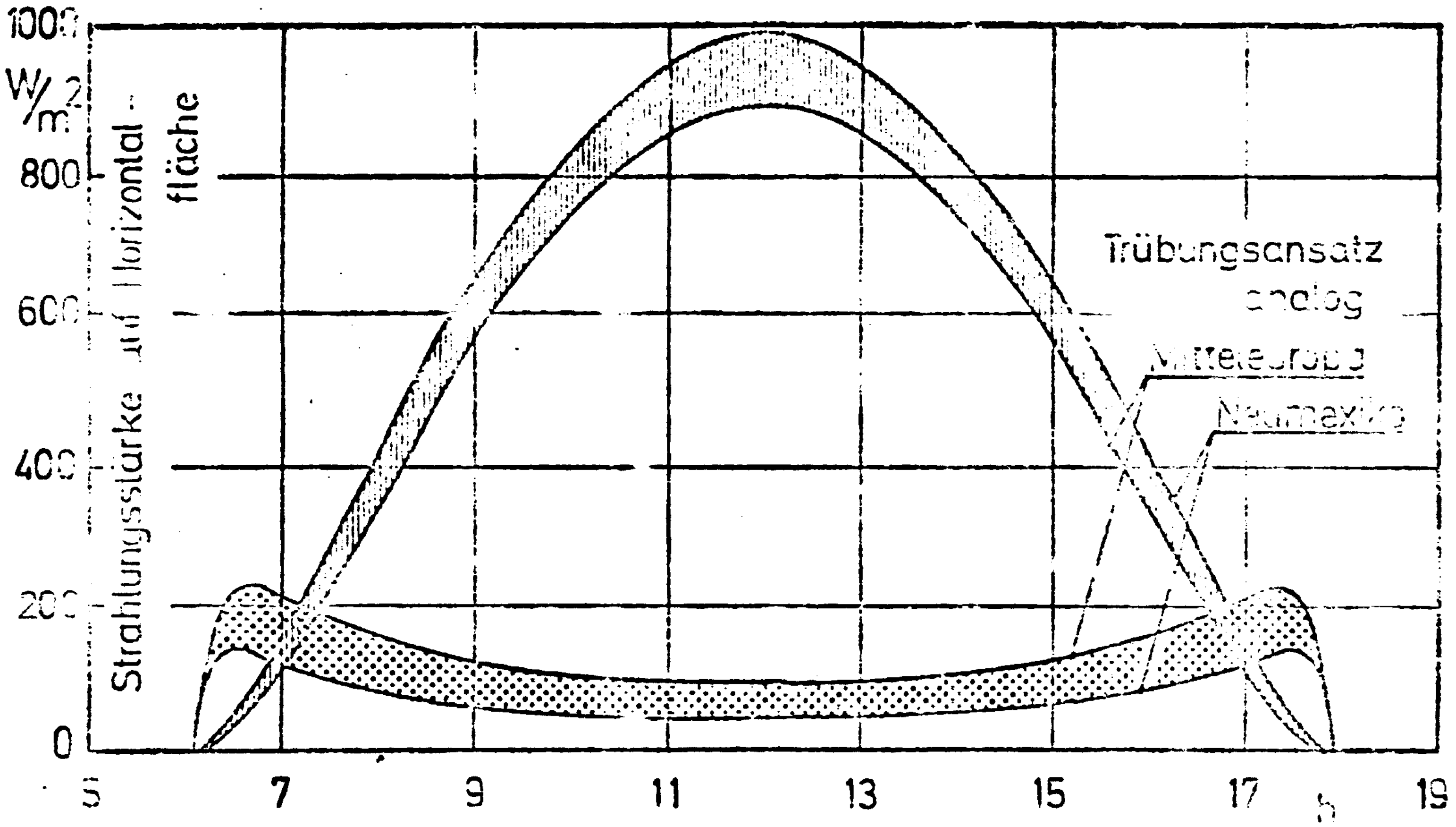
ITEM	DM/kW_e
Steam engine + generator + framing support + control system (engine/generator)	2.030,--
condensator	360,--
pumps, pipelines, insulation, control system (cycle)	510,--
storage, insulation + storage-water-container	1,330,--
collectors	2.770,--
	DM 7.000,-- or about $2,800

In the United States many small companies have emerged aiming to construct focussing solar collectors which track the sun automatically. One of them, Sun Power Systems Corporation in Tempe, Arizona, has developed cylindroparabolic solar collectors. One of the proposed has (according to their publications) the following performance data and specifications:

Description of system: Aluminium parapbolic troughs arranged in series; the amount of troughs needed per specific installation is determined by BTU requirements. Troughs are kept constantly focussed on the sun by an electronic device which incorporates a high-temperature defocussing capability, a low-temperature freeze protection, and a temperature comparator which guarantees that the unit only heats water in the storage facility.

Trough Dimensions: (Standard size) 4' x 10' (effective area 36.7 ft^2)

Trough Surface: Annodized aluminum, guaranteed in excess of five years. Dust has no significant effect on efficiency.



DIRECT RADIATION FOR 10° LATITUDE SOUTH

Difuse Radiation

Fig. 1

BTU produced daily per ft^2: (32° N. Lat.   100% sunshine)
June 21: 1885*
Dec. 21: 1149   Avg.: 1517

BTU produced daily per trough: (32° N. Lat.   100% sunshine)
June 21: 69,190
Dec. 21: 42,167   Avg.: 55,679

*834 BTU are needed to raise one gallon of water 100°F.

Concentration ratio: 44:1

Absorber fluid: Water.

Absorber fluid flow rate: 5 gal./min., although the system works equally well with faster or slower flows.

Water temperature: 350°F. (Closed loop system circulating water from eight collectors through a 40 gal. insulated storage tank).

Maximum operating pressure: 300 psi.

Collector weight: 1.5 lbs./ft.^{2}: 55.05 lbs./trough (includes all framing, components, water).

Absorber material: 1" hard copper pipe with selective black coating.

Framing material: Tubular steel (rectangular) .065 wall.

Tracking motor: 2.8 rpm; gear ratio 1780:1; amp load 1 amp; accurate within 10 min. of sun; 450 in./lb.

Collector end fittings: Adaptable.

Storage: Recommended storage 1.5 gal./ft.^{2} of collector.

Orientation: North-South orientation is preferred, but not necessary. A flat roof is preferred, but not necessary.

Esthetics: System is very low profile; it can easily be placed behind a parapet wall and thus be unobtrusive.

Adaptability: System can be retrofitted to any existing structure. System can be expanded by adding extra troughs, should energy demands increase.

Maintenance: No maintenance is required. Collectors can be hosed off occasionally, but this is not necessary.

Storm damage susceptibility: In overcase conditions troughs are automatically returned to night-time position to minimize storm damage.

Warranty: One year on all materials and components except those components under warranty limitations imposed by othor manufacturers.

The problem with these simple focussing collectors, which certainly work, is that the short duration of experience is not sufficient to seriously evaluate the lifetime and the performances and the effects of climatic conditions and dust. Present costs of such simple solar collectors are about \$100 per m^2.

The following comments could be stated:

- Medium and high temperature solar engines could use conventional steam engines and steam turbines which have already been successfully utilised for a long time (in the early years of this century, Schumann installed a successful solar steam engine in Egypt); but small turbines do not yet exist on the market;
- The thermal efficiency of these engines is better than that of the low temperature engines because the Carnot efficiency is higher.
- These engines require direct solar radiation, which is not always available.
- Focussing solar collectors should track the sun and this could be technologically resolved with reasonable costs. No systems have yet been tested over a long period.
- This system is expected to be more successful in the case of large rather than small installations.
- When the problem of solar storage has been resolved to a great extent, many of the problems of these installations which are to be used in sunny countries could be diminished.

1.3 Hot air engines

Principle of the Stirling Engine

+) " In a conventional engine the heat is supplied by burning a quantity of fuel inside the chamber. In the Stirling engine, the heat is added by an external flame through a heat exchanger (heater head) to the working gas inside the engine.

First a cool volume of gas, entrapped by a piston, is compressed (Fig. 1a) and then heated by an external heat source (Fig. 1b). As the gas heats, its pressure increases and the piston is driven downward to turn the crankshaft. After expansion (Fig. 1c), the gas is cooled by an external cooling source (Fig. 1d). Its pressure decreases, and the gas is once again compressed. Since the pressure during the hot expansion is much higher than during the cool compression, there is a network output from the engine. The complete cycle takes place in one revolution of the crankshaft as opposed to two revolutions required by conventional engines.

Since exchanging the heating and cooling sources is a cumbersome process, Robert Stirling, after whom the cycle is named, conceived a refinement to overcome this problem. His invention replaced the alternating use of hot and cold sources by addition of a mechanism called a displacer piston which serves to move the gas between a stationary hot chamber and a stationary cold chamber (Fig. 2).

+) Extract of "The Stirling Engine for passenger car application" by Postma, van Giessel and Reinink : Sty of Automotive Engineers 1973

The displacer piston mechanism allows the heating source to be stationary at one end of the cylinder and the cooling source to be stationary at the other end (Fig. 3). When the displacer piston moves upwards (Fig. 3a) the hot working gas from the upper portion of the cylinder is first moved through the heating coil or heater tubes. The gas then flows through the cooling coil where it is cooled until most of the working gas is in the cold section below the displacer piston. Because the gas is cool, its pressure is low. Moving the piston downward (Fig. 3b) forces the working gas back through the cooling coils and into the heater tubes where it is heated and forced into the hot section above the displacer piston. Since the gas is hot, its pressure is high. There are no valves in the flow path, so that when the upper chamber is at high pressure, the lower chamber is also at high pressure.

One more addition is required to complete a practical Stirling engine. The regenerator, (Fig. 4) is located between the fixed heating and the cooling sources and stores otherwise wasted heat during the cooling process and permits recovery of the heat during the heating phase. This stored heat is equal to several times the heat added from the outside heat source.

Fig. 5 shows the displacer section combined with the power section to form the basic Stirling cycle power unit. Fig. 5a shows the cooled gas being compressed by the power piston as in a convential internal combustion engine. In Fig. 5b , the compressed gas is being heated and its pressure increased because the displacer piston is moving a portion of the gas into the upper or hot part of the displacer section. The pressure increase is felt on the lower piston. In Fig. 5c the hot, high pressure gas has completed its heating cycle due to the descending displacer piston and the power piston has completed its power stroke driven by a high pressure gas. Fig. 5d shows the displacer piston moving upward to force the working gas into the cool portion of the chamber, thus decreasing its pressure. The power piston is now ready to repeat the compression stroke and the cycle is completed.

The remaining mechanisms required to form a simple Stirling cycle are those needed for driving the displacer piston at a fixed relationship to the power piston (90° out-of-phase) (Fig. 6). This can be done by a crank and chain.

SIMPLE STIRLING CYCLE

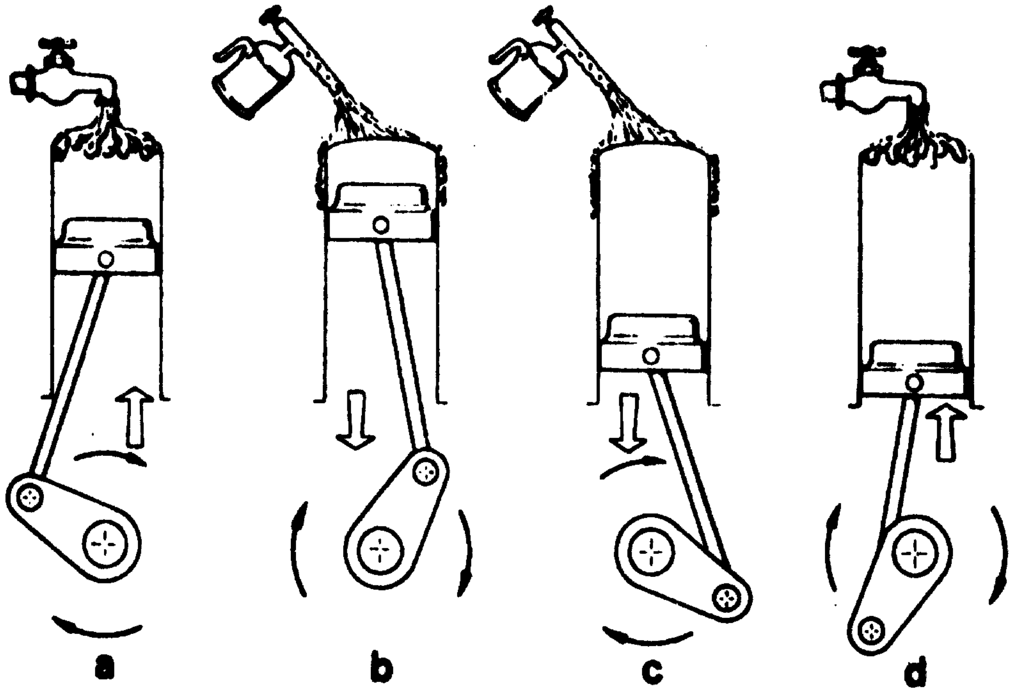


Figure 1

DISPLACER PISTON – INTRODUCTION

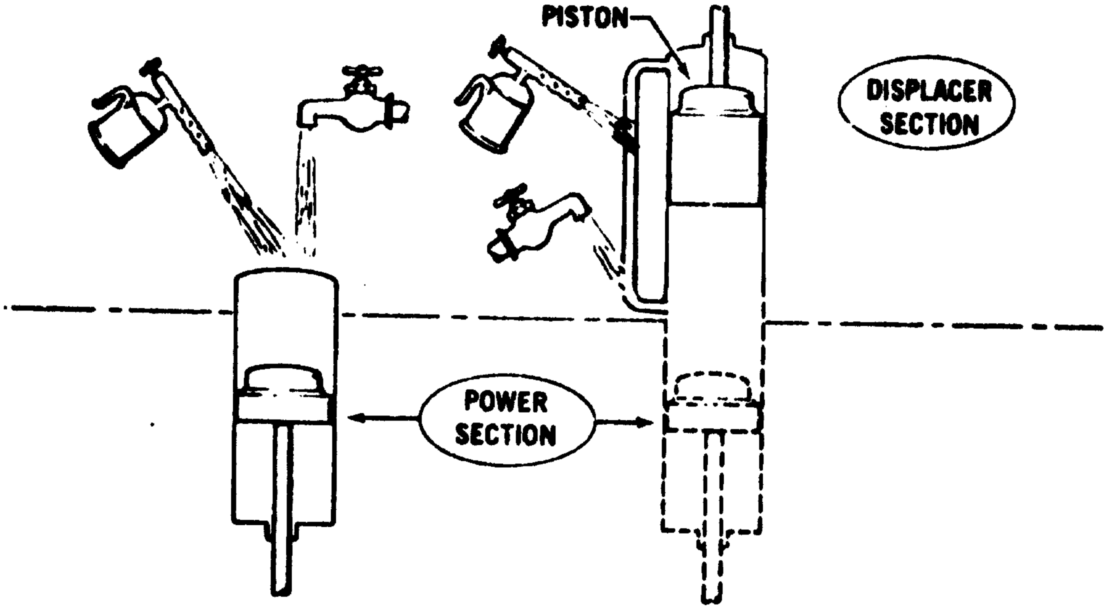


Figure 2

DISPLACER PISTON

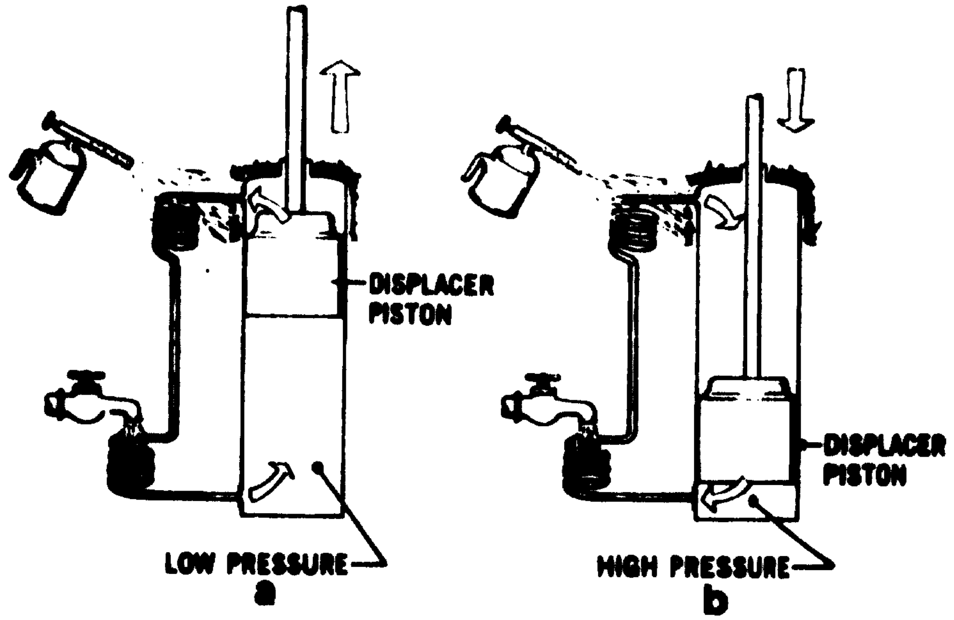


Figure 3

REGENERATOR

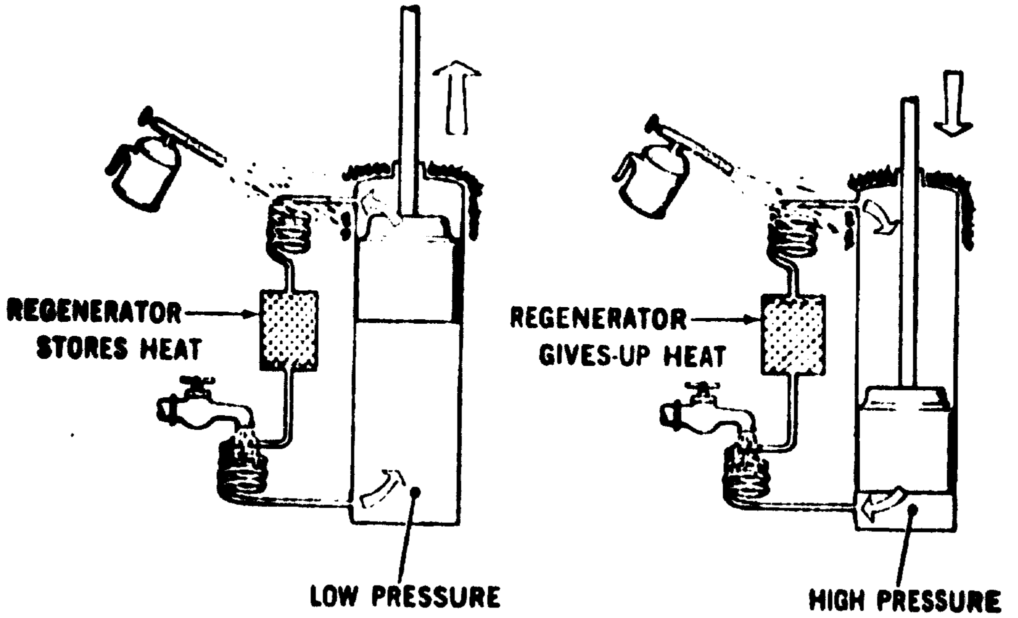


Figure 4

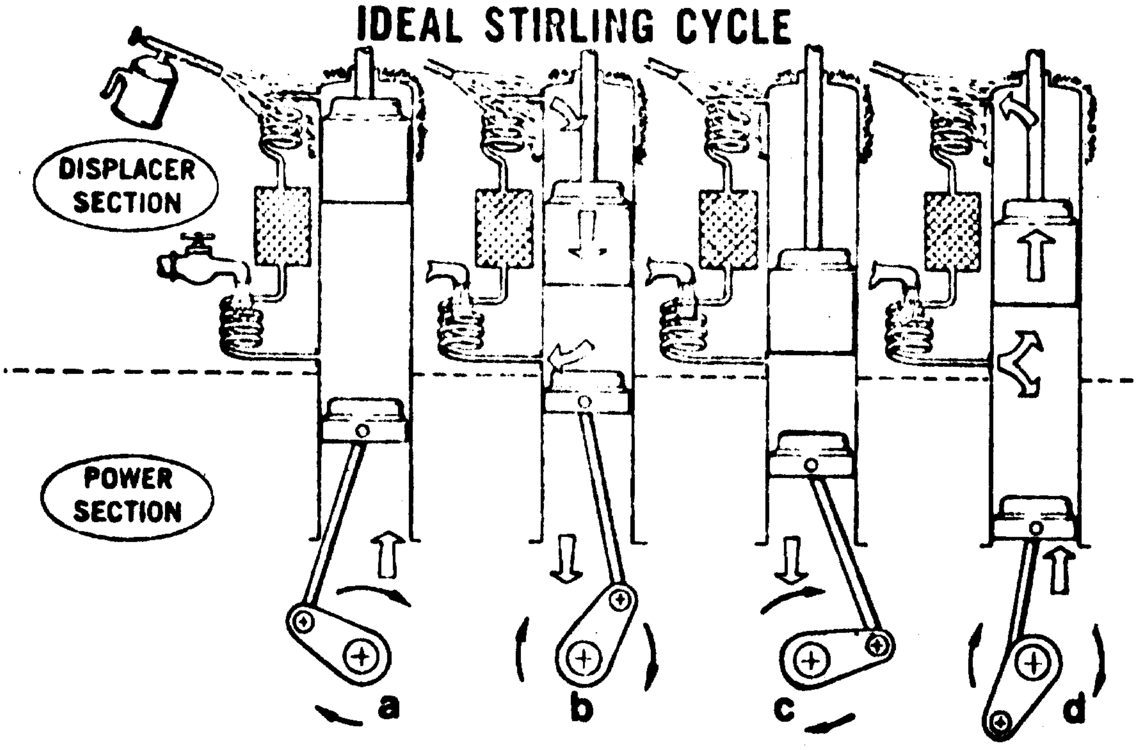


Figure 5

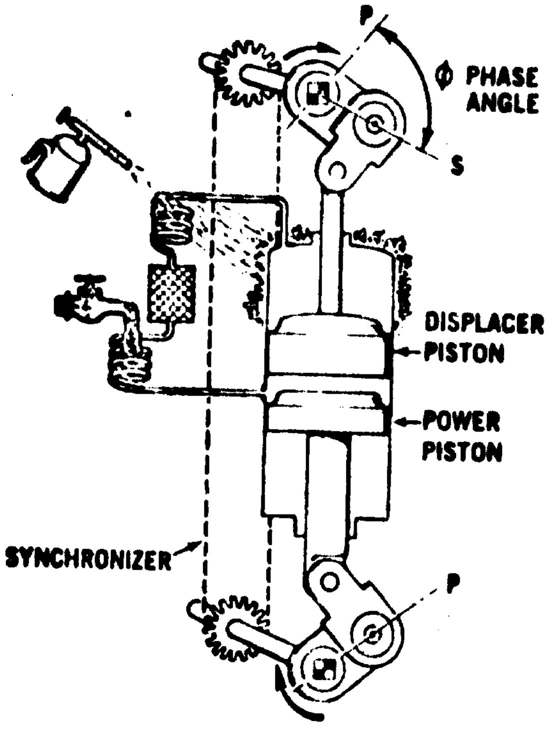


Figure 6

Closed cycle hot air engine

1.3.1. Philips solar hot air engine

Philips has developed small hot air engines in the past; one engine of 1 horse power at 1500 rpm has been modified by KHANA in India to be experimented with solar energy. The heating system, in the form of a cylindrical head of 6 cm diameter, designed to burn kerosene oil, was removed and concentrated solar energy was used to heat the engine. A set of mirror reflectors with a surface of 8 m^2 has been used, the engine could operate a 200 watt electric generator. The theoretical efficiency of the Stirling cycle could not be reached.

1.3.2 Farber closed cycle hot air engine

Several prototypes have been developed in the Solar Energy and Energy Conversion Laboratory in the University of Florida. One interesting prototype is a supercharged, water-injected solar hot air engine in which an adjustable checkvalve allows the engine to supercharge itself by drawing in fresh air or water during the below-atmospheric pressure part of the cycle.

The engine could be used with solar energy and can be used directly without modification to burn wood, coal or liquid fuels. If used with solar energy it is only necessary to open the door and to concentrate the solar energy upon the end of the displacer cylinder inside the furnace box. This engine can be built with very simple machine tools.

A displacer cylinder is mounted on top, which has an inside diameter of 2 3/4 inches and is 10 1/8 inches long internally. Inside this displacer cylinder moves a displacer with an outside diameter of 2 11/16 inches and a length of 8 inches. The displacer, wit a stroke of 2 inches, has enough clearance both radially and at the ends to move freely in the displacer cylinder.

The displacer cylinder is designed so that it can be heated at one end by gas, oil, solar energy, etc. and cooled at the other end by air or by a water jacket (closed or open circuit). The displacer is moved by a $\frac{1}{2}$ inch rod entering through a sleeve bushing. The present improvements resulted at least in part from the difficulty of keeping the bushing absolutely gas tight without introducing unnecessary friction.

The displacer cylinder is connected by a 3/4 inch pipe nipple to the power cylinder with a piston of 2 3/8 inches diameter and a stroke of 1 ½ inches.

The linkage between the displacer and the power piston allows timing of the engine. For normal operation the displacer leads the power piston by about 100 degrees.

The operation of the engine depends upon the alternate heating and cooling of the working fluid. When the fluid is heated, pressure builds up and then pushes the power piston down. When the working fluid is cooled, the pressure in the engine decreases, allowing the power piston to be returned by the energy stored in the flywheel.

The alternate heating and cooling of the working fluid is accomplished by the displacer moving the working fluid back and forth between the hot walls and the cold walls of the displacer cylinder.

The performance of the engine is further helped by regeneration along the displacer and the displacer cylinder walls. Heat is stored in those walls during part of the cycle to be released and used during another. The working fluid, streaming back and forth, alternately giving off this heat and then absorbing it later thus preventing it from leaving the system, provides internal regeneration.

The engine is started when the pressure inside is equal to atmospheric pressure. So during operation, for part of the cycle, it will dip below atmospheric pressure. During the operation of the engine under normal conditions this dipping below atmospheric pressure during part of the cycle is enhanced by leakage of the working fluid (air) through the displacer rod bushing, out- during the high pressure part of the cycle and in - during the below atmospheric pressure part of the cycle.

Efforts have been made to prevent or minimise this leakage but it was found quite difficult to do this and have it continue, without increasing the friction losses considerably. For this reason two alternative methods of solving the problem were developed and they are described below.

Air injection: Since, it was not easy to eliminate the leakage during the high pressure part of the cycle, a small adjustable ball check valve was installed as shown in Fig. 1 . This made it easy for fresh air to enter the system quickly during the below-atmospheric pressure part of the cycle. This very simple addition allowed the engine to operate with a larger average amount of working fluid resulting in higher power output.

Water injection: When the inlet to the small adjustable ball check valve was dipped into water, water was injected into the system rather than air. This allowed even larger amounts of fluid to be added to the system, since it was added in the liquid phase, resulting in even greater increases in power output. Another advantage of water injection (or other liquids) is that it enhances the heat transfer at the hot end greatly.

The conclusions of the author are the following:

- Self-acting air or water injection can considerably improve the performance of the simple closed cycle hot air engines.
- Water injection is more effective because it allows larger quantities of fluid to be injected and it increases the heat transfer at the hot end of the engine through phase change.
- Engines of the type described here can be classified as "Hybrid" since they combine the advantages of the Stirling cycle with those of others.

Open cycle hot air engine

The engine takes atmospheric air, compresses it, then heats it by solar energy; the compressed air expands and exhausts in the atmosphere. A compressor is combined with the engine (which could also be a turbine). The advantage of this system is that the heating regime of the air and the speed of the engine are independent.

1.3.3 KHANA engine

A small open-cycle hot-air engine was dismantled from an old kerosene oil-operated fan and was overhauled. Its worn-out parts were replaced and suitable modifications were carried out before its use. It operated at an average speed of 250 rpm. Heat at the cold end was dissipated through large thick fins cast along with the body of the engine. To give smooth and continuous running, a $1\frac{1}{2}$

Fig. 1

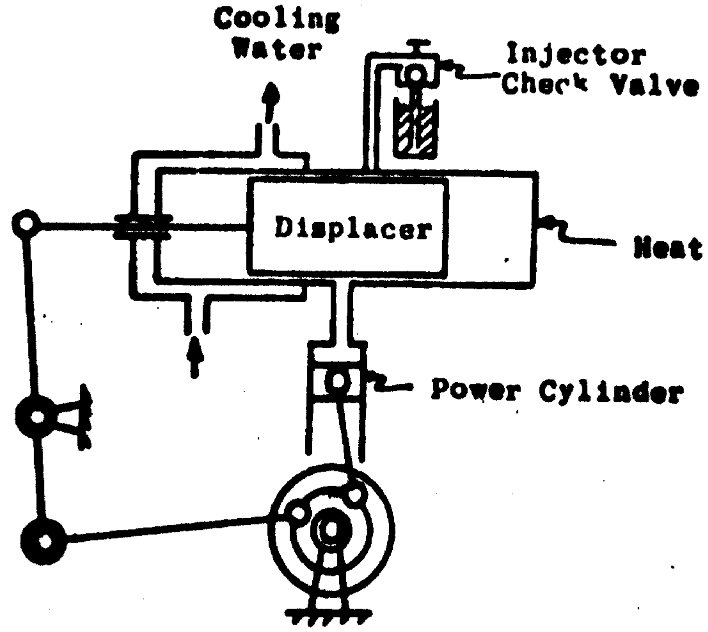
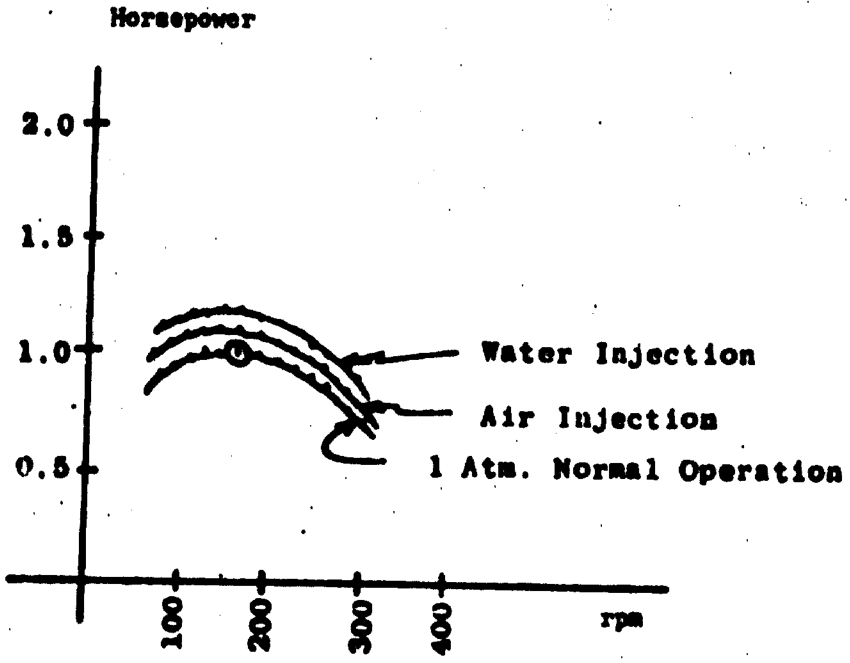

Cooling Water
Injector Check Valve
Displacer
Heat
Power Cylinder

Fig. 2


Horsepower
2.0
1.5
1.0
0.5
100
200
300
400
rpm
Water Injection
Air Injection
1 Atm. Normal Operation

thick hollow disc, which formed the false bottom, was slipped over the bottom of the expander cylinder. The disc was made of copper sheet and the empty space was filled with dry sand. It formed a perfect fit and ensured complete contact between the metal surfaces. The entire cylinder length of $8\frac{1}{2}$ inch including the false bottom was enclosed in a pyrex glass tube closed at one end and of slightly larger diameter. Both these arrangements helped to raise the temperature of the hot end and to realise uninterrupted and steady running of the engine.

Coupled to a small reciprocating water pump, this engine was suitably mounted with the three metal reflectors described above and used for experiments on pumping water from different depths. The coupled unit developed about 1/16 h.p. and not 1/8 h.p. as expected according to some authors.

Later, another hot-air engine of nearly double the capacity of the one used earlier was procured, modified and mounted in the vertical position on an iron tripod stand. It was used with plane-glass-mirror concentrators. Coupled to the water pump, the engine developed about 1/8 h.p. A small cylindrical parabolic metal reflector was placed behind the cylinder to help heat the hot end of the engine uniformly and thereby ensure its smooth running.

1.3.4 Farber engine

A prototype has been realised in the Laboratory of Solar Energy and Solar Energy Conversion at Florida University.

Comments:

The open cycle hot air engine, although having a speed depending on the regime of heat exchange, seems to be more reliable and easier to manufacture in developing countries.

1.4 Solar pumping

Conventional pumps could be operated by solar engines; however, prototypes of installations for pumping water without moving parts are being developed in the Birla Institute of Technology and Science, at Pilani, India.

Principle: A mixture of petroleum liquids with a boiling temperature range of 35° to 40° is evaporated in flat plate solar collectors and then flows to a closed tank full of water which is situated in a wall. The pressure of the working fluid allows the water to rise to an upper level, depending on the pressure of the mixture. The vapour could condense during the night in the solar collectors. This discontinuous mode of pumping is very simple but the quantity of pumped water is relatively small. The vapour could also be condensed by flowing to a condenser cooled by the pumped water. In using 2 water tanks, a set of valves adequately controlled, semi-continuous pumping could be obtained. Besides the collector and the flash tank, there are two water tanks located close to the water source and a condenser at ground level. The pipe-network interconnecting the tanks is as shown in Fig. 1.

The working fluid drawn into the collector is vapourised and returned to the flash tank. To start with, it is assumed that the water tanks are full of water. The vapour from the flask tank is let into one of the water tanks, thereby pumping is effected. The discharging water condenses the vapour in the shell side as it goes through the condenser coils. After the first tank is emptied, the vapour is switched over to the second tank. Simultaneously the first tank is connected to the condenser. The vapour of the first tank is condensed by the water that is being pumped from the second tank. As condensation proceeds, the pressure in the first tank reduces and water enters through the non-return valve. Thus, as the second tank is emptying the first one is being filled. On reversing the cycle, by manipulation of the valves, the first tank will pump while the second one draws water. This way, continuous pumping of water can be achieved.

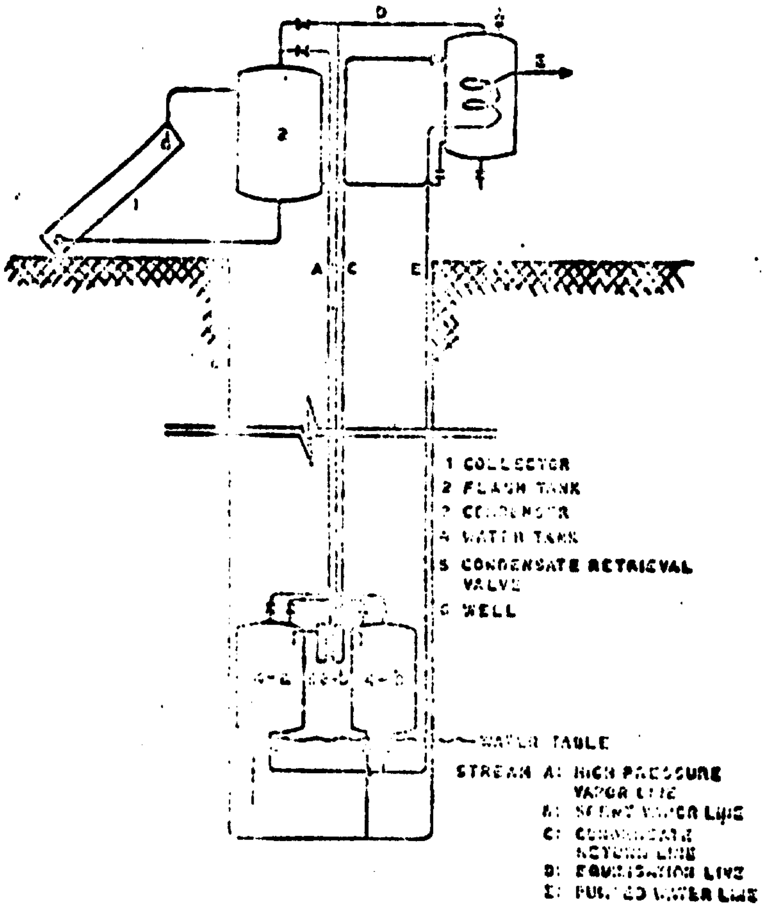


FIG.1 SKETCH OF WATER-COOLED PUMP

To prevent working fluid going into the water line, a water seal is always maintained inside the water tanks. The working fluid which is condensed in the water tank can be pumped at the start of each cycle to the condenser . Pumping of the condensate is done by the condensate retrieval valve, which is similar in principle to a steam trap. Further this can be transferred to flash tank, periodically or at the end of the day, by pressure equalisation.

The capacity of the pump can be increased by adding more collectors. This affects only the cycle time.

The working fluid should be

- immiscible with water
- having normal boiling point slightly higher than the atmospheric temperature;
- non-toxic;
- non-inflammable;
- cheap and readily available.

Pentane fulfils all the requirements except for its inflammability.

A petroleum fraction having a close boiling range with properties similar to that of pentane will be cheaper and more readily availabl than pentane. The petroleum fraction, which is a mixture of hydrocarbons, offers an additional advantage. It can be tailor-made to suit the atmospheric conditions of a particular region. For example in a region where the night temperatures are around 2° C and the day temperatures are 15° C, by choosing mixture which has more of light hydrocarbons of boiling range 15-20° C even at very low solar collector temperature, pumping of water can be achieved to a considerable height. In regions like Pilani (located at the edge of the Thar Desert) where extreme climatic conditions occur the working fluid properties can be modified to suit seasonal variations by adding small amounts of light or heavy hydrocarbons to get high performance of the pump.

Solubility of the working fluid: strictly speaking any two fluids are mutually soluble in each other to some extent, hence continuous contact with fresh water in each cycle results in some loss of working fluid. Fortunately, the working conditions in the pump are such that close to interface the fluid is still for most of the time resulting in very low mass transfer rates and as a consequence, there will be negligible loss of working fluid.

Mr. D.P. Rao, who is developing this technique of solar pumping, has proposed many theoretical solutions, one of which is the following:

100 m^2 flat plate solar collectors, 150 m^3/day of pumped water with manometric head of 18 m., two water tanks each with a diameter of 90 cm, and a height of 150 cm. With a cost of \$35/m^2 of solar collector, the cost of such a pumping installation is estimated at \$6,000.

Comments:

These prototypes are promising, and detailed results of the experimentation are expected by the end of 1976. Many technological problems have not yet been solved, in particular the control of the system of valves, the present proposed electrical control does not meet the requirements of a rural solar pump which should be independent of any external source of power.

2. DIRECT CONVERSION OF SOLAR ENERGY INTO ELECTRICAL ENERGY

The photovoltaic cells operate on the principle that semiconductors produce an electric potential when they are illuminated by the solar radiation. The silicone and CdS photocells are the best known on the market. Important R and D programmes are undertaken to improve the performances, to simplify the technology and to reduce the cost. One could speak in terms of a cost of $15,000/peak kw in 1976. Research programmes aim to reduce this cost to $8,000 in 1980 and to some hundred dollars in 1985.

The silicone cells have been proven to have a long lifetime, but that of the CdS cells still seems to be questionable.

It is felt that in the present state of the art, the available technology is still too sophisticated for the majority of developing countries, and that manufacture even of a small series could not be planned for the medium term. For those reasons this subject will not be further discussed in this report, in spite of its very promising future.

3. SOLAR REFRIGERATION AND SPACE AIR CONDITIONING

Air conditioning designates the treatment and handling of air to obtain in the conditioned space well-defined values of temperature, humidity, velocity and purity of the air. Only the cooling aspect will be considered here, so the solar refrigeration and space air conditioning could be associated. The temperature is generally lower in the case of refrigeration, especially when speaking in terms of ice production or the majority of cases of food preservation. Well-defined values of temperature and humidity could not be obtained in the case of air conditioning without an external source of energy to operate fans, pumps and control systems.

Solar refrigeration could be achieved through a solar engine operating a conventional compressor but in this report only absorption machines heated by solar energy will be discussed. This kind of machine could have a continuous or intermittent functioning regime. In the continuous regime an external source of power is necessary at least to operate the pumps and control system. The best known fluids used in the present state of the art are ammonia-water and lithium bromide-water. The first combination is more suitable for low temperatures which could be obtained with flat plate solar collectors.

Principle of operation (Fig. 1)

Let us consider the combination of NH_3 - H_2O. The mixture NH_3 - H_2O is heated directly by solar energy in the generator (boiler) or indirectly by water heated by solar energy. When the temperature of the mixture rises, the NH_3 begins to evaporate because the water can absorb less ammonia when its temperature increases. The vapour flows to a condensor (2), which is water- or air-cooled, where it condenses. The operation now becomes similar to that in a conventional refrigeration system with compressor. A sub-cooled liquid is available in the outlet of the condensor. The pressure of the ammonia, which increases when the temperature increases is controlled by the condensing temperature. The liquid expands through a valve and begins to evaporate: its temperature and pressure decrease. The cold and low pressure vapour reaches the evaporator, in which it absorbs the heat of the product to be cooled (chilling water for air conditioning purposes, brine for ice production. . .)

The temperature of the vapour increases and it flows to an absorber where it meets a spray of a weak mixture of $NH_3 - H_2O$ and it is absorbed. (A weak mixture designates a low concentration of ammonia in the water). The phenomenon of absorption is exothermic, and in order to keep the temperature of the mixture in the absorber within the limits permitting the desired concentration to be obtained, the absorber should be cooled. The concentration of the mixture increases and it is pumped to the generator (1) and the cycle is closed. This operation could be continuous or intermittent where operations should be interrupted for recharging.

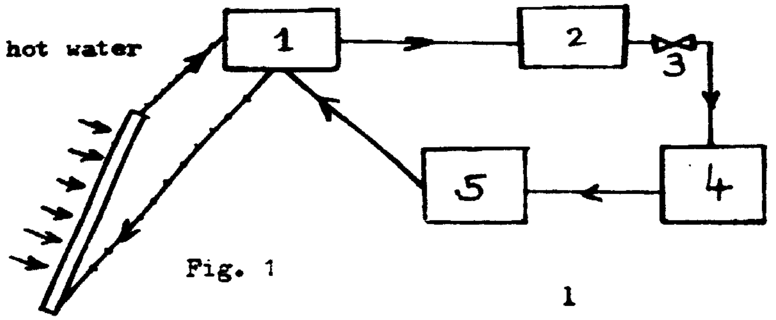
From this schematic description the following remarks could be made:

- cooling is necessary in the condensor and in the absorber. Cooling by natural convection requires very large surfaces of heat exchangers;
- powered pump(s) is necessary at least to pump the mixture from the absorber to the generator. Thermosyphon, if applicable, greatly decreases the productivity;
- operating should be continuous in the case of solar air conditioning; and
- a heat exchanger between the condensor and the absorber could improve the productivity.

Some experiments are taking place (for example at the Refrigeration Institute of the Technical University at Delft, in the Netherlands) for producing 4 Kg of ice per day with 2 m^2 of flat plate solar collector, with an intermittent absorption machine $NH_3 - H_2O$ independent of any external source of power. Condensation of the ammonia vapour is obtained during the night by sky radiation through the flat plate solar collector.

First Case Study: An Intermittent $NH_3 - H_2O$ solar refrigeration system, Farber Solar Energy and Energy Conversion Laboratory, University of Florida

A 4 x 4 ft. flat plate solar collector acts as generator. It consists of a one inch steel pipe running from a 1 1/4 inch bottom header to a 2 1/2 inch top header. The one inch steel pipes were spaced on 4 inch centers and soldered to a 20 gauge galvanized iron sheet. This element was then placed into a galvanized sheet metal



1. boiler (generator)
2. condensor
3. expanding valve
4. evaporator
5. absorber

Fig. 1

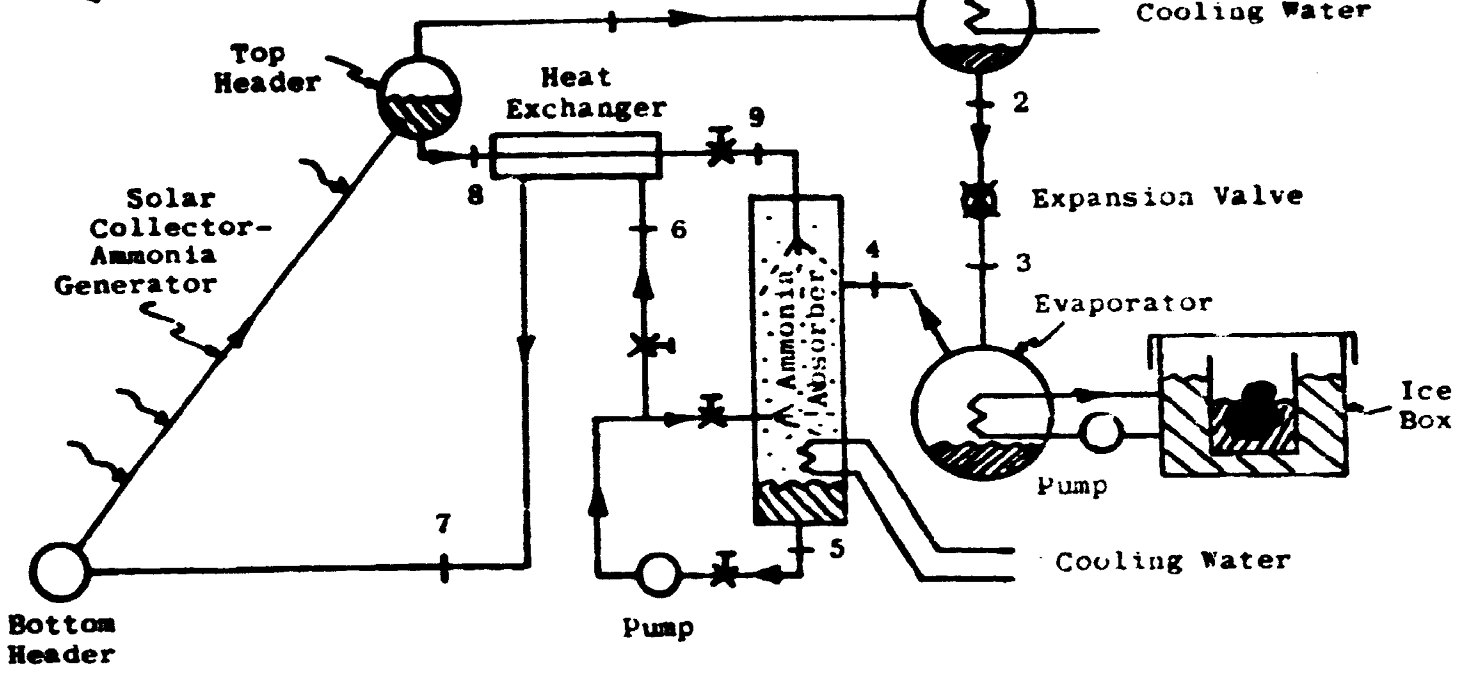


Fig. 2

box with a single glass cover and one inch of styrofoam insulation behind the solar absorber - ammonia generator element.

The complete unit was incline 30 degrees with the horizontal, a compromise to provide both good solar collection and good two phase flow and heat transfer characteristics in the inclined tubes running from bottom to top. Since the unit is stationary it was faced south to give the best average orientation for the whole day.

Condenser: The condenser consists of a 3 inch pipe shell containing 4 standard 1/2 inch black iron pipes, 48 inches long providing a heat surface of 3.5 square feet.

Evaporator: The evaporator is made from a 4 inch pipe shell containing 7 standard 1/2 inch black iron pipes, 48 inches long providing a heat transfer surface of 6.15 square feet.

Ammonia Absorber: The absorber was fabricated from a 6 inch pipe shell containing 11 standard 1/2 inch black iron pipes, 36 inches long, providing a 6.16 square feet of heat transfer surface which in addition serves as support for the liquid film in which part of the ammonia vapor is reabsorbed.

Ice Box: The ice production and storage unit is a galvanized sheet metal box 1 1/2 x 1 1/2 x 1 1/2 feet with four inches of styrofoam insulation around it, protected by a thin plywood outer layer.

Head Exchanger: The heat exchanger is a simple, single pass, counter flow, double tube type.

Pumps: The circulating pump for the water antifreeze solution is of the standard centrifugal type.

The ammonia-water solution circulating pump is of the rotary, nylon roller type. A bypass loop on the pump allows control of the amount of solution distributed to the various parts.

Auxiliary Equipment: Four valves in the system in addition to the expansion valve allowed control of the flow rates in different sections of the system.

Numerous pressure gauges, thermometers and thermocouples and liquid level sight glasses allowed the monitoring of the conditions of the system at all times.

The ammonia-water solution concentrations varying from 48 to 60 percent of ammonia by weight.

The system was hydrostatically tested to a pressure of 300 lbs/in^2 to be considered safe for operating pressures in the low two hundreds. This corresponds to a temperature in the solar absorber - ammonia generator of about 150°F.

To freeze the water in the metal container in the ice box, the design temperature of the evaporator was between 15 and 20°F or a pressure in the neighborhood of 40 psia.

Figure 2 presents the input as well as the results of the operation on July 6, 1968. It was a perfectly clear day although a considerable amount of solar energy arrived as diffused due to the high moisture content in the atmosphere. An indication of this fact was the slight temperature increase of the solar absorber -- ammonia generator even before the direct sunshine hit the front surface of the unit.

In Figure 3 the total energy arriving on each square foot of the solar absorber - ammonia generator unit is given for any hour of the day.

At the start of the day the expansion valve was closed and the system was allowed to warm up. The heat capacity of the solar absorber - ammonia generator is about 46 Btu/F which had to be supplied at the beginning of the day during warm-up for each degree temperature rise.

Part of this energy was returned to the system in the late afternoon hours when the stored heat was released due to the drop in temperature.

The effective control of the pressures and temperatures in the solar refrigeration system was produced by varying the flow rates in the different parts of the system by adjusting the various valves.

Because of the pressure limitations of the system the solar absorber - ammonia generator temperature was limited to about 150°F. The ammonia evaporator temperature was held between 15 and 20°F.

Operating the solar refrigeration system as shown in Figure , about 39,300 Btu fell upon the solar absorber - ammonia generator during that day. Allowing temperatures of the ammonia - water solution up to about 150°F and concentrations in the system from 48 to 60 percent of ammonia by weight, 41 lbs of ice were produced that day. This is 2.56 lbs for each square foot of solar collector surface per day.

Conclusions of the author:

- The work described in this paper demonstrates that a compact solar refrigeration unit can be designed and constructed giving satisfactory performance.
- A considerable amount of solar energy can be collected even on cloudy days by the flat plate solar collector and operation of the solar refrigeration system is possible at solar absorber temperatures as low as 110°F.
- Utilizing Solar Energy to produce ice solves the problem of storage and at the same time makes the benefit of the unit useable at several places at the same time.
- The unit 4 feet by 4 feet can produce better than 40 lbs of ice from 75°F water on a good day.
- Combining the solar collector and the ammonia generator into one unit eliminates the rather large heat losses between the solar absorber and the ammonia generator, observed on previous systems.
- The extensive theoretical analysis of the system, especially for the combined solar absorber - ammonia generator reported elsewhere, has shown that the design can be theoretically determined and the desired performance obtained.

Comments:

- combining solar absorber and ammonia generator in one unit is interesting when this concerns small units but in the case of large units, problems of circulation of the 2 phase fluid and of tightness could arise;
- The maximum productivity is about 20 kg of ice per day for a system including 2 pumps operated by external sources of power and a water cooling condensor and absorber. This means that only about 2,500 kcal per day of cooling are delivered by the system. This corresponds to about 1 KWH and a part of this is delivered in the form of mechanical or electrical power.

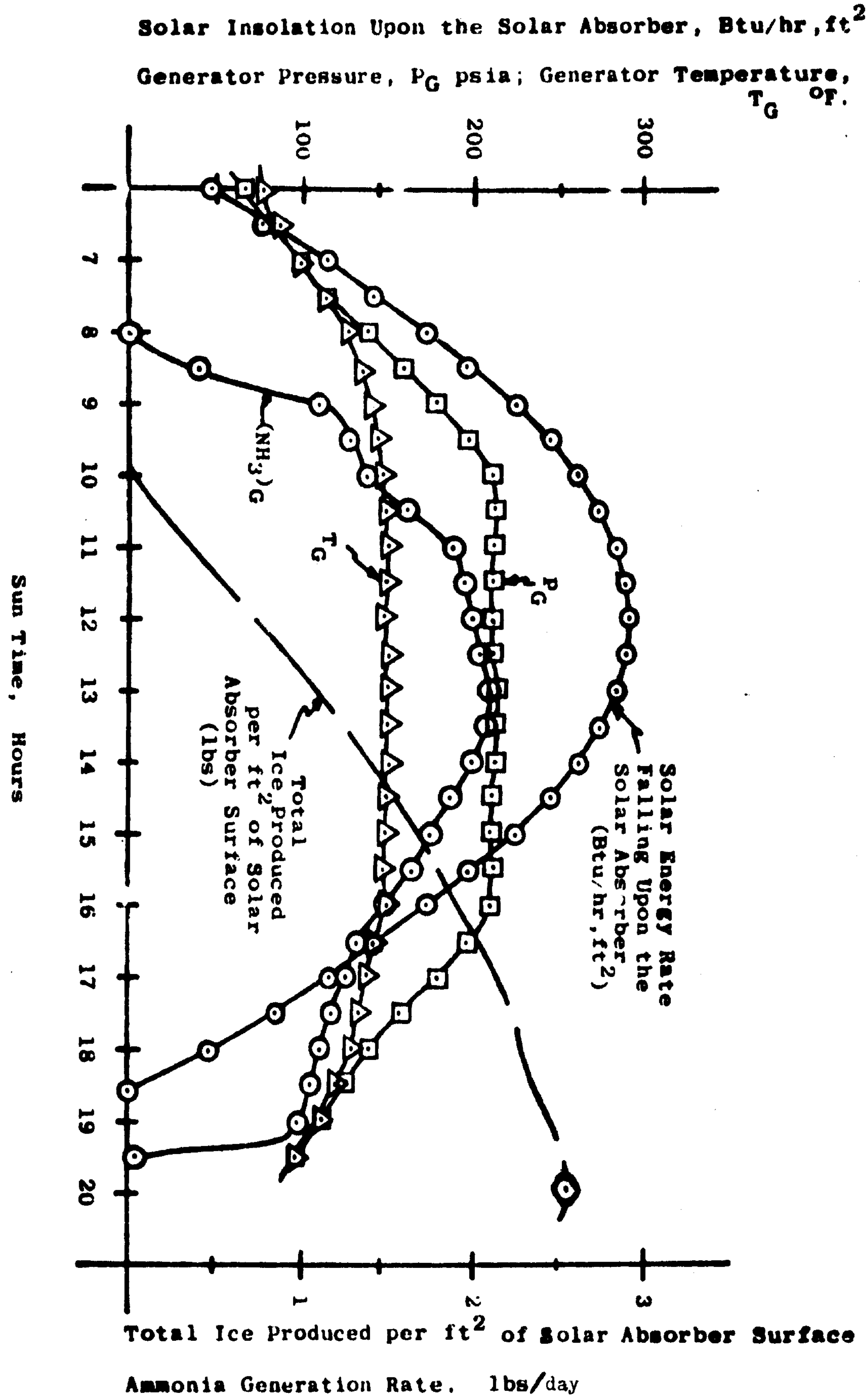

Solar Insolation Upon the Solar Absorber, Btu/hr,ft^2
Generator Pressure, P_G psia; Generator Temperature, T_G °F.
100
200
300
7
8
9
10
11
12
13
14
15
16
17
18
19
20
$(NH_3)_G$
T_G
P_G
Total Ice Produced per ft^2 of Solar Absorber Surface (lbs)
Solar Energy Rate Falling Upon the Solar Absorber (Btu/hr,ft^2)
Sun Time, Hours
1
2
3
Total Ice Produced per ft^2 of Solar Absorber Surface
Ammonia Generation Rate, lbs/day

Fig 4

Second Case Study: An Air-Cooled Ammonia-water Absorption Air Conditionier at Low Generator Temperatures, by Kim Dao et al., Energy and Environment Division, Lawrence Berkely Laboratory University of California, July 1976

General Description of the Experimental System

An ammonia-water absorption air conditioning system has been fabricated and tested as part of an ERDA-supported project at the Lawrence Berkeley Laboratory. The system was designed to operate at generator temperatures in the range of 175 to 210°F, compatible with the temperature range of flat-plate solar collectors.

The air conditioner was constructed using as a base the condenser, absorber, precooler, evaporator and the solution pump components from an Arkla gas-fired ammonia-water absorption water chiller (Model ACB-60-00) which had a nominal cooling capacity of 5 tons. The total power of the pumps and fan is 1,6 kw. The fabrication consisted of the addition of the following components: generator, preheater, rectifier, storage tanks, adjustable expansion valves and measurement instruments (6 pressure gauges, 25 thermocouples, 2 rotameters and 2 sampling tubes for concentration measurement).

The generator was a packed tower counter-flow heat exchanger. The strong solution dripped down through the steel ball-ring packing, making contact with four hot water coils in parallel. The total outside surface area of the water coils was 36 ft^2. The condenser and absorber were air-cooled, finned-tube, cross-flow heat exchangers with total outside tube area of 14 and 22 ft^2, respectively. The fins were 0.01" thick aluminum sheets spaced at 14 fins per inch.

Experimental Results:

The unit was started by pumping hot water at constant inlet temperature through the generator coils. The condenser-absorber fan and the solution pumps were turned-on when the generator pressure reached about 150 psig. It took about 15 minutes to warm up the system to approach running conditions. (The charge of solution in the system was about 65 lbs at 55% ammonia concentration.) The flow rates of ammonia and of the weak solution were then readjusted, by means of expansion valves, to desired values.

All runs made during the initial testing stage served to confirm cycle calculations based on the assumption of equilibrium states. That is, given the measured mass flow rates and the measured pressures and temperatures, the energy balances between the components can be satisfied within experimental error (about ± 5%) by using the thermodynamic equilibrium enthalpies. The mass balances can be satisfied by using the equilibrium enthalpies. The mass balances can be satisfied by using the equilibrium concentrations.

The system operation was very stable. No appreciable changes were observed after hours of operation. The stability of operation extended to circulation ratios as high as 27 pounds of absorbant per pound of refrigerant.

Operating the system at near cut-off conditions (i.e., Δx close to zero, where x is the concentration lb of NH_3/lb. of solution) demands more power and a larger pump to circulate the solution. Therefore imposing a limit on the pumping power, say, to 1/70 watt per Btu/hr of cooling load, constrains Δx to values above 0.03, or the circulation ratio to values of less than 16 (assuming a pump efficiency of 40%).

Figure (1) shows a graph of the equation for P = 3 psi, $\Delta x = 0.03$, and $T_A = T_C$; where T_A is the temperature of the absorber and T_C of the condensor. This graph summarises the possible operating temperatures for an $NH_3 - H_2O$ absorption air conditioner.

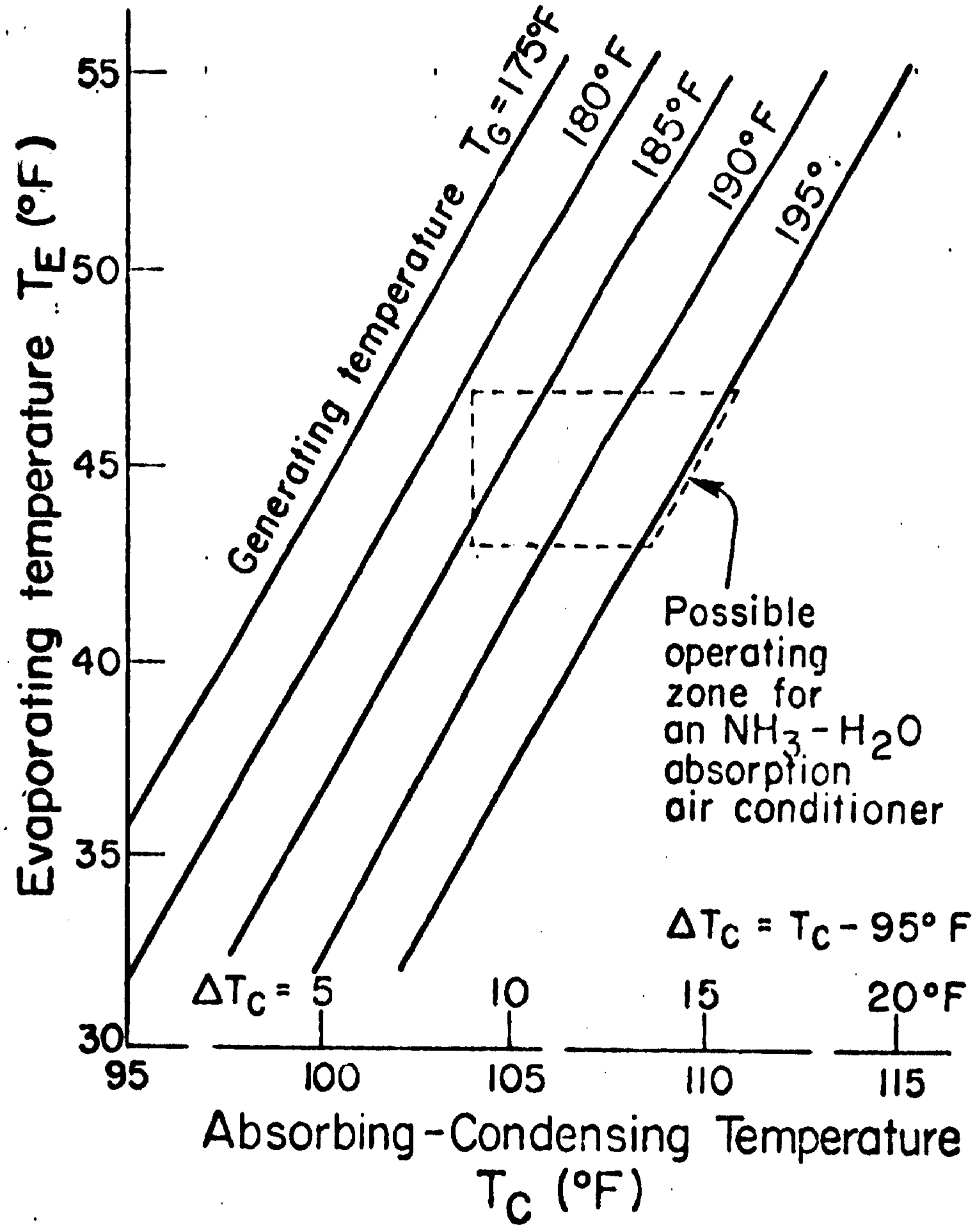


Figure 2: T_E as a function of T_C and T_A=T_C for a pressure drop across the absorber of 3 psi and a concentration difference of 0.03.

For acceptable cooling and dehumidification of the conditioned air using reasonably-sized chilled water coils, T_E is limited to $T_E < 47^{\circ}F$. Inexpensive flat plate collectors may reasonably limit the generating temperature to $T_G < 195^{\circ}F$.

The above practical constraints combine to require condensing and absorbing temperatures below 110°F. The constraint $T_C < T_A < 110^{\circ}F$ can be met by doubling both the cooling air flow rates and the size of the condenser-absorber, compared to those used in conventional gas-fired systems using finned-tube condenser and absorber. (These conditions are essentially satisfied already for the experimental chiller, since the used condenser, absorber, and fan from a conventional 5-ton chiller for our 3-ton solar unit.) Doubling the cooling air flow rates is a must, but new designs of more efficient condenser-absorbers may reduce the requirement of doubling the size (and cost) of these heat exchangers. Doubling the cooling air flow rates typically increases the power of the fan from 1/140 to 1/70 watt per Btu/hr of cooling, making the total power consumption equivalent to 35 Btu/hr of cooling per watt of electrical power input (as compared to a rating of about 8 Btu/hr per watt for a mechanical compressor unit).

The COP depends strongly on e_{PH} and x, and is quite insensitive to the values of the remaining parameters. To have a COP > 0.65 with $x = 0.03$, the preheater effectiveness e_{PH} must be at least 90%. This value of e_{PH} is not expensive to achieve, since there is sufficient pressure in the weak solution line to promote high heat transfer coefficients. A high value of e_{PH} is a must in order to avoid dumping into the absorber the heat contained in the weak solution.

Conclusion of the authors:

It has been demonstrated experimentally that it is technically feasible to use the ammonia-water absorption cycle for cooling, with a heat source temperature below 200°F and a heat sink temperature (using air cooling) below 110°F.

Third Case Study: Li-br solar Absorption Air conditioning System by Humma and Sepsi, Ohio State University USA, 1975

The system was designed to provide the air conditioning of a single story laboratory 2200 ft^2 built over a 4 foot deep crawl space. In addition to the 2200 square foot of conditioned space, there are 3 enclosed, but unconditioned, courtyards. The perimeter window area of the home is limited to 6 vision strips or 18 square feet of glass area. Natural lighting originates primarily from the courtyards. The building wall and flat roof framing members are steel, and support, in addition to the conventional building loads, over 3300 pounds of collector, framing and piping load. The walls and roof are insulated with 2 inches and 3 inches of calked joint styrofoam to minimize infiltration and heat transfer with the outside. The U values for the composite wall and roof sections are 0.07 and 0.05 Btu/hrft^{2}°F respectively.

The roof mounted collectors are oriented due south and are tilted up 45° from the horizontal. The collector array consists of 37 PPG baseline collectors (660 sq ft) all connected in parallel. The collectors are constructed with two sheets of 1/8 inch thick tempered glass over a flat black aluminum roll-bonded absorber. Heat loss from the back of the collector is controlled with 3-1/2 inches of fiberous glass insulation. The plumbing in the system is copper with di-electric unions at each of the two connections per solar collector. Great care was taken at start up to flush the system and fill it with distilled water. The system was operated this way for one year, then modified to accommodate a glycol-water collector loop working fluid.

The thermal energy storage system consists of two 5 foot diameter by 12 foot long steel storage tanks lined with a Tinkolite coating. The horizontally mounted tanks are in the crawl space under one of the courtyards. The entire courtyard volume around the tanks was filled in place with a urathane foam to minimize energy losses.

An Arkla 3 ton (9000 Kcal/h) Lithium-Bromide-water absorption direct expansion machine, modified by Arkla Industries to operate on hot water, is the solar cooling machine. Circulation within the machine occurs as a result of the thermal syphon pump effect, thus requiring generator inlet temperatures of 190°F or more to start circulation. In addition to the hot water heat source, the cooling machine requires a cool water heat sink. The heat rejection is accomplished with a 7-1/2 ton Marley cooling tower. The presence of this unit adds two energy consuming motors to the operation, a 1/2 HP cooling water pump and a 1/3 HP cooling tower fan.

Figure 1 gives the collector efficiency as a function of the characteristics Δt/HR. The absorption cooling machine requires a steady 55,000 Btu/hr to supply 36,000 Btu/hr of cooling. Under these conditions, the collector array must be collecting 83 Btu/h.ft^2. In the event the ambient temperature is 90°F and the collector inlet fluid temperature 165°C (ΔF = 95) then the collector efficiency required at 300 Btu/hr ft^2 is 28% which clearly pushes the array to its limit.

The early summer of 1975 storage tank temperatures never exceeded 160°F, and consequently no solar cooling was done. A check of the storage tank losses revealed a rather severe heat loss problem. With an adequate system of control, it was possible to obtain 200°F water periodically, however the system was extremely sensitive to passing clouds. A passing cloud would cause the flux to drop radically and the collector losses caused the loop temperature to drop rapidly. The motor operated control valves were unable to respond to such operating conditions, therefore this mode of operation was abandoned.

The Table hereafter presents a comparison between the energy required with a conventional vapor compression machine and with an absorption machine. This comparison shows that 3 times as much energy is required in the case of absorption cooling.

Absorption Cooling	(Btu/hr)
Solar Collector Pump	- 1900
Mechanical Room Pump	- 425
Generator Pump	- 1200
Arkla Blower	- 1900
Cooling Water Pump	- 1200

Vapor Compression	(Btu/hr)
Compressor	- 18430
Blower	- 2200
Condensor Fan	- 2100
	22730

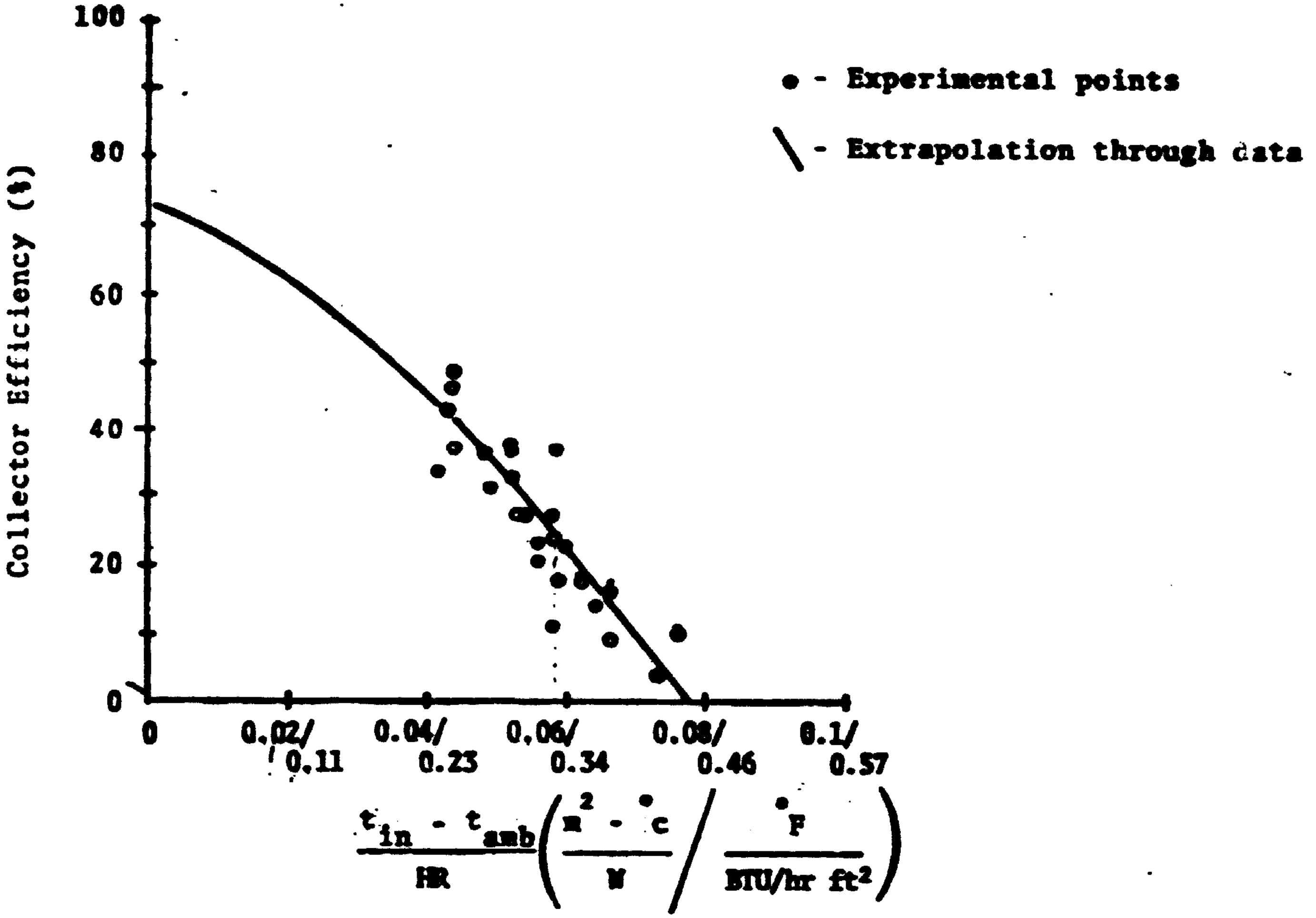


Figure 1 Collector efficiency as a function of Collector inlet temperature minus ambient temperature over insolation.

Cooling Tower Blower - 850 Cooling Delivered: 40,000

Heat Input - 55000

62475

cop = 1.76

Cooling Delivered: 36,000

$$cop = \frac{36000}{62475} = 0.58$$

Comments:

- To obtain 36,000 BTU/hour cooling, it is necessary to use six electric engines consuming 7475 BTU/hour in the case of the absorption machine. For the same cooling capacity in a conventional system, the consumed energy by 3 electric engines is 20475 BTU/hour. The use of solar energy saves about 13,000 BTU/hour or about 63% of the total electrical energy necessary in the case of a conventional system. This result is not negligible;
- Lithium-Bromide requires a minimum temperature of about 90°C which is very difficult to obtain with flat plate solar collectors, in the present state of the art, unless very expensive selective material is used;
- The system is bulky;
- The system is too complicated (6 independent engines);
- The control system is at least as complicated as that of the conventional engine.

4. SOLAR SPACE HEATING

Two modes of solar space heating are usually employed when solar energy is utilised:

Passive system:

The principle of this type of heating is shown in Fig. 1.

Solar radiation heats the absorbing surface B, constituted by a dark surface of the walls, which is generally oriented towards the south (in the northern hemisphere). The distance between this absorbing surface and the double sheet glass A, constitutes a duct in which air warms up and rises by thermosyphon and then enters the space to be heated by an aperture in the upper part of the wall. It heats the space, drops and returns to the duct by an aperture at the bottom of the wall.

Such a simple design is easy to construct. The walls constitute the storage system. At Odeillo in the south of France, such systems have supplied 60-70% of the total energy necessary for heating purposes.

Active system:

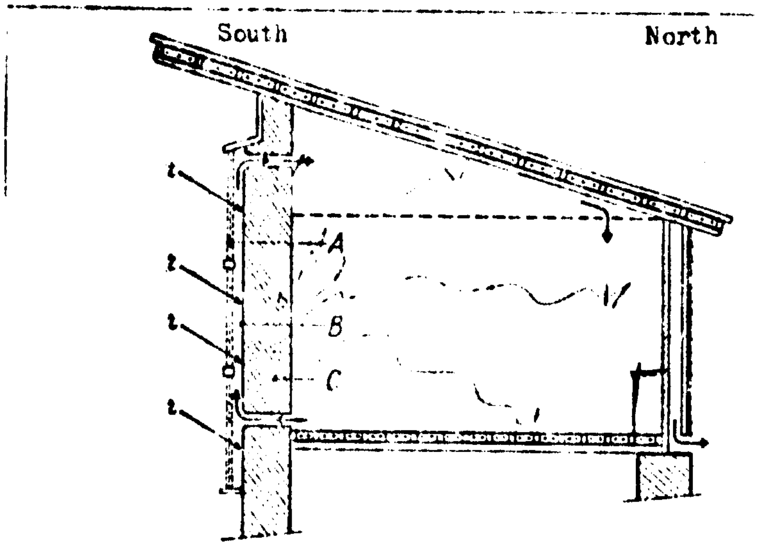
Water is heated in flat solar collectors and is circulated through a storage tank into radiators or convectors located in the space to be heated. Hot water could also feed coils, onto which air is blown and heating of the space is thus achieved by hot air.

In normal climatic conditions an auxiliary source of heat other than solar energy could generally be used. (Fig. 2)

Much development work has been undertaken in the field of solar heating in developed and developing countries: USA, FRG, Netherlands, France, India, etc.

From the technological point of view this system is already operational. Nevertheless R and D programmes are being undertaken to improve the performance, to find better architectural solutions, and to reduce the cost.

In many cases, as in conventional heating systems, domestic hot water could be associated to the solar water heating.



A. sheet glass
B. absorbing surface
C. wall
~~D. solar rays~~

Fig. 1

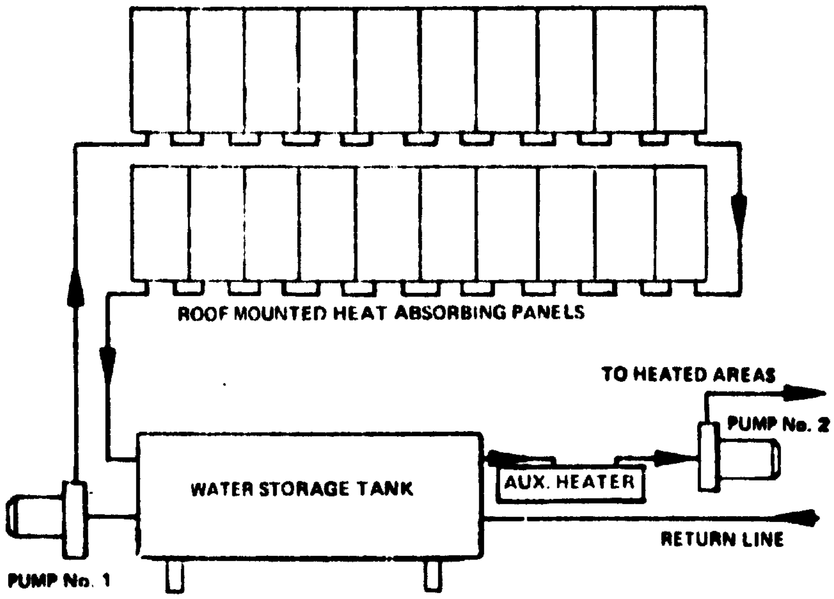


Fig. 2

5. SOLAR WATER HEATING

Solar water heaters are already used on a relatively large scale in Japan, the USA, Australia, Cyprus etc. They have already passed the phase of R and D and pilot projects and the technology is reliable and well-known. Several models exist on the international market. The most usual size has 2 m^2 flat plate solar collector and 200 litres tank storage.

In many countries solar water heaters could supply the total necessary hot sanitary water for domestic purposes all year round; in other countries with a less favourable solar radiation regime, it should be associated with a conventional source of energy.

The development of the utilization of solar water heaters is conditioned by the development of flat plate solar collectors which could serve other purposes, such as solar space heating, solar engines, etc.

As an example, the solar water heater developed by the Brace Research Institute of MacGill University, Canada, "How to build a solar water heater", revised in February 1973, could be classified as adequate for a wide range of developing countries. A scheme of this heater is given in Fig. 1.

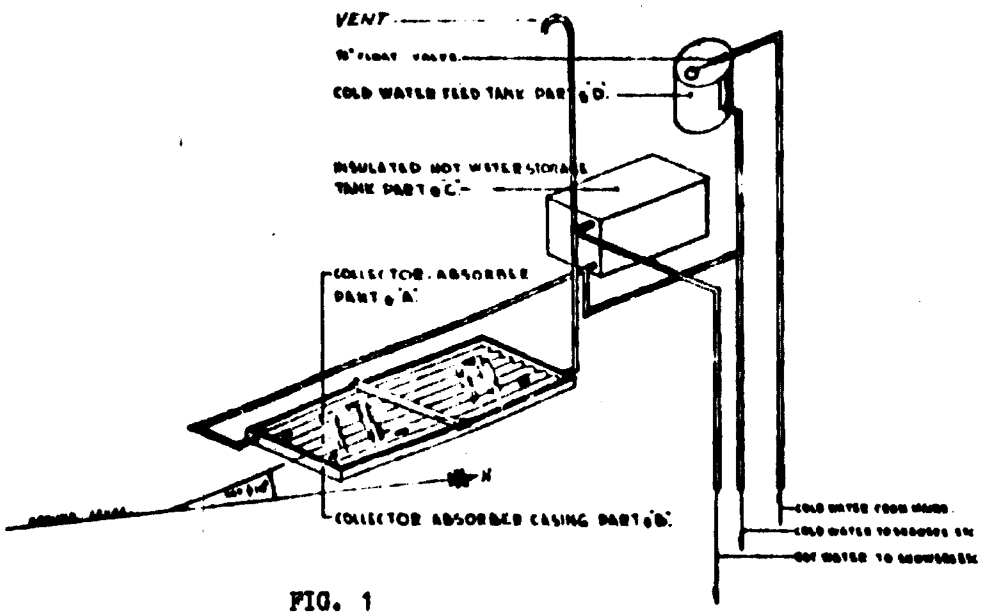

VENT
FLOAT VALVE.
COLD WATER FEED TANK PART D.
INSULATED HOT WATER STORAGE TANK PART C.
COLLECTOR ABSORBER PART A.
N
COLLECTOR ABSORBED CASING PART B.
COLD WATER FROM MAINS.
COLD WATER TO SHOWERS ETC
HOT WATER TO SHOWERS ETC

FIG. 1

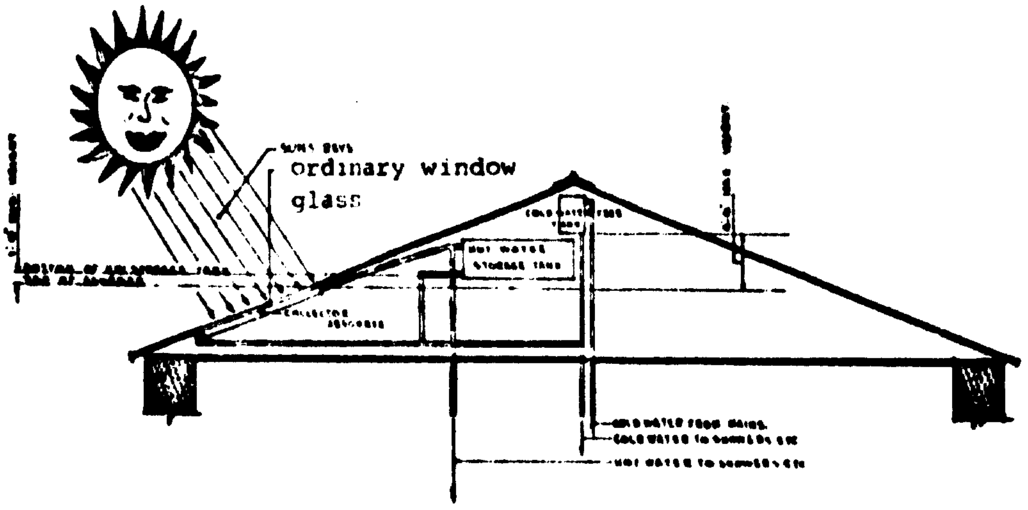

SUNS RAYS
ordinary window glass
COLD WATER FEED TANK
HOT WATER STORAGE TANK
COLLECTOR ABSORBER
COLD WATER FROM MAINS.
COLD WATER TO SHOWERS ETC
HOT WATER TO SHOWERS ETC

FIG. 2

6. SOLAR WATER DISTILLATION

General considerations

Distillation of sea or brackish water could be obtained by solar stills or by conventional methods such as multiple effect, thermal compression plant, inverse osmosis, electro dialysis, humidification - dehumidification, freeze desalination, In this chapter, only direct distillation in solar stills not requiring or depending upon external power sources will be discussed.

The principle of solar water distillation is the utilisation of the greenhouse effect. A layer of brackish or salt water is put in an air- and water-tight container covered with sheet glass or other transparent material. The bottom of the still is black, it absorbs a large part of the solar radiation and heats the water which will begin to evaporate. The vapour reaches the transparent cover, which is cooler than the vapour, which then begins to condense. A system of collection of condensed water is provided.

Many distillation plants of various sizes have been constructed in different countries. In 1973 Deliyannis of the Greek Atomic Energy Commission published a more up-to-date list given in table 1 and illustrated in figures 1 to 7. He also gave the monthly productivity of the Missyros plant for five years.

The number of parameters influencing the productivity of the stills is very high and these parameters are often interdependent. Among them the most important are:

- solar energy radiation regime;
- wind velocity;
- rainfall;
- design of the still (form, orientation, dimensions, materials, insulation, tightness ....);
- depth of the layer of water, regime of filling and flushing; and
- maintenance.

Table 1. The most Important Solar Distillation Plants.

COUNTRY	LOCATION	DESIGN	YEAR	M^2	FEED	COVER	REMARKS
Australia	Muresk 1	5	1963	372	Brackish	Glass	Rebuilt.
	Muresk 11	5	1966	372	Brackish	Glass	Operating
	Coober Pedy	5	1966	3160	Brackish	Glass	Operating
	Caiguna	5	1966	372	Brackish	Glass	Operating
	Hamelin Pool	5	1966	557	Brackish	Glass	Operating
	Griffith	5	1967	413	Brackish	Glass	Operating
Cape Verde Is.	Santa Maria	3	1965	743	Seawater	Plastic	
	Santa Maria	3	1968				Abandoned
Chile	Las Salinas	5	1872	4460	Brackish	Glass	Abandoned
	Quillagua	5	1968	100	Seawater	Glass	Operating
Greece	Symi 1	2	1964	2686	Seawater	Plastic	Rebuilt
	Symi 11	4	1968	2600	Seawater	Str. plst.	Dismantled
	Aegina 1	3	1965	1490	Seawater	Plastic	Rebuilt
	Aegina 11	4	1968	1486	Seawater	Str. Plst.	Abandoned
	Salamis	3	1965	388	Seawater	Plastic	Abandoned
	Patmos	6	1967	8600	Seawater	Glass	Operating
	Kimolos	6	1968	2508	Seawater	Glass	Operating
	Nisyros	6	1969	2005	Seawater	Glass	Operating
	Fiskardo	6	1971	2200	Seawater	Glass	Operating
	Kionion	6	1971	2400	Seawater	Glass	Operating
	Megisti	6	1973	2528	Seawater	Glass	Operating
India	Bhavnagar	5	1965	377	Seawater	Glass	Operating
Mexico	Natividad Isl.	4	1969	95	Seawater	Glass	Operating
Pakistan	Gwadar 1	6	1969	306	Seawater	Glass	Operating
	Gwadar 11	7	1972	9072	Seawater	Glass	Operating
Spain	Las Marinas	1	1966	868	Seawater	Glass	Operating
Tunisia	Shakmou	4	1967	440	Brackish	Glass	Operating
	Mahdla	4	1968	1300	Brackish	Glass	Operating
U.S.A.	Daytona Beach	1	1959	228	Seawater	Glass	Rebuilt
	Daytona Beach	1	1961	246	Seawater	Glass	Dismantled
	Daytona Beach	2	1961	216	Seawater	Plastic	Dismantled
	Daytona Beach	2	1963	148	Seawater	Plastic	Dismantled
U.S.S.R.	Bakharden	5	1969	600	Brackish	Glass	Operating
West Indies	Petit St. Vincent	2	1967	1710	Seawater	Plastic	Operating
	Haiti	4	1969	223	Seawater	Glass	Operating

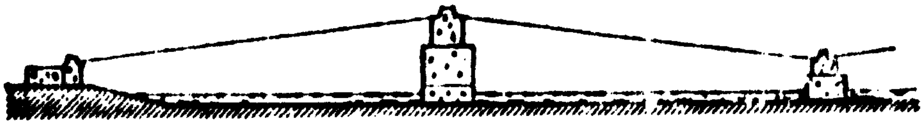


Fig. 1. Battelle-Löf design

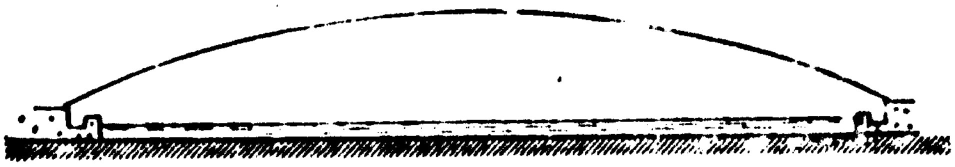


Fig. 2. Inflated plastic cover design

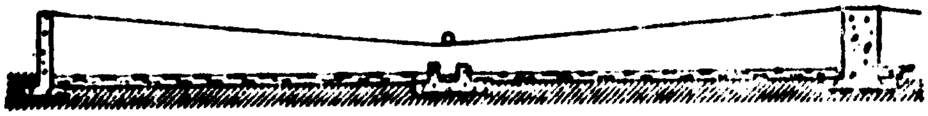


Fig. 3. V-shape plastic cover design

Fig. 4. Stretched plastic or inclined glass cover design

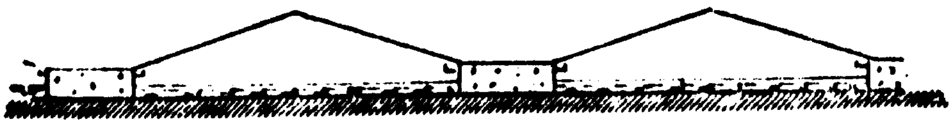


Fig. 5. C.S.I.R.O. - Australia design

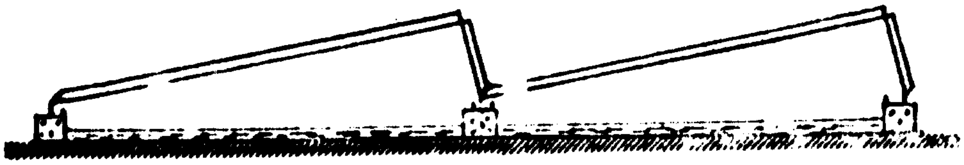


Fig. 6. Delyannis design

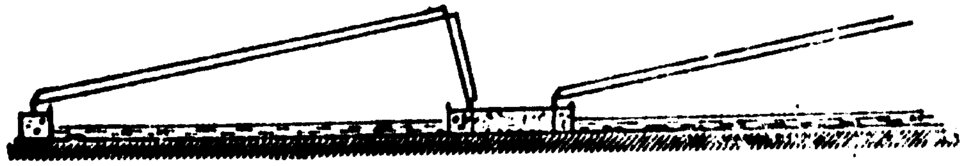
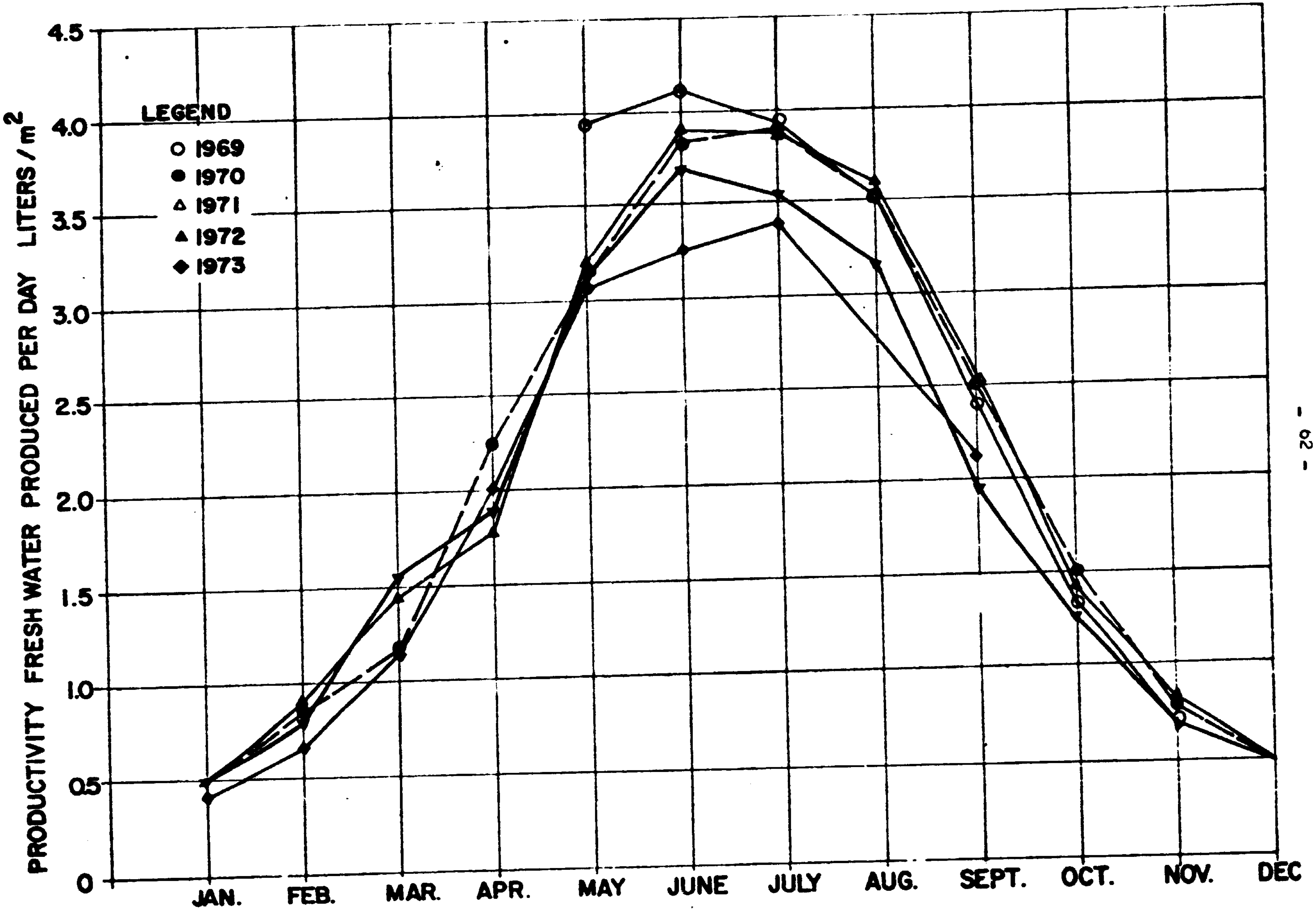


Fig. 7. Delyannis modified design



VARIATION OF PRODUCTIVITY WITH TIME OF
SOLAR DI ILLATION UNITS, MISSYROS, G EECE

+) "Since the building of the first large commercial solar still in Las Salinas, Chile, around 1872, the most significant gains in solar still technology have come by way of improved materials of construction. The productivity has not been increased much, but the maintenance and operating expenses have been reduced appreciably. For example, the 4800 m^2 still at Las Salinas was constructed of wood, glass and putty, and its operation required a clerk, a glazier, two full-time laborers, and occasionally a carpenter. By contrast, some recently built stills require only one full-time attendant and a few are designed to operate unattended for long periods of time. Glass, concrete, and asphalt materials appear to require only a minimum of maintenance.

Indigenous materials are usually preferred. However, in selecting materials, the overall economics must be carefully considered, including maintenance and rebuilding intervals as well as initial capital cost. The present trend is toward materials that will last 20 years with minimum upkeep. Such materials include concrete, glass, butyl rubber, and stainless steel.

The following lists still-component materials that have proved to be reasonably satisfactory in actual use around the world. For each component, the materials are listed in order of preference from the standpoint of durability. When a solar still is to be built directly on the ground using a basin liner, it is advisable to first use an insecticide and a weed killer to reduce the possibility of punctures.

Component	Materials
Basin liner	Butyl rubber (0.015 to 0.030 inch thick). Asphalt mats (0.12 to 0.25 inch thick). Black polyethylene (0.008 inch thick). Roofing asphalt (over concrete, etc.).
Cover	Window glass (0.10 or 0.12 inch thick). Wettable Teddlar plastic ++) (0.004 inch thick)
Support structure	Concrete. Concrete block. Aluminum. Galvanized metal. Redwood. ++)
Distillate trough	Stainless steel. Butyl rubber (lining). Black polyethylene (lining).
Sealant	Silicone rubber. Asphalt caulking compound. Butyl-rubber extrusions.
Piping and Valves	PVC (polyvinylchloride). Asbestos cement (for saline water). ABS (acrylonitrile-butadiene-styrene).
Water Storange Reservoirs	Concrete. Masonry "

+) Office of Saline Water, USA - Report No. 546

++) Relatively short lifetimes

Findings

A general consensus does not yet exist on the optimal design of a solar distillation plant. However, the following considerations seem to meet with general agreement:

- Local adequate materials and simple technology should be used as far as possible:
- Plastered brick or cement blocks able to withstand weather conditions, salt water effects, and to ensure tightness should be economically envisaged.
- Aluminium structure with sheet glass for the construction of the walls and the cover represents a good, but expensive solution and would not often be available.
- For the absorbing black surface two solutions could be favourably envisaged at the moment: Concrete with special bituminous paints, which has been successfully experimented in India, or thin butyl rubber sheets of about 1 mm, which has also been successfully experimented in Greece, Australia and other countries. The second material necessitates rather more difficult technology (vulcanisation or adhesive sealed to join the sheets). It is not affected by solar radiation or by high temperature or dry spots, but it is often not available in developing countries.
- Insulating the still at least in the base is not justified when the surface of these stills is large, because the ground acts as a semi-infinite medium through which there can be very small heat losses. The cost of the insulation materials and its installation does not seem very economical regarding the increasing of productivity in the case of large stills. The insulation of the sides of the still should not significantly increase the productivity due to the relatively small surface of heat exchange. However, the utilisation of available local insulation materials should always be studied but a large importance should be given to the avoidance of humidity of this material. +++)

+++) However, a layer of dry earthy material beneath the basin liner is usually sufficient for insulation purposes.

- Regarding the cover, sheet glass of about 3 mm thickness still seems to be the best solution. Use of a cover of two sheet glass layers is not justified. Experience shows that the use of different kinds of plastics is not yet conclusive. Several types of plastic materials have been tried (Tedlar, Mylar, PVC, Kel-F, Teflon, Nylon, Aclar, Polythene, etc.) in conditions less severe than in full-sized stills. The only materials that last 5 years are 5-mil teflon, 4-mill Tedlar and 5-mil weatherable Mylar. In general the lifetime of plastic material is very short and the effect of solar radiation could affect after a short time the productivity of the steel. In addition very thin covers do not withstand the effect of the wind.
- The tightness of the still is very important and till now an efficient cheap material does not exist on the market. Silicon rubber represents a very good but very expensive solution. A cold applied mastic bituminous compound used usually for repairs of leaky roofs has been used with success in India but the duration of the experience does not permit a forecast of what the lifetime would be.
- Regarding the depth of the layer of water in the still, a general agreement now exists stating that shallow layers have better productivity but due to inaccurate levelling of the ground dry spots on the absorbing bottom could appear if butyl rubber or equivalent material is not used, and a practical thickness of 5 cm seems to be a realistic solution.
- Regarding the inclination of the sheet glass cover, no general agreement exists. It is important to ensure the formation of a film which allows good condensation and a good passage of sun radiation. 10-20° seems to be acceptable. For a given horizontal surface to be covered, the increasing of the inclination increases the surface of the cover and the cost, and could decrease the productivity of the still.

- Geometry of the covering affecting the fraction of incident energy entering the still is negligible in large units where the shadow caused by the sides is small as compared with the evaporating surface.
- Basin stills are generally oriented with their long axis along the E-W or N-S direction. The orientation of symmetrical-cover or low-slope still does not affect productivity: asymmetrical and single-sloped covers should be oriented with the long axis in the E-W direction, with the low-slope or single-cover plate facing the equator direction (S in the north hemisphere, N in the southern).
- The still should serve as a rainfall catchment surface.
- The optimal regime of feeding the still with fresh water continuously or by batch is not yet defined;
- deposit of salt should be avoided, as it increases the reflectivity of the black surface and decreases productivity.
- Growth of alga and bacteria should be avoided, as it decreases productivity. However, the addition of a few ppm of copper salt should prevent the growth of alga.
- Periodical flushing of the still with fresh water could prevent the deposit of salt and the growth of alga.

- **UNIDO/UNICEF solar distillation plant in Somalia.**

UNIDO, with UNICEF financing, is implementing a solar distillation project in Somalia, the main component of which is a solar water distillation plant of about 2000 m^2 net evaporating surface. The expected water production of the still including the rainfall collection, is about 5 - 6 m^3 of fresh water per day.

The design of a 2000 m^3 solar distillation plant prepared by the Central Salt and Marine Chemicals Research Institute to be implemented in India has been adapted for Somalia after discussions with UNIDO, and slightly modified, particularly in optimising the piping, reducing the passages between the stills, changing the inclination of the cover glass to 15° instead of 20°, using aluminium instead of wood for the supports of the upper side of the sheet glass, changing the location of sea water, distilled water, and blending water tanks.

The plant is composed of fifteen blocks each consisting of 6 symmetrical and intercommunicating basins of about 13 m long and 1.5 m wide. The main materials to be used for the construction are: bricks, cement, sheet glass, tarplastic, tank-mastic paint, electrical cotton insulating tape to cover the joints of two medium sheet glass and to support the putty, small quantity of aluminium T sections, square tube and sheet foil, galvanised piping, 2 hand pumps. The estimated cost of this material in India is about US $ 23,000 and the estimated cost of labour is about 20 % that of material. The cost per net evaporating square meter of the distillation plant is about $ 14.

It has been suggested that in another distillation plant of 200 m^2, 12 units of 3. m^2 each will be constructed for comparison of behaviour of materials, effect of insulation, etc. The proposed characteristics of the experimental units are:

1 unit serving as reference designated by R
1 unit as R but inclination of sheet glass 10°
1 unit as R but inclination of sheet glass 20°
1 unit as R but depth of water 5 cm
1 unit as R but depth of water 10 cm
1 unit as R but depth of water 15 cm
1 unit as R but walls of hollow concrete
1 unit as R but walls of improved soil
1 unit as R but walls of bricks totally plastered in the interior and plastered on the joints on the exterior.
1 unit as R but walls of bricks plastered only on the joints interior and exterior
1 unit as R but with butyl rubber as liner.
1 unit as R with insulation layer beneath the basin constituted of dry straw or rice husks or sawdust

7. SOLAR DRYING

Drying food, agricultural products or fish by solar energy is a very old practice. However, in recent years improving the process by systemising it, protecting the products from rainfall, dust and insects, has been the subject of intensive R and D work in developed and developing countries. The survey entitled "A Survey of Solar Agricultural Drying" of the Brace Research Institute, MacGill University, Montreal, constitutes a very useful study. Most of this paragraph on solar drying will be constituted by extracts of this survey. Data are presented as case studies which deal with descriptions of the dryers, experimental results and drawings. Economical information has also been included. The classification of dryers adopted in the survey is the following:

- Passive Systems - dryers only using solar or wind energy for their operations.

Sun or Natural Dryers:

These dryers make use of the action of solar radiation ambiant air temperature and relative humidity and windspeed to achieve the drying process.

Solar Dryers - Direct

In these units, the material to be dried is placed in an enclosure, with a transparent cover or side panels. Heat is generated by absorption of solar radiation on the product itself **as well as** on the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product. In addition, it serves to heat and expand the air in the enclosure, causing the removal of this moisture by the circulation of air.

Solar Dryers - Mixed Mode (Direct and Indirect)

In these dryers, the combined action of the solar radiation incident directly on the material to be dried and air pre-heated in a solar air-heater furnishes the heat required to complete the drying operation.

- **Hybrid Systems** - dryers in which another form of energy, such as fuel or electricity is used to supplement solar energy for heating and ventilation.

Solar Dryers - Indirect: (with forced ventilation)

In these dryers, the solar radiation is not directly incident on the material to be dried. Air is heated in a solar collector and then ducted to the drying chamber, to dehydrate the product.

Solar Lumber Dryers:

These dryers have been put in a special category as they constitute an important application of this technology. In most cases forced ventilation is used as proper circulation of air helps control the drying rate so as to avoid case hardening.

Other Definitions:

Chamber Dryer - is one in which the material to be dried is dried in an enclosure.

Rack or Tray Dryer - is one in which the material to be dried is placed on an open rack or tray.

Some examples quoted from the survey are given below:

Case Study 1: Solar Cabinet Dryer

This dryer is essentially a solar hot box, in which fruit, vegetables or other matter can be dehydrated on a small scale. In essence it consists of a rectangular container, insulated at its base and preferably at the sides, and covered with a double-layered transparent roof. Solar radiation is transmitted through the roof and absorbed on the blackened interior surfaces. Owing to the insulation, the internal temperature is raised. Holes are drilled through the base to permit fresh ventilating air entry into the cabinet. Outlet ports are located on the upper parts of the cabinet side and rear panels. As the temperature increases, warm air passes out of these upper apertures by natural convection, creating a partial vacuum and drawing fresh air up through the base. As a result there is a constant perceptible flow of air over the drying matter, which is placed on perforated trays on the interior cabinet base.

Methods and materials of construction:

There are many forms which the construction of such a dryer can take. Nevertheless, the following general recommendations can be applied to all dryers of this type (Fig. 1)

- the length of the cabinet should be at least three times the width so as to minimize the shading effect of the side panels;
- the angle of the slope of the roof covering should be taken from Fig. 2 . This gives the optimum angle for drying seasons as a function of the latitude. The graph is equally applicable to areas north and south of the equator. Note that for latitudes less than 20° North or South of the equator, the slope of the transparent roof is constant at 6°. This is to allow a minimum difference in elevation from one side of the collector to the other in order to permit adequate convective air circulation over the drying area.
- the transparent cover should be made from two layers of either of the following:
    - glass panes (2 mm thick)
    - plastic film (about 0.13 mm thick)

In general the covers made with plastic film have a limited life. It is therefore necessary to use films which have been treated to give protection against ultra-violet radiation. The latter can be polyester, polyvinyl chloride or polyethylene. Generally films of the polyethylene or cellulose acetate types should not be used due to their limited life. They would have to be replaced at the end of each drying season and might not give as favourable results in service. Although it may be advantageous to replace covers seasonally in certain cases, trouble may occur with films not being able to withstand the high cabinet temperatures generated. These may reach as high as 80 to 100°C in some dryers. It is advisable in this type of unit to use ordinary window glass supported by a suitable frame. The use of a sealant to hold it to the frame is a possibility, but

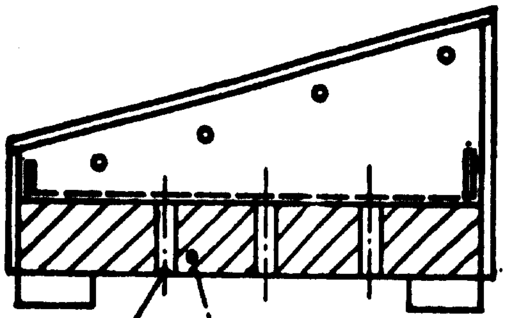
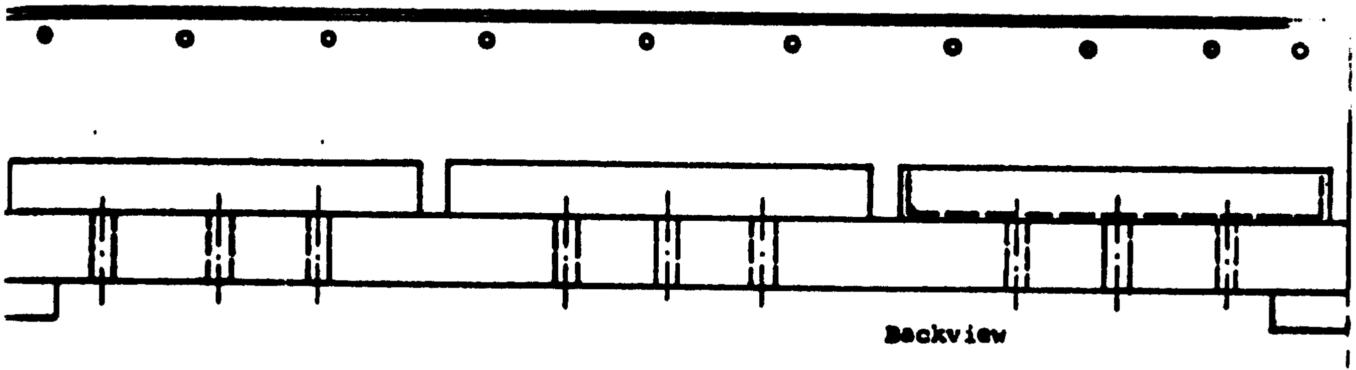


FIG. 1



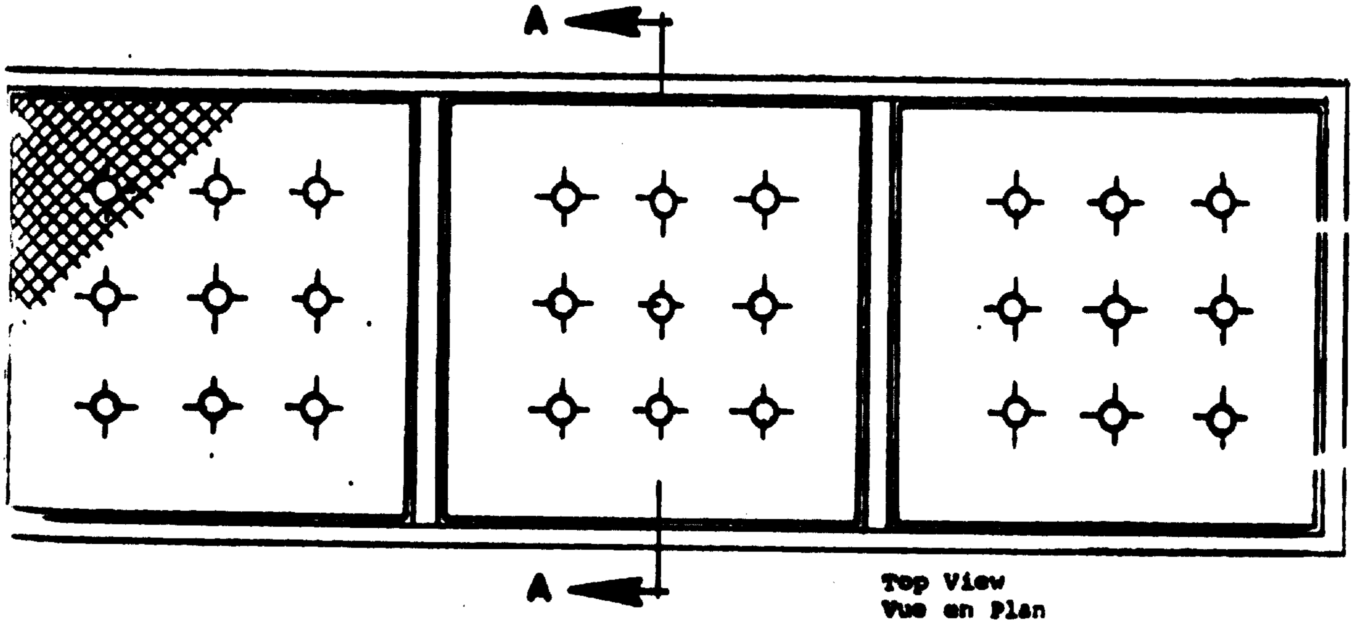


Figure 2. Plan of the Solar Cabinet Dryer
Plan du Séchoir Solaire

Scale - Echelle 1 mm = 1 cm

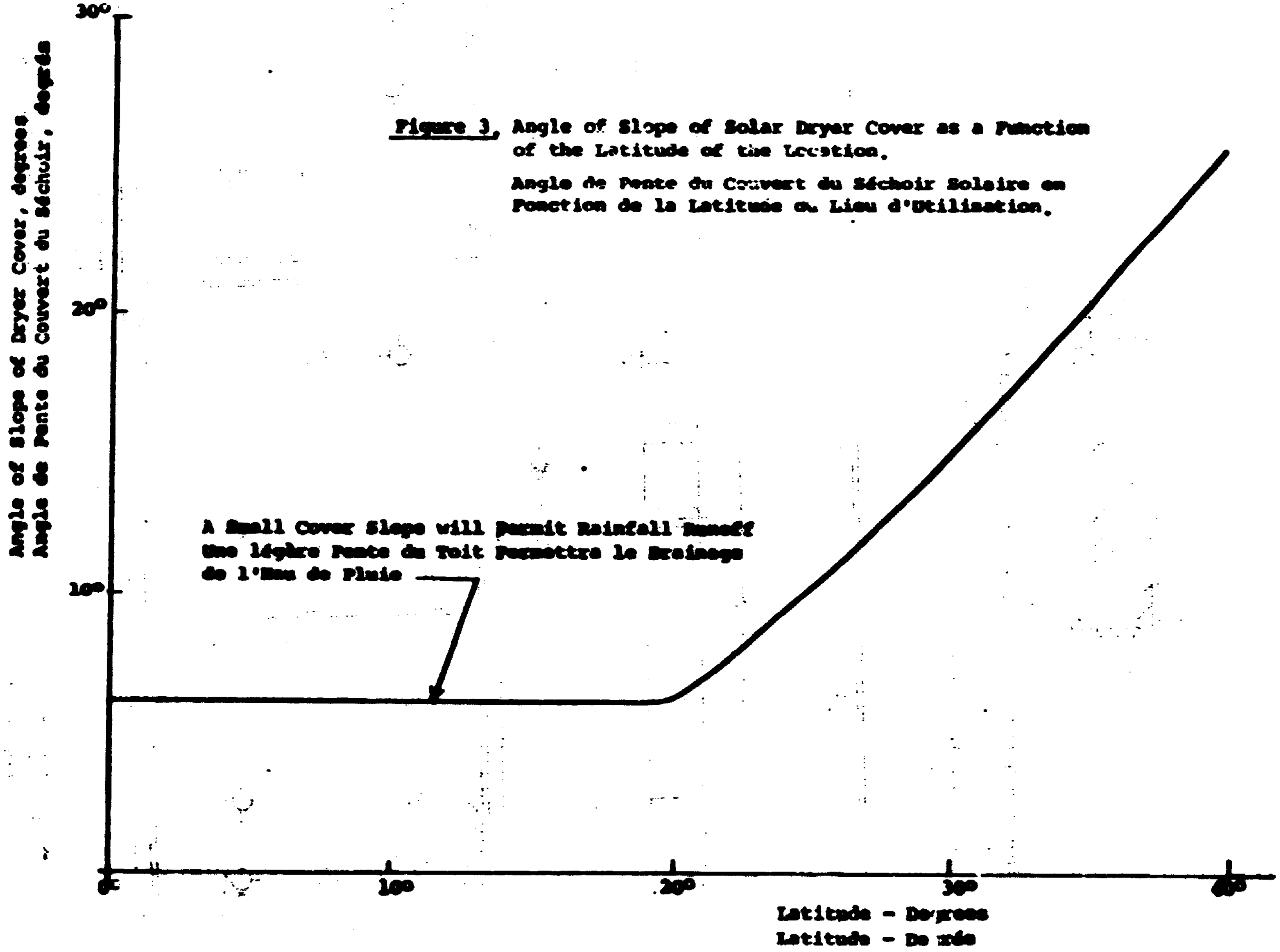


Figure 3, Angle of Slope of Solar Dryer Cover as a Function of the Latitude of the Location.

Angle de Pente du Couvert du Séchoir Solaire en Fonction de la Latitude du Lieu d'Utilisation.

if a sealant is not used, the glass should be held firmly in place by a suitable frame, painted black.

In general the framework of the cabinet may be constructed as follows:

- Portable Models: wood, metal, hardboard, plywood for the more sophisticated units: or basketwork, wicker or bamboo for the more primitive units. Perforated cabinet bases and side panels might possibly be fabricated by placing insulation between layers of blackened wicker or open basketwork. This would cut down costs and make use of local industry.
- Permanent structures: adobe, bricks, stone or concrete
- The insulation should consist of locally available materials such as wood shavings, sawdust, bagasse, coconut fibre, reject wool and animal hair. In areas affected by wood ants, termites or other noxious insects, the susceptible materials should be properly protected before being placed in the insulation base.
- The hot box should be constructed along the lines outlined in figures No. 1 and 2. The insulating layers should be at least 5 cm thick, both at the base and side sections. Holes should be drilled in the insulated base and fitted with short lengths of plastic and rubberized garden hose (or bamboo, etc., if available). Where insect infestation is prevalent, all cabinet apertures should be covered with fine mosquito netting, (preferably fibreglass) or gauze. Generally the high temperature of the cabinet interior discourages insects, rodents, etc., from entering and feeding on the drying produce. Furthermore, in arid areas where there is a high concentration of airborne dust and debris, the transparent cover eliminates product contamination.

- The transparent cover can be attached to a frame which can then be fixed to the chassis of the cabinet. Care must be taken to ensure that the cover is completely watertight so as to avoid deterioration of the interior and wetting of the insulation. All components of the cover framework should be painted black or some other convenient dark colour to absorb the maximum solar radiation. Hold down strips should be secured to the upper exterior rim of the cover frame to protect the film against excessive wind suction lift.

- Once the cover and chassis are secured, several holes should be drilled in the rear and side panels. These provide the exit ventilation ports to remove the warm, moist air. The number of holes is dependant on the climatic conditions and the nature of the drying material. A satisfactory method is to initiate the dryer with a minimum of side ventilation ports and to drill further holes as needed so as to prevent internal moisture condensation. This method prevents an excess of ventilatinn ports being drilled.
- The rear panel should be fitted with access doors to give entry into the cabinet. All doors should be placed on the rear side to prevent excessive shadowing of the dryer during handling operations.
- Trays should be constructed as indicated, of galvanized chickenwire or some similar material. They should be placed on runners a few centimetres high so as to ensure a reasonable level of ai[illegible]ulation under and around the drying material.
- The interior of the cabinet should be painted black. The exteriors of the side, rear and base panels should be painted with aluminum paint. If desired, the interiors of the side and rear panels can be covered with a layer of aluminum foil. If the latter is not available, paint these surfaces black.

The dryer operation is not complicated. The produce to be dried should be pretreated in the usual manner (i.e. blanched and fumigated) and placed on the perforated trays, at a loading rate of about 7,5 kgs/meter^2 of drying area. A small thermometer inserted into one of the ventilation ports will prove very handy. The thermometer bulb should be shielded from the direct rays of the sun. The upper temperature limits which can be withstood by agricultural produce vary substantially.

Where the drying produce might suffer from the direct sun-rays or where the light colour of the produce reflects much of the incident radiation, it is advisable to cover the loaded trays in the dryer with a black plastic mesh or black gauze. This should not inhibit the flow of air through the trays, but will absorb the radiation and transmit the heat to the produce through conduction and convection. The resultant temperature increase can be controlled by opening the rear access doors. This approximate temperature control system can easily be mastered with time and experience.

Case Study 2: Kanpur, India

Climatological data: it was found that the optimum tilt of the dryer was 13° in summer and 40° in winter at Kanpur location.

Maximum temperature in summer	45°C
Minimum temperature in winter	10°C
Hours of sunshine per year	4,000
Days of no sunshine per year	30

The dryer was used on experimental basis only from July 1971 to July 1972.

Drying data:

Material	Quantity Dried grm.	Pre Treatment	Moisture Initial %	Content Perferred Final %	Maximum Allowable Temp. °C	Drying time hours
prunos	750	sulphuring	85	15 to 20	77	18
peaches	275	none	80	5 to 6	77	11
peas	420	blanching	80	5 to 6	66	5
cauliflower	200	none	85	5 to 6	66	2.5

For purposes of comparison, the following table on drying data gives some indication of the temperature limits and possible throughputs available with a dryer of the size and specifications shewn in case study 1. The table gives yields for dry, arid, cloudless Mediterranean type climates.

Produce	Amount of Kgs Fresh Matter Dried per Unit	Maximum Allowable Temperature (°C)
Apricots	4 per two days	66
Garlic	2.6 per two days	60
Grapes	5.7 per four days	88
Okra	3 per two days	66
Onions	3 per two days	71

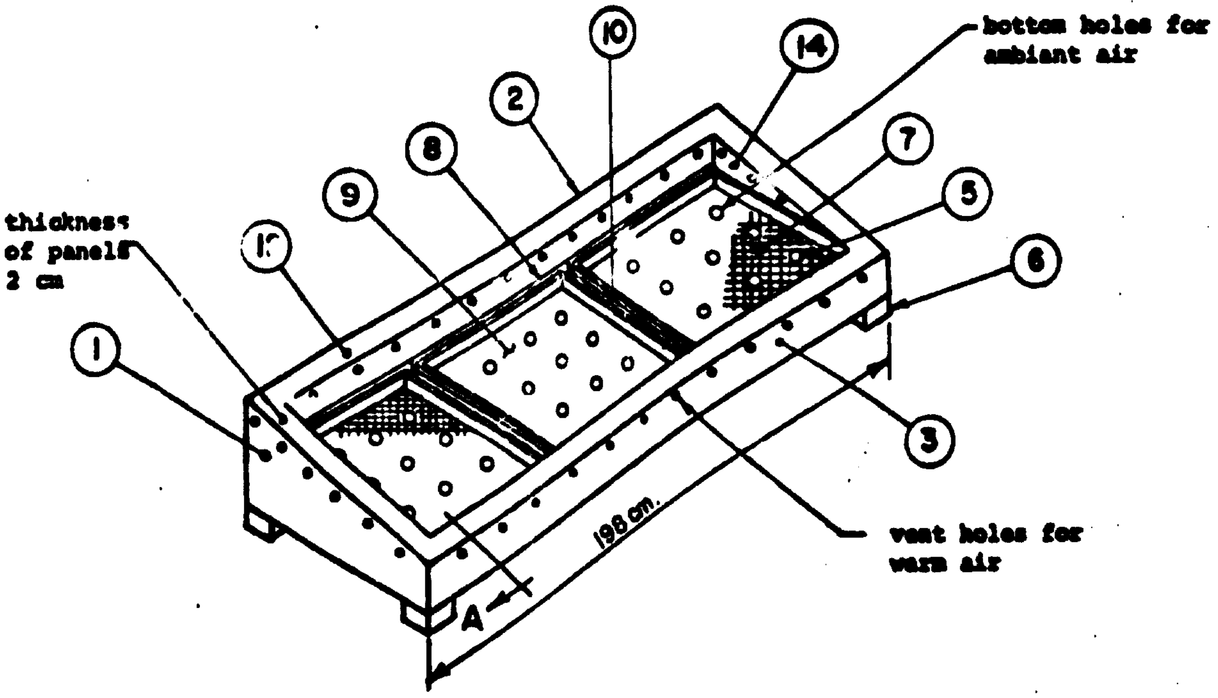
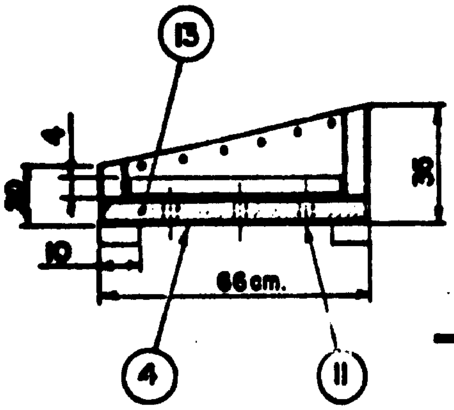


Figure 1. Plan of the Cabinet Dryer



SECTION "A"

14	INTERNAL SIDE WALLS	ALUMINIUM	2
13	INSULATION	WOOD WOOL	-
12	COVER FRAME	WOOD	1
11	NETTING	FIBRE GLASS	27
10	TRAY RUNNERS	WOOD	4
9	TRANSPARENT COVER	GLASS	3
8	DOORS	WOOD	3
7	TRAYS	WOOD & STEEL MESH	3
6	LEGS	WOOD	4
5	PIPE FOR BOTTOM HOLES	POLYTHENE PIPE	27
4	BASE	PLYWOOD SHEET	2
3	FRONT PANEL	WOOD	1
2	REAR PANEL	WOOD	1
1	SIDE PANEL	WOOD	2
	DESCRIPTION	MATERIAL	NO. REQUIRED

Operating conditions: It was observed that an average temperature of 75°C was attainable inside the dryer as compared to an average outside temperature of 35°.

Economic Details:

Cost of materials: About $20/unit in 1973

Item	Number of pieces required	Dimensions	Total cost Rupees
Glass sheet	3	61 x 62 cm	30
Indian chir Wood (volume)	0.045 cu.m.	-	60
Plywood sheet	2	198 x 66 cm	18
Aluminium sheet	2	0.25 m^2	8
Mesh for Trays	3	62 x 62 cm	25
Polythene pipes	25	12.7 diameter x 6 cm long	2
Miscellaneous	-	-	5
Labour charges	2 days	-	12
			150

Annual operating expenditure

Depreciation of the unit per year	16 Rs	
Interest on capital (at 10%)	16 Rs	
Contingencies	8 Rs	
TOTAL	40 Rs	(about $5)

Conclusions:

The estimated life of the dryer is 10 years. It is found that solar drying saves considerable time. Also the final product quality obtained from the dryer was found to be superior in taste and odour without being contaminated by dust and insect infestation.

In some cases it is preferable to have a plastic cover rather than a glass cover to prevent breakage by flying stones, etc. However, the glass would normally have a longer life so that, in the final analysis, the farmer himself must decide which is the more economical and acceptable for him. Presumably if the dryer was placed on a building roof, the glass might last 10 to 20 years without breakage.

With regard to labour costs it must be stressed that all the construction to be undertaken is quite simple and could be performed easily by the farmer himself using simple hand tools.

A very practical auxiliary application of the dryer is for warming foods and other materials. It is particularly advantageous as a self-contained source of heat at 70-80°C in the field and in isolated farm areas.

Case Study 3;Solar wind ventilated dryer (Syria)

Characteristics:

The dryer can be described as a drying chamber through which warm air, heated in a solar air heater collector, is drawn by means of a rotary wind ventilator.

The solar air heater collector used consists of a blackened hardboard sheet, insulated at the bottom and covered by a plastic (or glass) sheet. The collector is mounted facing due south, and tilted at an optimum angle for the area and particular season.

Air enters through the open bottom end of the collector. It passes up between the hardboard blackened bottom (absorber) and the cover. The effectiveness of the collector is increased by placing a perforated black mesh screen midway between the cover and the absorber: solar radiation which passes through the transparent cover is absorbed by both the mesh and hardboard. The mesh provides additional heat transfer surface area, and increased heat is supplied to the passing air. Collector efficiencies of over 75% have been achieved using this system.

The warm air outlet of the collector is connected to the base of the drying chamber, which holds twelve trays placed in two adjacent six-tier stacks. Hot air circulates up through the drying produce; additional heating is obtained from solar radiation transmitted through transparent sheets which cover the east, south and west sides of the drying cabinet. The rear vertical and bottom horizontal panels of the dryer are of blackened hardboard, which is insulated to reduce heat losses. A rotary wind ventilator is placed on top of a stack above the drying chamber. An adequate length of this stack is required both to achieve a chimney effect and to catch more wind.

The rotary wind ventilator is a moving corrugated vane rotor. As it spins in the wind, it expells air from the ventilator stack. The rotor is mounted on a ball bearing suspension. The friction is low and momentum keeps the head spinning even in sporadic winds. Quantitative tests carried out using the ventilators indicate that the rotary ventilator keeps spinning between gusts yielding a high, constant exhaust in spite of intermittent winds.

A stationary eductor placed on top of a chimney could be also used; however it must be understood that it would rely solely on natural convection during periods of no wind. This dryer was never optimized.

Materials of Construction:

Drying Chamber:

Transparent cover:	Mylar (transparent plastic film)
Frames:	blackened hardboard for the back wall and the bottom panels
Insulation:	straw
Trays:	wire mesh

Solar Air Heater:

Transparent cover:	Mylar
Absorber:	blackened hardboard bottom sheet with a black plastic mesh 2 cm above it
Insulation:	straw
Frames:	blackened hardboard sheets on bottom and side walls

Location: Douma (near Damascus) Syria

Latitude: 33°33'N

Longitude: 36°24'E

Climatological Data:

The climate of Syria is generally characterized by dry, cloudless summers, and cool, partly rainy winters. There is a substantial variation in monthly mean temperature, falling quite clearly into a four season year. Nevertheless, the spring and fall periods seem to blend partly into the traditional desert summer climate - high daytime temperatures, low relative humidities, clear cloudless days with an absence of precipitation for nearly 6 months. In most of the country the percentage of sunshine during the period of May through October is over 85%. During the period of June through September, the percentage is generally above 95%.

Practical Operation:

Number of units used in the past: 3 to 4

Periods of Operation:

On experimental basis:	1964-1968	(Units have also been tested
In field operations:	nil	in the West Indies)

Drying Data:

The unit successfully dried okra, cousa (Baladi variety), squash, jew's mellow, eggplant, tomato paste and yam. As an example of the drying yields attained by the unit, drying times for okra and for cousa were reported to be respectively 20 and 58% shorter than with a sun drying treatment. In addition, the final product quality obtained using this solar dryer was reported to be superior.

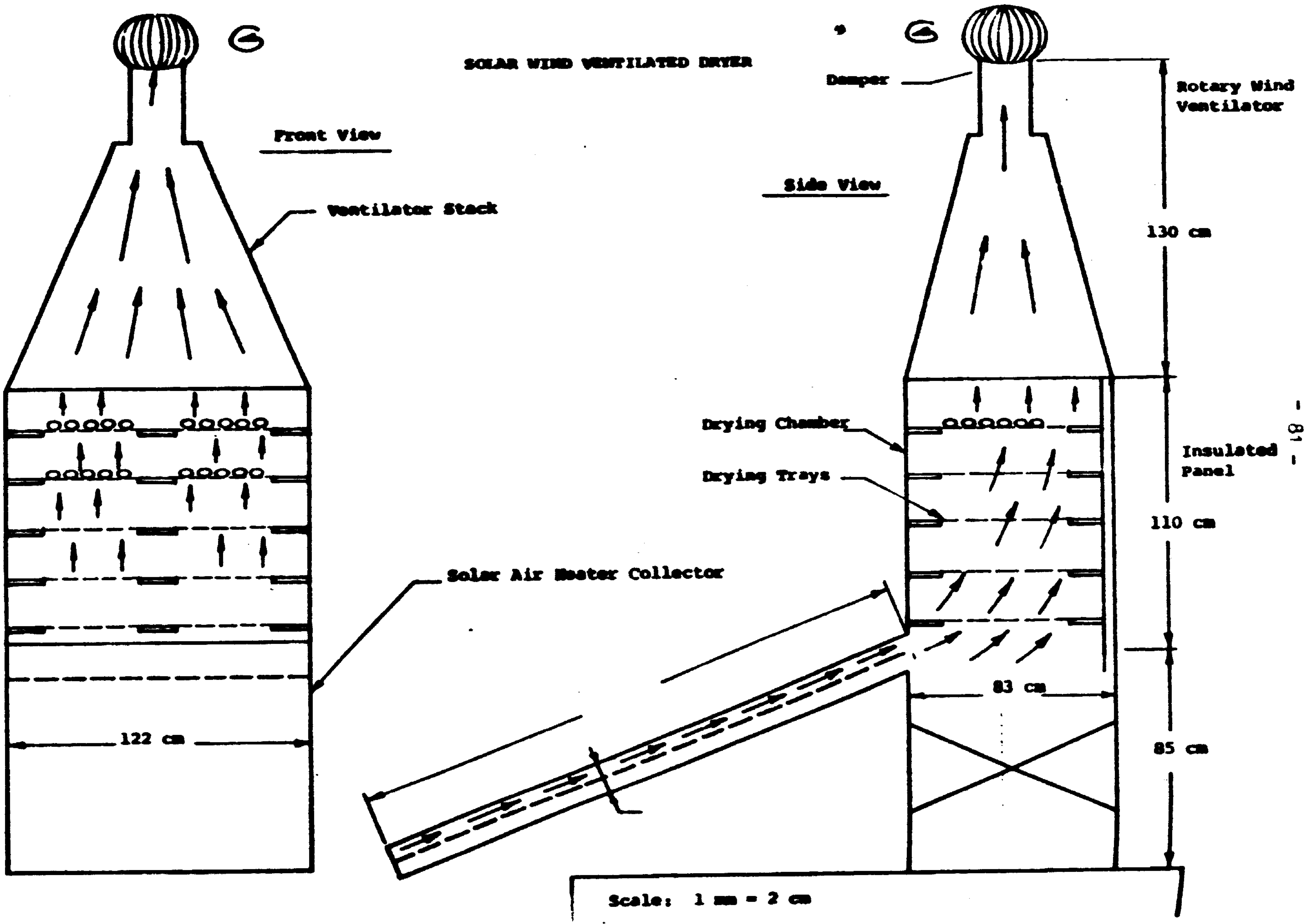
The efficiency of the solar air heater was reported to vary between 64% to 88% (ratio of useful heat absorbed into air stream over Energy transmitted through glazing).

Operating Conditions:

- Fairly sunny
- Ambient air temperature from 30°C to 34°C
- Temperature of the heated air entering the drying chamber on day of experiment: from 36,2 to 58,4°C

Comments on the Dryer:

For solar drying purposes, generally the greater the air flow within the drying chamber, the greater the yield will be. If the average wind speed is high, the use of a stationary eductor instead of



SOLAR WIND VENTILATED DRYER

a rotary ventilator will be just as practicable. In the case where higher temperatures are desired for drying particular crops, dampers installed in the ventilator stack will permit control over the air flow rate and thus the dryer temperature. If the ventilator diameter is small, it seems better to use a stack of a larger cross section which reduces smoothly to the ventilator section. This will reduce air friction and insure an adequate air flow.

Evaluation:

- The solar dryers are simple to construct and economical to use. However, local material and adequate technology should be used to the maximum. Farmers may be encouraged to construct their own solar dryers based on optimised models designed by local institutions which should be available for demonstration purposes.
- In case of using external sources of power the only possible source of power in small applications is, in the present conditions, wind energy. When using forced convection obtained by fans operated by thermal, electrical or solar engines, an in-depth feasibility study should be undertaken to find out which percentage of consumed energy could be delivered as mechanical energy (by engines). Many research projects are being undertaken in various developing countries and it seems that the following suggestion could be included in these research programmes when forced convection is used;
- Study of the influence of the temperature of solar heated air. This temperature could be varied until the maximum compatible with the conservation of the quality of the dried products by playing on the performance of the solar collectors and/or on the velocity of the heated air;
- Study of the influence of the Reynold's number of the flow of air across the dried product by changing the discharge of the fan;
- Reduction of the useful fluid power by optimising the pressure drop between solar collectors and the outlet of the dryer.
- In an intermittent drying regime, calculation and measurement of the moisture should be made at the end of each period.

CHAPTER II - TECHNO-ECONOMIC EVALUATION OF SOLAR EQUIPMENT

1. SOLAR ENGINE AND INTERNAL COMBUSTION ENGINE

The term "solar engine" designates in this study a complete installation of an engine powered by solar energy, and the term "internal combustion engine" will be limited to Diesel and gasoline engines (gas turbines of very small power do not exist yet on the market).

A large number of factors could be taken into consideration when undertaking a techno-economic comparison of this nature, but in order to simplify the study, these will be limited as much as is possible without significantly altering the validity of the comparison. The cost of the installed equipment, depreciation, maintenance and repairs, cost of consumed energy and impact on industrial development will be considered.

A general equation will be defined to find the maximum cost per installed kw of a solar engine, from which the solar engine begins to be more economical than a Diesel and/or gasoline engine. In order to base a simple equation which does not require the use of a computer, some assumptions will be made, bearing in mind always that a valid conclusion will be reached with acceptable accuracy.

Total-working hours:

A solar engine in favourable solar radiation conditions may work about 6 hours per day but it does not give its maximum output all of this time, so a figure of 1,500 hours per year at nominal power seems to be reasonable. This duration could be extended in the case of extensive heat storage.

Power of solar engines to be considered in the comparison:

Except for experimental purposes, use of fractional kw solar engines does not seem to be really justified in developing countries in the short and medium term. For instance, a $\frac{1}{2}$ kw solar pump could be replaced by a $\frac{1}{4}$ kw animal powered pump working 8 hours daily. The energy saving in using small solar engines is really small, for example, a $\frac{1}{2}$ kw solar engine will save only about 250 kg of fuel per year. The transport of such a quantity of oil would not pose real difficulties.

In the case of economically acceptable cost of solar engines, the 2 - 15 kw range could sell better on the market. However, in the future largest power could be envisaged on a commercial basis.

Power of Diesel and gasoline engines to be considered in the comparison:

A Diesel or gasoline engine could easily work 8 hours per day or about 3,000 hours per year. A set of 2 engines each having half the power of the solar engine, will be considered, so a stand-by will be available and a good reliability could be expected.

The power of small Diesel engines with 1000 - 15000 rpm existing on the market usually starts with 2 kw, then in this power range, only gasoline engines will be considered and for the range 10 - 15 kw Diesel engines will be considered.

1.1 Equation giving the cost per installed kw of solar engine on the basis of which its utilization begins to be economically feasible:

The coefficients in this equation will have the following significations:

a	inverse of the number measuring in years the expected lifetime of the engine (rate of annual depreciation);
b	coefficient giving the annual cost of repair and maintenance in percentage of the cost of the installed engine;
i	the rate of interest on the loans used to finance the cost of the installed engine;
q_f	annual weight in tons consumed fuel per kw of thermal engine;
q_c	annual weight in tons of lubricant consumed per kw of thermal engine;
c_f	cost per ton of fuel
c_1	cost per ton of lubricant
K	cost per kw of installed engine;
s	index related to solar engine;
t	index related to internal combustion engine;
D	Diesel engine;
g	gasoline engine;

It will be accepted that the annual cost of the loans made to finance the installation will be equal to half the rate of interest multiplied by the loans. Such simplifications will not significantly affect the accuracy of comparison because the term $\frac{1}{2}$ appears in the two numbers of the equation and it represents a relatively small importance in regard to the other terms.

Inflation will not be considered in this comparison. Based on the above considerations the following equation could be written:

$$(a_s + b_s + \frac{i}{2})\ K_s = (a_t + b_t + \frac{i}{2})\ K_t + q_f \cdot o_f + q_1 \cdot c_1$$

1.2. NUMERICAL APPLICATION

Assumptions should be made to quantify parameters of the general equation regarding lifetime, annual cost of repair and maintenance, interest, comsumption of fuel and lubricants, cost of energy, etc.

1.2.1 Expected lifetime of engines

Solar engine:

Commercial companies speak in terms of a life of 20 years. This figure seems, however, to be very optimistic. With the present technological conditions, the global lifetime of 10 years seems to be more realistic, and $a = 1/10$.

The lifetime of Diesel engine could go as far as 20,000 working hours depending on the range of power, the design and particularly on the rpm, the piston speed, the system of cooling, the material used, the accuracy and the process of manufacture, the conditions of exploitation (working hours per day, level of maintenance, climatic conditions...) A figure of 6,000 working hours will be considered. This figure seems to be reasonable in isolated places where changing the engine before major repairs are required is very economical. The coefficient a will then be equal to $\frac{1}{4}$

A lifetime of 3,000 working hours will be considered for the small gasoline engine and $a = \frac{1}{2}$.

1.2.2 Annual cost of maintenance and repair as a fraction of the cost of the engine

Solar engine:

Commercial companies sometimes refer to free (or insignificant) maintenance and repair of solar engine installations. A machine to be operated by a solar engine will always need maintenance and repair, and the solar engine installation will always need such services (breakage of sheet glass of solar collectors, replacement of deteriorated insulation, repainting of containers of solar collectors, possible need of repainting of the black surface of the solar absorbers, replacement of leakage or working fluid, plumbing). The cost of a full or partial salary of a guard who will ensure the day-to-day maintenance will not be considered because it will also be required in the case of the diesel and gasoline engines. The coefficient b would be of the order of magnitude 2 - 3% in case of solar thermal engines and 1% in that of electric engines powered by photo-cells, based on the lifetime discussed above.

1.2.3 Rate of interest

A rate of interest of 8% shall be considered, although the present cost of interest will be higher on the financial market.

1.2.4 Annual cost of energy

Diesel engine:

The consumption of gas-oil is about 0.25 kg/Kwh and that of lubricant is about 0.007 kg/Kwh.

In order to combine the cost of gas-oil and lubricant it will be assumed that the cost of lubricant is 5 times more than that of gas-oil. The new terms will designated "equivalent consumption".

$0.25 + 0.007 \times 5 = 0.285$ kg of equivalent gas-oil/Kwh

And for 1500 hours of annual work:

$0.285 \times 1500 = 427.5$ kg/kw.year

As the conditions of exploitation of the engine will not always be optimal, a majoration of consumption of about 17% may be considered: so

$q_f = 0.5$ ton/kw.year

Gasoline engine:

A majoration of 20% above that of diesel engines could be concidered, so

$q_f = 0.6$ ton/kw.year

A 10 kw solar engine working 1500 hours will be compared with a set of 2 Diesel engines with 5 kw each and 15000 rpm. Each one of these Diesel engines will work 6000 hours in four years. A 2 kw solar engine will be compared with a set of 2 gasoline engines of 1 kw each which will work 3000 hours in two years.

Taking into consideration the above assumptions, the following equations could be written:

In the case of Diesel engines:

$$(0.10 + 0.03 + 0.04)\ K_s = (0.25 + 0.20 + 0.04)\ K_D + 0.5\ C_f$$

or

$$K_s \simeq 3\ (K_D + C_f)$$

and in the case of gasoline engines:

$$0.17\ K_s = (0.50 + 0.20 + 0.04)\ K_g + 0.6\ C_f$$

$$= 0.74\ K_g + 0.6\ C_f$$

or

$$K_s = 4.35\ K_g + 3.53\ C_f$$

Knowing the local cost for installed kw of Diesel and gasoline engines for the considered range of power, and the local cost per ton of gas-oil and gasoline, the value of K_3 per installed kw of solar engine could be calculated from one or the other of these two equations.

As taxes vary from country to country, and in order to provide a valid order of magnitude of the economically acceptable cost of kw of installed solar engines, it will be assumed that no taxes shall be charged on the equipment, and its installation and on the consumed fuel;

The cost of gas-oil is more difficult to estimate; it depends on a large number of factors, inter alia: price of crude oil, the distance between the refinery and the supplier of crude oil and the cost of internal transport and distribution;

2.5 Some Numerical Values

For the 10 kw range of Diesel engines with 1500 rpm, the cost in the present conditions of the international market could be assumed to be $150/kw of installed engine. In the same conditions, the cost of gasoline engines in the 1 kw range could be estimated at $50 - 70.

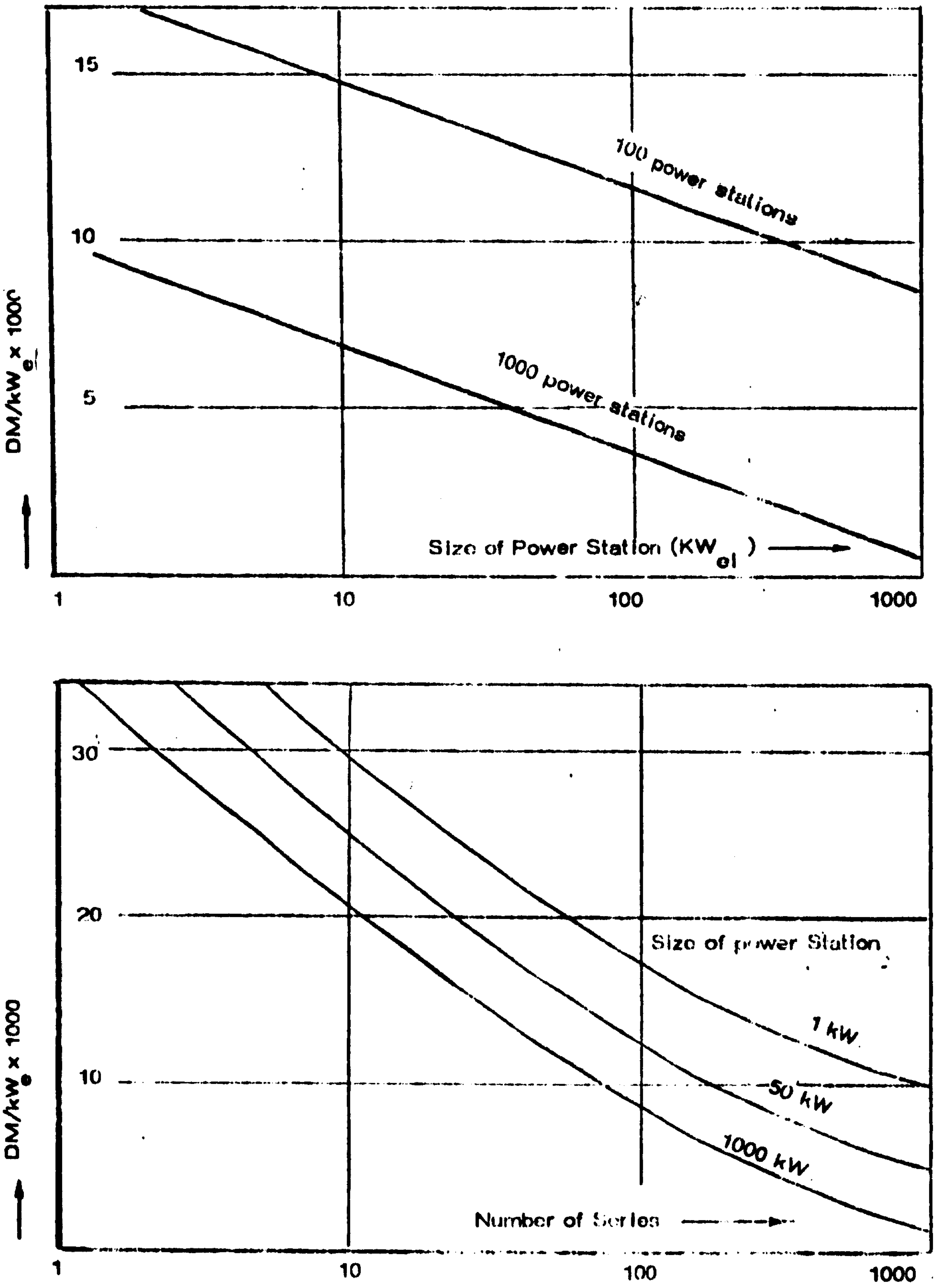
A leading company in the field of small Diesel engines has quoted a cost of $840 ex-works Europe for a 9 kw, 1500 rpm engine. Another well-known German company has indicated that the cost of a 28 kw, 1500 rpm is about $1,600 or $57/kw.

Based on a value of $150/kw of diesel engine and $150/ton of gas-oil, the cost per installed kw of solar engine without heat storage should not exceed $900 from the economical point of view.

In the case of the small range 2 kw solar engine, with $50/kw of gasoline engine and $150/tons of gasoline, the cost per installed kw of solar engine without heat storage should not exceed $834.

The present cost of solar engines varies very much:

- SOFRETES asks for at least $20,000/per installed kw;
- Sun Power Systems, Inc., asks for about $3,000/installed kw depending on the cost of the solar collector. According to a discussion with the author, the manufacturer asks $12,000 for his 10 kw engine, not including the solar collector. But the 10 kw could be obtained if the 55°C difference between the evaporating and the condensing temperatures could be obtained. This condition can not practically be realised with normal solar flat plate collectors and about 7 kw could be expected.
- M.A.N. gives in Fig. 1 the cost per installed electrical kw in function of the size of the engine and the produced number.



INSTALATION COST OF SOLAR POWER PLANTS AS FUNCTION OF SIZE OF POWER STATION AND SERIES PRODUCTION

Fig. 1

1.3. SOME CONCLUSIONS

On the basis of the above assumptions, the following conclusions could be made:

- It has been felt that calculations of the cost per unit of energy (KWH for example) will not be useful in the case of this report because the parameters vary too much from country to country and a general equation, as that outlined above, is more useful.
- A solar thermal engine within the range of 2 - 10 kw begins to be economically feasible when its cost does not exceed $1000/installed kw. The present cost on the market is 3 - 20 times more.
- In the case of solar engines operated by photocells $2000/installed kw seems to be economically feasible because the cost of repair and maintenance and that of depreciation are lower; also an electric generator has not been considered in the case of Diesel or gasoline engines;
- The economy of scale could not be fully applied in the case of solar thermal engines, due to the fact that the surface of solar collectors (the improvement of efficiency in case of larger engines could be in a first approximation neglected) is approximately proportional to the power of the engine. The solar collectors represent an important part of the total cost of the installations. However, the cost of other components, transport and installation would be largely reduced when the power increases;
- The investment is largely higher in case of solar engines, so the financing will be more difficult;
- The solar engine installation will occupy 20 - 50 m^2/ installed kw, the cost of occupied surface should be taken into consideration.
- In case of utilizing solar collectors as roofs for buildings, the cost per installed kw would decrease;
- In case of important solar storage the cost per installed kw will increase but that per KWH delivered will largely decrease. However, a feasible technology of solar storage is not yet available;

- It is difficult to obtain a constant speed on the shaft of a solar engine if a costly and maybe sophisticated system of control is not provided. A constant speed could be necessary for some applications;
- The machine which will be coupled to a Diesel or gasoline engine giving the same energy will have half of the power of that coupled to the solar engine, so its cost, transport and installation will be cheaper and easier;
- Local manufacture of solar equipment in developing countries could have a good impact on industrial development;
- It is difficult to measure the benefit of eliminating pollution by the use of solar equipment;
- As cost of fuel is increasing, solar engines are going to be in better competitive position.

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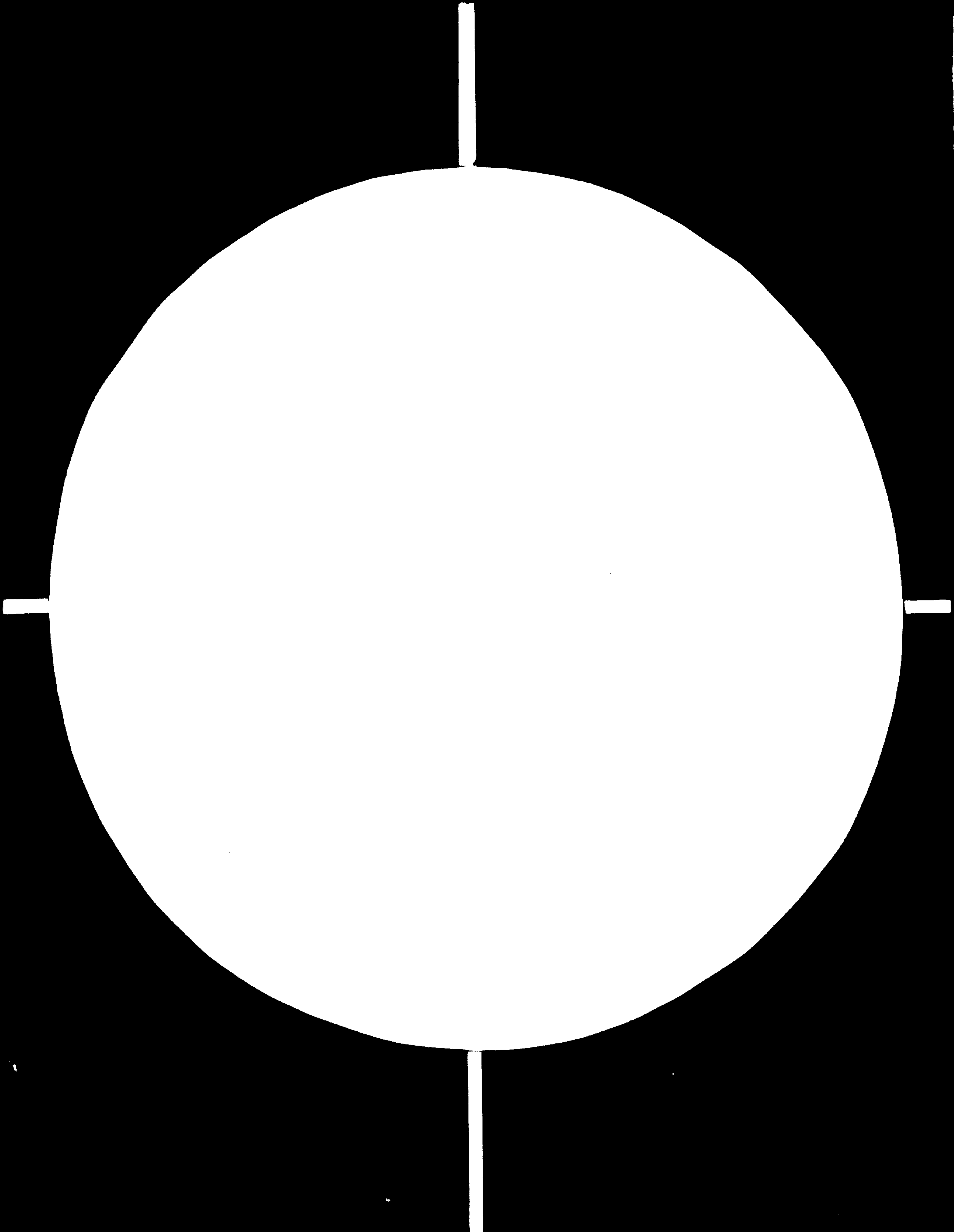

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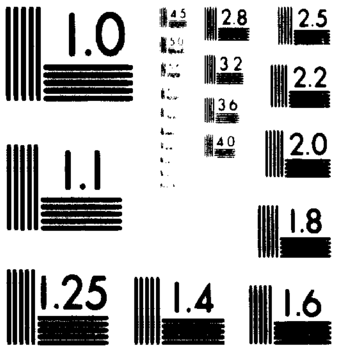

MICROCOPY RESOLUTION TEST CHART
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2. SOLAR REFRIGERATION AND SPACE AIR CONDITIONING

Based on the preceding chapter, Development and State of the Art, the following remarks could be made:

- Solar refrigeration and space air conditioning systems are still in the R and D stage;
- The system could not be independent of an external source of power which should supply till 30% of the energy necessary to a conventional system;
- The system is bulky;
- The control system in the solar absorption machine is not simpler than that used for a conventional system;
- The Li-Bi-water mixture is not recommended when using solar flat plate collectors;
- The cost of the solar system even in the event of mass production will be higher than the conventional one.

Mumma and Sepsy, as already mentioned in the case study on solar air conditioning performance in Central Ohio, had calculated that for the 9000 Kcal/h solar air conditioning unit with $480/ton of fuel, 20% annual escalation of cost of fuel, and 9% interest rate, 20 years are required to break the additional $3000 first cost of the unit and an appropriate fraction of the collector-storage control. This calculation is for the moment rather optimistic in favour of solar refrigeration unit.

Further R and D is necessary to simplify the system, to improve performances, to reduce the cost, and particularly to decrease the percentage of energy necessary from an external source of power.

3. SOLAR SPACE HEATING

As stated before, solar space heating can generally only be auxiliary to a conventional system and an external source other than solar energy should be utilised in the majority of cases. Many studies have been made on the economics of this mode of heating. The energy saving varies from 30 - 80% of the total consumed heat. It depends on, inter alia, the climatic conditions, the form, location, orientation, number of floors, the area of sheet glass in the external walls, materials, insulation and mode of utilisation of the premises.

A valid evaluation cannot be made unless the paramaters intervening in the problem are known. However, an optimistic perspective could be expected if adequate architectural solutions, well designed heating systems and cheap, reliable solar collectors are used.

4. SOLAR DISTILLATION

In a first approximation, the construction of solar distillation plants could be put into two categories:

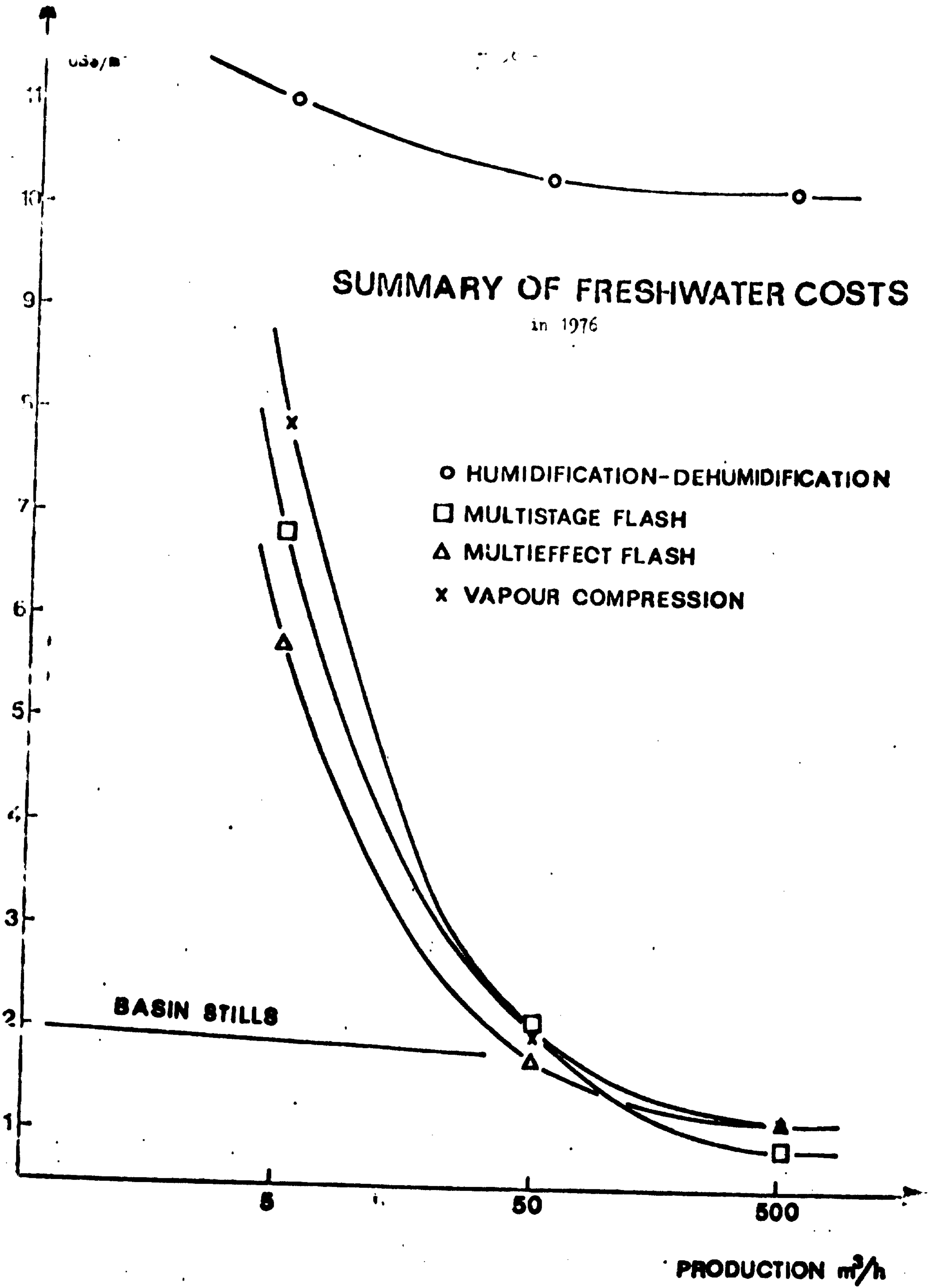
- Aluminium structure and sheet glass for the walls and cover, butyl rubber with or without insulation beneath it, and silicone rubber for sealing. This technology is reliable and its productivity is relatively high. The cost varies according to the local parameters. For example, in the case of the plant at Fiskardos in Greece, which has 2,447 m^2 net evaporating surface, 3510 m^2 total surface and 10-12 m^3/d of fresh water, the cost was about $35/net evaporating m^2. The approximative breakdown was the following:

Item	Approximative cost in $
Concrete constructions	15,000
Aluminium constructions	11,000
Butyl rubber	7,000
Glasses and labour	7,000
Sealastic	5,000
Pumps	2,000
Pipes-system etc.	8,000
Transportation fees	3,000
General Expenses (Insurances, Testrum etc.)	8,500
	62,000

The cost of excavation and levelling work is not included.

- Brick or hollow concrete blocks for the walls, concrete painted black for the basin, sheet glass with a small quantity of aluminium for the cover structure, and tarplastic for the sealing. The estimated cost of a 2,000 m^2 net evaporating surface was estimated at $14/$m^2$ of net evaporating surface, in India.

These two technologies seem to be reliable. The second one can easily be transferred to the least developed countries, where it can be reproduced without great difficulty.



SUMMARY OF FRESHWATER COSTS

in 1976

Fig. 1

Mustacchi from the University of Rome, in his paper to the UNESCO/WMO Symposium on Solar Energy, August - September, 1976, has calculated that for up to 50 m^3 of fresh water per day (which represent a solar distillation plant of 17 - 20,000 m^2 of net evaporating surface) the cost of production would be less than \$2/m^3 when using solar stills. He also stated that this latter type of installation is more economical than fossil-fired desalination up to 50 m^3/d. See fig. 1.

CHAPTER III - SOLAR ENERGY UTILIZATION IN DEVELOPING COUNTRIES.

1. EVALUATION OF SOME EXISTING EXPERIENCE IN DEVELOPING COUNTRIES

Greece

The major development in the field of solar energy is water distillation. The most important installations in the world are here - Nyseros, Fiskardos, etc.

The basic technology of Deliyannis' stills is an aluminium structure with sheet glass for the walls and roof. The black absorbing surface is constituted by thin sheets of butyl rubber; tightness is ensured by rubber silicon sealant. This technology seems to be reliable, but it requires materials which are not often available in most developing countries and its cost is relatively high. Such stills can only be reproduced if good technicians are available.

India

India has an ambitious programme in solar energy R and D, including:

Solar water desalination:

There is already one installation in Bhavnagar for 0.9 m^3/day and another of 5 m^3/day is under construction. The principal materials are bricks, cement, glass, a small quantity of aluminium and wood and electrician cotton insulating tape. The black absorbing surface is concrete painted with tankmastic. The total estimated cost for this installation is about $28,000 or about $14 per effective evaporating m^2. The expected average production of this installation is about 2½ litres/m^2.day. This technology seems to be reliable and easily transferable to other developing countries.

Solar water heaters:

The Bharat Heavy Electrical Ltd. is awaiting the results of experiments on a variety of solar collectors before launching mass production, and it is difficult at the moment to forecase the cost. However, it is envisaged to construct solar collectors under the supervision of this corporation, using aluminium roll bond technique and a factory for such products already exists.

Solar space heating:

A system of heating by hot air has been developed but the economic evaluation of such a system cannot be made without the results of the ambitious programme of research and development on solar collectors.

Solar pumps:

The Birla Institute of Technology and Science in Pilani has already constructed two prototypes of a solar pump without mobile-parts. Those two prototypes are now under experimentation. The first evaluation shows that the water cold pump is promising and that the cost of the installed prototype could be of the order of magnitude of $2,000 per kw. A large number of technological problems are still to be resolved and it is hoped that by the end of 1976 a concrete evaluation can be made regarding the technological problems and the reduction of the manufacturing costs.

Problems exist in the field of solar drying, solar air conditioning and solar refrigeration, but no concrete results are expected for some time to come.

In the field of conversion of solar energy into mechanical energy, some work has been initiated but no results can be expected in the near future. Some collaboration is envisaged with the Government of the FRG and a project is under negotiation.

In the field of wind energy, the National Aeronautical Laboratory is working on prototypes using a technology similar to that used in western countries. Concrete results can be expected by the end of 1976. This work is conducted in three directions:

- improvement of the existing multiblade windmill model for irrigation
- 1 - 5 kw nominal, wind velocity 5 m/second with 2 - 3 blades and flap control, for electricity generation
- windmills to power pumps for salt works

They are trying to combine the pumping of water with the generation of electricity. They hope to have small windmills for about $1,000 per installed kw for a wind velocity of 5 m/second.

Mexico

The most important solar energy programme in Mexico is solar pumping, which is based on the SOFRETES (French) technology. A low temperature solar turbine of 25 kw driving an electric generator which in its turn drives one or another pump, depending on the power output, has been installed at San Luis de la Paz, about 350 km from Mexico City. It is already in operation but the cost is still prohibitive. 11 pumps of 1 kw are already installed, 8 are under construction and 1 solar pump to be driven by rotative solar engine will be installed in the very near future.

Interesting work has been done on the construction of solar collectors using asbestos cement as a container, aluminium roll bond imported as water ducting and absorbing surface, 2 sheet glass, silicon rubber sealant and fibre glass as insulating materials. The present cost is about $50 per m^2. Also a solar collector using a fibre glass container is in the R and D stage.

The cost of the solar pumps installed in Mexico is still prohibitive and some $20 - 30,000 per installed kw represents the existing rate. Mexico is planning to produce in large number the small range of solar pumps export to other developing countries. However, with the present reciprocating freon engine and the high cost of the other components of the system (solar collectors, heat exchangers...) it will be very difficult to withstand the competition of Diesel and gasoline engines.

2. DISCUSSION OF PROBLEMS AND SOLUTIONS

Developing countries should be interested in increasing the utilization of solar energy. Applications which could be feasible under the present conditions are:

- Solar sea and brackish water distillation for small and medium production. An order of magnitude of 30 m^3/ day seems to be reasonable.
- Solar domestic water heating on an individual or collective basis. This type of equipment is already very popular in countries such as Australia, Japan, USA and Cyprus and its competitiveness has already been proved. The technology of this application is rather easy and should be adapted to local conditions.
- Solar Drying. This type of drying has always been utilised in the open air. Now, with simple apparatus, it should be possible to obtain clean, healthy, and better quality products. Equipment is simple and could be manufactured without great difficulty. It is advisable that local institutions prepare adequate designs for demonstration purposes. Farmers could use these models to manufacture their own dryers. The use of assisted power solar dryers could be envisaged in places where energy is cheap and maintenance and repair are easily available. But it will not often be a good solution to transform the mechanical or electrical energy into heat to drive the necessary fans. Combining wind energy with solar drying could constitute a good solution.
- Solar Engines. Many prototypes already exist on the market. Some of them have been tested over a period of years, some for months, and others are only now ready for testing. Under the present conditions it is very difficult to advise developing countries to use these solar engines for purposes other than experimental. Their cost is still prohibitive and the technology has not yet been thoroughly tested.
- For solar electricity which is generated by solar engines, the above paragraph is applicable. If it is generated by photocells, even though the technology of silicone cells is reliable and many institutions claim that CdS cells are also reliable,

the present cost of these cells is very high and it is not advisable to use them at present in developing countries for purposes other than experimental. The technology of photocells is still under development and it is hoped that in a not too long term, they will have the same success that transistors have had. In such a case, small developing countries could envisage the assembly of such units, and large ones could envisage partial or total manufacture.

- Solar refrigeration. Units independent of external sources of power are under development but even for small cooling capacity, very large surfaces and very heavy weights should be expected from such units. In the case of intermittent or continuous absorption machines, the solar energy equipment will constitute an additional part to the conventional ones. The existing technology seems to be feasible, but an exact feasibility study should be prepared to determine to what extent and percentage external sources of power could be acceptable. The manufacture of ice is a good solution in many cases because it is transportable and can be used for the preservation of food or other products.

* * *

Given that the solar engines constitute a very important application of solar energy utilisation, and that this subject has not yet been popularised, the following paragraph will focuse on this application. More concern with engines of the range 2 - 15 kw will be given in this discussion.

- The cost of the engine itself depends on the number produced annually and also on the design (rotative, reciprocating, with several alternatives of each type). Much development work and know-how must be provided before a well-designed engine can be developed. Improvement of effiency is important but should not be at the cost of simplicity, robustness or the possibility of local manufacture in developing countries. Sophisticated control should be avoided in using small engines because this requires the availability of highly qualified technical workers to ensure maintenance and repair.

It is not desirable to have a heavy engine. This could reduce the price of the material, possibly the manufacture, and facilitate transport and installation.

- Head exchangers. The technology used by SOFRETES has evolved greatly and the new trend is now to use plate heat exchangers. Nevertheless, using standard heat exchangers produced by local refrigeration and air conditioning firms may present a solution - for example, Mr. Minto, President of Sun Power Systems, has indicated that he is using for his 10 kw engine an evaporator and a condensor manufactured by Carrier, the cost being approximately $2,000. SOFRETES, till now, charges about $5,000 per heat exchangers necessary for a 1 kw engine. So, in the case of large production, the cost of heat exchangers could be a couple of $100 per kw. The manufacture of such components in the majority of developing countries should not present real difficulties. Common materials should be used if possible to reduce the cost and to simplify the technology. Stainless steel, for example, is expensive and difficult to weld. If Butone could be used, stainless steel will not be necessary.
- Solar collectors. Flat plate collectors using direct and diffused solar radiation are now well known in developed and many of the developing countries. The cost varies between $35 and $100 per m^2. For example, those constructed in Mexico according to the SOFRETES design using aluminium roll-bond, fibre glass and asbestos canelletas with two 3 mm sheet glass cost about $50 per m^2. The cost of solar collectors could be, in many cases, reduced by using metal tubes and sheets (in case a roll bond manufacturer does not exist in the country, available local materials for containers and insulation--rice husk, straw. these materials could be chemically treated against the action of insects.) Unfortunately the cost of sheet glass is often very high in developing countries, without real justification.
- Regarding the sealing of solar collectors, a cheap and long-life sealing is not yet available on the market, and till now, silicon rubber seems to be the best material, but it is very expensive.
- Working fluid in solar engines. Many fluids have been experi-

mented with - butane, freon 12, freon 11 and freon 114. Each gas has its advantages and disadvantages. Criteria could be the following:

- Not very high pressure, to simplify construction
- non-corrosive, to avoid use of special metals
- small specific volume of saturated vapour to reduce the encumberment of engine and piping
- no bad effects on the health of personnel
- no risk of explosion and no affinity with the components of the atmosphere
- non-inflammable and not explosive when mixed with air
- not very expensive
- availability on the local market

These conditions are not always possible to obtain.

- in the case of a low temperature solar engine, the discussion of evaporating the working fluid directly in the solar collector is not yet closed. Insufficient experiments have been done on the subject to allow a valid conclusion. However, circulating a two phase fluid in large areas and long piping may present some difficulties and problems of tightness could arise. When using the water heated in flat plate solar collectors to evaporate the working fluid, a circulating pump to improve the heat exchange could be used. The characteristics of this pump should be optimised to compromise the consumed power by the pump and the improvement of the efficiency of the system.
- in the present conditions of the state of the art, it is not possible to be in favour of one or the other of the 2 types of solar engines of low and high temperature. Existing experience is not yet sufficient enough to allow a valid opinion. However, in the present condition, the high range of power, the steam engines and turbines, seem to be more recommendable.
- closed cycle hot air engine could be envisaged for its simplicity but further R and D is necessary before reaching a simple, cheap, easy to use, and reliable design;
- the experiments on the solar pump being developed in Pilani, India are promising, but important research is still necessary before reaching a cheap and reliable system.

3. UNIDO'S ROLE AND ACTIVITIES

UNIDO wishes to assist developing countries in the field of solar and wind energies.

This assistance could be ensured by:

- providing a valid evaluation of the existing technology and offering the services of an efficient information system;
- organizing seminars and expert group meetings;
- training technical personnel through fellowships, study tours and specialized courses to be organized in collaboration with multi- and bi-lateral institutions;
- strengthening the cooperation between developing countries; and
- implementing national, subregional and regional projects which may have for objectives:

In the long term -

- to provide agriculture, industry and social institutions with locally manufactured solar and wind equipment with adequate production costs using to the maximum local materials as well as the appropriate technology for the production and utilization of this equipment (simple design, robust equipment, easy running, easy maintenance, and labour intensive production, if possible), and to study the feasibility of solar, wind and biogas equipment;

And in the short term -

- to determine the equipment which could be economically used in the near future;
- to test and adapt to local conditions, equipment available in other countries, but in any case, developing countries should not constitute a free laboratory for developed countries, results of R and D should be shared equitably;
- to initiate pilot projects for manufacturing solar, wind and biogas equipment.

Financing such UNIDO/local, subregional and regional projects should be discussed between the concerned parties and especially with the financing sources.

UNIDO has already developed some small solar and wind energies projects, two of them in the field of solar distillation and they are based on technology developed in India and Greece.

UNIDO in collaboration with the Austrian Solar and Space Agency is planning to organize in the very near future an expert group meeting to be held in VIENNA, in which discussions will be conducted on the following subjects:

- Solar water distillation
- Solar water heating
- Solar drying
- Solar cooking
- Solar Refrigeration
- Conversion of solar energy into mechanical energy and solar pumping
- Windmills

The discussions in this expert group meeting will focus on the techno-economic aspects and on the appropriate technology, and it is hoped that it will permit the definition of technologies which could be used economically in the short and medium term in Developing Countries.

4. CONCLUSIONS AND RECOMMENDATIONS

- Solar energy is inexhaustible, omnipresent and non-polluting. It constitutes an inestimable source of energy which should be exploited to the maximum by developing countries;
- Utilization of solar energy in sea and brackish water distillation, drying of food products, water heating, and in some cases, space heating, already seems to be economically feasible;
- Solar engines, solar electricity, solar refrigeration and space air conditioning have already passed the R and D stage and will appear on the commercial market in the near future. However, their cost is still prohibitive. A proliferation of commercial companies in this field is emerging. They promise equipment with very optimistic performances including a very long lifetime, which has not yet been proved. Developing countries should be aware of this situation when negotiating the transfer of solar technology. The preceding chapters of this report could be advantageously consulted to give a first valid idea. UNIDO could, to some extent give valuable technical assistance;
- R and D must be strengthened in developing countries. Available scientific, technical and human resources should be optimally utilised, but R and D activities are time-consuming and very expensive. Regional and sub regional projects are therefore recommended to save time and money. The idea of implementing such projects with national nuclei, each specialising in one or more application, seems to be feasible.
- International and/or regional Expert Group Meetings organised preferably by neutral and specialised institutions, such as UNIDO, should be held periodically with a view to evaluate the existing technology in the field of solar and wind energies in order to define the appropriate technology for the developing countries, and to elaborate a programme of technical assistance aiming to develop the utilization of solar and wind energy, to intensify R and D, to initiate the manufacture of equipment and to strengthen the transfer of technology between developing countries;

- When comparing the feasibility of solar equipment, the increasing cost of energy should be taken into consideration and as solar equipment will be mass produced in the future, at least for some applications, its position in such a comparison will be better and an optimistic perspective can be expected for the utilisation of solar energy, for example, the cost of silicone solar cells was about $20,000/kw peak in 1975. They could now be obtained for $13,000;
- Cooperation among developing countries is already feasible. Many fields of solar technology could be advantageously transferred, and, at the least, coordination of R and D work should be initiated.

ANNEXES

ANNEX 1

In November 1974 the International Energy Agency (IEA) was established. Its current members are the USA, Austria, Belgium, Canada, Denmark, FRG, UK, Ireland, Italy, Japan, Luxemburg, Netherlands, Spain, Sweden, Switzerland, Turkey, New Zealand. Norway and the Commission of the European Communities participate as observers.

The IEA organisations consist of several committees - one of these is the Committee on Energy Research and Development. The Solar Energy Expert Group has developed five cooperative projects in the areas of solar heating and air cooling of buildings and solar radiation measurement and analysis. In November 1975 the IEA Governing Board approved undertaking cooperative work in seven new technological areas including solar power systems, wind energy, ocean thermal energy and bio mass conversion. Following is a description of five of the projects undertaken.

PROJECT I: DEVELOPMENT OF SOLAR HEATING, COOLING AND HOT WATER SUPPLY SYSTEMS

The objective of project I is to establish and organize cooperation between the participating countries in two areas that primarily are related to the system as a whole.

The first area covers modelling and simulation of systems in order to calculate the thermal performance. The second area covers measuring and reporting of thermal performance as well as reporting of information on durability and cost of systems. These two areas together form the overall objective which is to provide a basis for the cost effective optimization of systems.

A successful completion of this project will have the following results:

- information on and an evaluation of existing computer programmes for calculating thermal performance of systems,
- a standard international procedure for measuring thermal performance of systems,
- information on thermal performance, durability and cost of existing and especially for new systems,
- a procedure for designing economically optimized systems.

The scope of this sub-project is defined by the following four tasks:

(1) Assessing the status of modelling and simulation of solar heating and cooling systems.

(2) Setting up a standard procedure for measuring thermal performance of systems.

(3) Setting up a format for reporting thermal performance, durability and cost of systems. Collecting information according to the format.

(4) Setting up a procedure for designing economical optimized systems.

PROJECT 2: DEVELOPMENT OF COMPONENTS FOR SOLAR HEATING, COOLING AND HOT WATER SUPPLY SYSTEM

To accelerate the development of the components of solar heating, cooling and hot water supply systems by exchange of information and plans by the review of on-going and new development programmes in the participating countries.

The viability of solar heating, cooling and hot water supply systems for commercial application depends upon the effectiveness of the key components. Major R and D efforts are, accordingly, being undertaken in participating countries for improvements in performance, durability and cost reduction for the key components. The sharing of knowledge and technologies through this exchange of information and plans would greatly accelerate the development of more effective components and would eventually alleviate the financial and technological burden for these R and D efforts in the participating countries.

The key components of the solar heating and cooling system that will be included in this project are:

- solar collectors,
- thermal energy storage,
- solar air conditioning, and
- other major components, as appropriate.

PROJECT 3: PERFORMANCE TESTING OF SOLAR COLLECTORS

Development and utilization of standard test procedures to rate the performance of a broad class of collectors for use in heating and/or cooling applications.

The collector is a key component in a solar energy system. A variety of different collector designs with a broad range of qualitative differences are known. Performance testing in order to rate the technical and economical and potential of the component collector is an urgent task. Therefore, it is important to use standardized methods to determine the efficiency or the energy output of a collector, and to predict its reliability and durability. It is expected that performance rating can be achieved by specifying a few characteristic qualities, such as optical, thermal, and mechanical properties. A performance test procedure must allow one to measure or to state these properties. The interim test procedure (NBSIR-74-365) proposed by the National Bureau of Standards of the United States is a first step in this direction. This test procedure is already used or considered to be used in many member countries as a basis for further development. The difficulties inherent to the NBS procedure are due to a restriction in environmental conditions which allow to carry out a test in climatic regions such as in Middle Europe only during a few weeks of the year. These problems may be solved by applying simulators, i.e. by applying artificial suns and reproduceable climatic conditions in climatic chambers. The applicability of simulation is a main goal of this project.

The successful completion of all the tasks will (1) yield reliable data for system design, (2) provide engineering advice in collector design, and (3) provide a basis for quality standards. This implies that the test procedures have to be scientifically correct, sufficiently accurate, and as simple as possible.

The overall goal of the research work is to reduce performance testing to the evaluation of a set of characteristic parameters which define the optical, thermal, and mechanical properties. To achieve this goal four tasks have been identified.

(1) Development of recommended test procedures to determine thermal performance outdoors.

(2) Development of recommended test procedures to determine thermal performance indoors.

(3) Development of recommended long-term outdoor and accelerated indoor test procedures to determine mechanical performance .

(4) Concise documentation of the results in a collector reference book.

PROJECT 4: DEVELOPMENT OF AN INSOLATION HANDBOOK AND INSTRUMENTATION PACKAGE

The objectives of this project are (1) to compile and distribute a Handbook on insolation and related weather measurements for solar energy applications, and (2) to design, build, test, evaluate and recommend a portable, low cost insolation and related weather data instrumentation package to be used for measurements at the site of a solar energy system, both prior to and during its operation. This instrumentation package will provide essential data in a suitable format for a large number of solar energy application studies and system designs. It will also be used to gather necessary data for system or sub-system performance evaluations.

A significant and well developed body of knowledge and experience in insolation and related weather measurements exists in national meteorological centers throughout the world. There is, however, a need to summarize this knowledge for valuable and necessary guidance and support to the many developing national solar energy programs is lacking. The handbook to be developed as part of this project is directed at filling this need.

Each country, anticipating the future significant utilization of solar energy should have the means to measure the solar radiation and related parameters in all of its different climatic regions, and in regions of forecasted population or industrial growth, or at potential solar energy utilization sites. In addition to these general and specific site evaluation needs, the design and evaluation of solar energy systems and components requires certain essential solar radiation and weather data. The insolation instrumentation, which is the subject of this sub-project, will be designed to provide this information, within the constraints of low cost and portability.

The successful completion of this sub-project will (1) provide a valuable data resource - the Insolation and Related Weather Measurements Handbook, drawn together by international experts and disseminated to IEA member countries, (2) significantly facilitate the understanding of the insolation/weather aspects of systems tests and demonstrations in the participating countries, and (3) provide for a more effective and useable exchange of information on the performance of those systems thereby allowing each participating country to fill in the gaps in its own national program with the experience and results of activities in other countries.

Five tasks have been identified to achieve the two general objectives of this project. They are:

(1) Preliminary evaluation of the Instrumentation Package Performance Specifications and Identification of available Handbook material.

(2) Establish Instrumentation Package Performance Specifications.

(3) Design, Building and Testing of Insolation Instrumentation Packages.

(4) Comparative Testing of Insolation Instrumentation Package.

(5) Development of Insolation Instrumentation Package Recommendations.

PROJECT 5: USE OF EXISTING METEOROLOGICAL INFORMATION FOR SOLAR ENERGY APPLICATION

The objectives of this projects are (1) to determine the quantitative relationship between measurements of solar radiation and other relevant meteorological parameters, and (2) to develop an internationally uniform system of presentation of solar radiation, date in order to facilitate the calculations for utilizing solar energy.

The project will concentrate on two major tasks; (1) to advise on methods of estimating the solar radiation incident upon a horizontal or an inclined surface by means of solar radiation measurements or other relevant meteorological data, and (2) to improve the quality of current and past records of solar radiation and to make them available in standardized form.

The following reports or recommendations will be prepared:

- Recommendation of an internationally uniform format for presentation of solar radiation data for users and designers of solar energy systems.
- Catalogue of sources of solar radiation data and relevant meteorological data for planning and design of buildings and equipments utilizing solar energy.
- Report on methods of estimating solar radiation incident upon a horizontal or an inclined surface by means of meteorological data with special regard to the requirements of the designers and the users of solar energy systems.
- Recommendations concerning the meteorological observing stations in order to improve their measurements of solar radiation according to the needs of the users and designers of solar energy systems.

ANNEX 2

Source: Small Solar Power Systems

Austrian Solar and Space Agency, ASSA FA-3, August 1976

Ideally, an information system in the solar energy field should provide for the following functions:

- Support of R + D, by ordered dissemination of information on past and current research results.
- Technology transfer, by providing repackaged research and development results in a form suitable for direct application.
- Planning data, for example on climatic parameters, but also including cost and economic data, standards, legislative and regulatory aspects, etc.

The survey has so far concentrated on the support -of- R+D role, as probably being the most important at this early stage, when several countries are still in the programme planning stage. Nevertheless, in the long term the other information system functions are at least of equal importance. At present, most of the countries for which data has been obtained are not yet in a position to implement information systems in technology transfer and planning data in solar energy, although there are plans for such activities and in one case (the USA) these plans are in the early implementation stages.

The concept of a total information programme is also being discussed, particularly in the USA: such a system is designed to perform multiple functions, ranging from the traditional R + D support role through technology transfer to information aimed at local authorities, public utility organizations and even the general public, to promote the use of solar energy as a means of conserving or replacing other energy resources.

Even in the area of R + D support, however, the results of the survey so far obtained show that in most countries the situation has not yet crystalised to the point at which the special needs of the scientists and engineers active in the field have been assessed and a database constructed to meet the needs. The information resource in general is scattered throughout a wide variety of journals and laboratory reports, and except in the USA and possibly in the Federal Republic of Germany, is not yet being organized for easy access.

Scope and Coverage - The Information Resource

Solar energy, from a scientific and technical information point of view, is a sub-field of Energy as a whole, and like energy information generally is "transdisciplinary", i.e. the information required by a project team engaged in an R + D project is to be found in many of the sub-disciplines of physics, engineering and other sciences. For project planning, access to meteorological and possible geological information will be required, and for planning and assessment work, resource data and economics will also be necessary.

It follows that while subdivisions of the field may be useful for the purpose of classifying documents, the total stock of infomation cannot and must not be divided into isolated blocks, one relating to power systems, another to heating and cooling applications, a third and fourth to solar thermal and photovoltaic conversion methods etc. A database relevant to solar electric power generation cannot be uniquely identified as a separate entity distinct from that for any other area of research, development or application. Indeed, in many analytical and assessment studies in solar energy using, for example, systems analysis or technology forecasting techniques, access to other areas of energy information might be required in addition.

The scope and coverage of scientific and technical information in solar energy is well illustrated by the following solar energy category definition in the current ERDA Energy Information Database subject category listing.

"Information on conversion of solar radiation to useful amounts of electric energy, the use of solar energy for heating and cooling, or any other use of solar energy that might contribute to the total energy budget. Information relating to all technical aspects of the design, research and development, manufacture, testing, and operation of solar cells and solar collecters are included. Also included is information on materials with indicated utility in solar cells or solar converters."

Size and Characteristics of the Database

Taking the above definition of scope and coverage, there are probably some ten thousand relevant articles, reports and monographs, mainly in the English language, which constitute the basic information resource. This probably does not include much material from Eastern Europe and the USSR, and may not include literature published in Japanese. Also, there may be an (unknown) quantity of material produced by individual firms not published or otherwise made available for dissemination: the estimate certainly includes a high proportion of results from work done by industry under government agency contract, in the case of material originating in the USA. It can be expected that the proportion of so-called "non-conventional" literature (i.e. laboratory and contractor reports, which do not appear as formal publications) will be high, as is usually the case in mission- or application-oriented R + D fields. For example, in atomic energy the ratio of non-conventional to conventional literature is 1:5. The growth-rate of scientific and technical literature relevant to solar energy is increasing: a reliable estimate is that additions will reach a figure of 200 per month in 1976.

R + D Information in Europe (Sources available)

The survey of scientific and technical information activities in the IEA European member states is far from complete, but a source of information frequently mentioned was that contained in the computer files of the RECON (Remote Console) interactive information system operated by the Space Documentation Service of the European Space Agency, which can be accessed through a data network, ESANET. Nodes of this network are located in Denmark, France, the German Federal Republic, Italy, the Netherlands, Spain, Sweden and the UK. Access is, however, possible from other countries using normal dialled telephone connections. Some twelve computerised information databases are available for interrogation, of which the following have been identified as having some solar energy content:

NASA	(aerospace and related technologies)
INSPEC	(applied physics)
METADEX	(metallurgy, etc.)
ENGINEERING INDEX	(general engineering)
Government Research	

Abstracts (NTIS - technology)

All the above, except INSPEC are USA products. The occasional useful reference could also be found in other files available over the network, e.g. World Aluminium Abstracts Nuclear Science Abstracts and Chemical Abstracts Condensates.

Because this information resource is available to users in most of the European IEA member states, it is of some importance to estimate the probable relative coverage of the subject in these files, as compared with the toal national solar energy database.

While it could be argued that the total database does not yet exist, the nearest approximation to it is the content of the solar Energy Bibliography produced by ERDA, which now contains approximately 10,000 itsm. The total relevant content of the ESANET databases probably amounts to something over half this number, but no exact estimate can be made without a detailed overlap check which is costly and time consuming. Nevertheless, the existence of the ESANET resource and its general availability within Western Europe is a valuable asset to R + D work in that area. It does not, however, contain information on current research. With regard to future growth it may be that coverage of the subject from these databases may tend to deteriorate somewhat owing to the fact that as the US solar energy programme grows, much of the resulting material will appear on the ERDA database (ERDA contractor report etc.) in preference to the other databases. While non-ERDA solar energy material, where appropriate, will appear in the Engineering Index database, and NTIS will presumably maintain its present coverage, the problem would best be solved if the new ERDA database were available for interrogation over ESANET.

Turning to non-computerised sources, contracts in the IEA member States were asked to indicate what journals and other publications they found useful. Replies so far received are insufficient to permit conclusions to be drawn. The general impression is, however, that useful information is dispersed over so many publications that classical literature searches yielding a satisfactory percentage of the material relevant to a problem is a major difficulty even for those users with access to major libraries.

So far only two attempts to create a specialised energy database with a significant solar energy content have come to light during the survey, both in the Federal Republic of Germany, one at JÜLICH and the other at KARLSRUHE. The latter centre is the German focus for input to INIS and is therefore the centre of German information services in the atomic energy field. It is understood that this activity is being extended to cover the whole energy field. The JÜLICH solar energy databank is in the planning stage.

R + D Information in the USA (Introduction)

The present position can best be understood in relation to the development of the ERDA Energy Information Database (EEDB). This is a computer database composed of all items reported in ERDA Research Abstracts, which covers all publications reporting ERDA-sponsored research, Energy Abstracts for Policy Analysis (also an ERDA publication), the ERDA input to INIS in nuclear science and engineering and non-ERDA non-nuclear material appearing in the publication Energy Abstracts. This latter is a sub-set of Engineering Index but specialises in all engineering disciplines related to energy. Thus, both ERDA and non-ERDA material in the field of solar energy is included in EEDB. Material of non-US origin is acquired by exchange agreements. It is understood that EEDB will replace Nuclear Science Abstracts in July 1976. Solar energy information originating before the creation of EEDB arose from many sources apart from the published literature (the NASA and NSF programmes for example) but it is believed that all this material is included in a Solar Energy Bibliography published by the ERDA Technical Information Center.

Organization

The implementation of the ERDA scientific and technical information programme is the responsibility of the Office of Public Affairs. The Technical Information Center at Oak Ridge, Tennessee is responsible for all ERDA technical publications and creation of the database. The ERDA database is available for interrogation within the USA over the ERDA (formerly AEC) RECON network, serving ERDA centres and main contractors. The central node of the network is also at Oak Ridge in the Oak Ridge National Laboratory.

Solar Energy Content of EEDB

The sub-categories of solar energy included in EEDB are as follows:

RESOURCES AND AVAILABILITY

HEAT STORAGE AND REJECTION

SITE GEOLOGY AND METEOROLOGY

ECONOMICS

ENVIRONMENTAL ASPECTS

SOLAR ENERGY CONVERSION
PHOTOVOLTAIC CONVERSION
THERMIONIC CONVERSION
THERMOELECTRIC CONVERSION
PHOTOSYNTHETIC CONVERSION
PHOTOVOLTAIC POWER PLANTS
SOLAR THERMAL POWER PLANTS
ORBITAL POWER PLANTS

TOWER FOCUS POWER PLANTS

LINEAR PARABOLIC POWER PLANTS

OCEAN THERMAL GRADIENT POWER PLANTS

SOLAR RADIATION UTILIZATION

SPACE HEATING AND AIR CONDITIONING

COOKING
FURNACES
DISTILLATION
DRYING AND CURING
DESALINATION
WATER HEATING
HEAT ENGINES
SOLAR COLLECTORS AND CONCENTRATORS

Other Databases

Computer databases containing relevant materials are NASA, NTIS, and COMPENDEX (Engineering Index). The solar energy category of EEDB will, it is understood, contain material from these files. Pre-1976 relevant information from these files have been included in TIC's solar energy bibliography.

A bibliography on solar thermal energy is published by the Technology Applications Center at the University of New Mexico. It contains about 4,000 items, and is being updated. The extent to which its contents are included in the TIC Bibliography, which has wider scope, is not precisely known, but this ought to be nearly 100%, since sources are much the same. There is no computer tape service.

ANNEX 3

LIST OF CENTRES INVOLVED IN THE DEVELOPMENT OF SOLAR ENERGY UTILIZATION, WITH WHICH CONTACT HAS BEEN ESTABLISHED

- Ecole Nationale Supérieure des Arts et Métiers
  151 Boulevard de l'Hôpital
  Paris 13e
  France
- Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt
  Pfaffenwaldring 38 - 40
  7000 Stuttgart
  FRG
- Institute of Applied Physics
  1 Stieltjesweg
  Delft
  Netherlands
- Centre National de la Recherche Scientifique
  15 quai Anatole France
  Paris
  France
- University of Technology
  Delft
  Netherlands
- Laboratoire de Physique des Solides
  1 Place Aristide Briand
  92190 Meudon-Bellevue
  France
- Laboratoires d'Electroniques et de Physique Appliquée
  3 av nue Descartes
  94 Limeil-Brévannes
  France
- Centre National de la Recherche Scientifique
  Laboratoire de l'Energie Solaire
  B.P. 5
  66120 Odeillo-Font-Romeu
  France
- Central Salt and Marine Chemicals Research Institute
  Gijubhai Badheka Marg
  Bhavnagar 364 002
  India
- Birla Institute of Technology and Science
  Pilani
  Rajasthan
  India
- Nuclear Atomic Energy Commission
  Athens
  Greece

- National Council for Energy
  Athens
  Greece

- Physics Laboratory
  University of Patras
  Greece

- College of Engineering and Applied Sciences
  Arizona State University
  Tempe, Arizona 85281
  USA

- Solar Energy and Energy Conversion Laboratory
  College of Engineering
  University of Florida
  Gainesville, Florida 32611
  USA

- Brace Research Institute
  MacDonald College of MacGill University
  Ste. Anne de Bellevue HOA 1CO
  Quebec
  Canada

- Austrian Solar and Space Agency
  Garnisongasse 9
  1090 Vienna
  Austria

- Committee on Solar Energy and Research
  Australian Academy of Science
  P.O. Box 216
  Civic Square ACT 2606
  Australia

- Laboratoire de l'Energie Solaire du Mali
  B.P. 134
  Bamako
  Mali

- L'Office de l'Energie Solaire
  B.P. 621
  Niamey
  Niger

- Solar Energy Application Laboratory
  Colorado State University
  Fort Collins
  Colorado 80523
  USA

- Stichting TOOL
  P.O. Box 525
  Eindhoven
  Netherlands

- University of Campinas
  Caixa Postal 1170
  Campinas, Sao Paolo
  Brazil

ANNEX 4

BIBLIOGRAPHY

- <u>Small Solar Power Systems</u>, ASSA, FA-3, August 1976

  Results of an enquiry on Research and Development performed in the member countries of the International Energy Agency, IEA. Prepared by the Austrian Solar and Space Agency, ASSA. The Austrian Solar and Space Agency was charged by the Federal Ministry of Science and Research to carry out an enquiry amongst all member countries of the International Energy Agency concerning national activities in the field of small solar power systems. This enquiry includes work being carried out in member states on Research and Development of solar power plants and their subsystems as well as information systems covering this area.

- <u>Flat Plate Solar Collectors and their Application to Dwellings (Low Temperature Conversion of Solar Energy)</u>

  Prepared by A. Eggers-Lura for the Commission of the European Communities. The documentation section of this report surveys the present state of the art, and thereafter a summary is given of solar R and D work undertaken so far in the individual EED countries, in other European countries, and in countries outside Europe that have made important contributions to solar energy research.

- <u>Survey of Solar Energy Products and Services</u>, May 1975

  Prepared by the Science Policy Research Division, Congressional Research Service, Library of US Congress. This survey was conducted to obtain descriptive information on solar energy hardware and related services.

- <u>Solar Energy - A UK Assessment</u>, May 1976

  Prepared by the UK Section of the International Solar Society. A report of the panel convened by UK-ISES to analyse all aspects of solar energy systems and to assess the potential for solar energy utilisation and research and development needs in the United Kingdom and for export.

- <u>Solar Desalination - Status and Potential</u> A.S.I.S. Rome, May 1976

  Prepared by C. Mustaochi et al. for the Commission of the

European Communities.
The aims of this study include: a summary of the state of the art in the field of solar desalination; a choice in priorities for future programmes of research and development; an indication of the potential benefits of technological advance and of the appropriate siting of the research efforts.

- A Survey of Solar Agricultural Dryers Technical Report T99, December 1975. Brace Research Institute, Macdonald College of McGill University, St. Anne de Bellevue, Quebec, Canada

  This report attempts to review some of the solar agricultural dryers actually built by experimenters and practitioners in the field.
- Les problèmes du desallement de l'eau de mer et des eaux saumâtres
  J.R. Vaillant
  Eyrolles Editeur, Paris, 1970
- Solar Energy for Heating and Cooling of Buildings
  Patton, Noyes Data Corporation, 1975
- Solar Heating and Cooling
  Kreider and Kreith
  McGraw Hill, 1975
- Solar Energy for Man
  B.J. Brinkworth
  The Compton Press, Compton Chamberlayne , Salisbury, 1972
- The 1972 Handbook of Fundamentals
  The 1972 Handbook of Systems
  The 1972 Handbook of Applications
  The 1972 Handbook of Equipment
  Published by the American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.
- Solar Cells
  Edited by Charles E. Backus, IEEE Press, 1976
- Solar Energy - A Course of Lectures
  Edited by H. Messel and S.T. Butler
  Oxford, Pergamon, 1975
- Various publications of the Solar Energy and Energy Conversion Laboratory, University of Florida
- Various publications of the Lawrence Berkeley Laboratory, University of California

- Various publications of the Brace Research Institute, MacGill University
- Catalogues and literature from manufacturers and research institutions
- Papers presented to Symposia organised by UNESCO and WMO, and the Organization of American States
- Photovoltaic power and its Applications in Space and on Earth International Congress - The Sun in the Service of Mankind UNESCO, July 1973.

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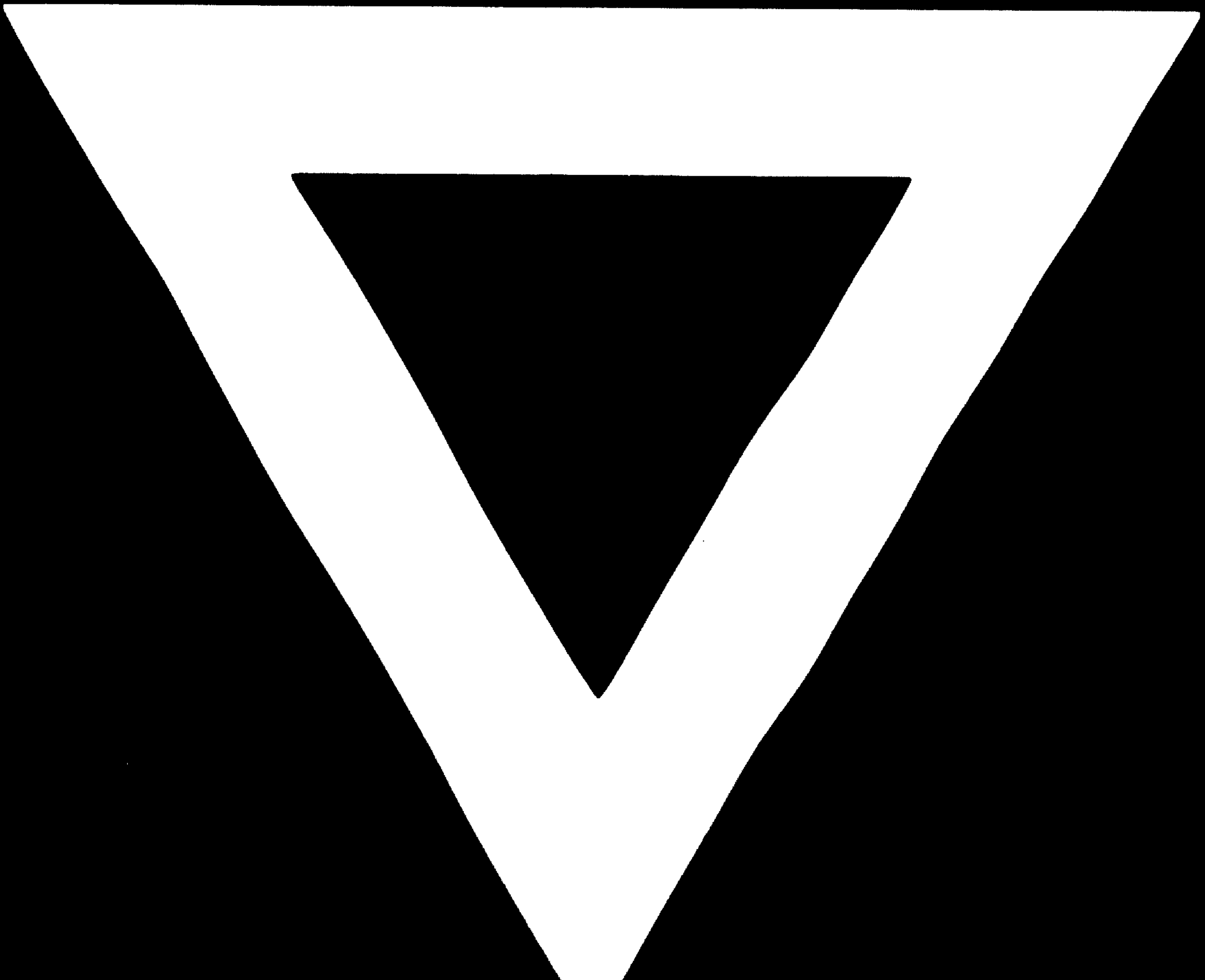

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