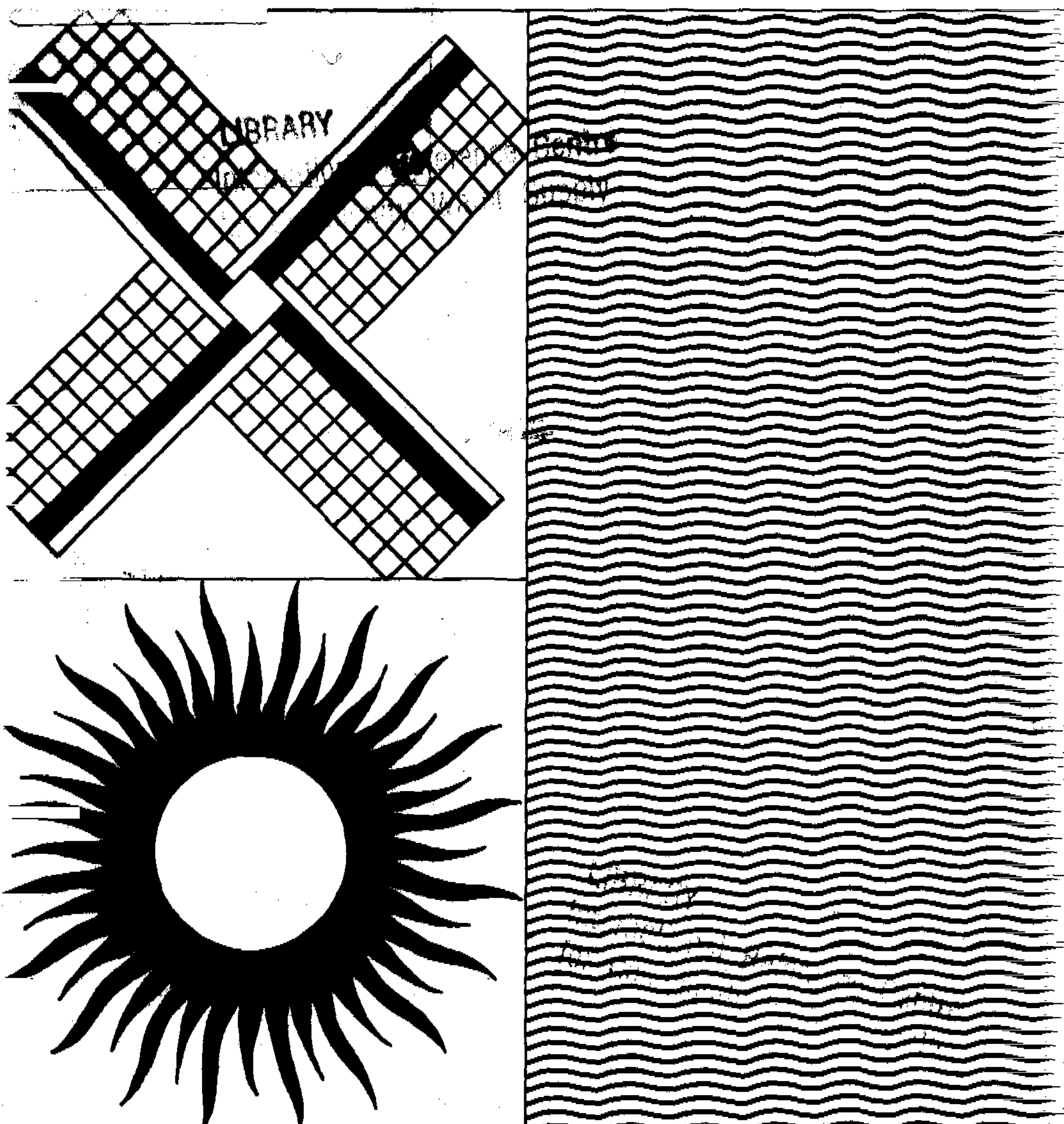
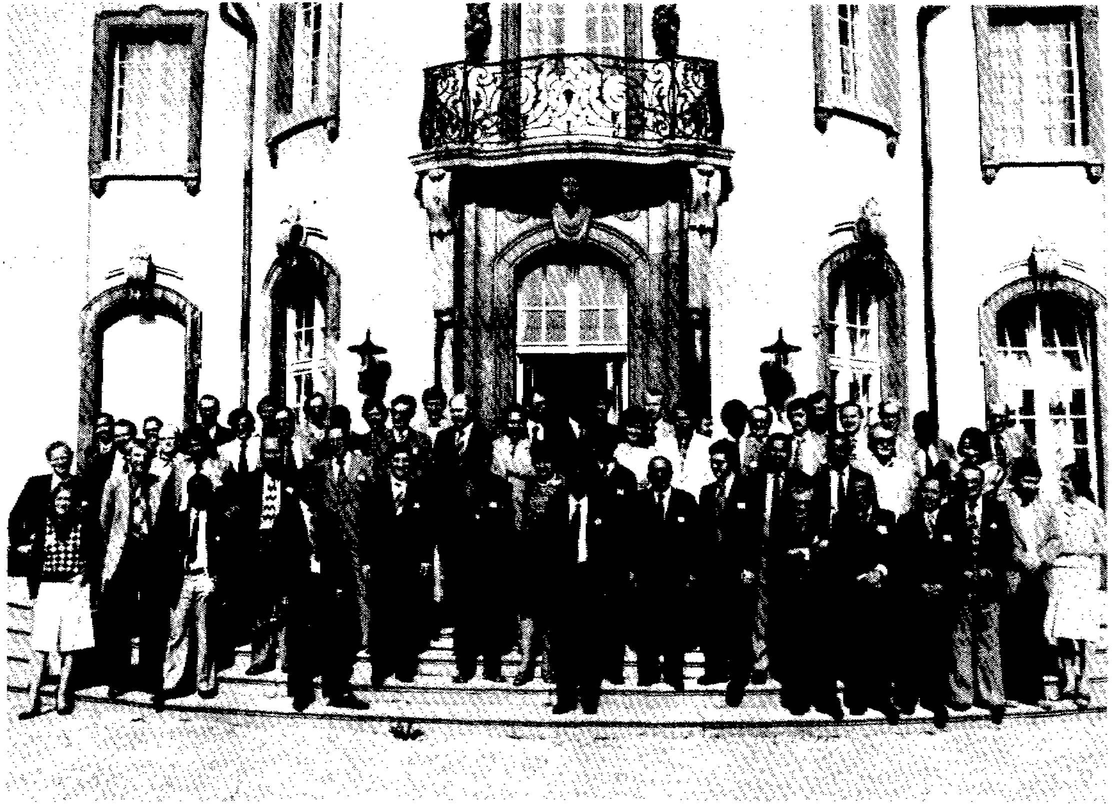
Appropriate Technologies for Semiarid Areas: Wind and Solar Energy for Water Supply



German Foundation

for International Development
Seminar Centre for Economic
and Social De



INTERNATIONAL CONFERENCE

APPROPRIATE TECHNOLOGIES FOR SEMIARID AREAS: WIND AND SOLAR ENERGY FOR WATER SUPPLY

15 to 20 September 1975
Berlin (West)

CONFERENCE REPORT

GERMAN FOUNDATION FOR INTERNATIONAL DEVELOPMENT

Seminar Centre for Economic and Social Development

FOREWORD

The drastic rise in oil prices in recent years has lent renewed impetus to worldwide efforts to develop alternative sources of energy. New, alternative and low-cost energy sources have become vital for the economic survival of many developing countries, in particular those which possess few raw materials and have no income to pay vastly increased energy bills. Drought disasters in the countries in the semiarid areas which have led to the mass death of humans and cattle have focussed attention on the connection between attempts to improve the water supply of these regions and the lack of appropriate technologies and energy needed to operate these technologies. The Seminar Centre for Economic and Social Development of the German Foundation for International Development has tackled the problem of appropriate technologies in a whole series of events and has already published discussion material on this subject reflecting the view of African countries.

The purpose of the Conference on Wind and Solar Energy for Water Supply in Semiarid Areas was to offer a further forum for discussing the present state and development potential of non-conventional technologies, adapted to the natural conditions and acute needs of the developing countries. The experts from both developing and industrial countries who were approached in connection with the Conference demonstrated a lively interest in the topic. Their contributions showed that there are already a number of well-tested and also newly developed methods for using wind and solar energy for water supply which, once they have reached the stage of mass production, will be able to contribute significantly to solving energy and water problems in the semiarid areas.

This Report is intended to make available the Conference material and discussion results to all interested persons in the research, economic, and political sectors and hence to provide impetus for the further development and practical application of these technologies.

The German Foundation for International Development wishes to express its gratitude to all the authors and Conference participants for having contributed to the success of the Conference and the preparation of this Report.

Brigitte Freyh
Director General

Dr Gerhard Fritz
Director General

CONTENTS

RESOLUTION

Under the auspices of the German Foundation for International Development there gathered at the beautiful and historic Villa Borsig in the suburbs of Berlin (West) fifty-five scientists, researchers and practitioners from all over the world representing twenty-seven developing and industrial nations and various international organizations with the objective of discussing the important and momentous issue of appropriate technologies for semiarid areas in the field of utilization of wind and solar energy for water supply.

The Conference, which took place from 15 to 20 September 1975, held four 1 1/2 hour sessions every day, during which the past, present and future endeavours and expectations of mankind regarding the utilization of these important natural energies were discussed. The Conference also dealt with forms and ways of international cooperation and exchange of know-how and then adopted the following general recommendations:

1. The Conference, recognizing the looming energy crisis and aware of the severe toll on the depletable sources of energy, appeals to all nations of the world to join hands in helping to save these resources, whenever possible, by the development and utilization of the alternative renewable energies of the sun and the wind.

2. The Conference, recognizing the significant amount of research and development that must be carried out in both developing and developed countries to come up with appropriate and economically viable technologies, calls upon United Nations agencies to reinforce and consolidate their efforts into this field, especially regarding information exchange and the support and coordination of activities, meetings, etc., and also calls upon member countries to augment this in letter and spirit both technically and financially. A coordinating committee or a central UN agency for wind and solar energy was one of the thoughts which the Conference

enthusiastically discussed and supported.

3. The Conference emphasizes the need for improving traditional technologies and also for moulding technology for practicable and economic utilization in developing countries. The Conference recommends that climatological conditions, potential skills of the users for operation and maintenance, economic and social benefits, and standards be matters of prior consideration by researchers, designers and manufacturers. Pilot projects are cited as solutions to avoid hidden risks. The need for consolidated efforts by international donors or suppliers and by recipient countries to help the vertical flow of technology to grass-root levels, i.e., to the users and their families, cannot be overemphasized. Training and maintenance units are most essential, especially for the remote isolated areas where the water supply problems may be most critical.

On behalf of the countries or organizations they represent, the Conference members would like to express their gratitude to the German Foundation for International Development for having organized this Conference.

I. CONDITIONS AND CONSTRAINTS FOR WIND AND SOLAR ENERGY IN WATER SUPPLY

SOME REMARKS ON THE USE OF WIND AND SOLAR ENERGY IN SEMIARID AREAS

Dr H. Tabor

1. Solar power units are unable, at the present time, to compete with electricity produced from central power stations even when the latter are fired by expensive liquid fuels.

2. In remote areas, not connected to a grid, cheap power station electricity is not available. This means that if local power is needed, it either comes from draft animals or from small diesel or gasoline engines.

3. In remote areas power from small diesels (or gasoline engines) is extremely expensive, not so much because of the cost of fuel, as because of the very high cost of maintenance and spare parts in these areas. The fuel component of the power cost may be of the order of 3-4 US cents per kWh, based upon present international posted prices of fuel oil, but the total local cost of power could easily be ten times this figure.

4. Because of the high actual total cost of local power from diesel engines, solar and wind machines now have a very good chance of competing provided that they are truly maintenance-free machines[1/], or that the maintenance is so simple that it can be carried out by the farmer himself. (Solar collectors should be stationary: tracking collectors are unlikely to be practical in the field conditions under consideration.)

5. Wind machines are generally simpler than solar machines. But as the power developed is proportional to the third

---

1/ The Ormat Company in Yavne, Israel, has developed hermetically sealed turbine-generators with extremely high reliability. They operate on low-temperature heat sources and could easily be adapted to simple solar collectors if a market were to develop.

power of the wind velocity, they are only practical in areas with fairly high and fairly constant wind levels. Wide fluctuation in wind speed is bad as little power is generated at low wind speeds and the machines may be damaged by excessive wind velocities.

6. The expected output from solar machines can be computed for any given area and the range of variation fairly well defined. For the pumping of water, there is no need to store the solar energy, but Fig I shows that, to pump the same amount of water as an engine working 24 hours a day, requires a rated capacity of the engine, pump and plumbing six times as great - and this is for clear days: on an annual average one might need to rate the installation at, say 10 HP, for a unit that does an average 1 HP throughout the year. This, of course, has a great effect on cost, and thermal storage of the collected solar energy on the input side may prove cheaper.

7. For the pumping of water, solar and wind units may have a further advantage over diesels because of size. In one African country, a number of 10 kW diesels were put at widely spread well heads. These pumped sufficient water to supply a large herd, which consumed all the grass for a large radius around the well. Indeed the radius became so large that the cattle became exhausted walking to and from the well head. A study showed that had there been ten 1 HP units instead of one 10 HP unit, the meat yield would have been greatly improved.

Diesels are less efficient, have shorter lives and require far more maintenance when small than when large. In the sizes we are considering, solar plants are not much affected by size.

8. All discussion on the application of small solar power units in developing countries is academic, unless the richer countries are prepared to donate them or to provide easy financing. All solar devices are capital-intensive and developing countries have too many calls on their limited capital.

9. 9. A discussion on small solar power units was held at the 1973 UNESCO Conference on "The Sun in the Service of Mankind". The attached report provides some insight as to the real nature of the problem.

ROUND TABLE ON SMALL POWER SUPPLIES[1/]

An unscheduled round table on small power supplies was held at the request of a number of delegates with about 70 participants. It was agreed that "small" referred to supplies of 100-200 watts and upwards to twenty or more kW.

The opening speaker reminded the audience that it was just 90 years ago that a solar-powered steam engine was demonstrated by Mouchot in this very city of Paris and that it was perhaps discouraging to see how little real progress there had been (at least in mechanical systems) in 90 years: a number of systems had been described and some actually built, with entrepreneurs usually losing money. Why, when there was such an obvious need in developing countries, had there been no serious introduction of solar power into these areas? One obvious answer was the capital-intensive nature of solar devices (which, even in mass production, would be greater in first cost than conventional power sources,) further aggravated by small-scale production in the early stages, making the capital cost higher still.

Technical analyses and calculations conducted in the US as long as thirty years ago had shown that solar engines operated by flat collectors were feasible and that the cost of power produced (without storage) was variously estimated to be between 2-10 US cents at a time when central plants were producing at a quarter of a cent.

In that connection it was pointed out that the absolute cost of power in a developing region was not to be compared with the costs in any developed countries but with the costs of any alternative power at the local site: some local

---

1/ UNESCO Congress on The Sun in the Service of Mankind, Paris, July 1973 power was often a matter of life or death to a community and examples were given of the catastrophic effects of drought in the Sahel region and of the lack of pumping facilities in South America. Diesel pumps could be used but, apart from the problem of fuel supplies, a breakdown could cause a catastrophe if the supply of spare parts took too long. Solar plants, unlike diesel plants, could be small and put exactly where they were needed and could, in theory at least, be much more reliable. It was, in fact, stressed that solar devices, if they were to be successfully introduced, would have to be of high reliability (a point that had been stressed in the Unesco advisory panel.).

Related to the question of reliability,—as well as to the question of local manufacture versus import from the developed countries—it was encouraging to hear that in many developing areas the problem of maintenance had eased: in the last decade technicians had been trained and this could and would facilitate the dialogue between developed and developing countries and the transfer of technology.

Concerning local manufacture versus import there was no clear answer and one had to be pragmatic and consider each case on its merits. Local manufacture, whilst highly desirable, was often limited by the absence of critical materials or components (resulting in constraints in technical design) and the total volume of production might be rather small. On the other hand, it was favoured by lower labour costs and an intrinsic shortage of foreign currency. Production in developed countries could be on a larger scale, was unconstrained technically but suffered from the severe difficulty of not knowing the local conditions of operation, or the real detailed needs in developing countries (ex: pumping depth, capacity, number of units required, etc.); without detailed data the best-intentioned firms or institutions could make no progress. Whilst a delegate expressed the view that much data was available in the developing areas, a major recommendation of an international panel of the US National Academy of Sciences on Solar Energy for developing regions had been the need to assess the real needs of energy and the local alternatives available, in the developing countries.

There were a few short remarks on technologies, simpler than those normally considered for solar power units, that might be considered for local development and manufacture.

To summarize, the problem was economic, social and organizational, not technical. Reliable solar power plants could be built today which in some cases could be competitive with other local sources of power, taking into account such problems as fuel and spare-part availability. This competitive status could only exist if solar units were produced in reasonable quantities which required more precise details of the market requirements and a solution to the difficult problem of financing the high first cost of solar devices.

APPROACHES TO WATER PUMPING IN ARID AND SEMIARID LANDS

Simon B. Watt, United Kingdom

Summary

This paper described the approaches to water lifting that we have embraced during our work of publishing manuals of information on low cost/low skill technologies.

It emphasizes the broad nature of the approach, considering the way that the water is to be used before looking at the possible ways of pumping. Technology is seen to be as much social in content and meaning as physical, - this argument is fundamental to a sympathetic understanding of "appropriate technologies."

The costs of water pumping are very briefly outlined, and the various power sources suitable for pumping are briefly discussed.

1. Introduction

It is now becoming widely recognized that the techniques and tools of production developed and used in the industrialized countries, are often inappropriate for other countries that have not accumulated a high capital base, do not have extensive educational facilities, reserves of skilled manpower, or access to cheap raw resources and large markets. These arguments are put forward by development economists, who are concerned that the development process is passing by the majority of the poor in many developing countries. They suggest that the only true measure of development is the success of planning policies in reducing poverty, unemployment, and inequality;[1/] the way towards these successful policies lies as much through the adoption of more appropriate techniques of production, as it does through distributive investment policies.[2/]

The basic approach of advocates of "appropriate technologies" is to examine carefully and compare different techniques in the light of various criteria. These criteria cover a deep and broad perspective on human life and experience, and are often a criticism of the direction of contemporary industrial societies.[3/]

That a choice of direction does exist is often ignored, as human progress becomes linked inescapably to high cost, high performance, and high skill techniques of production. Techniques that are more appropriate to the real needs of the majority of the people in the world are sometimes overlooked:

"Evidence suggests that in many instances in which labour-intensive and efficient technologies are available, more capital-intensive technologies are nevertheless chosen for production. The reasons given are extensive, and include subsidized capital prices, wages in excess of the marginal productivity of labour, the ease of importing packaged technologies which are generally capital-intensive in nature, lack of information about alternative technologies, the desire to minimize management problems associated with the employment of labour, and the pride which engineers and top management may associate with sophisticated methods of production."[4/]

The arguments for "appropriate technologies" are probably well known to most of the delegates at this seminar. In this paper we have attempted to describe an approach to water pumping in arid lands that takes into account the overall picture. The final choice of technique can only be a political decision and our main contribution as practical engineers must be to describe what is physically possible and how we are to do it.[5/]

During the last few years, many questions have been asked about the ability of "industrialized man" to sustain himself as fossil fuels become depleted. The questions perhaps have even greater significance for the majority of people living in the developing nations.

The 1954 UNESCO symposium on wind and solar energy for arid lands, held in New Delhi, recognized the folly of living off the accumulated capital of fossil fuels, instead of from the income or renewable sources of energy.[6/] The symposium recommended, amongst other things, that a small pilot project should be set up in an arid zone to investigate the possibility of satisfying the energy needs of a small community by integrating solar, wind, and vegetable matter sources. It is surely a great pity that this recommendation was not taken up.

Advocates of "appropriate technologies" will have sympathy with the views expressed at the symposium. The various speakers stressed the need for a wide variety of techniques to suit the different conditions in arid lands. The paper by E. W. Golding "The Economic Utilization of Wind Energy in Arid Areas", and his comments in later discussions, put an eloquent case for designing wind powered water pumps to suit the needs and abilities of the people who are to use them. He recommended that government departments should carry out wind surveys, and actively plan to support the introduction and local manufacture of low cost equipment.

Many countries are now beginning to carry out investigations of this sort,[7/] and most of these demonstrate that wind powered pumping can make a substantial contribution to the water needs of small, rural communities. Wind power would need to be backed up by auxiliary power from diesel, electric, animal or man. The critical factors which determine the viability of wind pumps are the wind regime, and the high initial cost of the equipment.

It is the purpose of this paper to give some perspective to wind powered water pumping in arid and semiarid lands, and to give an example of a low cost/low skill windwheel that has been very successfully used over the years around the Mediterranean. The countries in arid zones that are most likely to benefit from the approaches outlined in this paper are, of course, those not endowed with large reserves of fossil fuels.

2. Some Notes on Water Use in Arid and Semiarid Lands

This paper has been written to demonstrate the approach that we have adopted for water pumping on a low cost/low skill basis. It is therefore necessary to discuss briefly the way that water is used in arid areas, before we can consider the best way to pump water.

Arid lands are characterized by very low rainfalls, and hot dry climates. The rainfall pattern, the season, duration, intensity, and quantity, vary widely from area to area. Historically, many arid areas were the seat of several very advanced agricultural civilizations that flourished, then disappeared.

The state of balance of plants and soils in these harsh environments is fragile, and is easily upset by overgrazing and poor farming practices. Once the vegetation is overgrazed, it cannot recover quickly, inedible plant varieties take their place, or serious erosion may begin. Arid lands can,however, produce very high yields of crops, provided that water is available; farming practices are steadily being developed which make the best use of the low rainfalls.

Perhaps the most important and potentially the most dangerous use of water in arid lands is for stock watering. Many authorities consider that the drought conditions in the Sahel region have occurred not simply because of lack of rainfall, but also by overgrazing which has prevented the survival of essential vegetation.

We consider below the use of water for domestic, stock, and agricultural purposes.

2.1 Domestic water use

One of the most pressing needs of people living in arid lands is to improve the quality and quantity of their water supplies used for drinking, cooking, and washing. Contaminated and insufficient water is one of the major causes of illness for mankind, and any programme of development is incomplete unless it considers better water, improved sanitation, and hygiene education.

Traditional domestic water supplies are collected from surface and roof run-off and stored in cisternes, water tanks, haffirs, etc., or out of the ground from wells or quanats. All of these methods have been used since man began to live in arid areas, and history is rich with the innovations and skills displayed in his search for water.

Water supplies being such a vital need, are inevitably vested with deep cultural meanings and traditions. Many rural water supply installations set up by outside agencies have been abandoned even in dry areas, either because the users did not trust them, or because they did not have the skills and resources to keep them going. A more recent approach by water engineers and planners, is to adopt a policy of upgrading the existing water supplies at the lowest possible cost to obtain the best possible improvement.[8/] The preferences for the supply source of the users must be one of the most important considerations if the supply is to be paid for, built, and maintained by the users.

An interesting example of this approach is the work of Hans Guggenheim amongst the Dogon people in Mali.[9/] He persuaded local people to line traditional grain storage bins with ferro-cement to store rain water that collected off the roofs during the wet season. Roof water is not as open to contamination as surface water, and the tanks are well understood by the local people. The tanks use both traditional skills and modern techniques and appear to be highly successful and acceptable. On the other hand, they will only be able to store a fraction of the water that is needed throughout the year, and the alternative source of well water also needs improvement.

It is the obvious failure of techniques and equipment in rural areas that is forcing engineers and economists to look more carefully at the choices of technology available. Hand pumps for lifting up well and tank water, for instance, have a notorious record of unreliability, and many well construction programmes choose large diameter, hand dug wells, in preference to small diameter tubewells, because water can be lifted by a rope and bucket instead of a hand pump. Hand pumps cause many problems and much despair amongst engineers when the pumps are not repaired and the borehole is then abandoned. This failure demonstrates that a different approach is called for, and much work is going on now in many countries to develop pumps that can be made locally and maintained with local skills and tools.[10/] The pumps are being designed with ease of maintenance built into them rather than to high performance standards or low costs. An unrecognized problem that pump designers overlook is that the pump is used by as many as several hundred different people during the day, and usually, if the pump is installed by government agencies, no one is prepared to accept responsibility for its maintenance. Training local people, organizing maintenance, gaining their confidence, must be an integral part of a well improvement or construction programme.

Domestic water supplies usually only need to deliver relatively small quantities of water each day, and their improvement should therefore consider first of all easy access and protection.

2.2 Stock watering

The recent tragic droughts in the Sahelian areas have caused many people to think carefully about the causes. Many geographers and climatologists think that the main causal elements are overstocking, poor range management, and an incorrect approach to development, rather than to major climatic changes.[11/] They contend that stock breeding has been encouraged to provide increased meat exports for the areas, but that the traditional values of the local people are based primarily on subsistence security and social prestige, which means that they keep the largest possible number of animals. The ecological balance of most arid areas is very fragile, and overstocking causes a collapse of vegetation growth and serious wind and water erosion then develops.

Providing stock watering points must be seen in this context, although veterinary health programmes, a reduction in raiding, a desire by the local people for more cattle etc., are also important reasons for the growth in cattle herds. Water is a limiting factor for animals as well as men, and deep-well water pumping must be seen as part of an overall ecological pattern if the advance of the barren Sahara is to be halted.

However, if deep well water is considered necessary for stock use, then we have little choice but to use the commercially available pumping equipment that has the best performance record and needs the least skills to maintain. We should not overlook the magnificent contribution that multiblade windwheel pumps have made in Australia, South Africa, the U.S.A., and elsewhere where stock management has been practised. In these areas stock rearing has been combined with survival grass crops, or even cattle trucking, to maintain a better ecological balance between the number of animals and the foodstuffs available.

One interesting suggestion that has been put forward, is for the replacement of water wells by rainwater harvesting tanks.[12/] These tanks would provide a natural water supply for animals in a direct relation to the amount of plant growth; in dry periods of low rainfall, when plant growth is weak, animals will have no water, and the owners will be obliged either to keep fewer animals or move them to more fortunate areas.

2.3 Agriculture

Arid lands, which are characterized by a deficit of rainfall, and a high rate of evaporation from the long hours of sun, are surprisingly fertile if water can be applied. Agriculture in arid and semiarid regions is carried out over a wide range of soil moisture conditions, ranging from seasons with below average rainfall, under which it may be difficult to avoid complete crop failure, to seasons with a moisture supply that may be almost or as favourable as conditions usually obtained in more temperate regions. The appropriate approach to crop production must be to both improve the efficiency with which water is used, and to increase the water supply.[13/]

The efficiency of water use can be improved by preventing the wastage of water in existing irrigation systems, selecting and managing crops in different ways, reducing evaporation and seepage and by many other ways which will be well known to the delegates at this seminar.

Supplies can be increased through upgrading the yield of the source by deepening a well, enlarging a dam, the reuse of water, and by rainwater harvesting and run-off agriculture. The last two methods probably have the most interesting potential.

Rainwater harvesting collects the water that runs off specially prepared areas, and delivers it to much smaller areas that can use the water more intensively. This sort of agriculture is called run-off farming, and was developed to very high standards over 2000 years ago in the Negev desert.[14/] The land around a wadi or a water course that is periodically flooded to saturate the soils, is a naturally occurring example of this. The water that is collected can be used to grow high value crops, or grass crops that provide forage for animals during periods of drought. Another development of run-off agriculture is micro-catchment farming, which collects water even on flat lands and drains it towards a suitable tree planted in a drainage hollow.

In arid and semiarid areas, crop yields are not generally proportional to the amounts of precipitation. Yield levels are determined by the amount of precipitation above the basic minimum required to enable the crop to achieve maturity. If, for instance, a grain crop needs a minimum of 250 mm of rain, a reduction of only 25 mm will result in total crop failure, whereas an increase of 50 mm of rainfall may double yields.[15/] Irrigation research in arid and semiarid lands is increasingly turning towards a system of survival water application, which attempts to achieve the best results with the smallest application of water, rather than to attempt to achieve the maximum possible yields over a smaller area. Most crops have periods in their growth cycle when adequate soil moisture is vital to prevent crop failure and water use should be concentrated during these periods.

Water pumping for agriculture then, cannot be seen separately from the approach that agriculturalists are adopting in arid lands. The pumping system may vary in sophistication from animal powered pumps lifting water of survival irrigation, to completely imported motor powered systems in the countries which can afford them. Cheap windwheel pumps such as the Cretan Sail and the multiblade devices, can possibly make a major contribution where surface stored or ground water is readily available.

All water pumping is expensive, and the natural rainfall should only be supplemented where there will be significant gains in crop yield.

3. Approach to Water Pumping and Pumping Costs

3.1 Some definitions

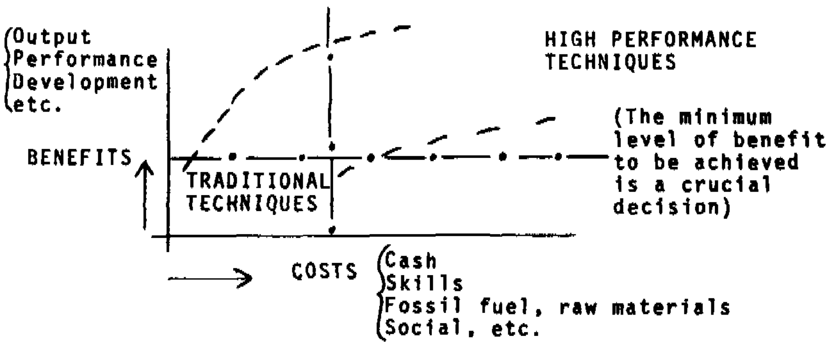
People usually associate the meaning of technology with the tools and equipment employed in production, and the way that they are used. However, if the question is asked about the exact relationship between technology and human societies, much confusion arises. A better way to understand the meaning of technology is to consider it as a language; skills or techniques then become equivalent to speech, and tools or hardware the equivalent of words.16/ This definition emphasizes that technology cannot be understood apart from its use in human societies, and the way that it is integrated into different cultures.

Economics is concerned with the best use of scarce natural resources to provide a livelihood for mankind. Many economists question the relevance of much of the high cost, high skill, high performance techniques and hardware to improve the quality of life for the majority of people in the world who are poor. Schumacher suggests that a strategy of development that allows the majority of these people to help themselves is more likely to be successful. He coined the term "intermediate technology" to stress the need for techniques and hardware that either improve what already exists, modifies high performance techniques, or innovates low cost, low skill equipment.17/

This is not, of course, a new idea. Gandhi put it in a memorable phrase - "production by the masses, not mass production." Mao Tsetung called this policy "walking on two legs," and some economists call it "integrated regional development." It means precisely that the vast mass of poor and hungry humanity must not be abandoned in favour of a few who can gain the control of what is known as "modern technology." On the other hand, the magnificent technical achievements of the last century must also not be abandoned, and a balanced programme of development has to be planned.

3.2 Approach to water pumping

Water pumping is only one area of interest in the broader language of technology. Within water pumping technology there exists a rich and a varied spectrum of techniques and innovations which have been and are still being used in many parts of the world. It is tempting to describe this spectrum from the perspective of costs and benefits - the spectrum is of course always changing as costs change, new inventions and breakthroughs are made etc.:



The costs include cash, skills, energy costs, and social costs, and it is obvious that these cannot all be related in cash terms. The benefits will include output, performance, social development, and these are also not directly comparable. However, describing the spectrum of technology in this way is useful because it shows in general terms what many practical people suspect, that modern technology has higher costs than traditional techniques, although with higher benefits. Also, that the spectrum observes generally the universal law of diminishing returns.

Traditional techniques become traditional when they are accepted and fully understood and are embraced within the culture of the society using them. The development strategy that attempts to achieve the greatest improvement at the lowest cost must make a careful balance between investing in and encouraging modern high performance techniques, and what we can call *intermediate techniques*, i.e. *those that* improve on the performance of traditional methods.

A study of the history of water pumping shows that pumping techniques developed in parallel with the power supplies. Centrifugal, axial, and turbine pumps are now in a high stage of development only because the power sources, internal combustion or electric motors, can produce power at comparable high speed. Animal and manpower cannot develop these high speeds without expensive gearing.

It is useful to understand the evolution of the spectrum of techniques in a way that shows the flexing, the tightening of control by improved skills and materials, over the more relaxed low performance range.

Engineers, with their zest for their art, concentrate on increasing the performance of the techniques, and are understandably inclined to abandon the inherently low performance part of the spectrum. High performance techniques need strict operational controls, better and more expensive materials, greater skills in their construction, more maintenance and expensive spares, in order to achieve the desired performance level. Without these, the techniques cannot work and quickly collapse. Low performance techniques on the other hand need fewer controls, can use local or cheaply imported materials, can be built with more general craft skills, and require less skilled maintenance. High performance techniques can be described as having a "tight fit", or "flexed" - low performance techniques can then be seen as having a "loose fit" or "relaxed".

An example of this can be seen with well construction programmes for rural water supplies. Small diameter boreholes can be constructed quickly to penetrate a long way into the aquifer, but they need hand pumps which will be costly if they are to stand up to the rough handling they will receive. Large diameter, open wells, are built by hand and penetrate less than three metres below groundwater level. However, hard and costly experience has shown that hand pumps are not maintained and when they break, the borehole has to be abandoned. Large diameter wells can be pumped by a rope and bucket and this technique of well construction is therefore usually chosen despite the increased risks of pollution.

3.3 Development of pumping techniques

One of the problems facing planners when they are engaged in development work is the difficulty of deciding whether to improve existing equipment and traditional techniques, import tried and tested equipment from other countries, or to modify commercial equipment to suit local conditions. An example from China of an improved windmill is shown in Fig. 1.

Whatever the decision, it is essential to understand that technology is not only about hardware,-the attitude of the users to the hardware is of equal importance. Some of the factors that must be considered are outlined below:

a) Traditional craft skills available

Craft skills are usually sadly neglected by most educators in favour of literate skills. Craft skills, which are the means by which most productive work is carried out, are the foundations of development, and it is often overlooked that most innovations in technology have been first and foremost rooted in these skills. Modern, industrial R & D programmes are usually more concerned with controlling and streamlining the work force than with improving the quality of the product. Mahatma Gandhi was well aware of the dangers of ignoring craft skills, and his "Khadi" movement to persuade political leaders to weave their own cloth was an attempt to improve the public status of the actual physical work of weaving.

All peoples have craft skills of some sort that they are familiar with, and a technique that they can manage with existing skills is far more likely to succeed than one which needs new skills. The word "craft" has originated from the original meaning of "craftiness," someone who uses his cunning to make materials do as he wants.

b) Access to a body of scientific knowledge

Many traditional techniques do not develop in efficiency either because the users find them adequate for their needs, or they do not understand the basic principles of operation of the technique. The history of technology is a veritable maze of false starts, sudden improvements, the transfer of knowledge, etc., and it is only now becoming generally understood how the cultural roots of a society determine how its technology is allowed to develop.

Access to a wider body of scientific knowledge can be instruction manuals, technical advice, or by seeing for oneself how an improvement can be made.

c) Confidence

One of the worst errors in believing that technology is mainly about physical techniques, is to ignore the user. A better approach is to see techniques as a physical way that people earn their livelihood. From this perspective the attitude of the user is as important as the equipment itself. Confidence allows people to explore and make decisions about tools and equipment that they could not make if they were unsure of themselves. Confidence is of course a vital state of mind throughout all areas of human experience, and is one of the reasons for the policy of encouraging self-reliance in China.

d) Capital

We have already discussed briefly what we could consider to be appropriate strategies for development, and it is obvious that for many areas of activity, some subsidy is needed even to commence development, either by extension work, demonstration, or cheap loans. The total neglect of investment in the rural sector usually occurs because the cash returns are small or even non-existent. But it should be understood that the mass of people often provide large and hidden subsidies to the capital-intensive sectors. A distributive policy of investment lies at the root of "appropriate technologies".

e) Extension

Showing people how to use and maintain the technique, providing them with materials, supervision and confidence, giving them cash subsidies, is the way of extending techniques amongst the population. Extension work is of the greatest importance in development, even though it has low prestige in many countries. One successful working demonstration is worth a thousand written pamphlets.

3.4. Designing maintenance into pumping equipment

One of the criteria for choosing the most appropriate pumping technique must be ease of maintenance. Indeed, some people believe this to be the most important criterium. Many developing countries are littered with the remains of equipment that has been abandoned because of breakdown due to lack of maintenance. It is not properly understood that the network of skills, spares, supply lines and advice, which have been built up over the years in the industrialized countries, are poorly developed in many other parts of the world. As practical engineers, we will all probably have stories of equipment that has been abandoned either because a vital spare part has not been available, or because the equipment has not been designed to operate in the different physical conditions.

A strategy for designing appropriate techniques will either build maintenance into the equipment, by ensuring adequate spares and training, or by using parts and materials and skills which are locally available. Bearings provide a good illustration of this, especially for arid lands. The designer can choose a sealed bearing that is expensive but will (it is hoped) run for a long time before it needs to be replaced or he can use cheaper unsealed bearings that need to be replaced at frequent intervals. Since many countries do not have established bearing industries and supply networks, the choice is often to use costly sealed bearings. If the designer chooses a technique that operates at lower speeds, then he has a wider choice of bearings; he can use oil soaked wood blocks, for instance. High speed lift wind wheels need high speed bearings with all the problems of sealing them against dust and grit; low speed drag machines on the other hand, run successfully on oil soaked wood block bearings that can be cheaply replaced.

Designing maintenance into the equipment is absolutely essential if it is to be used by people who have poor access to spares and skills, and we suggest that this should be one of the most important points of discussion for this seminar.

3.5. Costs of water pumping

We have already suggested in this paper that pumping techniques should not be considered before water use, and this is especially true with regard to agriculture in arid lands. It is not uncommon in many dry parts of the world to see water which has been laboriously pumped out of a well soaking back into the soil before it even reaches the crops. Cropping patterns, the system of land and water use, and even land tenure, are therefore even more important than the way the water is lifted. This holistic picture, the overall view, is the basis of what we call the "*appropriate technology*" approach.

Some economists believe that man and animal powered low lift water lifting devices have been made redundant by diesel or electric motor powered pumps, except in areas where there are spare animals and plenty of people to do the pumping.[18/] This opinion has and will change as fossil fuels become scarcer and more expensive. Indeed, we should not be surprised that fossil fuel based power is cheaper than man and animal power, as fossil fuels represent the savings of millions of years of sunlight. Men and animals, on the other hand, can only use solar energy collected over a few food cycles at the most.

Wind and solar energy will have to provide an increasing proportion of all our energy needs. The solar pumps that have been developed to date are prohibitively expensive and the commercial wind power pumps are also generally more costly to buy and install than small diesel sets. However, a range of locally made wind power pumps, of varying size and sophistication, will reduce these costs considerably. For small subsistence farmers, a home madé, cheap, and reasonably efficient wind powered pump will make a substantial contribution to removing the bottlenecks in the farming cycles; the main difficulty lies in persuading him to persevere with his machine.

If we are to consider water pumping and farm mechanization in a typical arid or semiarid land, we must be aware of several very obvious points:

a) The populations are usually sparse and dispersed, and the distribution of electricity, fuels, services etc., is very much more costly than for concentrated populations.

b) The network of spares, repair facilities, advice, workshops, etc., is usually not well established; it has been estimated, for instance, that a tractor in an isolated area will cost nearly four times as much over its working life than an equivalent machine in the country manufacture.

c) The majority of the people in arid and semiarid lands operate on a small scale, and they are not fully integrated into the rituals of a cash economy. Many live a nomadic or seminomadic life.

d) Investment capital spent totally within a developing country is likely to generate nearly twice as much economic activity as the same amount spent on imported goods.

An attempt to cost water pumping is therefore very difficult. Many of the people in rural areas, because of lack of capital, skills, and their remoteness, will probably never be able to use expensive commercial equipment, and a realistic comparison of different water pumping techniques is not easy.

Subsistence farmers generally hold a totally different view of development than that held by development economists. In addition, few economists have a thorough grasp of the technological possibilities available, and it is our responsibility as practical engineers to turn our minds sympathetically to the experienced needs of the people in rural areas, and the ways that these needs can be met at the lowest cost in skills, organization, work, or cash. This means that we must look carefully at the whole spectrum of water pumping techniques and power sources.

Several detailed studies of the costs and benefits of a wide range of pumping and irrigation techniques, for instance, overestimate many times the initial costs, through a lack of understanding of alternative techniques that could have been used.[19/] There is much truth in the saying - "where there is a will, there is a way," and many researchers into the history of technological development find that developments only take place when they are needed and looked for, - within the laws of nature, of course.

The general nature of the costs of water pumping have been given in FAO Paper No. 60, "Low Lift, Water Lifting Devices for Irrigation," by A. Molenaar. The benefits of water use have already been briefly discussed in this paper and there is overwhelming evidence that water in arid areas can be used much more effectively than it is at present.

The cost of water pumping can be divided into two parts, the overhead costs of initial investment, depreciation, and perhaps interest charges, and the running costs of operating the pumping equipment. High performance techniques usually have high initial costs, with low running costs. Low performance techniques, if they are made locally, have low initial costs, but the running costs are higher. The scale of their use is perhaps the most important criterium of choice, as expensive equipment cannot be written off against a project unless it is used intensively; low performance equipment is almost always used on a small scale.

Molenaar discusses the overall costs and scale of use, with amount of water lifted, and his general conclusions are still realistic, except that the costs of fossil fuels and high performance equipment have escalated far beyond the costs of traditional techniques. It is not our intention to enlarge on his publication in this paper. We would like to suggest, however, that the marginal cost of labour does not usually take into account the great benefits that can be achieved if certain bottlenecks are removed from farming activities, or if the farmer can construct and repair his own equipment.[20/]

The approach of removing bottlenecks in the farming systems and pumping techniques in order to achieve the most for the least effort, can be best understood from a thermodynamic perspective than an economic one based on cash.

Sources of power available for water pumping

The energy resources of the earth fall into two categories, solar and non-solar. Solar-derived resources include intercepted solar radiation, wind energy, products of photosynthesis, fossil fuel deposits, and the power of falling water. Non-solar resources are basically tidal and geothermal energy, and the energy of both fission and fusion nuclear fuels. Fossil fuels in the shape of oils provide perhaps the most convenient and power packed energy source known to man, but we are all aware that these are limited in supply. Wind and solar energy will provide in the future the best long-term hope for power for most of the world, but we should see this against the wide range of power sources that are both available and used in arid and semiarid lands.

Sources of energy and power are a very large subject, and it is only possible in this short paper to give a very brief description of those that are immediately suitable for water pumping in arid areas with their dispersed populations.

4.1. Man power

Man powered pumps are widely used to lift the small amounts of water needed for domestic supplies, stock watering, and micro-irrigation. For larger scale irrigation and water lifting, other power sources should be employed whenever possible to release the skills and time of men for more productive work.

In many parts of the world, however, farmers and their families are often the only source of power available. This is not as close to slave labour as might appear at first sight, as small amounts of water pumped over a few weeks can save a crop or double its yield. In Bangladesh, for instance, farmers are irrigating small areas of land from their hand pumps to achieve an extra crop. The exhibition of locally manufactured water pumps in Peking, 1958, had a majority of man powered devices, reflecting the hard economic conditions at that time. Man powered pumps are generally small and portable, and therefore have a capacity suited to small fields.

The most efficient use of man power is through his legs, not through his arms. Leg muscles are stronger than the muscles in the upper part of the body, and a healthy man can comfortably develop about 75 watts (0.1 h.p.) over long periods by pedalling and 0.4 h.p. for short periods of a few minutes.[21/] The many low lift pumping devices used throughout S.E. Asia over the centuries, generally used leg power.

Man powered pumping devices are small, usually cheap to make, and should not be overlooked in areas where a small amount of work will bring a good return.

4.2. Animal power

Animal power is widely used in most parts of the world. Draught animals if they are well looked after, and the equipment is suitable, can make a substantial contribution to irrigation farming. Very often, animals used for general farm work, - ploughing, ridging, seeding etc., are released for long periods, especially during the dry season. This spare capacity of the animals can be very usefully employed in water pumping.

Draught animals need great care and must be managed with affection and respect if they are to work well. The cost of veterinary care, feeding, harnessing, purchase cost, must be balanced against the work that they can manage and the side benefits of meat, hides, manure, etc.

The following table[22/] is often quoted to show the power output from various types of animals:

Animal	Weight (Kg)	Draft Force (Kg)	Average speed m/sec	Power (Kgm/sec)	(H.P.)
Horse	400-700	60-80	1.0	75	1.00
Bullock	500-900	60-80	0.6-0.8	56	0.75
Cow	400-600	50-60	0.7	35	0.45
Mule	350-500	50-60	0.9-1.0	52	0.70
Donkey	200-300	30-40	0.7	25	0.35

In areas where animals are not trained and used for general farm work, the cost of buying and training the animals must be related directly to the benefits resulting from water pumping.

The common animal powered pumping devices range from a draw rope pulling a water filled leather bucket up out of a well, to vertical axis geared turbine pumps. The first is very inefficient, as the animal is obliged to retrace its steps without doing any work; the second is very expensive, and requires skilled maintenance. To use animal power effectively the pump should demand a constant loading and power take off gearing is necessary. This gearing can vary from simple timber cogged wheels, to specially made steel crown and pinion gears.

These power take off gears are prohibitively expensive, sometimes being even more expensive than a small motor pump set. There must be an urgent need for the local manufacture of these gear sets, which could be made in a small workshop. The "Liberation" type gears and pump shown in Fig. 2 was distributed widely throughout China to encourage local manufacture.

4.3. Wind power

Wind power has been used throughout history for a wide variety of tasks - corn grinding, timber sawing, etc., in addition to water pumping. During the last 50 years, wind power has been neglected by power engineers, and the recent upsurge of interest obviously reflects doubts about the long term use of fossil fuels.

Pumping water is probably the most useful way to use wind power, as the machine can be allowed to run over the whole day, and work whenever there is enough wind. Wind powered pumps are used widely on the Great Plains of the USA, throughout Australia, and many parts of Africa, and they have been developed to great robustness and simplicity. Fig. 3.

A great variety of wind power devices are known. For use in arid and semiarid lands, they should be able to use the gentle wind régimes, withstand the high temperatures and dust, and be designed for simple local maintenance or totally sealed for periodic maintenance by skilled fitters. The multiblade wind wheel device, developed on the Western Plains of the USA in the 19th century, and manufactured commercially is very robust, but needs some skills for repairs; the sail wind wheel, still used in Crete, is locally made and locally repaired. They are both slow speed, high torque devices, and may be manufactured without difficulty on a regional or local basis.[23/]

Wind wheels developed historically, on a craft basis, and the optimum size for simple water lifting devices seems to have been arrived at on an intuitive basis. The power from a wind wheel depends on the square of the linear dimension, the weight and cost depends on the cube; to double the size of a wind wheel is to therefore quadruple its power, and to multiply its use of material and cost by a factor of eight. Most simple water pumping wind wheels have a diameter of less than 5 metres.

Wind wheels must be designed to start and work in very low wind speeds, and have a governing device built into them to prevent them from being destroyed in high winds. Wind wheels must be designed like a toy bicycle to work on the power of a child, yet be able to withstand or cut off from an equivalent power source such as that from a motor car engine, during strong gales.

Because wind power is so variable, it is necessary to have a back up power source from man, animals or diesel engines, for periods of calm. Matching and applying these back up power sources to simple wind powered pumps presents many difficulties and adds to the complexity of the equipment.[24/]

Wind pumps should also have storage tanks so that water pumped during periods of strong wind can be used during periods of calm, or whenever it is needed.[25/]

4.4. Solar power

Solar energy is perhaps the largest source of power available to man, and great efforts are at last being made to convert it into mechanical power suitable for water pumping, with varying degrees of success. Integrated daily solar energy on a horizontal surface on good days in low latitudes can be as much as 6 to 8 kilowatt hours per square metre, - but this value will be very much less on cloudy days. The great difficulty is to convert solar energy into a different form of power that can be stored and used.

At the present moment, existing solar water pumps are expensive and very complex although new discoveries and mass production will inevitably bring the price down. One of the potentially most promising devices is the Fluidyne engine, that has no moving parts, and works on a Stirling cycle.[26/]

4.5. Electric and fossil fuel power

Diesel and petrol powered pumps are well known and need no further comment here. Experience will have shown the most suitable types that can be successfully used in arid areas. Centrally generated electric power, with its very high transmission costs, will probably always be out of the question for most of the areas we are considering.

Slow speed, high torque wind wheel devices

The multiblade and the Cretan sail wind wheel devices have been widely used for many years to pump water. They are not as glamorous as the high speed devices, but their robustness has been well proven, and we should not overlook them because of their lower efficiencies.[27/]

Multiblade devices are fully described in the various trade literature available. They operate safely in relatively slow wind speeds, although they are as likely to fail as any other piece of equipment if they are not well designed or maintained. Fig. 4. If they were manufactured on a local basis, substantial reductions in cost are possible. The devices have either geared drive transmissions, or are direct acting through a crank wheel and connecting rod; the latter is the simplest and cheapest, using wooden bearings and an oil bath lubrication system.

References

1/ Seers, quoted in "Appropriate Technologies for Small Developing Countries", P. Johnson, University of Sussex, 1973.

2/ "The Nature of the Development Process: some Propositions for Discussion by ACAST". A.H. Bunting, University of Reading, U.K. 1973.

3/ See for instance - "Is Indian Science Truly Indian?" by A.K.N. Reddy, Science Today, January, 1974.

4/ "Employment in Developing Nations". E.O. Edwards, Report on A Ford Foundation Study, Columbia University Press, New York, 1974.

5/ Many organizations in many countries are now engaged in this kind of work. For information, contact ITDG Parnell House, 25 Wilton Road, London SW.1,U.K.

6/ 'Inaugural Address', S.K.D. Maiaviga, p. 19. Proc. of New Delhi, UNESCO symposium, Wind and Solar Energy, 1954.

7/ See - "The Use of Windmills in Tanzania", M.E. Parkes. Research Paper No. 33. University of Dar-Es-Salaam, Tanzania, September 1974.

8/ "Technology Assessment & Research Priorities for Water Supply & Sanitation in Developing Countries". I. Burton, IDRC, Box 8500, Ottawa, Canada. 1974.

9/ See report from Wunderman Foundation, 575 Madison-Ave., N.Y. 10022, U.S.A. 1974, quoted in New York Times, Feb. 3rd, 1974.

10/ For information and contributions, contact Dr Hans Van Damme, International Reference Centre for Community Water Supply, WBO, The Hague, Holland.

11/ "African Environment", Vol 1 No. 2, April, 1975. Special Issue on the Sahelian Drought. Enda, B.P. 3370, Dakar, Senegal.

12/ "The use of rainwater harvesting tanks in the Sahel", H.G. Ionides. Appropriate Technology Journal Vol. 1 No. 3, 1974, ITDG, London.

13/ "More Water for Arid Lands", 1974. This excellent short review is available free of charge from National Academy of Sciences, Washington DC, U.S.A.

14/ "The Negev, the challenge of a desert". M. Evenary, L L. Shanan, N. Todmar. 1971. Harvard Univ. Press Cambridge, Ma 02138, U.S.A.

15/ Quoted from "*Crop Production in Dry Regions*". I. Arnon. Plant Science Monograph. Leonard Hill Pubs. London 1972.

16/ "Alternative Technologies & the Politics of Technical Change". David Dickson, 1974, Fontana Press.

17/ "Small is Beautiful", E.F. Schumacher, 1974, and his many other writings on the subject.

18/ "The Economics of Irrigation", C. Clark. 1970 Pergamon Press.

19/ See "Wells & Welfare" Deepak Lal, OECD Study Series, 1972. Lal advocated the support of hand dug wells for small farmers to increase crop production, but based his data on wells up to 10 metres in diameter. Smaller wells 1 1/2 metres in diameter are as effective and are less than 1/6 the cost.

20/ "*An approach* to identification of the factors which limit crop production in African farming communities". *R.D. Mann, 1971. ITDG Publications.*

21/ "Pedal Drives for Borehole Pumps", S.S. Wilson. 1975. Dept of Engineering Science, Oxford University, U.K.

22/ "Field Engineering", F. Longland. Gov. Printer of Tanganyika, Dar-Es-Salaam 1952.

23/ ITDG are preparing a development programme for locally made wind powered pumps, to be carried out in collaboration with the Kenyan Government.

24/ "Some problems in the utilization of wind power in India", R.V. Ramiah, UNESCO Symposium on Wind & Solar Energy, 1954, p. 102.

25/ ITDG have a forthcoming publication on ferro-cement water tanks, to take volumes from 1/4 to 100 cubic metres of water.

26/ "Appropriate Technology Journal" Vol. 1 No. 4, Article by Peter Frankel quoting some sources of information. Also Paper No. 5, by C. West, AERE, Harwell. ISE conference, Paris. July 1974.

27/ "Wind power in Sudan", S.S. Wilson, Dept. of Engineering Science, University of Oxford, U.K. Report on visit to Sudan in January, 1975.

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP I: CONDITIONS AND CONSTRAINTS FOR WIND AND SOLAR ENERGY IN WATER SUPPLY

The development of wind and solar energy technologies is now absolutely essential if the coming crises of rapidly depleting fossil fuel reserves is to be averted or minimized. This is important for all areas of the world. We should not overlook the fundamental nature of wind and solar energy as decentralized sources of power that have particular relevance to dispersed populations in rural areas with their high distribution costs.

The Working Group agreed that the following factors should be considered when planning the introduction of wind and solar energy technologies in water supply:

I. Wind Energy

1. Climatological conditions

The wind regime must be suitable for water pumping and must be able to power the machine for at least part of the day. Minimum wind speeds of less than 3 m/s are not possible to harness in most machines.

Available wind data should be collected to determine isovents. Particular sites with strong, steady winds should be located for early use.

Before expensive machines are installed, the wind regime must be understood in order to reduce the risks of costly failure. However, for low-cost, locally made machines, extensive data collection over long periods is not essential. Local knowledge of wind conditions is often adequate. The special climatological conditions that affect the use of wind machines such as dust storms, extreme temperatures, etc., must be acknowledged in the design of the equipment.

The water supply that is to be pumped must be adequate in flow rate. The quality of the water must be known, since it may be corrosive or damaging to the pumping equipment.

2. General performance characteristics of alternatives

The general performance characteristics of the wide range of wind machines that have been constructed must be clearly understood, if the best alternative is to be chosen. The types of machines that start and operate most effectively in low wind regimes should be isolated and examined in detail. The flexibility of each type of machine for either manual or automatic control should be investigated to see what proportion of the total costs of each technique can be saved by designing for manual control.

3. Economic considerations

The alternative available pumping techniques should be examined and compared as to costs, etc. The costs of wind machines for both small- and large-scale use should be compared for viability; small-scale, low-cost machines have particular relevance for small farmers. The proportion of costs that can be saved by substituting local manufacture or by the assembly of pre-made parts should be investigated.

4. Potential skills of users

Existing wind machines of the users must be examined to determine the potential for improvement. Existing craft skills of the users should be examined to see if these can be improved with stronger materials, better tools and equipment, etc. The technical potential of the users should be assessed, and their history of adopting new techniques must be understood. Local construction should utilize local skills and available materials whenever possible.

5. Maintenance

The ability of the users of the machines to maintain the equipment should be assessed. Possibly a maintenance structure will have to be established. The levels of skills for the maintenance and servicing of different techniques must be understood. Maintenance is expensive for dispersed populations and is one of the most important considerations. The confidence of the equipment users in their ability to manage and maintain the equipment is vital.

6. Introducing wind and solar energy technologies

The capacity of the existing institutions to introduce the techniques should be assessed. It was agreed that strengthening the capacity of these institutions would be the best way to introduce the technologies, perhaps through extension services. Pilot projects should be set up to demonstrate the potential of wind-powered pumping.

7. Social considerations

The views of the users of the machines are of great importance, if the machines are to be accepted. Development should take place at grass-roots level, and the users should, if possible, be involved at all stages of introduction. This is of special importance for the people who live in rural areas and who have poor access to centralized repair facilities.

The potential of the technologies to behave as a distributive investment must be understood, especially their capacity to provide jobs.

The equipment must satisfy the genuine needs of the users. In particular, they must reduce the work of women.

II. Solar Energy

1. Climatological conditions

Arid and semi-arid lands have high total solar insulation, and lack of sunlight is not considered to be a major limitation, except for cloudy periods during the year. There is a lack of data on diffuse radiation which will affect the design of the equipment. The quality of the water to be distilled, pumped, or treated must be understood.

2. General performance characteristics of alternatives

The efficiency of the various types of equipment must be understood. The design of the equipment to track the sun can be made to be automatic or manual.

3. Economic considerations

The existing sources of water should be examined to see if they can be improved at cost lower than that of introducing solar distillation.

The comparison of solar pumping techniques with existing equipment should be related to long-term use. The costs of solar water heating must be compared with conventional existing techniques.

The proportion of costs that can be saved by the manual operation of each type of equipment should be investigated.

4. Potential skills of users

5. Maintenance

6. Introducing wind and solar energy technologies

7. Social considerations

The considerations for factors 4 through 7 are the same as for wind energy.

II. WIND ENERGY

EFFICIENCY AND ECONOMIC COMPARISON OF DIFFERENT WEC - (WIND ENERGY CONVERTER) ROTOR SYSTEMS

Heiner Dörner

In order to draw a comparison between different types of WEC rotor systems it is convenient to compile a list of all the demands of such systems for all installation sites. This list which does not constitute a valuation, contains the following demands:

- simplest handling of the plant without special training of the user
- long operational life (20 to 30 years) with few maintenance intervals
- resistance of the components against all climatological conditions such as heat, cold, dryness, atmospheric humidity, salt air, rain, snow, icing up, rime, lightning and quicksand
- output at low wind velocity
- simplest construction design with easily exchangeable components (module groups)
- divisibility of the plant with regard to size and weight for the purpose of transporting the module groups
- low capital and operating costs.

The above demands require exact knowledge of construction design, as shown in a simple example.

A motor car with a mileage performance of 200,000 km has had an operation period of approximately 4000 to 5000 hours. During this time the car was frequently in the workshop and the driver was permanently present to help with breakdowns. A WEC must be in full action approximately 7,000 hours in a single year and should run, more or less, unattended.

A WEC consists of the following main components or module groups:

rotor	(rotor blades, pitch control, wind direction control, controlling mechanism)
gear unit	(cogwheel, single-stage or multistage, chain drive, tooth belt drive)
generator	(direct current-, alternating current-, synchronous- or asynchronous electrical machines)
tower	(steel, reinforced concrete, self-supporting or guyed, divisible or single part)

For a comparative examination we assume that the energy from the wind will be transformed into electrical energy to drive a water pump and also offer electricity for other purposes. The comparison is to be made between four rotor systems:

free running turbine with horizontal axis	(HAC)
shrouded propeller (aerogenerator)	(SA)
SAVONIUS rotor	(SR)
vertical axis turbine	(VAC)

Before starting the comparison, further, fundamental remarks must be made. The design of an optimal WEC has to fulfil three important qualifications:

high velocity ratio (this is the ratio of blade tip velocity u to wind velocity v, called λ)

high aerodynamic efficiency (according to BETZ (1926) the free running turbine can only extract 60 per cent from the energy of the air flow)

minimal expense in material.

At a given wind velocity v the swept area A of the system will determine the wind volume per unit of time. Thereby the fraction of the whole energy containing the air flow, which is changed first into mechanical rotating energy and then into electricity, is fixed. High velocity ratio reduces decisively the expense for the energy transformation. Of first order for the design of WEC is a radical structural *emaciation. Only then can an optimal economic configuration* be obtained.

The Horizontal Axis Converter (HAC)

Prof. Hütter of the FWE (Forschungsinstitut Windenergie-technik) has much experience with this type of wind energy converter. In the early 1950's Prof. Hütter developed in the ALLGAIER-WERKE, Uhingen, Germany, a standard unit with a pitch-controlled three- and later just two-blade high tip speed ratio rotor. This high-speed converter, including in one block rotorhub, gear, generator and an automatic system to position the rotor perpendicular to the wind direction, has been adjusted to a tubular tower. High-speed converters are plants where the ratio of tip speed u to wind velocity v is higher than 3.5. The speed of the ALLGAIER WEC could be accurately kept at a constant rate, regardless of wind velocity, by means of a flyball governor. Provided that a sufficiently strong wind blew, the generator voltage of 220/380 volts was so accurately maintained that directly connected bulbs burned without flickering. This speed governor also reliably limited the wind pressure on the rotating wheel to the maximum value of 250 kg. (Figures 1, 2 and 3)

Thus the plant was safely protected against storms and could be left unattended even in heavy storms. The velocity of the blade tips was higher than during heavy storms.

The tower built with a safety of ten and securely anchored to the foundation was subjected to minor stress only.

The starting of the ALLGAIER WEC was extremely easy due to the carefully shaped metal blades with their automatic adjustment to highest starting torque when the plant was at a standstill. The plant operated in very low winds up to 2.5 m/s.

The automatic shifting of the wheel was achieved by means of a small side governor wheel which, through its high gear ratio with single-step back gearing and self-locking, amply-dimensioned worm, could turn the entire head smoothly and gradually into the wind. In this manner the use of vanes mounted on long arms, causing the wheel to swing and vibrate when subjected to gusty winds, was eliminated. Therefore a

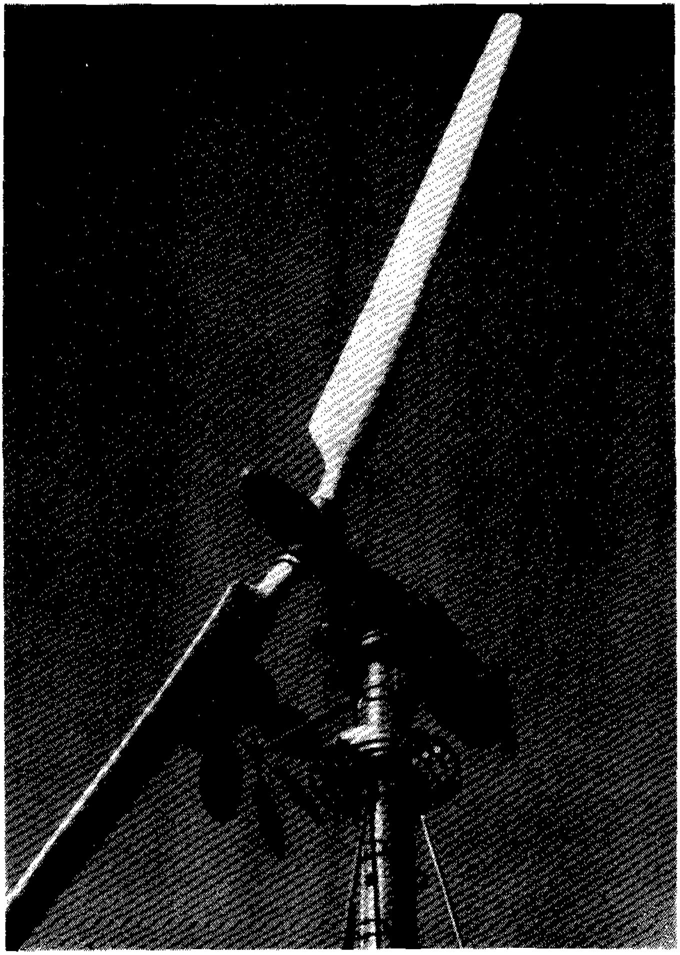


Figure 1 ALLGAIER wind energy converter WE 10, System Dr. Hütter. Composite blades

Figure 2 ALLGAIER 3-blade wind energy converter

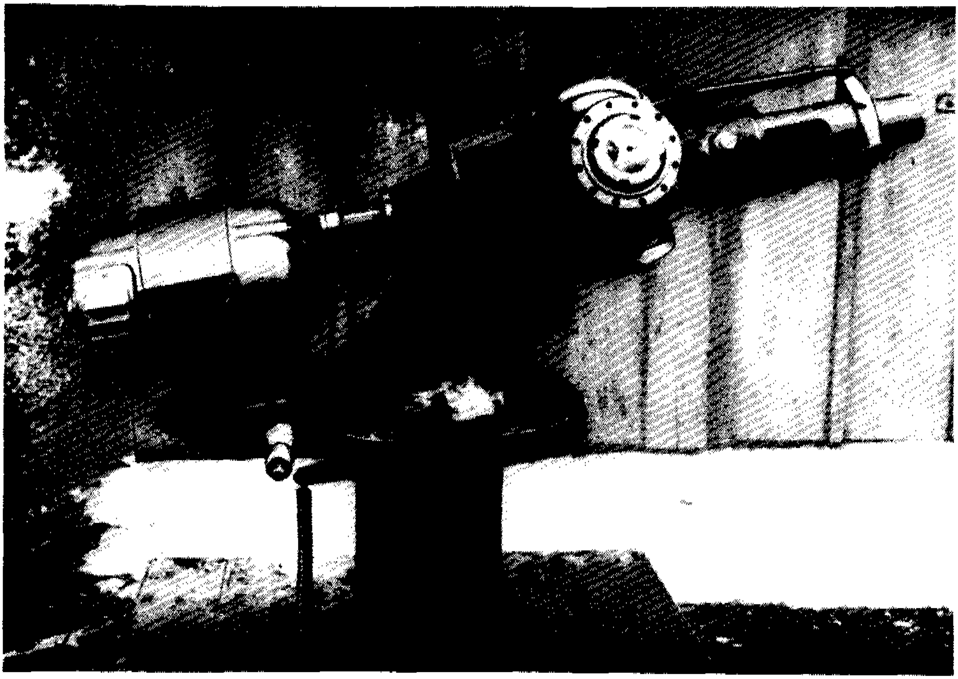


Figure 3 ALLGAIER wind energy converter
WE 10/6KW power unit

much longer service life of the plant was assured.

The ALLGAIER WEC generated a three-phase current of 220/380 volts and was equipped with a 3, 6 or 8 kW synchronous generator. Full output of the generator was obtained in a moderate breeze at wind velocity 6 to 7.5 m/s. The ALLGAIER WEC could be termed a low-wind converter. This is very important for all installation sites.

For water supply the water was stored in elevated tanks or in underground reservoirs. Depending on wind conditions and total conveying height, and provided that the total amount of energy produced was used for this purpose, the following water quantities were available:

Total Conveying Height	Water Depth under Ground Level	Quantity Supplied cub. metres per day	cub. metres per hour
5	1	800 - 1000	33 - 63
10	5	400 - 700	16 - 29
20	15	200 - 350	8.5 - 14.5
40	32	100 - 150	4 - 7.5
60	50	60 - 120	2.5 - 5

Figure 4: Water quantities available with an ALLGAIER WEC

The total energy of the ALLGAIER WEC amounted to 12,000 to 20,000 kWh per year. A service life of at least 20 years was guaranteed; with the exception of two oil changes a year the plant required no further maintenance.

Some technical data on this WEC:

Diameter of wheel	10 metres
Surface area of wheel	78 sq. metres
Area of each blade	1.3 sq. metres
Standard height of tower . . . . (higher towers on request)	8.4 metres
Height of platform above ground . . .	7.2 metres
Standard speed of wheel	100 rpm
Speed of generator	1500 rpm
Power of generator	7.5 kva = 6 kw

Figure 5: Technical data on the ALLGAIER WEC

Units of this type have been produced in small quantities and delivered mainly for the energy supply of farms in 12 countries of four continents in the world. (Figures 6, 7 and 8) (1)

For the comparison of the different rotor systems we chose a WEC of this conventional type. All the experiences made in two decades are taken into account. The comparative converter has a horizontal axis and a pitch-controlled two-blade high-speed rotor. It uses a generator with 1500 rpm, which means that a gear unit with a gear ratio of 1:15 must be connected to the rotor shaft, because the rotor shaft has, regardless of all wind velocities, a constant rate of revolutions equal to 100.

The technical data on this two-blade rotor are:

rotor diameter D_{HAC}		11.28	m
swept area A_{HAC}	$0.785\ D^2_{HAC}$	100.0	m^2
area of each blade F'_{HAC}		1.6	m^2
area of blade material F_{HAC}	$0.025\ D^2_{HAC}$	3,2	m^2
depth of profile $\bar{t}_{HAC}$		0.25	m
ratio $D_{HAC}/\bar{t}_{HAC}$		45	
output at 5.6 m/s wind velocity		3.3	KW
output at 7.7 m/s wind velocity (and more)		6.0	KW
power coefficient $c_{PmaxHAC}$		0.48	
at tip speed ratio λ_{maxHAC}		14	
area number $P_{HAC} = A_{HAC} \cdot c_{PmaxHAC}$		48	m^2
comparison number $V_{HAC} = \lambda_{maxHAC} \cdot c_{PmaxHAC}$		6.72	
rotor rpm, constant		100	
rotor tip velocity		60.0	m/s

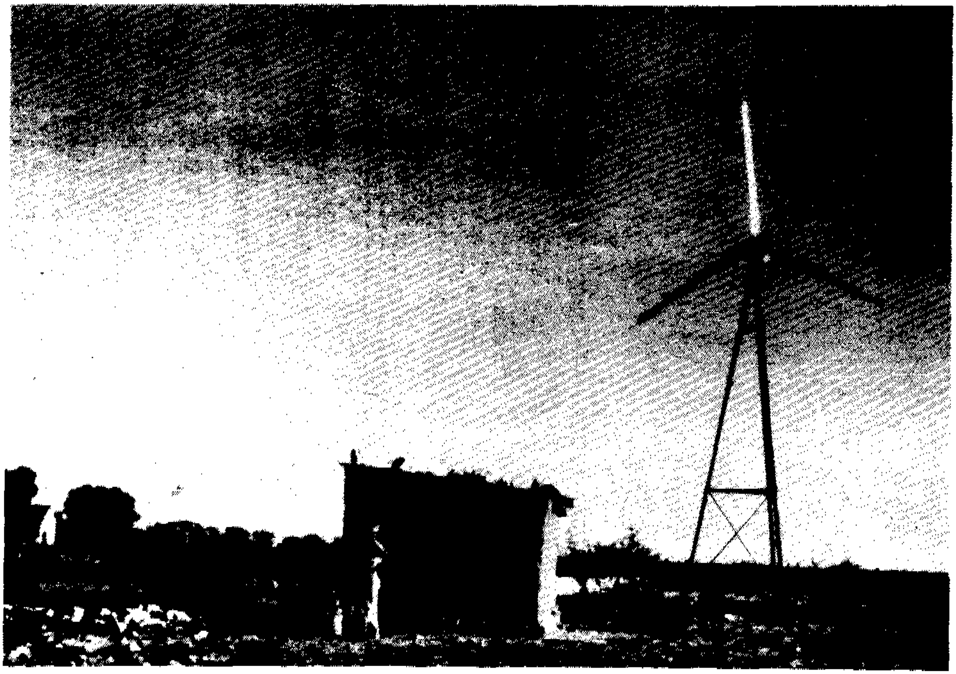


Figure 6 ALLGAIER/HOTTER 6 KW standard unit on Becker's farm, Gungams, Southwest Africa, 1951

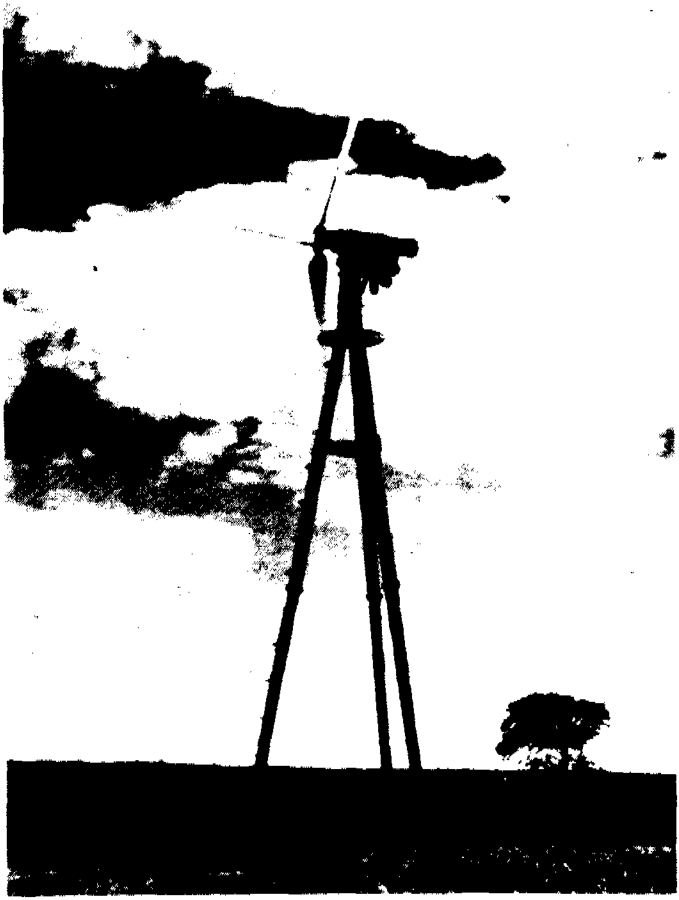


Figure 7 ALLGAIER/HOTTER wind energy converter, Africa

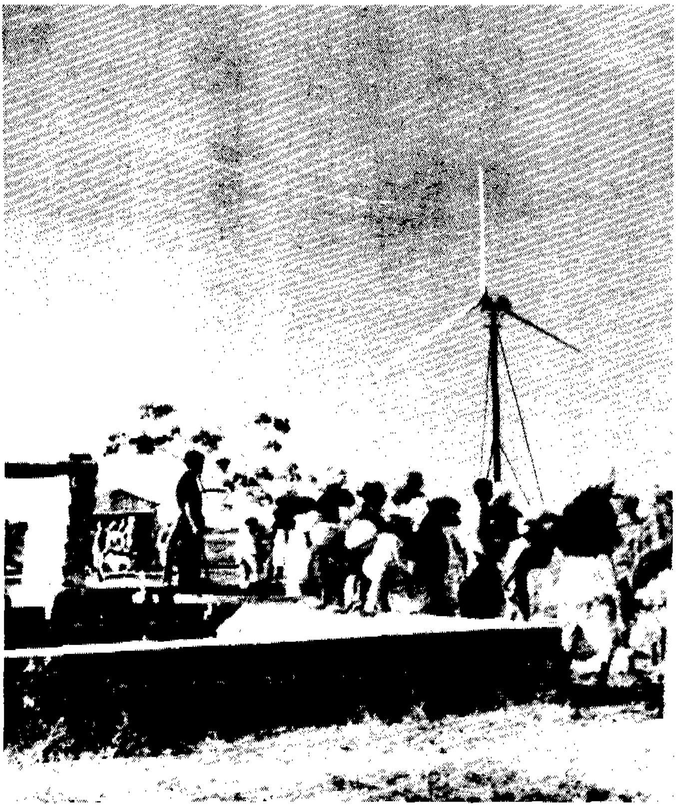


Figure 8 ALLGAIER/HOTTER WE 10 Installation for waterpumping, India 1960

The power coefficient-characteristic is shown in Figure 9.

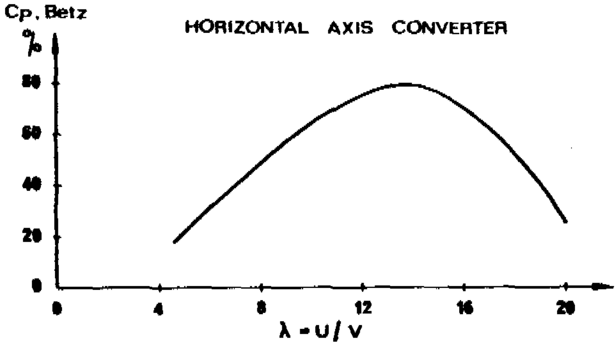
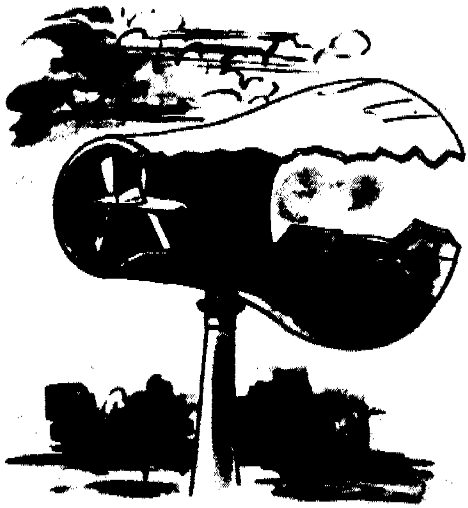


Figure 9: C_p - characteristic for a horizontal axis wind energy converter

The plant is designed in such a manner, that the single module groups such as rotor, gear unit, generator, and automatic control unit, are easily separable and interchangeable. The single pieces of the tower are dimensioned so that no one has to handle parts which are too long or too heavy. This is of utmost importance for assembling, maintenance and transportation. The rotor blades are manufactured in glass-fibre reinforced plastics (GRP), thus guaranteeing a virtually unlimited fatigue life. Each rotor blade of 5.64 m length weighs 20 kg and costs, in mass production, approximately DM 800. This price was investigated by sailplane producers and is an empirical value. The price for the gear unit (1,500/100) is DM 1,800 and for the 6 kW generator DM 3,760. The tower of the WEC, built of reinforced concrete, is about 10 m high, weighs 2500 kg, and resists a horizontal load of 1000 kg acting on the top. Production at the installation site is possible. In mass production the cost is DM 1,100 per unit. If we use a steel tube as a tower with the same loading, the weight is only 550 kg, but the price scales up to DM 1,500. With this rough calculation of costs, a horizontal axis converter could be mass-produced for between DM 15,000 and 18,000. The specific price per kW would be, therefore, approximately DM 2,500 to 3,000.

Shrouded Propeller (Aerogenerator) (SA)



(Figure 10: Artist's impression of a shrouded propeller)

An idea which is continually appearing is to encase turbines with a large tube to extract from the airflow a higher performance per unit area of the rotor. (2) The equation found by BETZ explains the performance of a free-running turbine in terms of the axial momentum loss of the airflow. Radial forces are neglected, an assumption which is permitted for the free-running turbine. The shroud profile produces an additional circulation around the shroud, inducing a supplementary velocity in the rotating area. These vortices also cause a higher flow rate.

If we choose the right airfoil section for the shroud, we can extract more than twice as much energy from the airflow as from a free-running turbine. Certainly these profiles are sensitive to flow separation. Detailed examinations in this field of research were made by Ozer IGRA in March 1975. (3) In these experimental tests the rotor was simulated by a sieve. The simple shroud with an airfoil NACA 4412 had a rotor diameter of 64 per cent of the maximal diameter and its length was 1,449 times the diameter. The maximum power coefficient, related to the throat of the shroud, reached the value of 1,156.

The equivalent data for the shroud propeller, built of the same area of material as the HAC (3.2 m^2), are:

diameter of shroud D_{SAmax}	0,84	m
diameter of throat D_{SAmin}	0,54	m
length of shroud l_{SA}	1,22	m
swept area of rotor A_{SAmin}	0,23	m^2
swept area of shroud A_{SAmax}	0,55	m^2
area of shroud material F_{SA}	3,2	m^2
output at 5,6 m/s windvelocity	0,027	KW
output at 7,7 m/s "	0,072	KW
output at 10,0 m/s "	0,157	KW
powercoefficient c_{PmaxSA} (A_{SAmin})	1,156	
powercoefficient c_{PmaxSA} (A_{SAmax})	0,48	
at tip speed ratio λ_{maxSA}	10,7	
area number $P_{SA} = A_{SA} \cdot c_{PmaxSA}$	0,27	m^2
comparison number $V_{SA} = \lambda_{maxSA} \cdot c_{PmaxSA}$	5,14	
rotor rpm	2122,0	
at rotor tip velocity maximum	60,0	m/s

If we want the same output at 5.6 m/s wind velocity as we obtain from the HAC, the data for a shrouded propeller are:

diameter of shroud D_{SAmax}	9,38	m
diameter of throat D_{SAmin}	6,00	m
length of shroud l_{SA}	13,60	m
swept area of rotor A_{SAmin}	28,27	m^2
swept area of shroud A_{SAmax}	69,10	m^2
area of shroud material F_{SA}	400,77	m^2
ratio D_{SAmin}/D_{SAmax}	0,64	
output at 5,6 m/s windvelocity	3,3	KW
output at 7,7 m/s windvelocity	8,8	KW
output at 10,0 m/s "	19,3	KW
powercoefficient c_{PmaxSA} (A_{SAmin})	1,156	
powercoefficient c_{PmaxSA} (A_{SAmax})	0,48	
at tip speed ratio λ_{maxSA}	10,7	
rotor rpm	191,0	
at rotor tip velocity maximum	60,0	m/s

This large shroud would have a surface of material of 400 m^2, not including the rotor blades and mounting vanes for the shroud itself. If we assume that the shroud structure weighs 8 kg/m^2 and costs per m^2 DM 10, this tube will cost with a calculated length of 13.6 m DM 32,000. The weight of this huge apparatus comes to 3,200 kg. To dimension the tower, the most unfavourable loading case must be taken into account, that is to say, when the air flows rectangular to the shroud's axis. Thereby we have a swept area of 127.5 m^2 which is exposed to an assumed wind velocity of 60 m/s. With a drag coefficient of c_{DR} = 0.5 the tower has to resist a horizontal loading of more than 13 tons. In comparison, the horizontal loading of the two-blade HAC is only approximately 1,000 kg with an estimated drag coefficient of 1.5.

If we compare the shrouded propeller with the free running turbine, we have to refer the power coefficient to the shroud's largest diameter and not to the throat diameter. In this case, the redefined power coefficient is $c_{PmaxSA} = c'_{PmaxSA} A_{SAmin}/A_{SAmax} = 0.48$. It is obvious that, if we refer the power coefficient to the largest diameter of the shroud, the SA works with the same power coefficient as the HAC. The expense in material for the shrouded propeller (125 times the area of material for the two-blade HA rotor) is absolutely beyond discussion. The tower structure has to sustain more than ten times the horizontal loading of the HAC.

For completeness it should be said that, with ring-flaps mounted at the outlet of the shroud, the power coefficient can be raised up to 1.42 with reference to the throat diameter, but only to 0.165 with reference to the largest diameter (flaps extended). The immense consumption of material for this design is even less suitable to extract energy economically from the airflow.

The SAVONIUS Rotor (SR)

In 1929 the Swede SAVONIUS developed a special type of rotor (4). Two or three vanes are fixed between two end plates in such a manner that a slot remains between them. The rotor axis is vertical. The airflow acts upon the vanes in such a way that a high pressure area is created on the concave side and a low one on the convex side. It seems at first as though the SAVONIUS rotor works on the principle of drag utilization, as for instance, the cup-anemometer. Exact examinations have shown that the SAVONIUS rotor can reach a tip speed velocity above unity, because there exists an additional circular flow which increases the tip speed velocity.

If the vanes are formed in a special way a power coefficient of $c_{PmaxSR} = 0.23$ (Figure 11) can be obtained. The SAVONIUS rotor is a low speed rotor. The construction needs a large area of material and therefore this rotor is expensive.

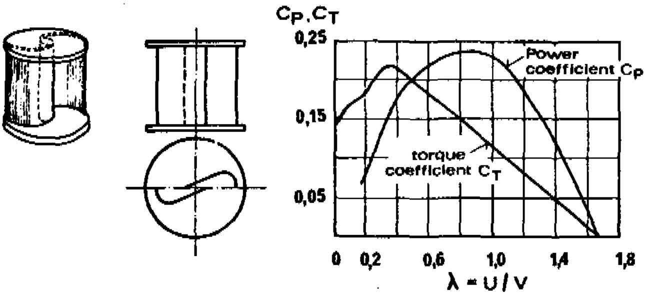


Figure 11: c_P and c_T - characteristics of a SAVONIUS rotor

If a SAVONIUS rotor is built with diameter equal to height and the same area of material is used as for the two-blade HAC, the following data result from the calculation:

diameter equal height of SAVONIUS rotor D_{SR}	0.96	m
swept area of SAVONIUS rotor A_{SR}	0.92	m^2
area of SAVONIUS vane material F'_{SRV}	1.746	m^2
area of SAVONIUS end plate material F'_{SRE}	1.448	m^2
area of SAVONIUS rotor material F_{SR}	3.2	m^2
output at 5.6 m/s wind velocity	0.022	KW
output at 7.7 m/s "	0.057	KW
output at 10.0 m/s "	0.125	KW
power coefficient c_{PmaxSR}	0.23	
at tip speed ratio λ_{maxSR}	0.85	
area number $P_{SR} = A_{SR} \cdot c_{PmaxSR}$	0.21	m^2
comparison number $V_{SR} = \lambda_{maxSR} \cdot c_{PmaxSR}$	0.196	
rotor rpm at 10.0 m/s wind velocity	176.5	
at rotor tip velocity	8.5	m/s

A similar SAVONIUS rotor, but with the same output as the HAC, at a wind velocity of 5.6 m/s, must have these data:

diameter equal height of SAVONIUS rotor D_{SR}	11.76	m
swept area of SAVONIUS rotor A_{SR}	138.30	m^2
area of SAVONIUS vane material F'_{SRV}	260.70	m^2
area of SAVONIUS end plate material F'_{SRE}	217.20	m^2
area of SAVONIUS rotor material F_{SR}	477.90	m^2
output at 5.6 m/s wind velocity	3.30	KW
output at 7.7 m/s wind velocity	8.57	KW
output at 10.0 m/s "	18.77	KW
power coefficient c_{PmaxSR}	0.23	
at tip speed ratio λ_{maxSR}	0.85	
rotor rpm at 10 m/s wind velocity	13.8	
at rotor tip velocity	8.5	m/s

The weight of the SAVONIUS rotor would ne nearly 3,000 kg for a metal structure. The price at 8 kg/m^2 and 10DM/kg material would be about DM 30,000. This price for the rotor alone makes this system unsuitable for a converter with this range of performance. The resulting drag on the rotor in a heavy storm (60 m/s) at a standstill would be approximately 14.4 tons, assuming a drag coefficient of c_{DR} = 0.5 (as for a tube). The control of the SAVONIUS rotor is electronic so

that λ is constant and rpm variable. It would therefore be best to produce direct current, if any.

The Vertical Axis Converter (VAC)

In the year 1925 the Frenchman Darrrieus took out a patent for a windmill with vertical axis. Today this concept is propagated vehemently by several institutions. Besides the NASA Langley Research Center and the European Company VFW/FOKKER in Amsterdam, the National Research Council Canada (NRC) is mainly engaged in the high-speed vertical axis converter. This institution has also published some experimental data (5,6,7). For the comparison carried out here, the papers of Peter South and Ray Rangi were used. (Figure 12) Comprising two blades, two bearings and a shaft, the vertical axis rotor was posed as the optimal system. The two-blade vertical axis rotor has constant chord, symmetric airfoil blades with their span parallel to the axis. A simple calculation shows that a high-speed rotor with straight rigid blades parallel to its axis of rotation would be subjected to a very high bending moment due to centrifugal forces and would necessitate extensive bracing. A perfectly flexible blase, on the other hand, under the action of the centrifugal and aerodynamic forces, would conform to a shape in which the only stresses would be tensile. The resultant shape of the blade would then be approximately a catenary. Hence, if we curve the blades into the form of the catenary, the bending stresses will be negligible. For simplicity of manufacture, a constant chord blade has distinct advantages and since the blades comprise the major cost item in the rotor, it is reasonable to assume that the cost of the rotor is proportional to the length of the blade. The blades of the NRC rotor model with 30" diameter were extruded from aluminum and are NACA 0012 (symmetric) airfoils of 1" chord length. Later the rotor blades for the 14 ft. diameter rotor were made from cold rolled sheet steel and were also approximately NACA 0012 with a 6" chord = 0,1525 m = t_{VAC}.

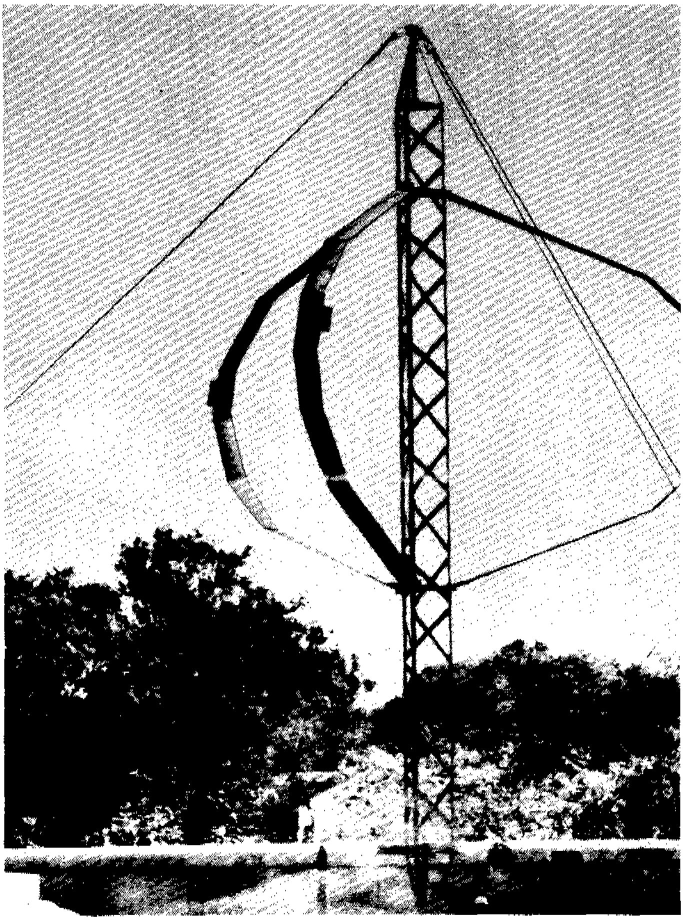


Figure 12 Three-blade vertical-axis-turbine

Further technical data:

rotor diameter D_{VAC}		4.27 m
swept area A_{VAC}	$0.69\ D^2_{HAC}$	12.58 m^2
total blade length l_{VAC}		12.74 m
area of each blade F'_{VAC}		0.97 m^2
area of blade material F_{VAC}		1.94 m^2
depth of profile $\bar{t}_{VAC}$		0.15 m
ratio $D_{VAC}/\bar{t}_{VAC}$		28
output at 5.6 m/s wind velocity		0.493 KW
output at 7.7 m/s "		1.254 KW
output at 10.0m/s "		2.783 KW
specific rated output Υ_{VAC}		220 W/m^2
power coefficient $c_{PmaxVAC}$		0.37
at tip speed ratio λ_{max}	------	6.0
rotor rpm		268.0
at rotor tip velocity maximum		60.0 m/s

To build a vertical axis converter with the same area of material as the horizontal axis converter (3.2 m^2), the comparative rotor has the following technical data (including two SAVONIUS rotors for starting):

rotor diameter D_{VAC}	2.89 m
swept area A_{VAC}	5.76 m^2
total blade length l_{VAC}	8.62 m
area of each blade F'_{VAC}	0.444 m^2
area of blade material F_{VAC}	0.888 m^2
depth of profile $\bar{t}_{VAC}$	0.103 m
diameter and height of SAVONIUS rotors D_{SVAC}	0.58 m
area of each SAVONIUS rotor F'_{SVAC}	1.156 m^2
area of SAVONIUS rotor material F_{SVAC}	2.312 m^2
total area of material	3.2 m^2
ratio $D_{VAC}/\bar{t}_{VAC}$	28
ratio D_{VAC}/D_{SVAC}	5
output at 5.6 m/s wind velocity	0.221 KW
output at 7.7 m/s "	0.574 KW
output at 10.0 m/s "	1,257 KW
specific rated output π_{VAC}	220 W/m^2
power coefficient $c_{PmaxVAC}$	0.37
at tip speed ratio λ_{maxVAC}	6.0
area number $P_{VAC} = A_{VAC} \cdot c_{PmaxVAC}$	2.13 m^2
comparison number $V_{VAC} = \lambda_{maxVAC} \cdot c_{PmaxVAC}$	2.22 m^2
rotor rpm	325.0
at rotor tip velocity maximum	60.0 m/s

To ascertain how large the vertical axis converter must be to gain the same output at 5.6 m/s wind velocity as the horizontal axis converter, that is to say, L_{VAC} = 3.3 kW at 5.6 m/s, the following technical data list applies:

rotor diameter D_{VAC}	11.17 m
swept area A_{VAC}	86.08 m^2
total blade length l_{VAC}	33.32 m
area of each blade F'_{VAC}	6.645 m^2
area of blade material F_{VAC}	13.29 m^2
depth of profile $\bar{t}_{VAC}$	0.3989 m
diameter and height of SAVONIUS rotors D_{SVAC}	2.23 m
area of each SAVONIUS rotor F'_{SVAC}	17.19 m^2
area of SAVONIUS rotor material F_{SVAC}	34.38 m^2
total area of material	47.67 m^2
ratio $D_{VAC}/\bar{t}_{VAC}$	28
ratio D_{VAC}/D_{SVAC}	5

output at 5.6 m/s wind velocity	3.3 KW
output at 7.7 m/s "	8.579KW
output at 10.0 m/s "	18.791KW
specific rated output π_{VAC}	220 W/m^2
swept area of SAVONIUS rotors A_{SVAC}	9.95 m^2
rotor rpm	102.6
at rotor tip velocity maximum	60.0 m/s

At this point a decisive problem occurs. The VAC is not self-starting. For running up this rotor needs a value of λ of approximately 2.6 to reach λ = 6 and to rotate in the optimum of $c_{PmaxVAC}$ = 0.37. If the wind velocity changes, the electronic control keeps the rotor always in the optimum point of c_p. To obtain constant rpm of the rotor shaft, the VAC has to operate with a very low, average power coefficient. This results from the distinct peak of the c_p - λ curve. (Figure 13)

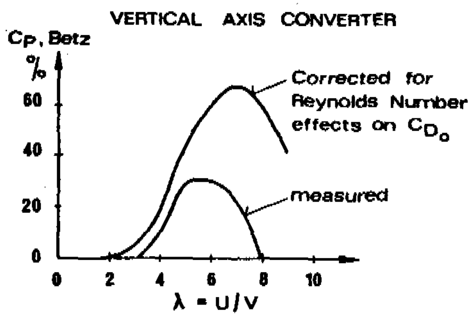


Figure 13: c_p - characteristic of a vertical axis converter

The fact that this rotor has no self-starting property, is of importance. It is necessary to establish an auxiliary drive to bring the VA rotor to sufficient rpms. At this moment the rotor turns faster and faster and in our example you can, for example, gain 3.3 kW at 5.6 m/s wind velocity. Until now the self-starting has been effected with two SAVONIUS rotors mounted at the top and the bottom of the rotor, near the bearings. For these two SAVONIUS rotors we need about 34 m^2 of additional material, that is to say, additional to the blade material with an area of 13.29 m^2. The diameter equal to the height of the SAVONIUS rotor is 2.23 m or approximately 20 per cent of the VAC diameter. The electronic control to λ = constant and therefore changing rpm points to the production of direct current. A generator for direct current with 1,500 rpm and an output of 6 kW costs DM 2,700.

The costs of extruded airfoils made from aluminum with a chord of 150 mm amount to 6 DM/kg with a 2.1 kg/m long rotor blade. The two-blade rotor for the NRC VAC with a diameter of 4.27 m would cost roughly DM 160.

The cost estimate for the comparative VAC shows that for an extruded airfoil a chord of 400 mm the weight is 15 kg/m blade length. The price for the two-blade rotor with a total blade length of 33.32 m would be nearly DM 3,000. The weight is 500 kg. If the extruded rotor blade is changed into a shell structure, we can estimate the following construction (Figure 14): The leading edge of the profile is an extruded spar from aluminum. The aft part of the section has

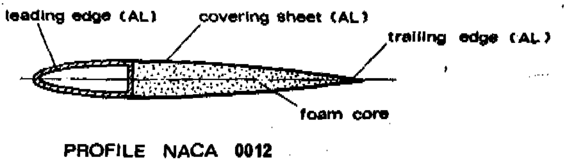


Figure 14: Possible structure of an airfoil section (8)

a foam core with a covering of Al-sheet. The trailing edge is also of aluminum. This structure weighs about 6.6 kg/m for an airfoil NACA 0012 with 400 mm chord length. Therefore this rotor weighs 223 kg. The price for this weight-saving-construction is estimated very low at 15 DM/kg. This means the VA rotor with the same output as the HA rotor would cost DM 3,350. If glass-fiber reinforced plastics are to be used for this rotor, the weight would diminish to 5 kg/m (400 mm chord). The total rotor weight is 170 kg but it costs at 40 DM/kg approximately DM 6,700. Additionally there is the expense of the two SAVONIUS rotors, roughly DM 5,000 for 34 m^2 surface (GRP) and a weight of 85 kg each (2,700 DM for a metal structure, 136 kg each).

The necessary gear unit must have a gear ratio with the factor 2 compared with the gear unit for the HAC. The price for this larger unit amounts to DM 2,200.

For the tower we assume the same price as for the HAC although an additional part is needed with the length of half a diameter. Neither this increase of cost, nor the cost for an airbrake or for control flaps and the actuating rods, nor the cost for the disconnection mechanism of the SAVONIUS rotors have been taken into account.

The HA rotor with its simple automatic shifting into the wind, side governor wheel and single step back gearing and self-locking worm, never approaches this increase in cost.

The VAC is not self-starting. Below a wind velocity of approximately 5 m/s there is no output. To obtain at a wind-velocity of 5.6 m/s the same output as from the HAC, we would have to use more than 14 times the area of material as for the 100 m^2 HAC. An area of roughly 17 m^2 is exposed in an emergency case (heavy storm, standstill of the rotor) to a wind velocity of 60 m/s. The resulting drag must be supported by the structure and the tower. Even if we use a metal structure, the capital costs for a VAC cannot be reduced to the level of the HA rotor costs in GRP. If we were to take a composite rotor blade, the VA rotor would be 5 times more expensive compared with the 6 kW HAC. With regard to the fatigue life, a metal structure is not acceptable.
in developing countries areas with an average wind velocity of more than 5 m/s are not found very often. Therefore with the technical standard of today it is not possible to employ the VAC economically.

Conclusion

The history of western America, southern Africa, and many islands in the Mediterranean shows the outstanding role wind energy plays at the beginning of the development of an area. In semiarid areas where the density of energy requirement is initially very low, the energy transfer costs are so important that the WEC is in many cases, for example for waterpumping and electricity supply (light, communication, cooking, cooling), the most economic solution. The energy transportation costs include naturally the transportation of the energy carrier substance (e.g., oil barrel transportation with pack animals).

The next figure (Figure 15) shows clearly the comparison between the described WEC rotor systems with respect to the same area of material. It also indicates the proportions and the very different swept areas through which energy can be extracted from the airflow. The last figure (Figure 16) demonstrates obviously the other possible comparison. The four rotor systems and their dimensions for the same output at a certain wind velocity are depicted. Here it is evident too that the rotor with the least material expense is the most economic. The quality number Q shows clearly the superiority of the horizontal axis converter to the other examined systems.

The existing opportunity should be taken up by developed and developing countries. The former can give the knowhow, and the others can satisfy vital energy needs. This, with the aid of their own energy, will bring progress in all countries.

Comparison of different WEC rotor systems constructed with the same surface of material (3,2 m²) at a windvelocity of 5,6 m/sec.

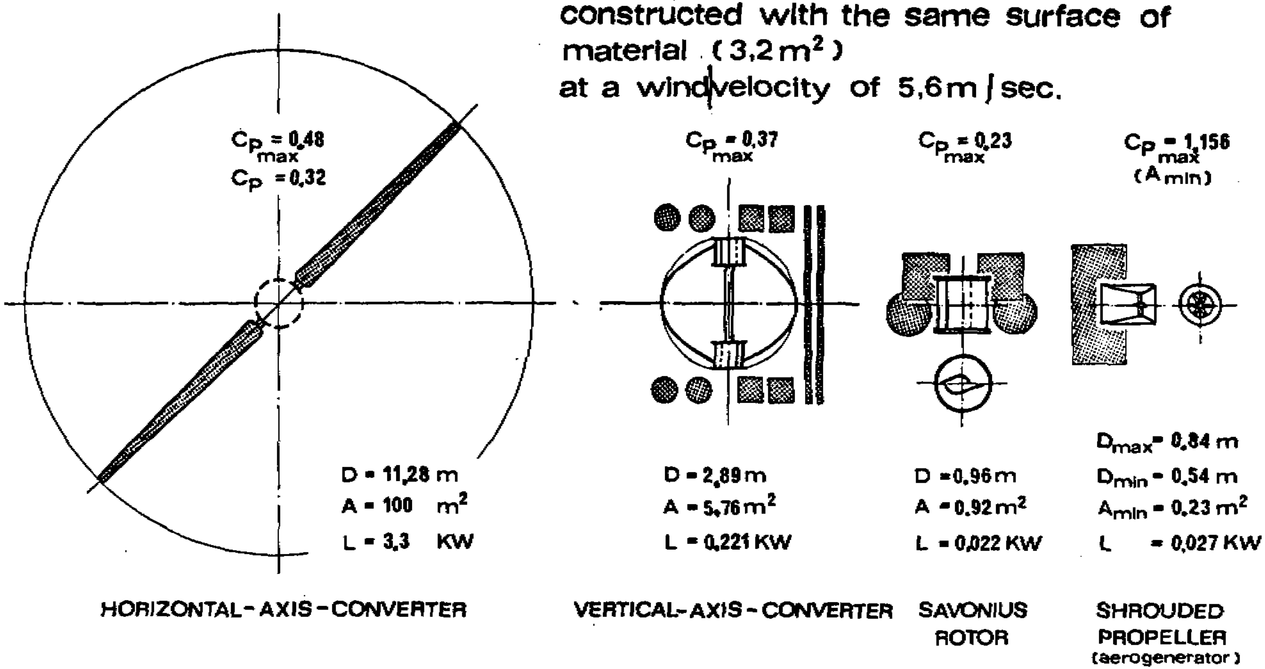
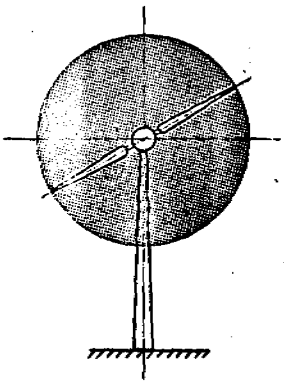


Figure 15

Comparison of different WEC rotor systems, output 3,3 KW at 5,6 m/sec. windvelocity, drag (DR) at 60 m/sec., rotor weight (W) structure in GRP, quality number (Q) = swept area A/area of material F.

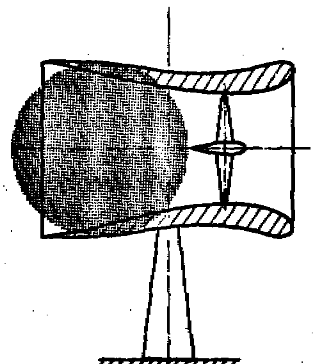
$D = 11{,}28\,m$
$A = 100\,m^2$
$D_R = 10\,195\,N$
$C_{DR} = 1{,}5$
$W = 40\,kg$



HORIZONTAL - AXIS - CONVERTER

Q = 31,25

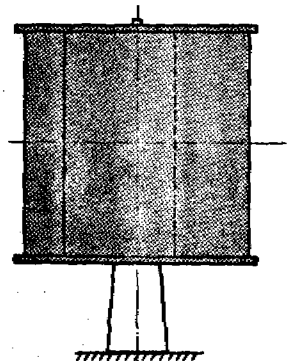
$l_{shroud} = 13{,}6\,m$
$D_{max} = 9{,}38\,m$, $D_{min} = 6{,}0\,m$
$A_{max} = 69{,}10\,m^2$, $A_{min} = 28{,}27\,m^2$
$D_R = 135\,477\,N$
$C_{DR} = 0{,}5$
$W = 2\,004\,kg$



SHROUDED PROPELLER
(aerogenerator)

Q = 0,17

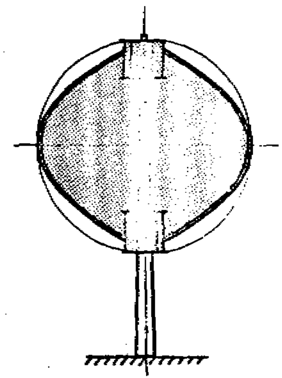
$D = H = 11{,}76\,m$
$A = 138{,}30\,m^2$
$D_R = 146\,872\,N$
$C_{DR} = 0{,}5$
$W = 2390\,kg$



SAVONIUS ROTOR

Q = 0,29

$D = H = 11{,}17\,m$
$A = 86{,}08\,m^2$
$D_R = 24\,808\,N$
$C_{DR} = 1{,}5 / 0{,}5$
$W = 338\,kg$



VERTICAL - AXIS - CONVERTER

Q = 1,81

References

(1) Hütter, U.; Betriebserfahrungen mit der 100 KW-Windkraftanlage der Studiengesellschaft Windkraft e.V. Stuttgart. Zeitschrift "Brennstoff-Wärme-Kraft", Band 16, No 7, S. 333-340, Juli 1964.

(2) Oman, R. A.; Foreman, K. M.; Grumman Aerospace Corporation; Advantages of the Diffusor-Augmented Wind Turbine. Wind Energy Conversion Systems, Workshop proceedings NSF/NASA, 11 to 13 June 1973, Washington, D.C., NSF/RA/W-73-006, December 1973.

(3) Igra, O.; Ben Gurion University of the Negev; Shrouds for Aerogenerator; March 1975.

(4) Witte, H.; Windkraftwerke. Rudolf A. Lange Verlag, Possneck, in: Arbeitsgemeinschaft Thüringischer Verleger, 1950.

(5) South, P.; Rangi, R.; National Research Council, Ottawa, Canada. Preliminary Tests of a High-Speed Vertical Axis Windmill Model. LTR-LA-74. March 1971.

(6) South, P.; Rangi, R.; National Research Council, Ottawa, Canada. A Windtunnel Investigation of a 14-ft-diameter Vertical Axis Windmill. LTR-LA-105. September 1972.

(7) South, P.; Rangi, R.; National Research Council, Ottawa, Canada. The Performance and Economics of the Vertical-Axis Wind Turbine Developed at the National Research Council, Ottawa, Canada. Calgary, Alberta, 10 to 12 October 1973. Annual Meeting of the Pacific Northwest Region of the American Society of Agricultural Engineering.

(8) NN; Deutsche Studiengesellschaft Hubschrauber e.V. Stuttgart-Flughafen. Lastenhubschrauber L-21 und L-31 Gewichtsermittlung, Schwerpunktbestimmung und stat. Vorrechnung. Bericht 28-3, April 1957.

FLAPPING-VANE WIND MACHINE AND ROD-PISTON PUMP, AN INTEGRATED DELIVERY SYSTEM FOR LARGE WELL DEPTHS AND SMALL FLOW RATES

Dipl.-Ing. Peter Bade

The energy of the wind has been used for centuries in many different types of windmills for delivering water. In modern times, progressive development of the traditional windmill has resulted in the high-speed wind turbine and the slow-speed wind motor.[1/] Both types are employed as prime movers for driving centrifugal pumps and reciprocating pumps.

Centrifugal and reciprocating pumps both have certain ranges of flow rate and delivery height in which one type operates much more efficiently than the other.

For the centrifugal pump, the quality criterion is defined by the specific speed of rotation n_s:

$$n_s = n\sqrt{\frac{Q \cdot g \cdot \rho}{75 \cdot H^{3/2}}}$$

where Q is the delivery flow in m^3/s and H is the delivery height. At low delivery flows, n_s becomes smaller with increasing delivery heights, and eventually reaches a lower limit value at which the relative delivery capacity is very small and the pump efficiency falls off sharply. If the pump speed is increased to improve the efficiency, cavitation can result and the pump will then be destroyed. Krisam[2/] gives a value of $n_s = 30$ as the limit for the economical employment of the centrifugal pump, which means that a centrifugal pump running at 50 r/s with delivery flows Q which are lower than the functional values f(H) given in Fig. 1 operates very disadvantageously.

Dipl.-Ing. Peter Bade is scientific assistant in the Institute for Civil Engineering Hydraulics and Water Management at the Technical University of Berlin, and member of the Adapted Technology group there.

On the other hand, the reciprocating pumps which are employed, for example, as deep-well rod pumps in the petroleum industry, work economically at small flow rates and large delivery heights.[3/] For large flow rates, however, the mechanical effort with this type of pump increases steeply, and the reciprocating pump eventually becomes uneconomical.

In a very detailed work, Vadot[4/] gives sizing and design criteria for the various wind-pump systems, so that we can dispense here with a detailed description of this problem, but we can summarize the main considerations with respect to pump systems with rotary wind machines as follows:

1. The rotary motion of the rotational wind machine must in every case be converted by way of gearing or other motion converters to the reciprocating action of the piston pump.

2. The speed of the high-speed wind turbine (n = 3 to 8 r/s) and of the slow-speed wind motor (n = 1 to 4 r/s) is too low for the centrifugal pump and too high for the reciprocating pump.

3. At low flow rates and large delivery heights, where the reciprocating pump could be employed, the aerodynamically optimal wind turbine cannot be employed owing to its too low starting torque.[3/, 4/, 5/]

Many studies have shown, however, that the particular need is for adapted water delivery systems to provide small daily requirements, i.e., small flow rates at large delivery heads from depths of more than 100 metres in the arid and semi-arid development zones.[6/, 7/]

The highly developed pump systems with rotary wind machines are unsuitable for water delivery in these cases owing to the involved technology, the expensive maintenance and the large investment costs.

Introduced here is a wind-driven deep-well piston pump in which the movement behaviour of the component parts of the wind-power machine and the pump is matched, and in which the technology is much less demanding compared with that of the rotary wind machines.

The wind machine adapted to the motion of the reciprocating pump must provide directly an up-and-down movement in the frequency range of 0.2 to 1 1/s without another motion converter being interposed. The piston pump must have a long stroke so as to ensure that any gas bubbles which may be present in the well water do not adversely affect or prevent delivery. Haddenhorst et al[8/] refer to this problem, among other things, in oil production from deep-well probes. The drive for deep-well pumps—as they have been used for centuries—was effected in its most simple form by leverage using human or animal power or, as in the case of oil-well beam pumps, by means of an electric motor driving a crank gear with sliding block.

Now, in order to utilize the force of the wind, the lever principle is also used here, with the linkage of the deep-well pump engaging at the shorter lever end, with a vane or blade on the much longer lever arm on the opposite side of the lever fulcrum. The vane can swing freely about its horizontal main axis between an upper and a lower angular stop. The pivotal point of the vane is behind the resultant of the vane lifting force or buoyancy in the wind direction, so that the vane—depending on whether its effective approach angle is positive or negative—is swung by the lifting force to the upper or lower angular stop.

The vane can thus assume two angular positions relative to the longitudinal axis of the lever arm. At the same time, during the up-and-down movement of the lever arm the effective approach angle is continuously changed (Fig. 2). This coupling of the vane approach angle with the angular position of the lever arm now effects the change of the effective vane approach angle from a maximum through zero as the lever arm moves from up to down or vice versa. When passing through the zero approach angle, the lifting force of the

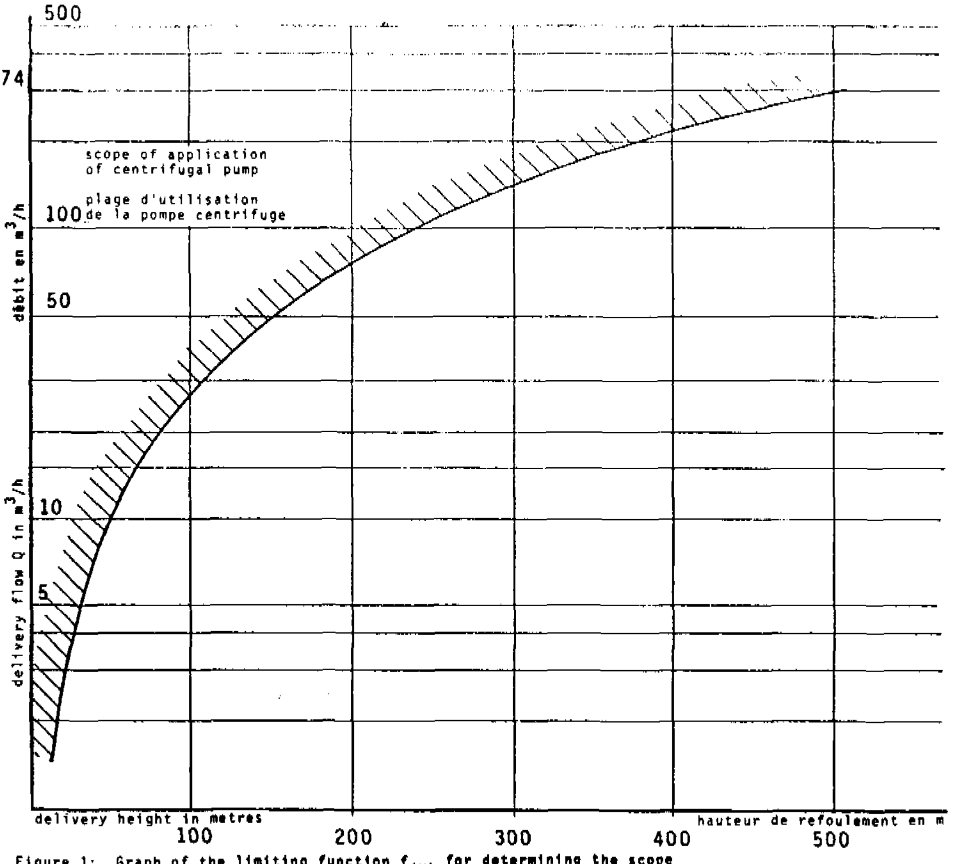


Figure 1: Graph of the limiting function $f_{(H)}$ for determining the scope of application for a centrifugal pump of specific rotational speed $n_s = 30$

Figure 1: Cours de la fonction limite $f_{(H)}$ pour la détermination de la plage d'utilisation de la pompe centrifuge, vitesse spécifique $n_s = 30$

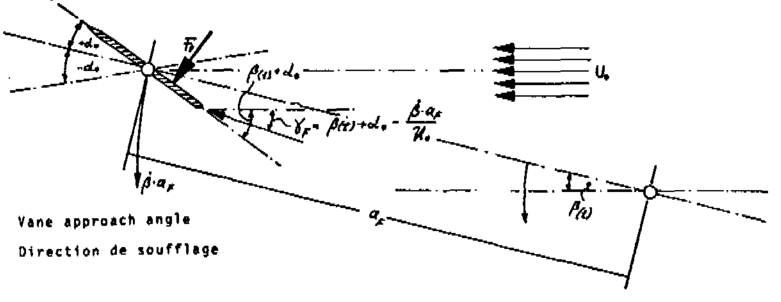


Figure 2: Vane approach angle

Figure 2: Direction de soufflage

Figures 1 and 2: FLAPPING-VANE PUMP

Limiting function for centrifugal pump application and vane approach angle

Figures 1 et 2: POMPE AVEC MACHINE EOLIENNE A AILE BATTANTE

Fonction limite pour l'utilisation de la pompe centrifuge et la direction de soufflage vane reverses its sign and the vane will be swung from one angular stop to the other. The up-and-down movement of the lever arm, and hence the working motion of the reciprocating pump, therefore derives from the periodically changing direction and magnitude of the lifting force of the vane. Although the vane approach angle can attain a large value at the upper or lower maximum position of the lever arm, there is practically no danger of a break in the flow and hence a loss of lifting force, since owing to the periodically changing circulation around the vane there is always a stable starting boundary layer.

In order that the vane can swing automatically into the wind direction, the lever fulcrum is carried in a pedestal which can rotate about the vertical on a mast. The vertical axis of the mast is exactly in alignment with the axis of the pump rod. By means of balancing weights on the outer end of the pump lever, the oscillatory system is brought into stationary equilibrium.

Let us now consider the working behaviour and motion of such a wind pump with reference to a concrete example. The pump system is to have a mean daily output, Q_{mean}, of 100 m^3/d at a delivery height H of 40 metres. The average wind velocity at the site is U = 5.2 m/s. Evaluation of the annual availability of wind, the optimal matching of pump flow rate and size of the water storage tank as well as the yield of the deep well give a minimum wind velocity of U_o = 4.6 m/s at which this wind machine must begin with water pumping.

We now obtain the following main particulars of the equipment:

Delivery height	$H = 40$ m
Vane surface	$A_F = 29$ m^2
Piston cross-section	$A_p = 0.016$ m^2
Piston diameter	$D_p = 0.143$ m
Pump lever	$a_p = 1.2$ m
Lever arm	$a_F = 20.0$ m
Mean pump stroke	$h_p = 0.6$ m

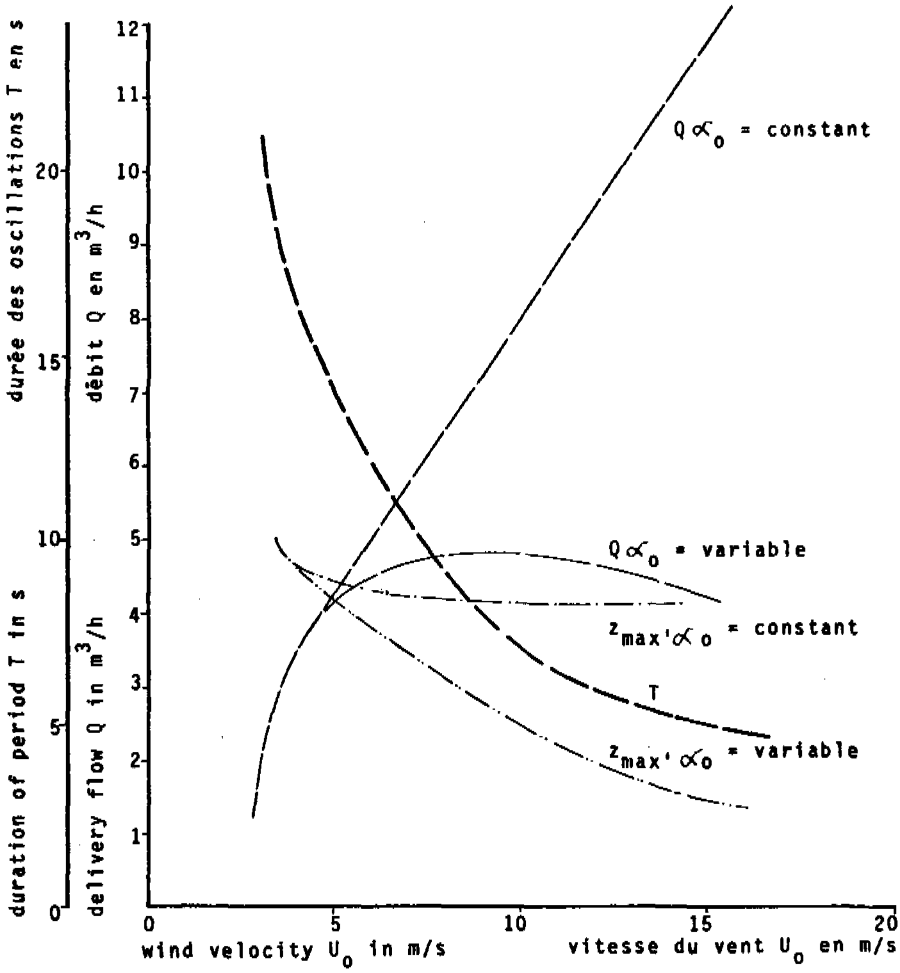


Figure 3: FLAPPING-VANE PUMP

Delivery flow, duration of period and maximum amplitude at constant and variable angle α_0

Figure 3: POMPE AVEC MACHINE EOLIENNE A AILE BATTANTE

Débit, durée des oscillations et amplitude maximale, dans les cas des angles de butée α_0 constant et variable

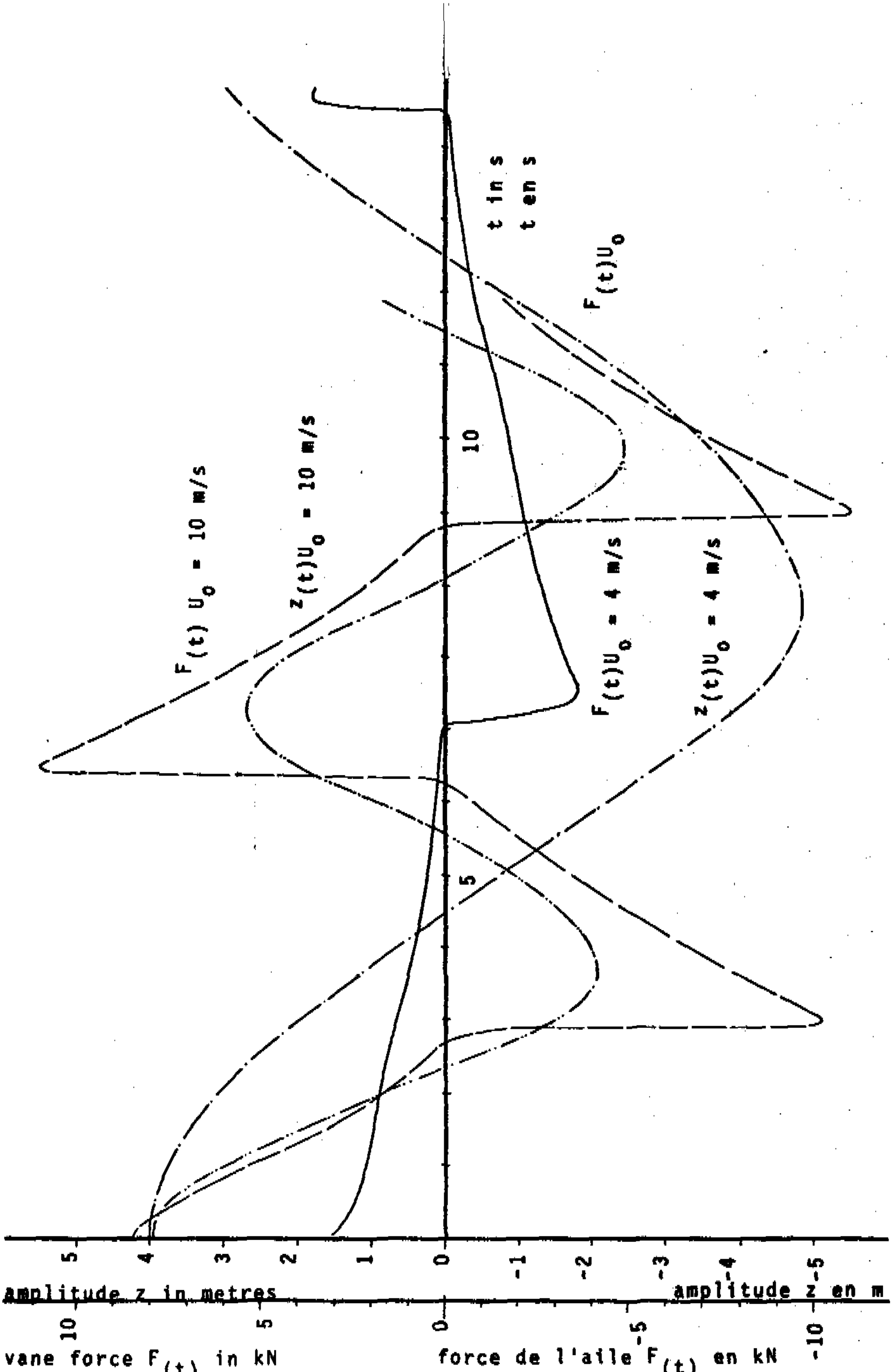


Figure 4: FLAPPING-VANE PUMP

Graph of amplitude of vane pivot and the vane force during time t

Figure 4: POMPE A AILE BATTANTE

Ordre chronologique de l'amplitude du pivot de l'aile et de la force de l'aile en fonction du temps

To determine the motional behaviour, the non-linear, non-homogene differential equation of the motion was solved by a differential method and the results plotted on a graph.

Fig. 3 shows the hourly output $Q_{h(U)}$ in relation to wind velocity U and the periodic duration of one oscillation $T_{(U)}$. The curves are plotted, firstly, for a constant angle $\alpha = \pm 22^{o}$ and, secondly, for angles which become smaller with increasing wind velocity. In the latter case, an almost constant mean flow rate can be maintained independently of the wind velocity. Fig. 4 shows the time course of the amplitude of the vane pivot and the vane lifting force for wind velocities U of 4 and 10 m/s. In the present example, the basic arrangement of which is shown in Fig. 5, the techniques of aircraft construction are employed. For example, the vane is made of plastic, while the lever arm is of aluminium-tubes.

For certain areas of application where there is a lack of the design, production and operating expertise required for highly-developed lightweight constructions, the design can be modified so that the main components such as vane, lever arm, mast and perhaps also the pump and rod can be made of simpler and well-tried materials. For example, the lever arm can be of light timber construction, while the rigid vane can be replaced by a sail construction made of strong cloth. The drawings in Figs. 6 and 7 illustrate some of these possibilities.

Bibliography

1/ Notebaart, J. C.: Windmühlen. Mouton Verlag, Den Haag-Paris, 1972

2/ Krisam, F.: Die Grenzen der Verwendbarkeit der Kreiselpumpen. Die Technik, Vol. 3, No. 7, July 1948

3/ Klampel, v. H.: Förderung grosser Flüssigkeitsmengen aus Nassölsonden. Erdöl-Erdgas-Z. Vol. 88, Nov. 1972

4/ Vadot, L.: Water-pumping by windmills. La houille Blanche, No. 4, Sept. 1957

5/ Beurskens, J. et al: Windenergie. Technische Hogeschool Eindhoven, Vakgroep Transportfisica, Dict. No. 3,323, 1974

6/ Berg, H. D.: Möglichkeiten der Wassererschliessung in Somalia, East Africa. Wasser und Boden, No. 1, 1975

7/ Ramdas, L.A. and K.P. Ramakrishnan: Wind energy in India. Wind and Solar Energy, Proc. New Dehli Symp. UNESCO, 1956

8/ Haddenhorst, H. G. u. K. Horn: Die Förderung von Gas-Öl Gemischen mittels Tiefpumpen. Erdöl-Zeitschrift. Vol. 76, Sept. 1960

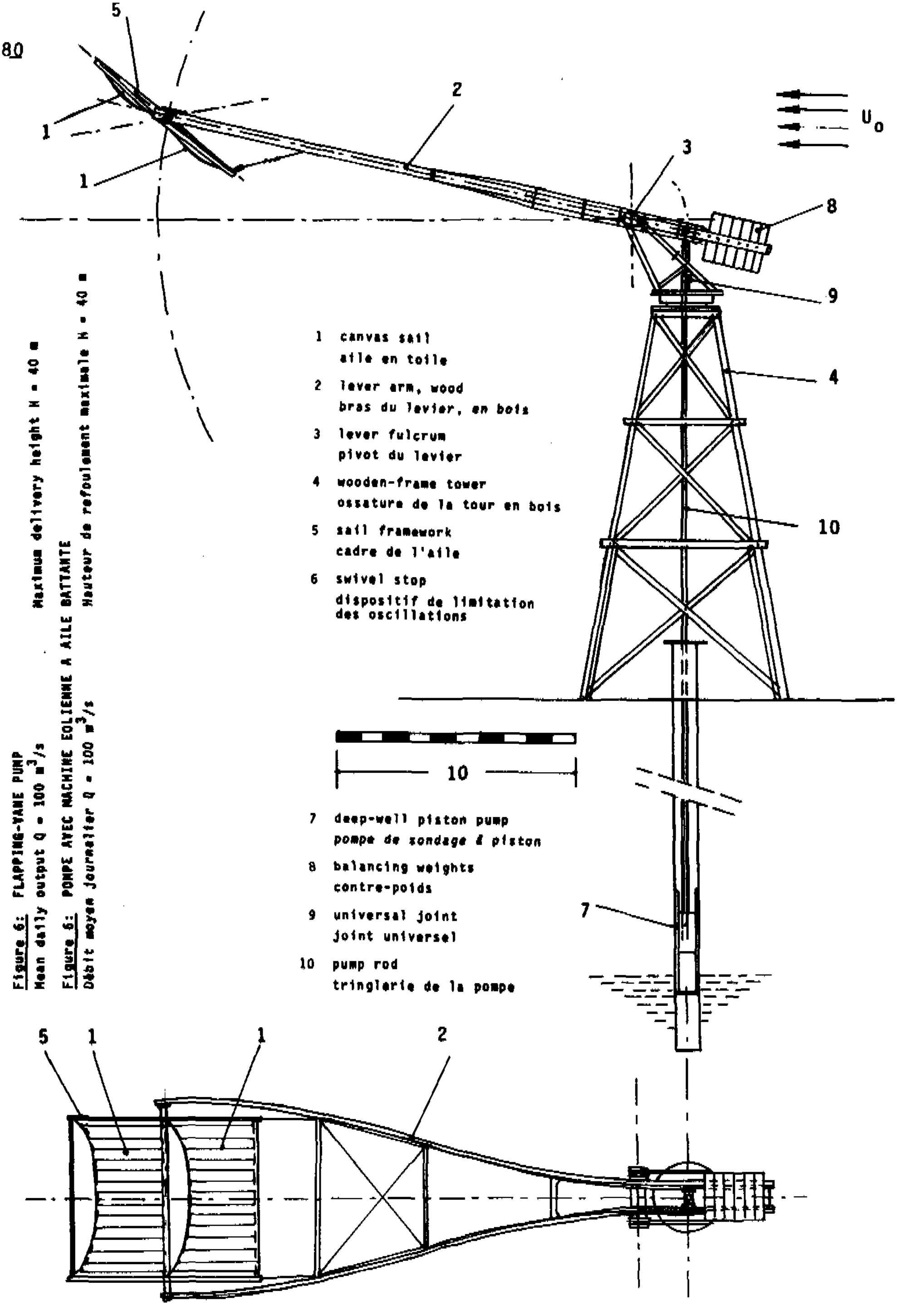


Figure 6: FLAPPING-VANE PUMP
Mean daily output $Q = 100\ m^3/s$ Maximum delivery height $H = 40\ m$

Figure 6: POMPE AVEC MACHINE EOLIENNE A AILE BATTANTE
Débit moyen journalier $Q = 100\ m^3/s$ Hauteur de refoulement maximale $H = 40\ m$

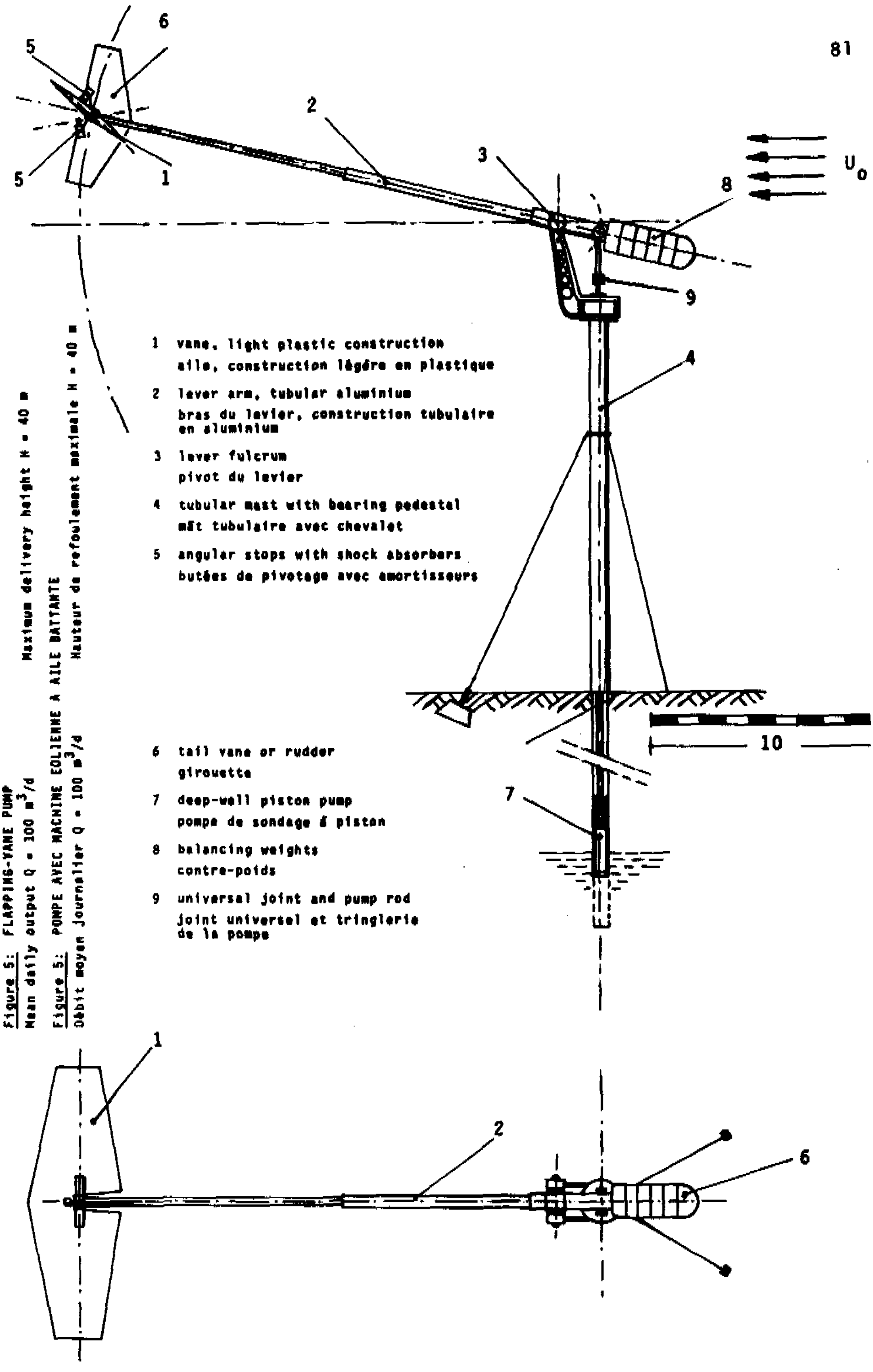
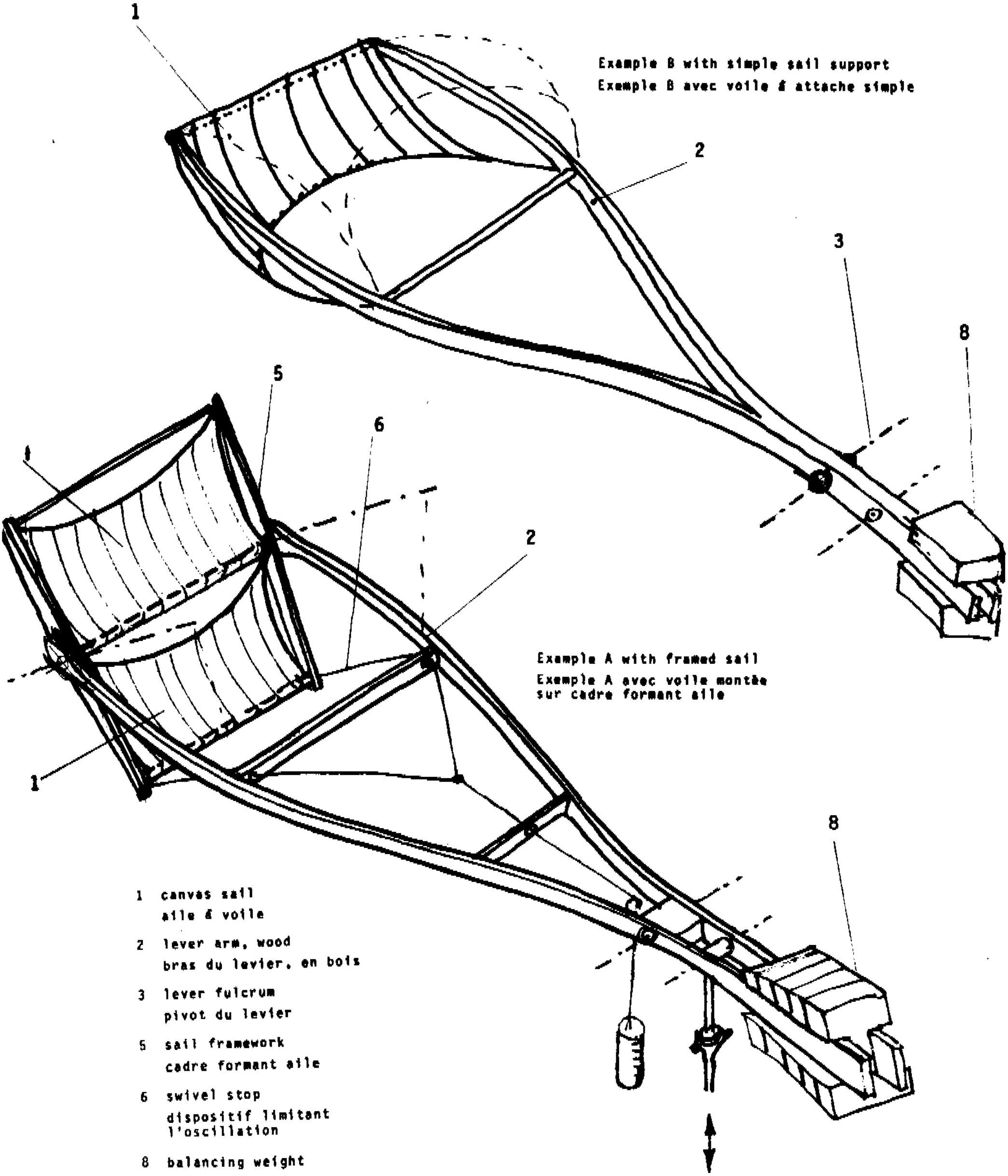


Figure 5: FLAPPING-VANE PUMP
Mean daily output $Q = 300\ m^3/d$ Maximum delivery height $H = 40\ m$

Figure 5: POMPE AVEC MACHINE EOLIENNE A AILE BATTANTE
Débit moyen journalier $Q = 100\ m^3/d$ Hauteur de refoulement maximale $H = 40\ m$

Figure 7: FLAPPING-VANE PUMP
Arrangement of lever and sail in wood and canvas

Figure 7: POMPE A AILE BATTANTE
Exècution du levier et de l'aile en bois et toile



1 canvas sail
aile á voile

2 lever arm, wood
bras du levier, en bois

3 lever fulcrum
pivot du levier

5 sail framework
cadre formant aile

6 swivel stop
dispositif limitant l'oscillation

8 balancing weight
contre-poids

FLAPPING-VANE WIND MACHINE

Dipl.-Ing. Peter Bade

1. Patent Specification

1.1 Introduction

The following specification describes the invention of a flapping-vane wind machine to produce a force effect with an up-and-down movement from the energy of the wind.

Wind machines heretofore known and used provide energy by way of a rotational movement. The classical windmill and the "American wind motor" are probably the best known examples of this method of energy conversion.

However, a number of machines, such as the reciprocating pump, must receive their energy by way of an up-and-down movement. To drive such machines, therefore, the rotational movement of the classical wind machines must be converted to an up-and-down movement by means of gearing and lever mechanisms.

The wind apparatus by Melzer[1/] and the oscillating vane as described by Vadot[2/] do provide a force effect with an up-and-down movement, but owing to the complexity of the mechanical guiding of the vane, which simultaneously moves up and down and swings from one angular position to the other, practical application has not yet been found.

1.2 The invention and its mode of action

The flapping-vane wind machine proposed here produces a force with periodic up-and-down movement from the effect of the force of the wind on one vane or several vanes arranged in lattice form above each other, without complicated guiding of the vane, solely from the motion of the vane relative to the direction of approach of the wind.

1/ Heys, J. W. van: Wind und Windkraftanlagen, Berlin 1947

2/ Vadot, L.: La Houille Blanche, No 2, Mars/Avril 1957

One (or several) vanes (2) are rotatably mounted on the end of a long swinging lever (1) so that they can swivel freely about their horizontal axis transversely to the axis of the swinging lever (1) between two stops (4). In this way, a vane symmetrical about its generatrix can assume the angular position α or $-\alpha$ relative to the axis of the swinging lever.

The horizontal axis of the vane (2) lies behind the resultant of the vane lifting force F_w seen in the direction of the wind, so that with a change in the direction of force F_w as a result of a change in the effective vane incidence angle γ, the vane will be swivelled from one angle α to the other.

Swinging lever (1) is rotatably mounted in a fulcrum (3) at a distance R_0 from the swivelling axis of the vane, so that the swinging lever can move up and down about this point. The angle between the axis of the swinging lever and the horizontal is β. As a result of the up-and-down movement of the swinging lever, the incidence angle of the vane γ will change at the same time dependent on angle β between the axis of the swinging lever and the horizontal (Fig. 1).

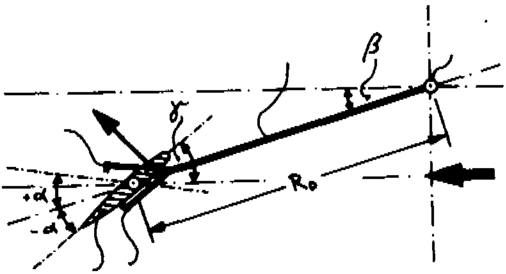


FIG. 1

As angle β changes as a result of the up-and-down movement of the swinging lever, the effective incidence angle of the vane γ receives an additional angular component $\delta(t) = \frac{R_o}{U} \cdot \frac{d\beta}{dt}$ where U is the wind velocity (Fig. 2).

The effective time-dependent vane incidence angle γ is therefore expressed as follows:

$$\gamma(t) = \alpha + \beta(t) - R_o \cdot \frac{d\beta}{dt} \cdot \frac{1}{U} \quad \text{(Eq. 1)}$$

In the extreme positions of angle β of the axis of the swinging lever at

$$|\alpha| - |\beta| = R_o \cdot \frac{d\beta}{dt} \cdot \frac{1}{U} \quad \text{(Eq. 2)}$$

the effective incidence angle of the vane γ undergoes a change of sign, the vane swings from one angular position to the other, and as a result of the now very large opposite vane force, the direction of movement of the swinging lever is reversed and the swinging lever is forced into the other extreme position.

Owing to the coupling of angle α of the vane with the angle β of the swinging lever, the latter executes up-and-down movements as a result of the periodically changing direction of the vane force F_w.

The fulcrum (3) of the swinging lever is supported in a bearing pedestal (7) which is arranged on a mast (8) in such a way that it can rotate about the vertical. The height of the mast should be such that the vane does not touch the ground at the maximum angular position and can always work in an undisturbed wind current.

At a distance R_a from the fulcrum (3) is the point of engagement of a connecting rod (10), which acts on a thrust rod (6) through a universal joint (11). With this arrangement the movements of the swinging lever deriving from the vane forces F_w are transmitted to the machine with the lever ratio R_o/R_a.

With the periodically changing incidence angle of the vane, the vane stream experiences a periodically changing circulation and hence a periodic, very stable boundary layer. This prevents interruption of the flow at large vane incidence angles γ in the extreme positions for β, and high vane surface loadings permit a good utilization of the vane surface, which is kept as small as possible for constructional and economic reasons.

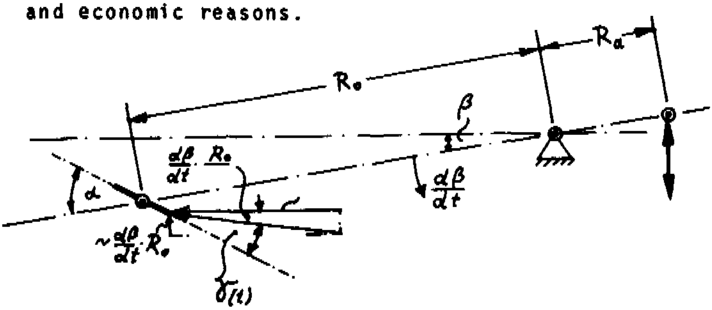


FIG. 2

Equation 1 shows how the motion quantities depend on the wind velocity U, such that with an increasing U the value dß/dt increases faster than the wind velocity itself. Also, the frequency of the up-and-down motion increases but the amplitude becomes smaller, so that the system is self-regulating with respect to output.

In order to protect the vane bearings from excessive shock loading when the vane flaps, the angular stops (4) are fitted with shock absorbers.

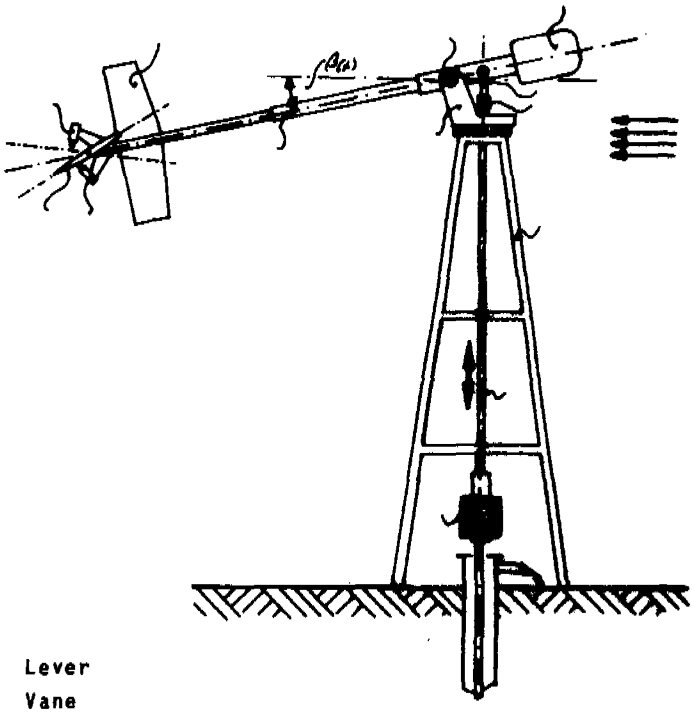
Weights (13) attached to the lever arm at the end remote from the vane serve to keep the system in static equilibrium.

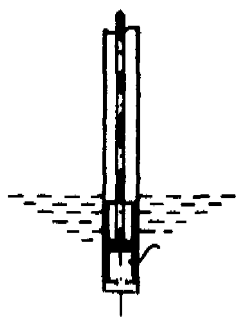
The flapping-vane wind machine to which this invention relates will, owing to the back-and-forth and up-and-down force action provided specially by it, find application on such machines for which this moving force action is characteristic.

The invention is therefore specially useful in conjunction with a reciprocating pump (14) for pumping liquids from great depths. Both single-acting and double-acting pumps can be used.

Use as prime mover for the production of electricity by means of linear or immersed-coil generators is also possible, likewise a combination of pump and generator as energy supply station for use in remote areas, since the construction, servicing, and maintenance of such an installation will be extremely simple.

Fig. 3 shows the arrangement of a flapping-vane wind machine installation in diagrammtic form.





1. Lever
2. Vane
3. Fulcrum
4. Angular stop
5. Wind direction
6. Thrust rod
7. Bearing pedestal
8. Mast
9. Tail vane or rudder
10. Connecting rod
11. Universal joint
12. Shock absorber
13. Balancing weight
14. Reciprocating pump
15. Linear generator

FIG. 3

2. Patent Claims

2.1 A flapping-vane wind machine, characterized in that one or several vanes (2) capable of swivelling about their horizontal axis between an upper and a lower angular stop (4) are mounted on a free end of a swinging lever (1), and the horizontal swivelling axis of the vane (2) lies in the direction of wind flow behind the point of application of the resultant of the lifting force F_W of the vane.

2.2 A flapping-vane wind machine according to Claim 2.1, characterized in that the swinging lever (1) can move up and down in a pedestal (7) through the angle $\pm B$ about the fulcrum (3), which is at a distance R_0 from the swivelling axis of vane (2) and acts with a shorter lever distance R_a through a connecting rod (10) and a universal joint (11) to move a thrust rod up and down, through which machines are driven.

2.3 A flapping-vane wind machine according to Claims 2.1 and 2.2, characterized in that the pedestal (7) is mounted on a mast (8) so that it can rotate about the vertical in such a way that the rotational axis of the pedestal (7) is in alignment with the axis of the thrust rod (6).

2.4 A flapping-vane wind machine according to Claims 2.1, 2.2 and 2.3, characterized in that the thrust rod (6) moving up and down is directly connected with a linear generator and a reciprocating pump.

2.5 A flapping-vane wind machine according to Claims 2.1, 2.2, 2.3 and 2.4, characterized in that the angular stops (4) are equipped with shock absorbers for damping of the swivelling motion of the vane or vanes (2) from one angular position α to the other.

6,000 HAND-CRAFTED SAILWING WINDMILLS OF LASSITHIOU, GREECE, AND THEIR RELEVANCE TO WINDMILL DEVELOPMENT IN RURAL INDIA

Marcus M. Sherman

1. Abstract

The author visited Lassithiou, Crete, Greece, to ascertain the reasons for the widespread use of windmills there and to determine if any of the details of their design could be incorporated in the design of water-pumping windmills currently being developed for widespread use in rural India. The success of the Greek windmills may be attributed to their use of inexpensive and lightweight cloth sails, maximum use of local hand-craftsmanship in construction and simplicity in design of the steel turntable, the wooden main bearings, and the crankshaft.

2. Introduction

Lassithiou is a broad fertile plain isolated in the mountains of Crete, the largest of the Greek islands. Zeus, the kind of Greek Gods, is said to have been born in a cave overlooking the area. Farmers from several villages surrounding this plain produce export quantities of beans, cabbage, corn, potatoes and other vegetables through intensive cultivation of 1-2-acre plots during the warm season of May through September. Winds during this season are light to moderate. The general prosperity of this area may be partially attributed to the widespread use of Aeolian energy for the pumping of irrigation water.

In the Mediterranean region large stone tower windmills rigged with triangular cloth sails were traditionally used for grain grinding and oil pressing. In 1918 this traditional windmill design was adopted to smaller lightweight structures for pumping water. At the present time at least 6,000 of these simple devices are in seasonal use. Not including pump and storage tank, a Lassithiou windmill costs 10,000 drachmas to instal (Rs 2,500).

3. Lassithiou Windmill Design

The Lassithiou windmill design consists of eleven basic elements: base well, pump-storage tank, tower, turntable, carriage, tail, main bearings, crankshaft, hub, spars, and sails.

3.1 Base well

A 15-cm thick concrete slab covering a 2-m diameter, 10-m deep well forms the base of the windmill.

3.2 Pump-storage tank

Mounted on the base in the centre of the tower is a 13-cm diameter, 15-cm stroke piston pump made of a discarded W.W.II German cannon shell, fitted with a leather foot valve and a leather-sealed piston. Pumping 2 litres per stroke, 40 strokes per minute, this pump fills a 3 metre x 4 metre x 80 cm deep concrete storage tank in two hours. The pump costs 1,200 drachmas (Rs 300) and the storage tank 4,000 drachmas (Rs 1,000).

3.3 Tower

The four-legged 5-metre high, 1.5-metre square base tower is made from 5-cm mild steel angle iron riveted with flat steel cross bracing. The tower is bolted and wired to the base.

3.4 Turntable

The turntable riveted to the top of the four tower legs is made of a 160-cm long piece of 5 cm MS angle iron bent into a 50-cm diameter ring to form a flat horizontal bearing surface for the carriage to rotate upon.

3.5 The carriage

The carriage is simply a rectangular-angle iron frame 35 cm wide and 140 cm long. The carriage is bolted down with four bolts to two 35-cm pieces of angle iron riveted to a 48-cm diameter flat steel ring which rotates on the bottom inside surface of the turntable ring. This arrangement keeps the carriage firmly attached to the top of the tower while at the same time allowing it and the attached shaft, sails, etc., to rotate vertically when the wind direction changes.

3.6 Tail

A triangular tail of corrugated sheet steel 1.5 m x 1.5 m x 1 m is supported by two 2-metre long pieces of angle iron from the rear of the carriage.

3.7 Main bearings

Two 34-cm wide, 15-cm high, 8-cm thick blocks of hardwood, each with 1 5 cm diameter hole bored in the centre of the large surface are bolted to the front and rear of the carriage to support the crankshaft.

3.8 Crankshaft

The crankshaft is made of a 5-cm diameter, 160-cm long MS steel rod which has a 'U' shape bent into the centre. The 'U' section has an inside width of 7 cm and a height of 7.5 cm, thus giving a stroke of 15 cm. A 2-cm-diameter steel connecting rod attached with two bolts to a wood crank bearing transfers the rotatory motion of the crankshaft into vertically reciprocating motion of the pump piston.

3.9 Hub

The front end of the crankshaft is inserted through a 30-cm diameter, 15-cm thick wooden hub into which eight 5-cm square holes are chiseled in the perimeter to receive the squared ends of the spars. The hub is fixed to the end of the shaft by a bolt passing through both. An improved hub made of two 30-cm diameter, .5-cm thick steel discs separated 5 cm apart by 16 small rectangles of 10 cm x .5 cm steel to form eight square holes has recently been adopted. A 60-cm diameter flat steel ring around the hub is bolted to each spar to keep them secured within the hub.

3.10 Spars

The eight 2.8-m long spars made of wood radiate out from the hub to form a total windmill diameter of 5.4 m. Small stones are attached to the tips of some spars when balancing is necessary. A central supporting spar of angle iron extends 2 m out in front of the hub along the main axis of the crankshaft. Steel wires radiating back and out from the tip of the central spar to the tips of the radial spars provide bracing against strong winds. Steel wires between the tips of all the radial spars provide additional bracing. A 60-cm diameter flat steel ring around the hub is bolted to each spar to keep them secured tightly within the hub.

3.11 Sails

A triangular cloth sail 2.6 m x 1.2 m x 2.4 m is attached along the long edge to each of the eight radial spars. The loose corner of each sail is secured with rope to the tip of the adjacent spar, thus forming a strong uniform surface for catching the wind. The sails can be wrapped around the spars to control the amount of sail area exposed to the wind.

Note: All measurements are accurate ± 10%.
Photographs are available with the author.

4. Conclusions

The lessons to be learnt in India from the windmills of Lassithiou are:

4.1 Cloth sail windmills can be successfully used for irrigation in some isolated areas.

4.2 Wood is superior to metal for low-speed windmill spars because of its flexibility and light weight.

4.3 The wooden hub used in Crete is similar in construction to a typical Indian bullock-cart hub.

4.4 The steel shaft normally used for making bullock cart axles can readily be fashioned into an excellent windmill crankshaft.

4.5 Wood may be used for the main shaft bearings and connecting rod bearing.

4.6 Ball bearings are not required for the turntable.

4.7 MS steel angle iron can be used to construct durable towers where long strong wood poles are not available.

4.8 A storage tank is important for controlled irrigation.

Note: As a result of these investigations an improved design for a windmill to be manufactured and used in rural India was developed in 1975 by the author and others with technical and financial assistance from Indian Agricultural Research Institute, New Alchemy Institute, East, and Oxford Committee for Famine Relief (OXFAM).

AN INTERIM REPORT: THE DESIGN AND CONSTRUCTION OF AN APPROPRIATE WATER PUMPING WINDMILL FOR INDIAN AGRICULTURE

Marcus M. Sherman

I. Introduction

In many parts of India there are adequate supplies of groundwater which are unavailable to farmers for irrigation during the dry season because of inadequate power sources for pumping. Electricity is commonly available for only four hours of pumping per day, due to heavy energy consumption in the cities and overexpansion of the rural power grid without a corresponding increase in generating capability. Many farmers can never use electric pumps because Government regulations prohibit installation of electric pumps within 128 metres of each other.

Three to eight horsepower diesel oil pumps are frequently used for irrigation but are very expensive to operate because of the high cost of imported oil and high maintenance costs. The traditional bullock-operated pumps remain the most common and reliable source of irrigation water for subsistence farming. Water for domestic use is usually lifted by hand with a rope and bucket from open wells.

During the early 1960s the Wind Power Division of the National Aeronautical Laboratory[1/] developed, tested, and produced 200 12-bladed fan-type windmills which demonstrated the feasibility of using wind power to pump water in India. Several types of imported European and American multi-bladed windmills have also been used to harness India's abundant wind energy resources. However, due to high capital cost of the windmills and high level of technical skills required for maintenance of industrially produced all-metal windmills, windpower is not commonly exploited in India.[2/]

In 1973 the Indian National Council of Science and Technology Expert Committee on Wind Power[3/] in their project on water pumping windmills stated that great possibilities exist in further development of windmills for irrigation as well as water supply, even in areas having low wind velocities of 8-10 k.p.h. They concluded that fabrication of water pumping windmills by indigenous manufacturers is possible and should be encouraged and popularized.

Having observed what appeared to be a classical "*take off*" of wind pump technology in Crete and Cyprus, Duncan Allsebrook,[4/] OXFAM water technology advisor, noted that the elements involved seem to be:

a) the private import of a few sophisticated, efficient windmills;

b) an agricultural economy without the benefit of mechanical implements;

c) rainfall totalling less than 30 inches per annum, with a pronounced dry season;

d) large, flattish basins or plateaus with fertile soils and shallow water tables (15-60 feet below surface);

e) farmers willing to experiment with more intensive agriculture, particularly vegetable gardening and orchards, than has been possible under conditions of limited irrigation;

f) the existence of a large corps of local craftsmen, particularly carpenters, masons and blacksmiths.

II. Design Criteria

In order to surmount many of the difficulties encountered by previous wind power development efforts in India, the following design criteria were chosen for an appropriate windmill prototype.

a) Low wind

The windmill must operate in low wind speeds of 6-8 k.p.h. characteristic of many areas of India during the dry winter and must be adjustable to operate in higher wind velocities up to 40 k.p.h.

b) Pump

The windmill must have high starting torque and low r.p.m. to operate a large bore piston pump or a large diameter diaphragm pump.

c) Irrigation

The windmill must lift 28,570 litres per day from a ten-metre-deep well at an average daily wind velocity of 4-6 k.p.h. in order to irrigate one hectare of field with 2 cm water per week.

d) Low cost

The capital cost must be below Rs 3,000 to be competitive with the capital cost of a diesel or electric pump set.

e) Local materials

All windmill construction should be of common sizes of locally available materials to minimize cost and simplify repairs.

f) Local skills

All construction skills should be those of local craftsmen in order to stimulate the rural economy and increase the degree of involvement of the village people.

g) Operator

It was assumed that the operator would be at the site each day, therefore automatic blade adjustment would not be required.

h) Low maintenance

Maintenance costs and skills should be low.

i) Traditional pump

The windmill should not interfere with the continued operation of the traditional pumping device on the same well.

j) Labour-intensive

Basically, a labour-intensive, capital-conservative design was required.

III. Description of the Windmill

This windmill is the fourth in a series of prototypes that have been built near Madurai, South India, by members of the Madurai Windmill Committee, Rev. C. P. Heineman, T. O. Heineman, Manoharan Selvaraj, M. S. Pillai, S. T. Arasu, M. M. Sherman.5/ 6/ 7/ It is an adaptation of the traditional Greek sail-wing windmill design which is widely used on Crete.8/ 9/ A 25-foot sail-wing windmill with six sails in the classical Greek configuration has been designed by Hans Meyer10/ and tested by Brace Research Institute.

Local purchase of materials commenced on 3 February 1975, and construction of the windmill by the author, A. Manoharan Selvaraj, S. M. Thirunavakarasu, and various local craftsmen continued at a regular daily pace until completion on 25 March when the first pumping trial was made. A public demonstration was given on 29 March.

When the author left Madurai on 19 April 1975, the windmill was operating well, pumping 1,635 litres per hour from a depth of 9.2 metres at an average operating speed of 12 r.p.m. in low winds, estimated to be 6-8 k.p.h. Maximum speed observed was 25 r.p.m.; minimum speed before stopping was 8 r.p.m.; starting speed was 12 r.p.m.

The components of this Indo-Greek windmill pumping system are: well, storage tank, foundation, pump, variable stroke pump lever, tower, turntable base, turntable carriage, tail vane, crankshaft connecting rod, crankshaft, shaft bearings, hub, arms, sails, and operator.

a) Well

The prototype was erected over the corner of a 5 m x 6 m x 8 m deep well dug into a fractured rock aquifer. The well was also fitted with a traditional kumalee bullock pump and a 5 h.p. electric pump. The windmill is located over one corner of the well so it does not interfere with the operation of either of these pumps.

b) Storage tank

A concrete or stone storage tank with at least 30,000-litre capacity is necessary to provide a large quantity of water in a short period of time once daily for flooding the fields. A storage tank may serve as a multipurpose structure by being used for aquaculture and partially as foundation for shelter.

c) Foundation

The foundation of the windmill consists of six heavy steel anchors, four of which are imbedded in concrete in 1-metre-deep, .5 m-diameter holes outside the corner of the well and two of which are fastened to a large stone pillar laid across the corner of the well.

d) Pump

The pump used in the first testing of this windmill is a piston pump with a 10 cm bore and a 61 cm maximum stroke. The pump is attached in the bottom of the well at the end of 9.1 m of 5 cm steel pipe suspended from the stone pillar. The top of the pump piston connecting rod passes up through and out of the top end of the pipe and is secured to the end of the variable stroke pump lever.

e) Variable stroke pump lever

Because the seasonal intensity of the wind varies, it is desirable to vary the load on a windmill for optimum use of the available wind. This is accomplished with a 2.5 m long 5 cm x 20 cm teak beam mounted at the base of the windmill by a fixed axis point at one end and attached to the pump piston rod at the other end. The bottom end of the wooden crankshaft connecting rod is fixed to this lever by a steel bracket at a point between the ends of the lever. This point can be varied to change the length of stroke delivered to the pump connecting rod. The pump lever is also important because it increases the stroke of the crankshaft from 13 cm at the crankshaft to a minimum of 18 cm and a maximum of 36 cm at the pump connecting rod. Increasing the stroke is useful because it permits the use of a smaller bore piston pump which is available in the local market.

f) Tower

The tower is made of six 8-m-long teak poles bolted at the bottom to the steel anchors in the foundation and bolted at the top to the base of the turntable. The base of the tower is 1.8 m in diameter. There are two sets of cross braces nailed to the inside of the tower and a set of internal guy wires. Ladder steps are nailed to the inside. Five additional steps nailed around the tower one metre above ground provide a standing platform for the operator while he is adjusting the sails.

g) Turntable base

The base of the turntable consists of a steel truck tire rim with an inside diameter of 23 cm. The truck rim is drilled and bolted to the tops of the teak poles. The smooth circular platform formed by the inside of the rim is the bearing surface upon which the turntable carriage sits and rotates.

h) Turntable carriage

The turntable carriage is a 1.5 m x 36 cm rectangular iron angle frame which is secured to the turntable base by four bolts which are fixed to two 25 cm pieces of angle iron which rotate on the bottom inside surface of the turntable base. This arrangement keeps the carriage firmly attached to the top of the tower while at the same time allowing it and the attached tail, crankshaft, sails, etc., to turn when the wind direction changes.

i) Tail vane

A 1.3 m x 2.5 m rectangular tail made of bamboo matting in a light teakwood frame is supported by a 3.7 m long piece of heavy duty bamboo pole from the rear of the turntable carriage with two "U" bolts and is braced with guy wires. The tail keeps the sails always facing the wind.

j) Crankshaft connecting rod

This connecting rod was made of two 5 cm x 5 cm x 3 m teak poles bolted together end to end. The bottom of the rod is bolted to a hinged steel bracket which can be moved to different positions along the pump lever. The top of the rod is bolted to a steel swivel which in turn is bolted to a wooden bearing attached to the crank. Since the connecting rod is always in tension and never in compression there are no braces or guides necessary. The swivel allows the crankshaft, etc., to turn in response to changing wind direction without twisting the connecting rod or pump lever.

k) Crankshaft

The crankshaft is the main shaft which directly transfers the horizontal rotary motion from the windmill sails into the vertically reciprocating motion necessary to operate the piston pump. There are no gears or pulleys in the driving mechanism. The crankshaft is made of 3.2 cm mild steel rod which has a crank of 3.2 cm mild steel rod welded at the centre to give a total stroke of 13 cm. A cotter pin at the tail end of the shaft keeps the shaft from sliding forward out of the bearings.

l) Shaft bearings

The crankshaft is supported directly behind the hub and directly behind the crank with two 5 cm thick blocks of hardwood, each with a steel ball bearing in the centre to hold the crank, These wooden bearing blocks are both bolted to the turntable carriage. The front bearing is slightly elevated so that the front of the crankshaft is raised 6^{o} up from the horizontal, thus preventing the tips of the bamboo arms from hitting the legs of the tower.

m) Hub

The hub functions as a connector between the arms of the windmill and the crankshaft. It consists of an ordinary ox cart wheel hub with eight wooden spokes. The spokes are braced to each other with wood. A bamboo arm is attached to each spoke with two "U" bolts. A hole in the centre of the hub fits onto the front end of the crankshaft and is secured by a 1.6 cm bolt "cotter pin."

n) Arms

Eight 4.5-m-long bamboo poles radiate out from the hub to form a total windmill diameter of ten metres. A central supporting spar of bamboo extends out two metres in front of the hub along the main axis of the crankshaft. Number eight gauge single-strand steel wires radiating out and back from the tip of this central spar to the tip of each bamboo arm provides bracing against strong winds. Wires between the tips of all the radial arms provide additional bracing. Bamboo arms have the advantage of high flexibility and tensile strength as well as widespread availability and low cost. Village craftsmen are familiar with bamboo as a building material. Disadvantage of bamboo is that it will split over a long period of time or if mishandled.

o) Sails

Cloth was chosen for the wind-catching surface of the windmill because it is lightweight, easy to handle, readily and cheaply available and it forms a strong uniform surface for catching the wind when supported at three or more points. The eight right-triangular sails were stitched by a local tailor from khaki cloth normally used for bus conductor uniforms. A 10-cm-wide sleeve on the hypotenuse side of each sail allows it to slip on and off the bamboo arms. The tip and hub ends of the sleeve are tied securely to their respective ends of the bamboo arms. The 90^{o} corner of each sail is secured by a rope of coconut husk fibre to the tip of the adjacent arm.

p) Operator

It is important to have a trained person daily at the site to control the windmill, direct water flow, and make minor repairs.

IV. Control Mechanisms

a) Manual

The operator is the primary control mechanism of this appropriate windmill. The windmill is stopped by one or two ground assistants who pull the ropes hanging from the end of the bamboo tail boom. This pulling of the tail into the wind turns the turntable carriage so that the sails turn out of the wind and stop rotating. The operator wraps each sail one or more times around each arm in order to decrease sail area in higher winds. During highest winds and gusty local storms the sails are fully wrapped and secured around the arms. It is possible to furl only two, four, or six sails during highest operating speeds. The operator adjusts the windmill to seasonal changes in wind velocity by moving the steel bracket at the bottom of the wooden connecting rod to different points along the variable stroke pump lever. Thus the pump stroke can be varied from 18 to 36 cm.

b) Automatic

The tail automatically points the full area of the sails toward the wind in front of the tower. Emergency automatic feathering of the sails is provided for by using a 1.3 cm coconut fibre rope as the tension member from the 90^{o} corner of each sail to the tips of the adjacent arm. When the wind speed increases to a high level this weakest connection in the energy transfer would break before loads on the other materials became destructive. The feathered sails would, however, flap against the tower, chafe, and perhaps tear, if not promptly attended to.

V. Construction Expenses

a) Materials

Hub	Rs 35.00
Lorry rim	40.00
Bolts	248.68
Washers, rivets, nails, cotters, etc. (hardware)	32.68

a) Materials (contd)

Steel flats, plates, rods, angles, clamps	Rs	549.92
5 cm pipes, fittings		264.87
Ball bearings (2)		36.00
G.I. wires		125.12
Wooden reapers, lever beam		271.14
Teakwood poles		197.00
Bamboos		136.50
Paints, turpentine		170.25
Stones		140.00
Cement		158.91
Cloth, thread		702.01
Tools		54.63
Miscellaneous contingencies		149.09
	Rs	3,311.80

b) Labour

Honorariums, salaries	Rs	900.00
Bata (food)		150.00
Labourers' cooly		46.00
Blacksmithy, welding, machine shop		317.25
Tailor		73.00
Masons		47.00
Carpenters		172.50
	Rs	1,705.75

c) Transportation

Local travel, bus, cycle rent	Rs	149.60
Transport for materials		164.00
	Rs	313.60
Total	Rs	5,331.15

VI. Power Equation

The eight-bladed Greek sail configuration of this windmill is ten metres in diameter and starts in a minimum wind velocity of 6-8 k.p.h. Theoretical useful power of the windmill is .133 KW at 8 k.p.h.

Power equation: $P = KAV^3 \, CpE_1E_2$

where:

- P = power in kilowatts delivered to water
- K = metric constant, .0000137
- A = $3.14 \, R^2$ (R = 5 metres)
- V = wind velocity (8 k.p.h.)
- Cp = power coefficient where .593 is theoretical maximum (.3 is used for the sail windmill)
- E_1 = efficiency of power transfer 95%
- E_2 = efficiency of pump 85%

Theoretically 5,222 litres/hour of H_2O can be pumped up ten metres in an 8 k.p.h. wind.

.133 KW x 737.56 ft lbs/sec x 3,600 sec ÷ 32 ft ÷ 8/lb = 1,379 gallons (5,222 litres).

Actually 1,636 litres (432 US gallons)/hour were pumped from 9.2 metres in 6-8 k.p.h. wind.

VII. Implementation Suggestions

a) Handicraft

Dutch, Mediterranean and Chinese history proves that less industrialized countries can provide themselves with a great deal of applied windpower if local skills and materials are used through the adaptation of handicraft techniques. In order for wide-scale utilization of windpower to occur in India, it is important that there be a widespread diffusion of the knowledge of the possibilities of windmills in favourable areas, in addition to adapting modern windmill technology to traditional skills and materials by regional engineering institutions. Particularly at the beginning of windmill implementation programmes, the design should be as simple as possible in order to effectively introduce windpower to people having no previous conception of its possibilities.

b) Demonstrations

Real demand by farmers for windmills must be created by actual demonstrations of windmills in practical operation. Questionnaires and information pamphlets should be available to interested persons.

The biggest problem of windmill implementation is that each installation must be engineered to a different load and different wind conditions. This problem may be overcome by developing a standardized technique to properly match local conditions of wind, groundwater depth and water requirements with proper pump sizes and windmill diameters and having regional centres for evaluation of windmill questionnaires and making recommendations for suitable windmill designs.

c) Kit

It may be insufficient to supply local craftsmen with blueprints and written instructions only. Stam[11/] suggested that it is better to provide a construction kit. Such a kit may include a strip story illustrated instruction, clearly understandable for people who cannot read, together with the essential welded metal parts that cannot be fabricated in a village. The kit should also contain a scale model built from bamboo and paper.

d) Alternative utilization

Efforts should be made to develop alternative means of utilization of wind power for interruptible, variable-speed mechanical tasks such as water pumping for public water supply, grain thrashing, winnowing and grinding, sugar cane crushing, wood cutting and turning, fodder chopping, compost grinding, oil pressing, cable plowing, stirring of slurry in methane gas plants, stirring of algae cultures, so that these power loads may stop consuming nonrenewable energy resources.

e) Current evaluation

The Indo-Greek windmill is currently being evaluated for use in windpower development schemes in India by the Gandhian Institute of Studies,[12/] Varanasi, and the Indian Agricultural Research Institute,[13/] New Delhi.

VIII. Conclusion

It is the author's opinion that this appropriate windmill design concept can be used economically in many rural areas of India due to its low cost, high power output, wide availability of the materials and construction skills and a capability for sail and pump adjustments for running in both high and low wind velocities. However, further development work is needed.

IX. Acknowledgements

On behalf of the Madurai Windmill Committee, the author takes this opportunity to express sincere thanks to J. and E. Staley of the Oxford Committee for Famine Relief (OXFAM), Bangalore, South India, for their support. He is pleased to acknowledge the assistance of Dr. K. Kanungo and Dr. D. K. Biswas of the Indian Agricultural Research Institute, New Delhi, in preparing detailed drawings of the windmill. The author is most grateful to the New Alchemy Institute - East for their continuing support of his travel expenses to and from India.

X. Addenda

Rev. C. P. Heineman, Treasurer of the Madurai Windmill Committee, reported on 21 August 1975 that:

"As yet, there has not been much show of interest around in villages, probably because the windmill is not working now. I feel there are some points that have to be overcome before this type of windmill could be established. It has so far required a lot of adjustment to get it to work after unwrapping the sails. Quite a few points show strain due to the construction materials used, and the power on the mill because of such a large diameter. As it stands at present, I am afraid it will get out of order frequently, and maintenance is not an Indian virtue. More of a compromise has to be made with utilizing sophisticated methods at points, and better materials. This is only my opinion."

Mr. T. O. Heineman, member of the Madurai Windmill Committee, reported on 28 August 1975:

"In considering capital cost it may be noted that the capital cost or materials cost of an experimental prototype will be quite different from the cost to a farmer of a proven design. Even the cost of a proven design will descend after one or two years due to various economic factors typical of all new products. Thus an experimental prototype costing Rs 4,000 (not including salaries of researchers and other establishment costs) could be copied by independent farmers for Rs 3,000 to Rs 3,500 and by entrepreneurs for even less.

Electric pump 5 h.p.: 40-50 thousand lt/hr.

Kumalee: 100 lt/bucket x 3 buckets/minute x 60 m/hr = 18,000 lt/hr.

Foundation: I believe that one of the things this prototype proved was that the stone pillar across well corner is unnecessary and mill can be completely aside well corner.

Tower: For durability, seasoning of the teak poles or any treatment to prevent splitting is essential. Unfortunately, letting poles lay around while they season means capital is being locked up which will raise costs. Otherwise the tower has been proven an asset of this design.

The turntable base is an asset of this design.

Turntable carriage: Perhaps wooden beams would give strength economically, with metal seats to ride on base.

The tail vane is a minor liability of the design. It must be redesigned to last years.

Crankshaft: I believe the car or truck crank is the answer for this, combined with brake drum for hub.

Hub: Believe that wood is best avoided here as strength and rigidity are crucial. The force exerted on the hub is tremendous, especially at point of transfer to shaft. The number of problems solved by a metal piece here would be many whereas the problem of weight of this metal would be easier to contend with. The hub is at the root of a number of problems with the arms.

Arms: I think bamboo has potential, but some problems: it gives with wind so much that sails hitting tower are so far the major problem with this mill. First, I'd like to try kull bamboo. And this I'd like to treat the same as flutes and pole vault poles for straightness and durability. The attachment to hub and the hub's spokes must be absolutely rigid as 1" play at hub can multiply along the length to the tip. Also the "nose" must be very rigid, again because just an inch of play can multiply into much play at sail arm tips. Under wind pressure I believe the bamboo flexes so that the tips actually move forward, loosening the circumferential wires and allowing the tied corner of sail to go backwards and hit tower. A certain amount of this flexing will have to be lived with and need not be a problem.

Sails: They will probably fray at the leading edge against the bamboo arm. Perhaps metal rings could be used. It might be noted that the sails are the most expensive, by far, single component and that, since power is proportional to square area, their quantity (in square units) cannot be scrimped on to reduce costs. But if any other way were conceived of to economize here, overall economy would be significantly effected.

Pump: Though not put in final form yet, I doubt if you can beat a piston pump of appropriate size.

I think the biggest problem of windmill implementation is that there is not nearly enough actual live experimentation. Since we are interested in low-tech. and cost, designs must vary from area to area depending on local resources. Since the mathematical number of variations of design, and permutation of design variabilities of each segment, is extremely large, I am very surprised that the various people involved in windpower development that I have seen have actually built so few prototypes. I'd like to see someone hand someone else Rs 100,000 and say: "See how many mills you can build in one year, and then I'll give you enough to see how many times you can rebuild each of those in successive modifications for the next year.". I think two years and 2×10^5 Rs later one could easily have created the splash that would ripple to and change every corner of India. The things that this windmill has proven are enough to warrant that. It attracted community interest and has overcome many major technical problems. Further development depends on people with general technical know-how and lots of creative application skills.

XI. References

1/ Nilakantan, P.; Ramakrishnan, K. P.; Venkiteshwaran, S. P.; Windmill Types Considered Suitable for Large-scale Use in India. Tech. Note No TN-WP-3-61, National Aeronautical Laboratory, Bangalore, India, August 1961, 37 pp. Also, Proceedings: UN Conf. New Sources of Energy, Rome, 21-31 August 1961, Vol 7, Paper W/23, pp 382-9.

2/ Sherman, M. M.; Wind Powered Water Pumps in India; Past, Present and Future Developments. Proceedings: Seventh Annual All India Workshop on Farm Machinery Research and Development, Punjab Agricultural University, Ludhiana, 1974.

3/ National Council of Science and Technology, Report of the NCST Expert Committee on Wind Power, Government of India, New Delhi, 1973.

4/ Allsebrook, Duncan; Personal Communication, 25 October 1974.

5/ Sherman, M. M.; A Windmill in India. The Journal of the Alchemists I; The New Alchemy Institute, Woods Hole, Massachusetts, 1973.

6/ Sherman, M. M.; The Sailwing Windmill and Its Adaptation for Use in Rural India. Proceedings: All India Conference on Solar Energy (Indian Institute of Technology), Madras, 1973. Also: Proceedings: National Science Foundation/National Aeronautics and Space Administration Workshop on Wind Energy Conversion Systems, Washington D.C., 1973.

7/ Sherman, M. M.; Madurai Prototype Sailwing Windmill. The Energy Primer Portola Institute, Menlo Park, California, 1975, p 61.

8/ Calvert, N. G.; Windpower in Eastern Crete. Transactions Newcomen Society, Vol XLIV, pp 137-144, 1971-1972.

9/ Sherman, M. M.; 6,000 Handcrafted Sailwing Windmills of Lassithious, Greece, and Their Relevance to Windmill Development in Rural India. Proceedings: All India Conference on Solar Energy, Motilal Nehru Engineering College, Allahabad, 1974.

10/ Meyer, Hans; Plans for a 25' Sailwing Windmill. Windworks, Box 329, Rt. 3, Mukwanago, Wisconsin 51349.

11/ Stam, H.; Adaptation of Windmill Designs, with Special Regard to the Needs of the Less Industrialized Areas. Proceedings: UN Conference on New Sources of Energy, 11961, Vol 7, Wind Power W/40, p 354.

12/ Hoda, M. M.; Gandhian Institute of Studies, Rajghat, Varanasi, India.

13/ Biswas, D. K.; Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, 110012, India.

AN AIR-OPERATED DEEP-WELL PUMP WITH TWO TYPES OF WINDMILLS

Jack Park

Based on operating experience with several types of wind-power devices, two specific windmill designs are being developed for pumping water from deep wells by means of compressed air.

The components of the windmill pumping system are illustrated in Figure 1. The two windmill designs are illustrated in Photographs 1 and 2. These two designs represent distinctly different design considerations.

Photo 1 illustrates a vertical axis Darrieus-type rotor in combination with sailwing blades. Three blades were tested with this prototype; more blades, or less, may be suitable, although three seem best from a vibration standpoint. This design is useful for regions of gusty winds of variable direction and, while its specific output power is slightly lower than the windmill of Photo 2, its yield of water-per-hour can be higher in such gusty locations.

Photo 2 illustrates a conventional horizontal axis wind rotor. The particular unit shown is an electric generator with the streamline cowling removed. The blades and carriage of this unit are being adapted to accept mounting at a suitable air pump.

Operation of the air pump system is as follows: windmill power operates an air pump of suitable size and design which pressurizes a manifold. Air pressure may, or may not, be stored in a pressure tank for demand pumping. This air pressure is piped to a submerged positive displacement air-operated water pump. Pump exhaust air and water are ducted upward to a water storage tank where exhaust air is released.

To digress, starting torque problems are reduced and the use of a high-efficiency, high-speed windmill is possible in this system, since high pressure is not required, and simple by-pass fuse-type air valves may be designed to permit easy starting. Additionally, an air-operated positive displacement pump has been designed which produces reasonable water flow without sensitivity to dirt and other foreign particle damage. This pump is currently constructed of plastics, and its suitability to windmill deep well pumping is being tested.

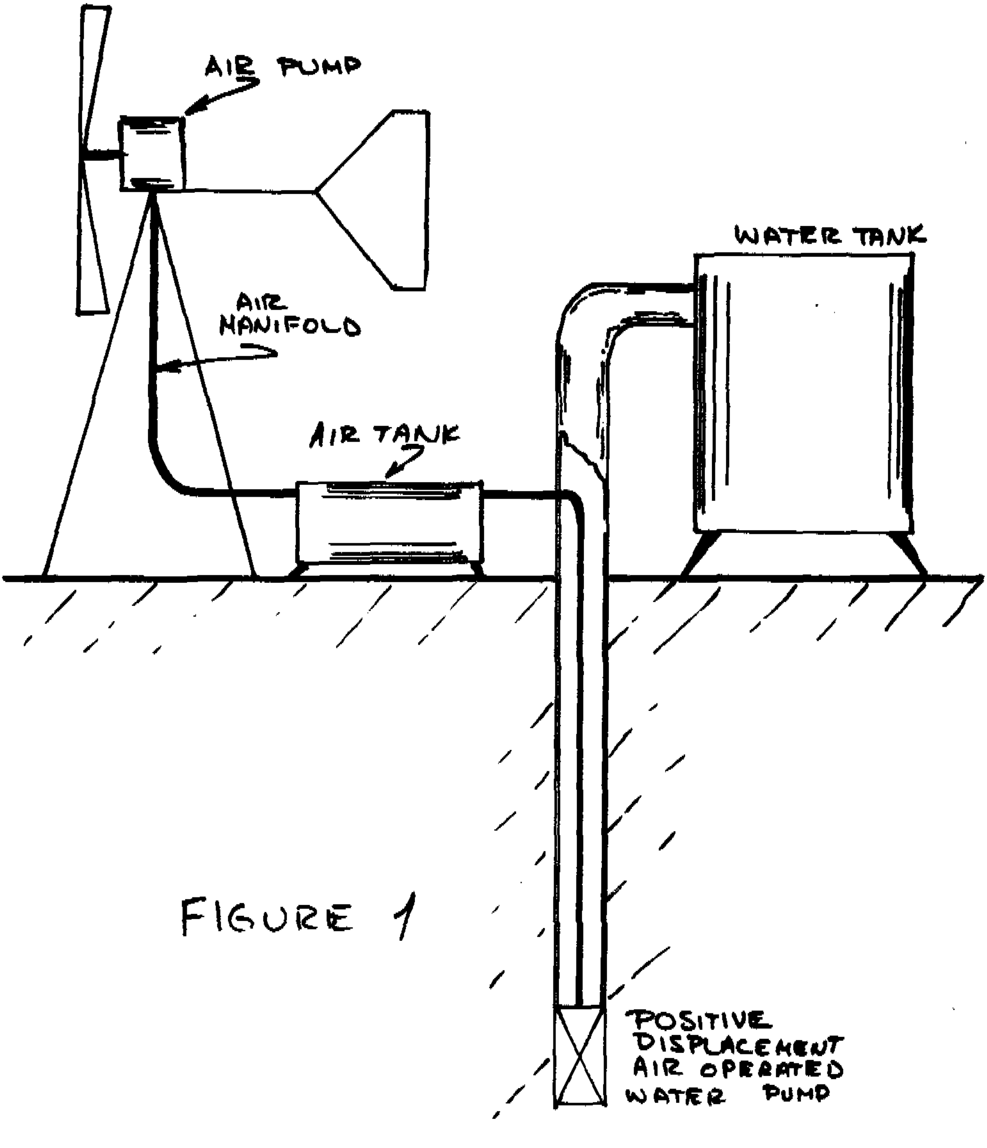

AIR PUMP
AIR
MANIFOLD
AIR TANK
WATER TANK
POSITIVE
DISPLACEMENT
AIR OPERATED
WATER PUMP

FIGURE 1

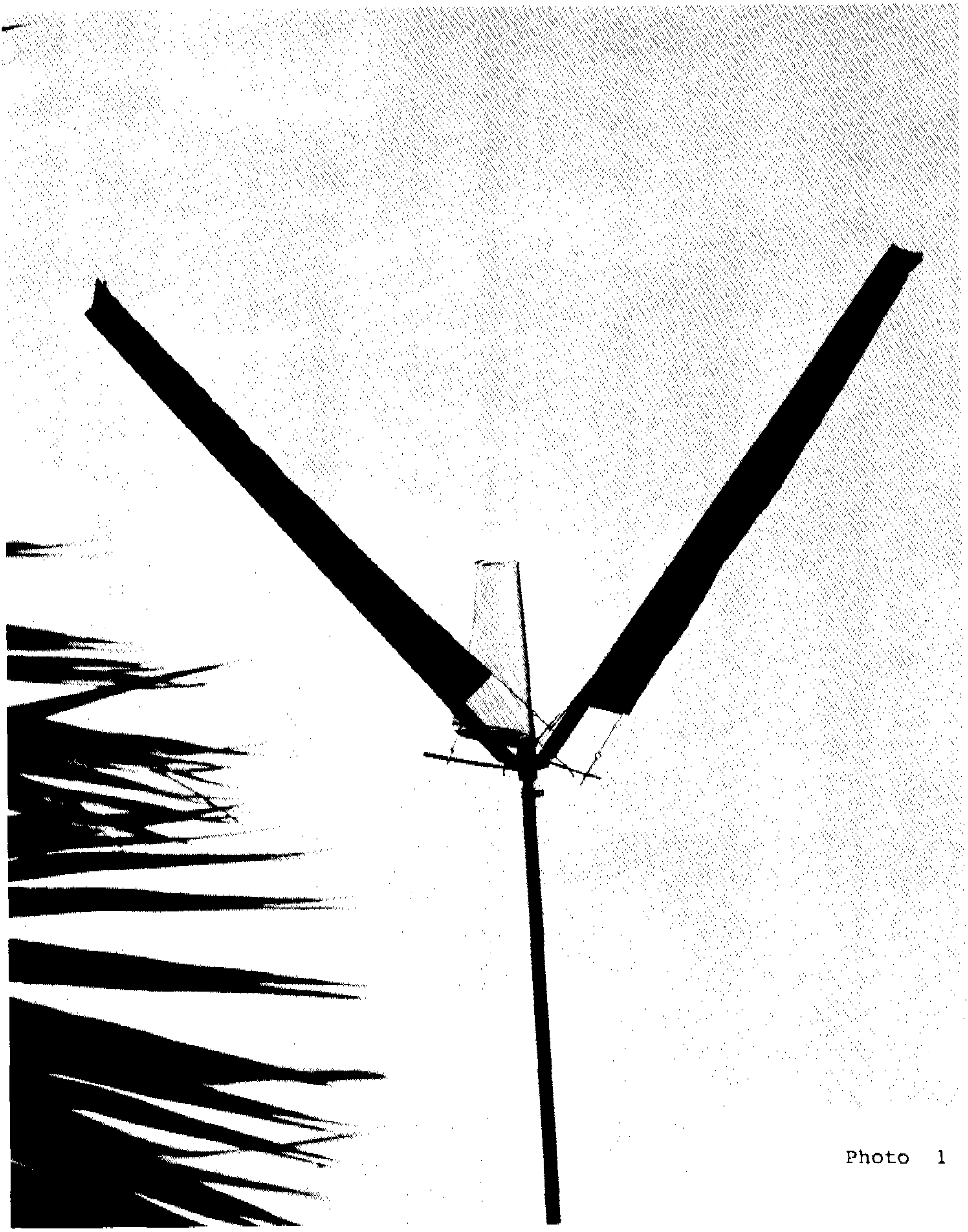


Photo 1

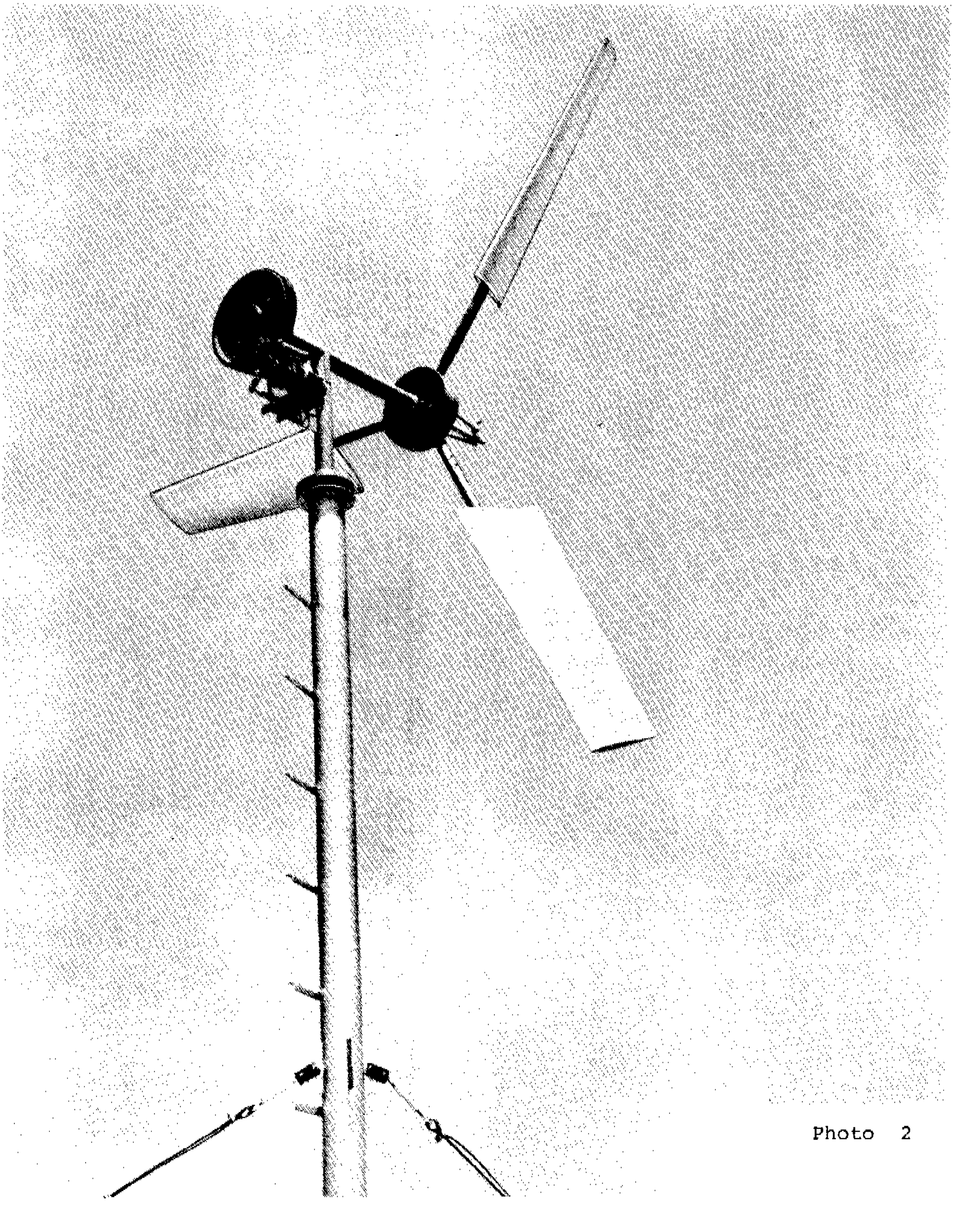


Photo 2

SIMPLE ANEMOMETRIC EQUIPMENT

Dipl.-Ing. Paul Dubach

1. Abstract

The search for simple equipment to be used in developing countries (appropriate technology) is facilitated if the totality of all possible solutions can be taken as a point of departure. These solutions can be found by means of the morphological method. A simple anemometric device built from local materials according to the run-out principle can be erected and operated by local people. The morphological method as well as the anemometric equipment are described in this paper.

2. Method For the Design of Anemometric Equipment

2.1 Introduction

Besides the precise collection of anemometric data over large areas by means of highly sensitive instruments for meteorological purposes, the local wind data collection for the design of small-scale devices is important for certain industrialized countries as well as for the developing countries. My experience as a lecturer of appropriate technologies with the Federal Technical School have shown that it is not quite so easy to design simple devices, as the measuring apparatuses are highly sensitive. That is why we use a method that enables us in principle to find all solutions of a given problem. Professor Dr Zwicky (see bibliography no. 1) calls this method the morphological method.

It should be mentioned briefly in this context that Professor Zwicky (1896-1974) was the initiator of Swiss Development Aid. In 1949, after a visit to Taiwan, he encouraged some Swiss citizens to form a Swiss Forward Team to Nepal (1950-51). This initial programme led in 1955 to the constitution of the Swiss Association for Technical Aid to Developing Countries (Helvetas) which I am representing here.

2.2 The Morphological Method

Zwicky defines morphology as follows: "Morphology is dealing with the shape and structure of problem fields for the purpose of finding in a methodical and systematic way the totality of the solutions to a given problem."

Fig. 1 shows the three kinds of morphology, among them the method of systematic field overlapping in the example of the periodical system of chemical elements (Meyer, Mendeleev 1869) which is universally known.

Fig. 2 illustrates in a more detailed manner the method of the morphological box.

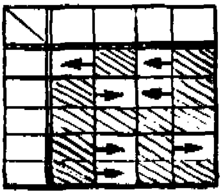
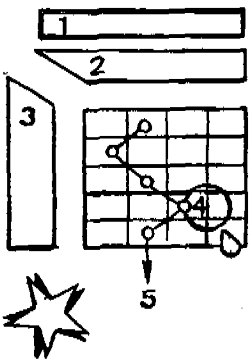
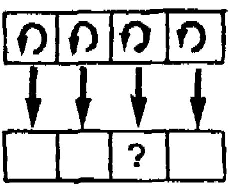
Symbol	Name and description of the proceedings	Application
	1) Systematic overlapping of fields. The necessary thinking principles are based on the capacity of counting and of recognizing coincidences and non-coincidences in space and time	**Integral planning and construction** **Example: periodical system of chemical elements**
	2) Morphological box 1st step: accurate definition of the problem 2nd step: localization of solution elements and barriers 3rd step: construction of a polydimensional scheme (box) where all possible solutions are grouped 4th step: evaluation 5th step: adoption of the optimal solution	The totality of relations between various phenomena Example: kinds of energy and their conversion on this basis: search for new fuels. Example: search for the entire class of jets running on chemical fuels
	3) Negation and construction 3.1 Based on known substances with properties e_1, $e_2 \ldots e_n$, search for new substances S' lacking the "e" property 3.2 Contestation of the universal validity of the laws of nature, by means of tests and observations made under extreme circumstances	Example: the invention of new detonators Example: the systematic discovery of new phenomena and new laws of nature

Figure 1

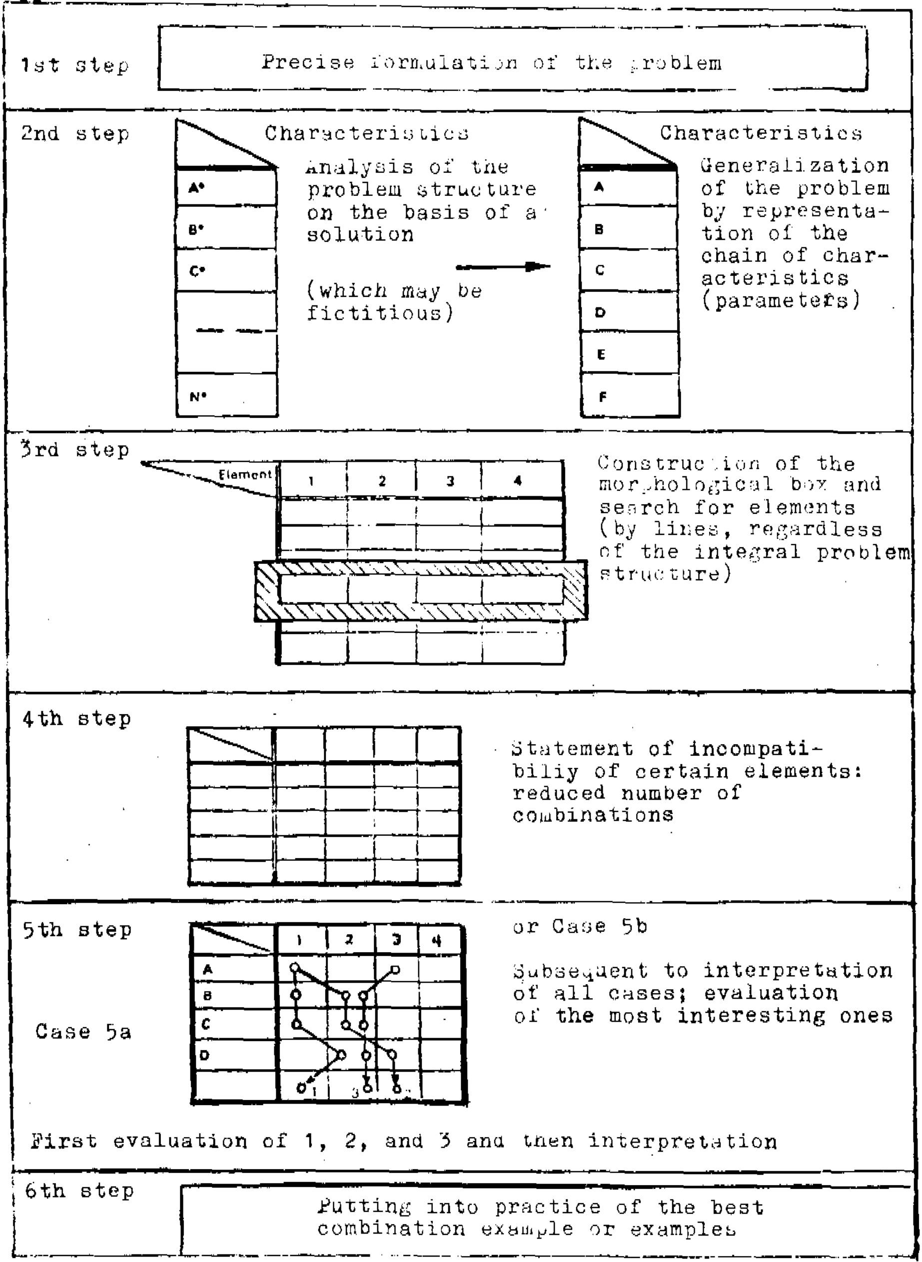

1st step
Precise formulation of the problem
2nd step
Characteristics
Analysis of the problem structure on the basis of a solution
(which may be fictitious)
A'
B'
C'
N'
Characteristics
Generalization of the problem by representation of the chain of characteristics (parameters)
A
B
C
D
E
F
3rd step
Element
1
2
3
4
Construction of the morphological box and search for elements (by lines, regardless of the integral problem structure)
4th step
Statement of incompatibiliy of certain elements: reduced number of combinations
5th step
Case 5a
1
2
3
4
A
B
C
D
or Case 5b
Subsequent to interpretation of all cases; evaluation of the most interesting ones
First evaluation of 1, 2, and 3 and then interpretation
6th step
Putting into practice of the best combination example or examples

Figure 2

2.3 Morphology of Possible Anemometric Equipment

A known equipment (shell anemometer) comprises elements that can be described according to their characteristics as follows:

A_5 B_2 C_3 D_5 E_1 F_1 G_2 H_2 J_3 K_2 L_1 M_1 N_6 O_1 P_5 Q_4

These characteristics are reported on the morphological box of fig. 4. For each line and for each characteristic, all elements fitting the characteristic concerned are then sought.

Every measuring device consists of sensors, converters, indicators, recording elements and recording devices. The conversion of the signals can take place by several stages. We will confine ourselves to two stages, which will result in the two-dimensional submorphology, as shown in fig. 3. Not all the 36 combinations are reported on the lines B, C, H and J.

Converter	mech. 1	pneum. 2	hydr. 3	electr. 4	therm. 5	opt. 6
1 mech.	11	12	13	14	15	16
2 pneum.	21	22	23	24	25	26
3 hydr.	31	32	33	34	35	36
4 electr.	41	42	43	44	45	46
5 therm.	51	52	53	54	55	56
6 opt.	61	62	63	64	65	66

Fig. 3 Submorphology

The morphological box (fig. 4) shows all elements known (to us). An anemometric equipment will comprise one element of each line. Even if not all combinations will make sense ($9 x 7 x 12 x 9 x 8 x 8 x 6 x 7 x 12 x 5 x 6 x 7 x 7 x 8 x 6 x 4 = 6,2 \times 10^{13}$ combinations), the exploitation of the morphological box will demonstrate that a number of interesting solutions for our purposes can be found.

Six of them are described as examples in the following.

M E	1	2	3	4	5	6	7	8	9	10	11	12&ff
A wind intensity sensor	nil	deflector	Pitot tube	displ. element	shell anemomtr.	windmill anemomt.	hot-wire	object obs.	retard. disk			
B wind intensity converter I	nil	pneum. mech.	pneum. pneu.	pneum. hydr.	pneum. electr.	pneum. therm.	pneum. opt.					
C wind intensity converter II	nil	mech. mech.	mech. electr.	mech. opt.	mech. hydr.	hydr. electr.	hydr. opt.	electr. mech.	electr. pneum.	electr. electr.	electr. opt.	hydr. electr.
D wind intensity	nil	obs. displ.	press. column	speed	pointer el.	screen	sound frequ.	object pos.	object pos.diff.			
E wind intensity recording	nil	point recorder	line record.	digital reading	photo	fluid	liquid	electron. ray				
F wind intensity	nil	vessel filling	vessel spec.pos.	paper	memory	screen photo	digital memory	condens.				
G wind direction sensor	nil	wind-T	multiple nozzle	object obs.	press. distr.cyl.	displ. elem.						
H wind direction converter I	nil	pneum. mech.	pneum. pneum.	pneum. hydr.	pneum. electr.	pneum. therm.	pneum. opt.					
J wind direction converter II	nil	mech. mech.	mech. electr.	mech. opt.	mech. hydr.	hydr. electr.	hydr. opt.	electr. mech.	electr. pneum.	electr. electr.	electr. opt.	therm. electr.
K wind direction indication	nil	pointer el.	shadow	displ. obs.	screen							
L wind direction recording	nil	point recorder	line record.	digital reading	fluid	electronic ray						
M wind direction registration	nil	paper	vessel filling	vessel spec.pos.	photo	screen photo	condenser					
N external energy	nil	potential	wind up spring	pile	electr. connect.	own generator	weight					
O additional charge	nil	hourly	daily	weekly	monthly	annually	after several years	permanent connection				
P calibration	nil	autom.	relative values	locally	in shop	calcul. coord.						
Q local material	all	most	partly	nil								

Figure 4: morphological box

Examples:
a) windmill type anemometer with direct reading
b) balloon observation on the radar
c) wind-T
d) hot-wire anemometer
e) windmaster
f) run-out anemometer

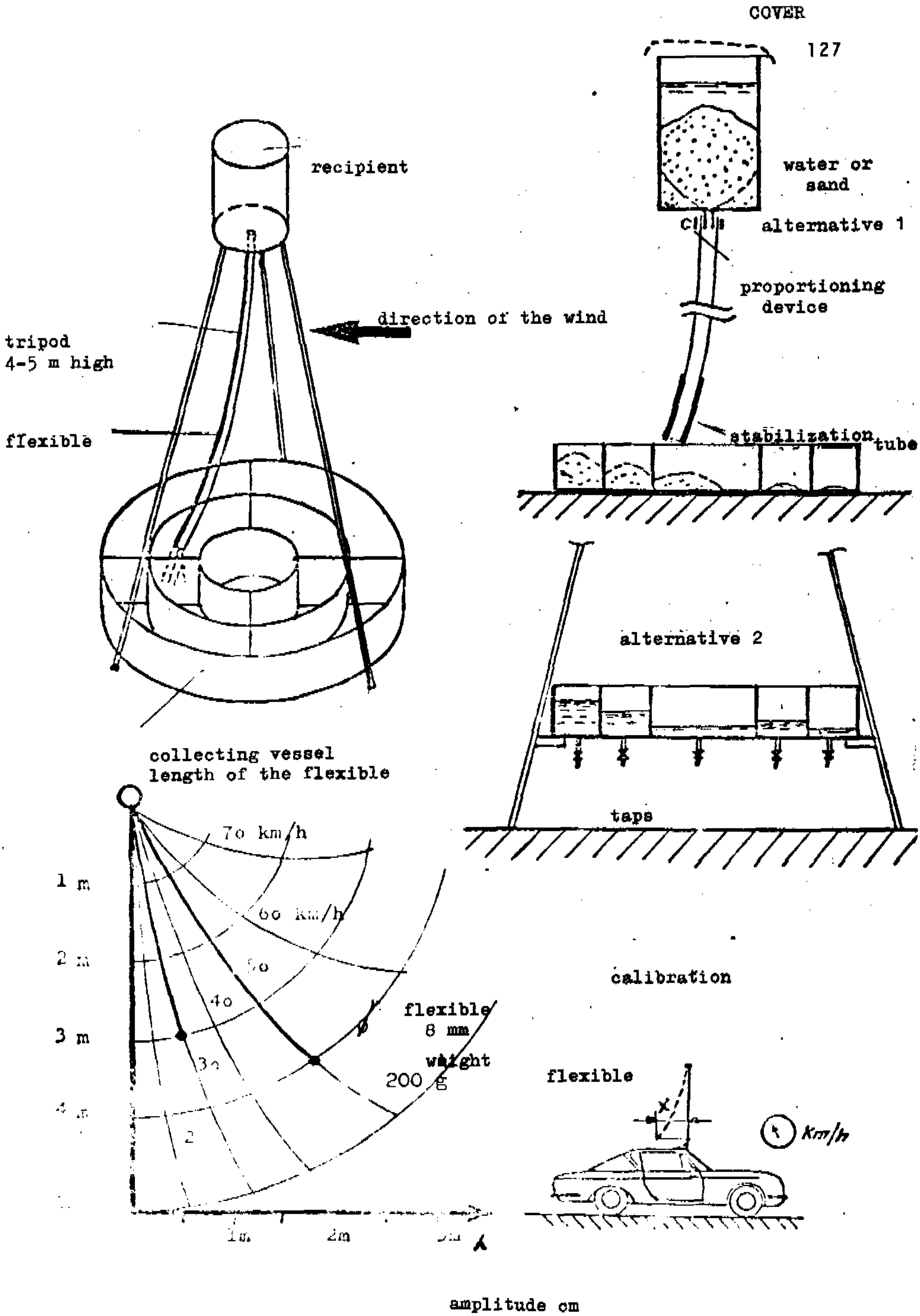
a)	A_6 B_2 C_3 D_5 E_1 F_1 G_1 H_1 J_1 K_1 L_1 M_1 N_6 O_1 P_5 Q_4
b)	A_8 B_2 C_3 D_9 E_8 F_6 G_4 H_1 J_3 K_5 L_6 M_6 N_5 O_8 P_6 Q_4
c)	A_1 B_1 C_1 D_1 E_1 F_1 G_2 H_2 J_1 K_4 L_1 M_1 N_1 O_1 P_4 Q_1
d)	A_7 B_6 C_{12} D_5 E_{23} F_4 G_1 H_1 J_1 K_1 L_1 M_1 N_5 O_8 P_5 Q_4
e)	A_5 B_2 C_3 D_5 E_1 F_1 G_2 H_2 J_3 K_2 L_1 M_1 N_6 O_1 P_5 Q_4
f)	A_4 B_2 C_5 D_2 E_6 F_3 G_6 H_2 J_5 K_4 L_5 M_4 N_2 O_4 P_4 Q_2

The elements N_2, P_4 and $Q_{1,2}$ are of decisive importance for the use of the devices in developing countries.

3. Construction of the Anemometer Apparatus

The device can be run either with water or with dry, fine sand. In both cases, a recipient (e.g. an old petrol barrel) will serve as a reservoir for the indicating fluid. The size of the recipient will be chosen according to the refill frequency. The recipient is mounted on tripods at least four to five metres high. In areas with high wind intensity, the tripod must be braced. In very rainy areas the device must be covered when it runs on sand. When water is used as an indicating fluid, then a possibility of correction has to be provided for by means of simultaneous, and separate, pluviometry. The same applies in cases of strong evaporation and longer reading intervals.

The collecting recipient (e.g. made of sheet metal) can be divided in as many rings and sectors as the measuring precision may require. A construction comprising four rings and eight sectors has given good results (fig. 5 shows three rings and four sectors). A collecting device which is mounted on the supports from the soil upwards gives the advantage of being able to discharge water or sand into measuring vessels. In such cases, it is convenient to use vessels whose bases are equal in squaring (a geometrical formula is given in the appendix.



COVER
water or sand
alternative 1
proportioning device
stabilization tube
recipient
direction of the wind
tripod 4-5 m high
flexible
collecting vessel
length of the flexible
70 km/h
60 km/h
50
40
30
2
1 m
2 m
3 m
flexible 8 mm
weight 200 g
2m
amplitude cm
alternative 2
taps
calibration
flexible
km/h

Fig.5

The best flexible will be one of rubber (according to experience) having an external diameter of about 10 mm and a thickness of 1 - 1.5 mm. The lower part of the flexible has to be stabilized by covering it with a tube. By means of a proportioning device, the quantity of the indicating fluid (water, sand, etc.) can be adjusted.

Calibration of the Devices

Each individual flexible with its stabilization tube must be calibrated in its original length. This is done best by mounting it on the running gear of a motor car. The "speed of the wind" will then correspond to the speedometer reading. For this calibration, the flexible has to be full of water or sand, for this changes its elasticity. The length of the stabilization tube has also to be checked to know whether it is sufficient. In order to adjust the lateral displacement (excursion) X to the width of the measuring rings, one can either modify the length of the flexible to a certain extent or apply an additional charge (thicker stabilization tube etc.). Fig. 5 shows the values of lateral displacement for a rubber flexible four metres long and 10 mm thick.

Calculation of the Ring Diameter (see fig. 6):

$$F = \frac{d_1^2 \cdot \pi}{4} \longrightarrow d_1 = \sqrt{\frac{4 \cdot F}{\pi}} \longrightarrow d_1 = \underline{1,1283 \; F}$$

$$8F = \frac{\pi}{4}(d_2^2 - d_1^2) \qquad = \qquad 8F = \frac{\pi}{4}\left(d_2^2 - \frac{F \cdot 4}{\pi}\right)$$

$$d_2^2 = \frac{4 \cdot 8 \cdot F}{\pi} + \frac{4 \cdot F}{\pi}$$

$$d_2 = \sqrt{\frac{4 \cdot 9 \cdot F}{\pi}} = \underline{3,385 \; F}$$

$$d_3 = \qquad = \underline{4,652 \; F}$$

$$d_4 = \qquad = \underline{5,641 \; F}$$

Example: $d_1 = 0,504$ m
$d_2 = 1,514$ m
$d_3 = 2,080$ m
$d_4 = 2,522$ m

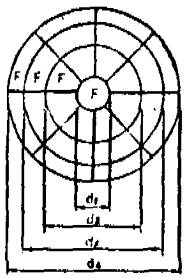


Fig.6

4. Bibliography

1) Zwicky, F.: Entdecken, Erfinden, Forschen im morphologischen Weltbild. Droemer Knauer, München, 1971.

2) Proceedings of the United Nations Conference on New Sources of Energy. Rome, August 1961, Vol 7, Windpower; United Nations, New York, 1964.

3) Seminar Windenergie, Jülich, 12. September 1974, Jülich, 1974.

4) Savino, J.M.: Wind Energy Conservation, Workshop Washington. Cleveland-O, Lewis Research Center, 1973.

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP II: WIND ENERGY

I. Needs

An exposê was given by Mr S. Ali on the problems of water supply in Somalia. In general it was felt that persons from western countries lack insight into the varying needs in different developing countries.

II. Anemometry

The discussion was opened by Mr Dubach, who called for a methodological approach in finding appropriate solutions to a problem with certain constraints. As an example, he explained the design of a very simple anemometer. It was generally felt that for in situ measurements (e.g., in hilly or mountainous areas) there is a need for simple, reliable, and sufficiently accurate wind-measuring equipment, especially integrating systems. Two approaches were mentioned. One was the sampling of data on a cheap tape, which could then be analyzed with the aid of computers elsewhere. The other was the involvement of the inhabitants in collecting the data, thereby serving the educational purpose of bringing about a feeling of strengths and values of winds in the area.

III. Design

Mr Park showed the process of development of a wind generator (4 m diameter) for electricity generation. The first conclusion, confirmed by Professor Hütter, was that the horizontal axis machine offers the least problems in terms of vibrations, costs, etc. The second was that pitch adjustment is the best solution for control problems. The third was that solving the problems of mounting the machine on a tower is as essential as the design of the machine itself.

Mills of the 5 m to 15 m diameter class are the most difficult because for economic reasons external control systems cannot be used; for bigger machines external control systems (e.g., hydraulic) comprise only a very small part of total costs.

The 5 m to 15 m diameter class seems most fit for water pumping, heat production, and cooling for farms, the 15 m class for communities for electricity generation with stand-by diesels. Very big machines (100 kW - 1 MW) are best suited for public electricity networks.

As regards deep well pumping (100 m or more), it was felt that electricity production in combination with submerged electrical pumps seems the best solution.

IV. Appropriate Solutions

As regards the technological sophistication of windmill designs, the general consent was that there is, at this moment, a place for every type of windmill, from the Greek (Cretan) mill with triangular sails to the more sophisticated propeller type, the choice depending on a variety of local conditions.

Two constraints, however, were put forward:

- the basic principle of the machine should be sound;
- the machine, regardless of its simplicity or complexity, should be designed according to 1975 available knowledge and insight.

V. Consideration of Conditions

Appropriate technology should consider the peculiarity of the conditions of each country.

In Somalia, where underground water is too deep (200 to 450 m) and the cost of a drilled well is about US$ 30,000, it became suitable to use electrical generating sets and submersible pumps instead of windmills for pumping water, because the former have the advantage of more output and more capability of lifting.

In the same way the most economic way to supply water for big farms in the agricultural area is to use bigger pumps providing 200 and more m^3 per hour. Windmills will find their appropriate application in the isolated rural villages, where they can supply water and energy.

III. SOLAR PUMPING AND ELECTRICITY SUPPLY

SOLAR THERMAL POWER STATION WITH 10 kW OUTPUT FOR PUMPING AND ELECTRICAL APPLICATIONS

Dr. Ing. W. Kleinkauf, Dr. Ing. Rainer Köhne, and
Dipl.-Ing. Michael Simon

The following coworkers are participating in the development of the solar power plant:

Dr. Ing. K. Schreitmüller	DFVLR
Dipl. Phys. F. Lindner	DFVLR
Dr. Phys. W. Eder	M.A.N.
Dipl.-Ing. R. Brunner	M.A.N.
Dipl.-Ing. R. Nika	M.A.N.

The sum of annual sunshine hours is very high for regions at latitudes between 30^{0} North and 30^{0} South. The values run from 2.800 and 3.000 up to 4.000 hours a year in extreme cases (Tchad, Libya). Solar energy devices for various purposes, e.g. current generation for communication systems or supply of mechanical energy for water pumping are therefore best suited for these countries.

Figure 1 shows the hourly variations of normal insolation on a clear day at solstice. The assumed maximum at noon is 950 W/m^2. The amount of insolation on a plane normal to the sun is very high already in the early morning.

The solar water pumps using flat plate collectors have still very low efficiencies, only about 1 - 3 per cent. Furthermore the head is very low because of the small power. In the following it will be pointed out that focusing collectors using mirrors or lenses to concentrate the solar radiation will have much higher efficiencies and essentially more capacity during the day than flat plate collectors.

In Figure 2 the diagram of such a plant can be seen: The working fluid (water) heated by solar collectors streams into the steam engine which either drives a pump directly or an electric generator. The steam is liquefied in the condenser and again pressed in the collector system by a water feeding pump. Whether a conventional flat plate collector or a concentrating collector should be used depends mainly on the costs and on the ease of maintenance. The costs are influenced by the total efficiency of the plant. The total efficiency essentially depends on the collector efficiency and the temperature of the working fluid.

The conventional flat plate collectors utilize partly the diffuse radiation, too, contrary to the concentrating collectors. This part is on the average lower than 10 per cent for the countries considered and plays therefore a minor role. Flat plate collectors have the crucial disadvantage of decreasing efficiency with increasing collector temperatures. 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. Furthermore turbines suitable for these fluids are not available as far as we know. The thermal efficiency increases correspondingly for higher collector temperatures. However, sufficiently high efficiencies can be reached 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 60 per cent - already for low concentrating factors between 15 and 20.

The focusing collectors must track the sun. By that the high efficiency remains nearly constant in the morning and afternoon. A further crucial advantage - contrary to the flat plate collectors - is that conventional available steam engines can be used because of the higher working temperatures.

In the next Figure 3 the efficiencies of a concentrating collector (cylindrical paraboloid) are plotted versus the insolation per square meter. The working temperature is 200°. For comparison the values of a conventional flat plate collector at 100° C and of a flat plate collector with an infrared reflecting inner glazing at 100° and 200° C are plotted too. The strong decrease of the efficiency for low insolation data is very distinct. Thus the total efficiency of such systems is considerably diminished in the morning and afternoon. Furthermore it must be recognized that the dashed lines are for the expensive collectors (infrared reflecting envelopes). Higher collector temperatures (200° C) result in an extremely strong decrease of efficiency.

The already high efficiency of the concentrating collector with values of about 60 per cent can be increased up to 63 per cent using infrared reflecting glass tube around the absorber pipe. It must be proved, however, whether this expenditure is worth being advocated for economic reasons or not. Contrary to the flat plate collectors two difficult mountings are possible for the cylindrical parabolic mirror: The horizontal E-W orientation of the focus line and the N-S mounting with a tilt angle corresponding to the latitude. In every case the collectors must be tracked from time to time. The E-W mounting offers the advantage of tracking the mirrors only once per week. This can be done manually but then only concentration factors of about five can be obtained. This results in a lower collector efficiency of about 45 per cent. Therefore a continuous tracking is preferred.

The E-W mounting yields a higher energy output than the polar mounting during a relatively short time interval at noon. The polar mounting however has a larger total energy output if times before 10.00 a.m. and after 2.00 p.m. are considered.

These relations are presented in the next Figure (4). The curves indicate the daily variations of the power input to the thermal cycle. The angle of incidence as well as the collector efficiencies depending on the current insolation data have been regarded. Curve "a" shows the relations for a conventional flat plate collector with double glazing (working temperature 100^0 C).

Curve "b" relates to the expensive flat plate collectors with an inner glazing reflecting the infrared radiation. The values for this collector at working temperatures of 200^0 C were plotted too (curve "c"). The curves "e, d" and "f, g" respectively relate to a concentrating collector (cylindrical parabolic mirror) for E-W and N-S mounting. As mentioned above the E-W orientation will be preferred for shorter time intervals, but for longer time periods the N-S mounting yields a higher total energy output. The utilized daily time period virtually depends on the available mounting area for the collectors. For a distance of about one meter between the collectors the time between 9.00 a.m. and 3.00 p.m. can be fully utilized. In the hours before and after this period the collectors are shadowing each other partly. In the next Figure (5) such a parabolic trough mirror can be seen. For constructive reasons the length and the width of the collector are about 2,5 and 1 m respectively. The outer diameter of the collector pipe is about 2 cm because of optical reasons. Thus a concentration ratio of 15 to 20 results. The tracking is operated by a self-locking worm gear driven by a small electric motor (30 W). The mirror rotates around the absorber pipe. Thermal expansion of the pipe in axial direction is compensated by corresponding knock-out spindles. Up to six collectors are connected by one string in the middle of which the tracking device is mounted. The collector pipe , which is the same for every mirror of one string, is centrally led through the knock-out spindles as well as the worm gear. It is supported at suitable positions by roller bearings.

The rough solar sensor consists of several photoconducting cells and tracks the mirror first within a two degrees view. Then a fine tracking occurs (view smaller than 1^0) by means of thermistors located above the absorber pipe within the glass tube. In the next Figure (6) the performance of this fine tracking is outlined. If the sun gets out to the left, only the right sensor will be responsive and vice versa. A third thermistor which never gets into the focus line compensates the ambient temperature by means of a bridge circuit. At night the tracking device returns the collector string to its pre-sunrise condition. In cases of emergency, for instance overheating of the absorber pipe, the mirror must be turned away. Then a thermal circuit breaker mounted at the hottest point of the pipe actuates a servomotor.

The tracking must be operated only every four minutes. The motor runs about five seconds with a rated speed of 1.300 r.p.m. Thus the needed energy can be neglected.

The next Figure (7) is an artist's view of a possible collector arrangement on a platform two meters above the ground level (E-W mounting). The power plant is located centrally under the platform. From the calculations on the water/steam circuit (total efficiency at least 6 per cent) an effective collector area of about 150 - 180 m^2 results for a 10 kW_e solar power plant. Thus 72 collectors are needed with a collector surface of 2.5 square meters. These can be comprised in strings with 6 collectors lying in 12 parallel rows. Further improvements mainly of thermal efficiencies will decrease the effective collector area to 100 - 120 m^2 corresponding to 8 - 10 per cent total efficiency.[+] To get an equal power output during eight hours the solar power plant will be mounted N-S with a tilt corresponding to the latitude. Thus the flow direction of the water/steam mixture is ascending, countering a possible separation.

The water vapour, which has a temperature of approximately 200 - 250° C and a pressure of 17 - 25 atm, can be exploited in steam turbines, lifting-cylinder machines or in revolving-cylinder machines. Since steam turbines of such a small size are of low efficiency and revolving-piston steam engines are not yet commercially available, the use of a lifting-piston plant, which was tested by M.A.N. years ago, is initially

+ In comparison the upper limit of future development potential would be nearly 20 per cent so that the mentioned values of 8 to 10 per cent are very realistic.

envisaged. Series-produced components for Diesel engines can be used in this machine. The following pictures, Figures 8, 9 and 10 show a longitudinal section of this solution, the characteristic piston with integrated cross-head serving to separate the steam-contact parts from the oil-lubricated parts. For 10 kW a 1-cylinder version would be used instead of the 3-cylinder one shown here. The maximum output of this engine series lies at some hundreds HP, using six cylinders.

The design is compact, has a high degree of efficiency and is suited for inexpensive series production. Work is presently being carried out on further-developed versions using even more cheaply produced large-series parts for Diesel engines.

For night operation a steam reservoir is initially envisaged, to be followed later by a hot-water pressure storage system. The hot water will either be fed solely to the steam engine or, in the case of excess capacity of the collectors at midday, also to the reservoir. At present the reservoir is a simple steel tank with insulation, designed to supply 1 kW throughout the night or 10 kW for a shorter time. When the system is operating on the reservoir, the hot water is fed, as steam, from the reservoir via a throttle valve and water filter to the steam engine.

A closed-circuit system is used, the expanded steam, after condensation in the condenser, being returned through a small pump to the solar collectors as water for reconversion to steam.

It would, however, be possible to modify the plant to operate in open circuit with salt water, the resulting condensate being made available as distilled fresh water for drinking purposes. A 10 kW plant would be capable of producing about 1,500 litres per day.

The mechanical energy of say 10 kW could initially be used to pump water: with a pressure head of 60 m, for example, 30 m^3/h or approximately 240 m^3/day could be produced. With a pressure head of 20 m production would be approximately 800 m^3/day.

Figure 11 shows some pump diagrams. Of course the mechanical energy can also be converted directly into electrical energy by means of a normal commercial generator running at 1,000 or 1,500 r.p.m. The electrical energy thus produced could be fed into the mains and used not only in pumping stations but also by other electrical consumers.

The costs of power generated in this way (including amortization of present-day manufacturing cost of the plant) are interesting.

Figure 12 shows also, as a comparison, flat collector arrays for which costs, using the same calculation basis, range up to DM 2.00 per kWh, depending on duration of sunshine, whereas for the chosen concentrated collector type costs of approximately DM 0.70 - 0.90 per kWh can be achieved even on the basis of prototype costs of approximately DM 130,000 for a few prototypes. For optimized plants manufactured in large series at a cost of approximately DM 50,000 to 70,000, electricity costs of less than DM 0,50 per kWh could be achieved. Additionally it must be remarked that the electricity cost varies with duration of usable daily sunshine, for example from 9.00 a.m. to 3.00 p.m. or 8.00 a.m. to 4.00 p.m. as to be seen in Figure 12.

The final table (Figure 13) includes again a summary of the specification data for the plant, figures being given not only for the present experimental prototype but also for the later, further-developed optimalized series plant.

M.A.N. STEAM ENGINES

Introduction

In the past years increasingly vertical engines having a high rate of revolutions have been introduced. The reason for this is obvious. These engines have a greater specific output per unit of displacement. Having the same output, they are smaller and lighter and therefore less expensive than a horizontal steam engine. In addition, they permit direct drive of rapidly running generators and of other machinery and cause negligible foundation and assembly costs.

Already several years ago M.A.N. started to work in this direction and developed within the framework of extensive development and research work an engine having a high degree of heat efficiency as well as all other advantages of a modern engine.

The main field of application of the engine will be in the heat-consuming small and medium industries, among others in the woodworking, ceramic, textile, leather, brick, brewery and foodstuffs industries.

The engine may also be used for the drive of steam railcars for steam cranes, auxiliary engines in power stations and as main or auxiliary drive in inland and deep-sea navigation.

CONSTRUCTIVE DETAILS:

The main constructive aspects are as follows:

1. The engine is single-acting.
2. The engine operates with valve gear.
3. The engine has no stuffing box.

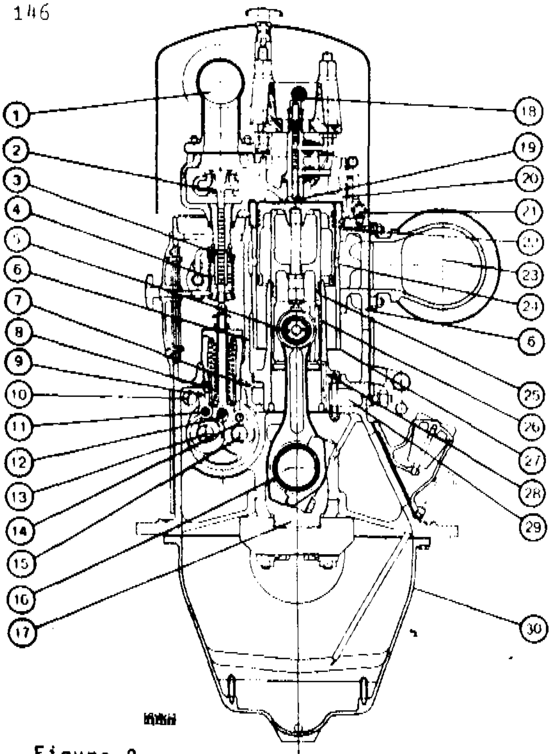
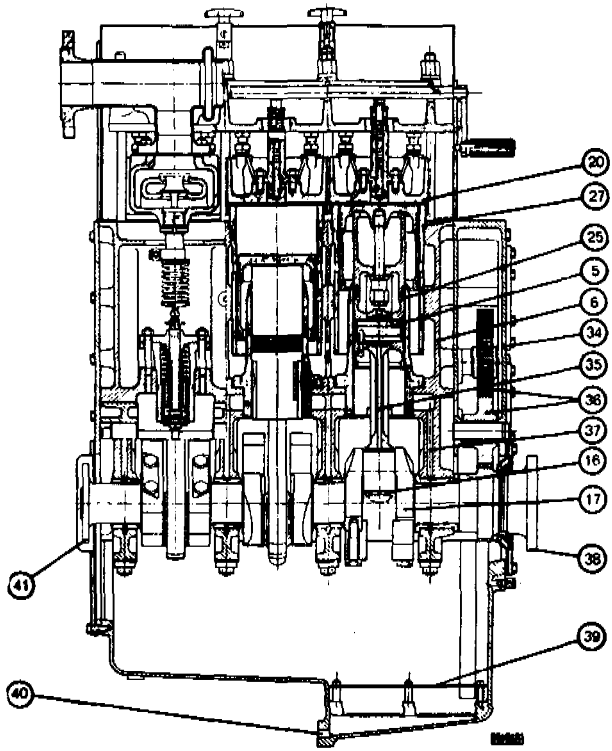


Figure 8

Graph 2 (Figure 8)

Section of a three-cylinder engine

1 Live steam supply pipe
2 Intake valve
3 Leakage steam exhaust
4 Valve spring
5 Crosshead pin with lubricating bores
6 Frame
7 Lubricating bore for push rod
8 Push rod
9 Nose on valve rocker
10 Starter shaft
11 Roll
12 Valve rocker
13 Vertical shaft
14 Roll
15 Lifting shaft
16 Crankpin bearing
17 Crankshaft
18 Shaft for operating drain valves
19 Decompression and drain valve
20 Cylinder head



Graph 3

Longitudinal cross section of a three-cylinder engine

21 Nonreturn valve
22 Belt canal for cylinder lubrication
23 Exhaust pipe
24 Exit slots
25 Crosshead sleeve
26 Oil groove in crosshead
27 Cylinder liner
28 Lubrication bore in the crosshead sleeve
29 Oil container
30 Oil pan) see
31 Piston) graph 4
32 Crosshead)
33 Piston rod)
34 Wheel-case
35 Lubrication bore in piston rod for crankpin bearing
36 Intermediate gear wheels
37 Lubrication bore in the frame for crankshaft bearing
38 Coupling flange
39 Oil strainer
40 Mud drain
41 Coupling flange

Figure 9

Graph 8 Assembly of a four-cylinder unit (maximum width 1100 mm)

42 Distributing slide valve
43 Servomotor
48 Starting lever
49 Latch (lever)
50 Pressure lubricator
51 Regulator

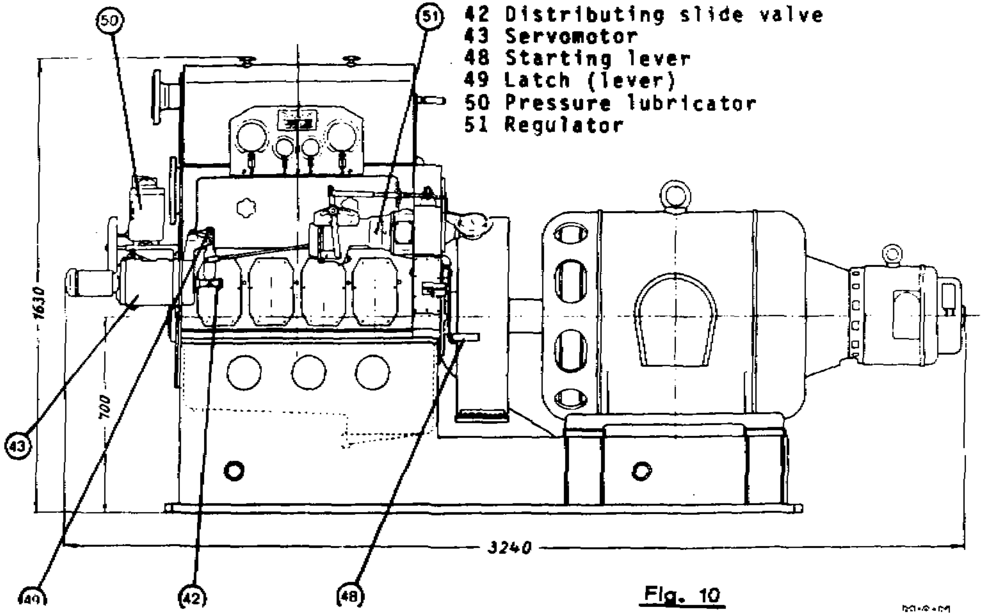
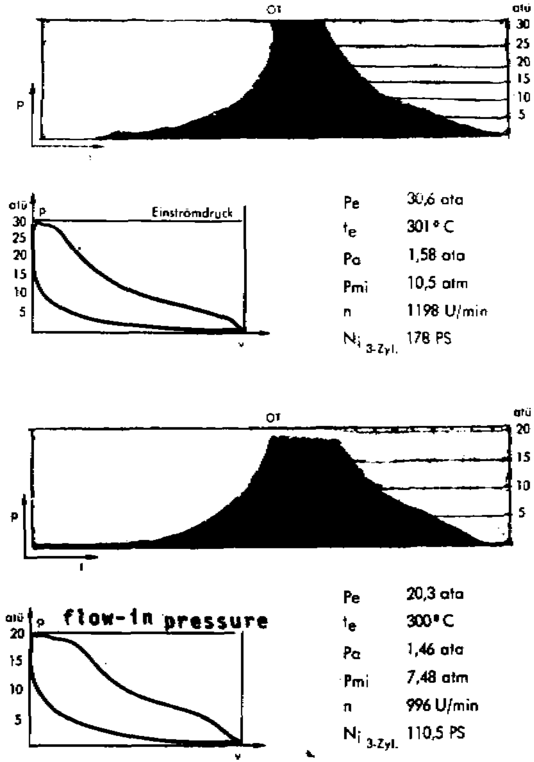


Fig. 10



Graph 7 Piston stroke diagram

Operation

The live steam passes through the supply pipe (1) to the cylinder heads (20). The valves control the supply of steam to the cylinder. The steam pushes the piston downward and escapes through the slots (24) into the exhaus pipe (23).

Main data

The engine is built with three, four and six cylinders for exhaust or back-pressure operation. The cylinder diameter is 150 mm and the lift 120 mm so that the piston speed is only 4 m/s at 1000 revolutions/min. The engine is designed for pressures of up to 30 atmospheres excess pressure and temperatures of up to 400^{0} C. The cylinder output is approximately 60 hp. The main dimensions can be seen in Graph 8.

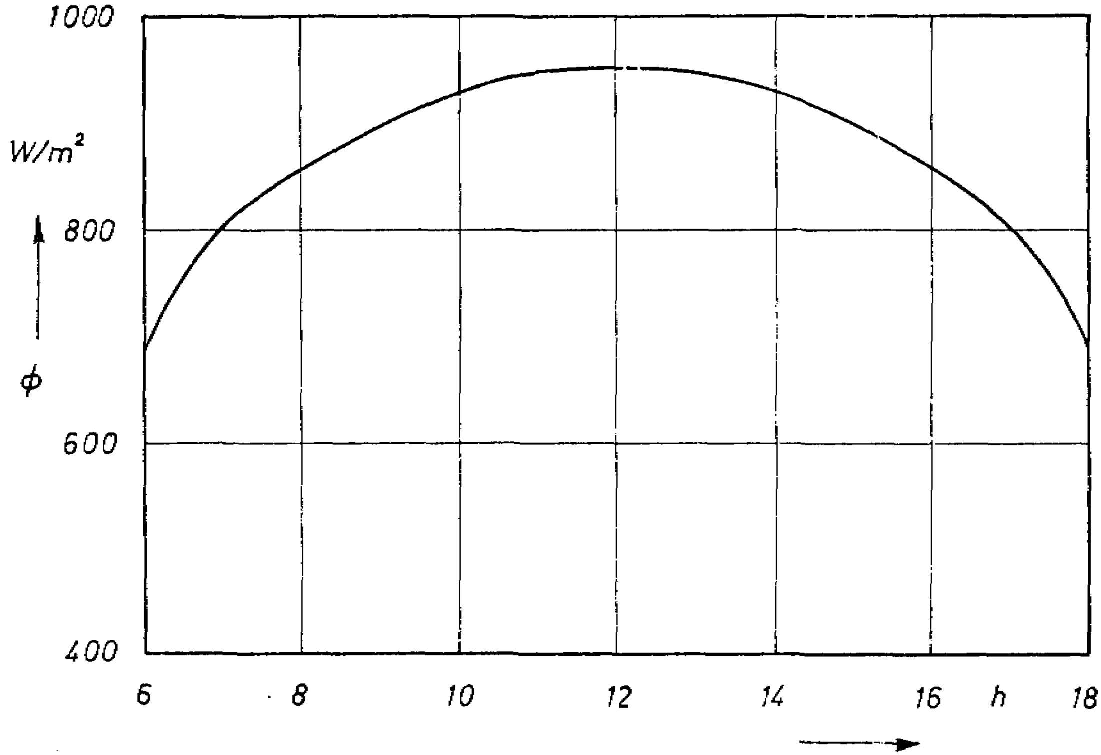


Fig. 1 Hourly variations of normal insolation (solstice)

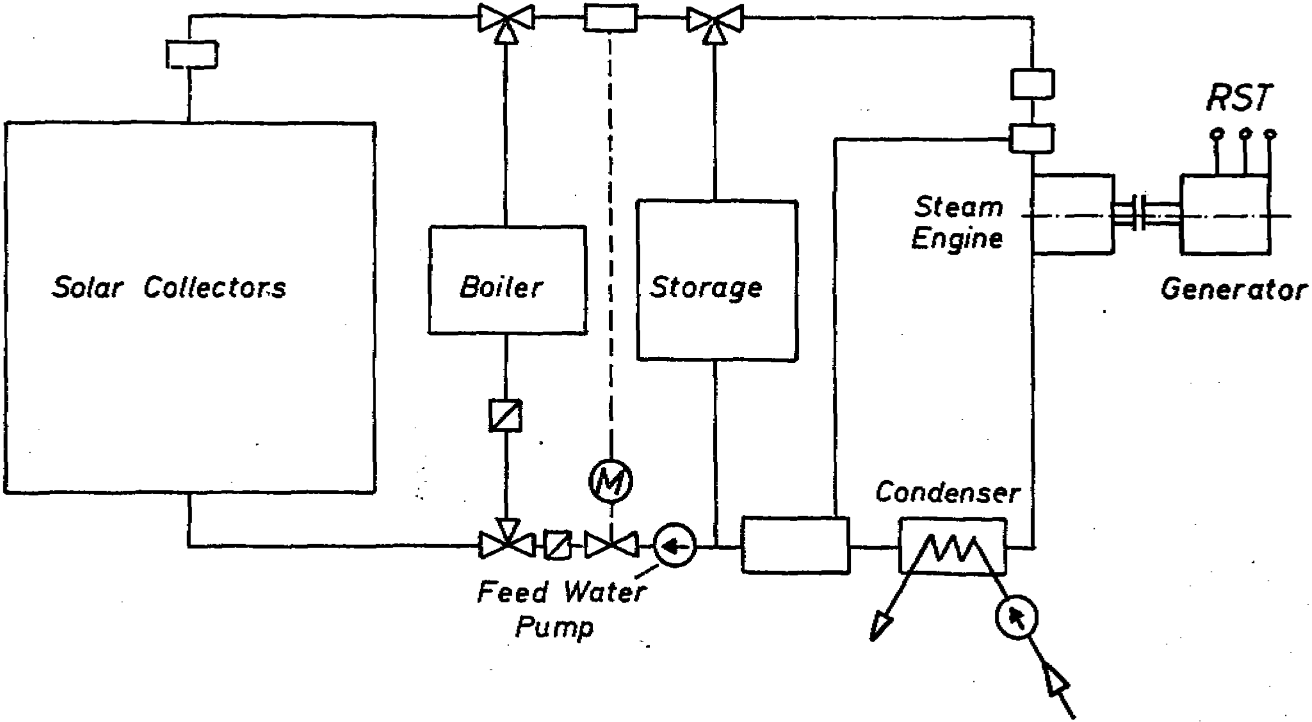
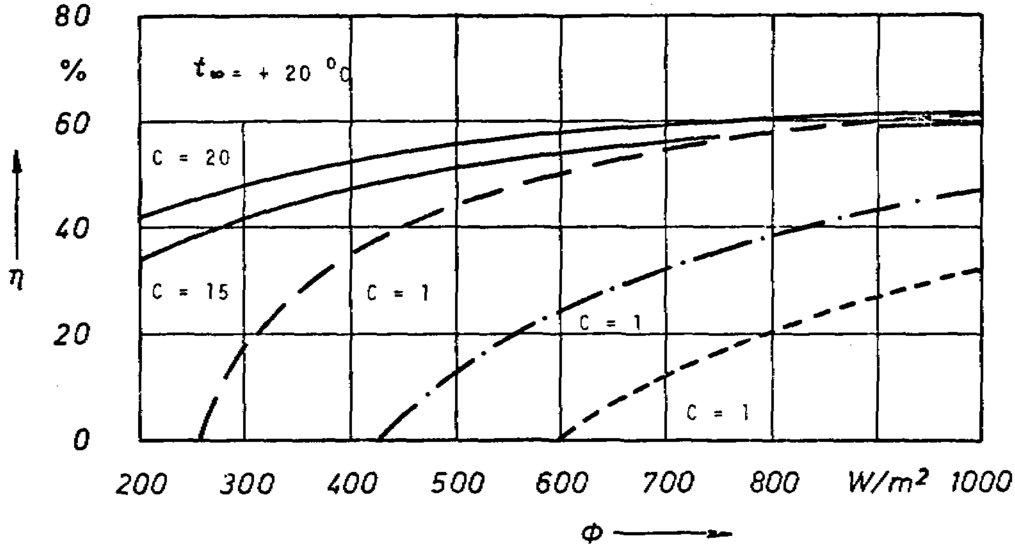


Fig. 2 *Diagram of Solar Collector System*



Concentrating Collector (t = 200° C)

t = 100°C

t = 100°C IR-refl.

t = 200°C

Flat Plate Collectors

Fig. 3 Efficiencies of concentrating collectors and flat plate collectors versus insolation per m3

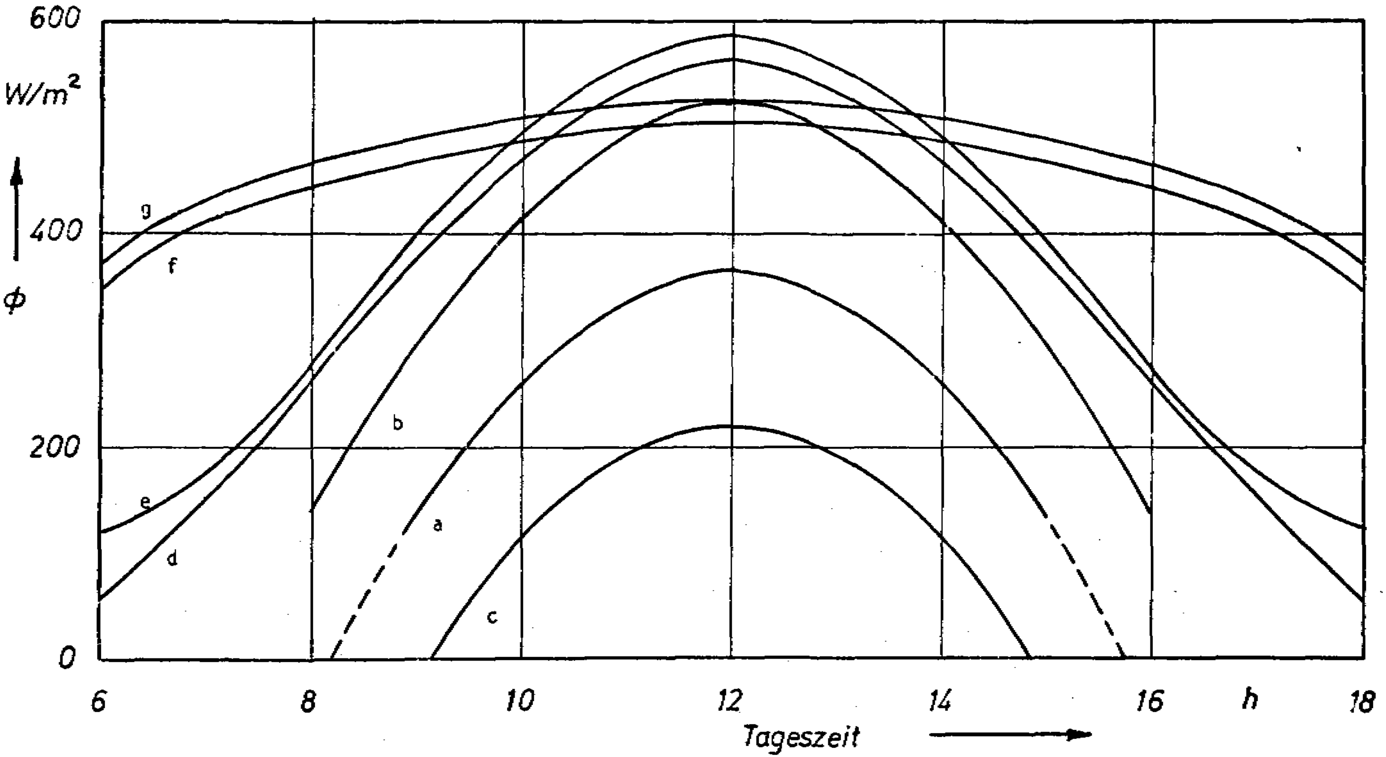


Fig. 4 Hourly variation of the available collector power

a) conventional flat plate collector (100°C)
b) flat plate collector with IR refle. glazing (100°C)
c) " (200°C) (solstice)

d) parabolic trough E - W C = 15
e) " " C = 20
f) " N - S C = 15
g) " " C = 20

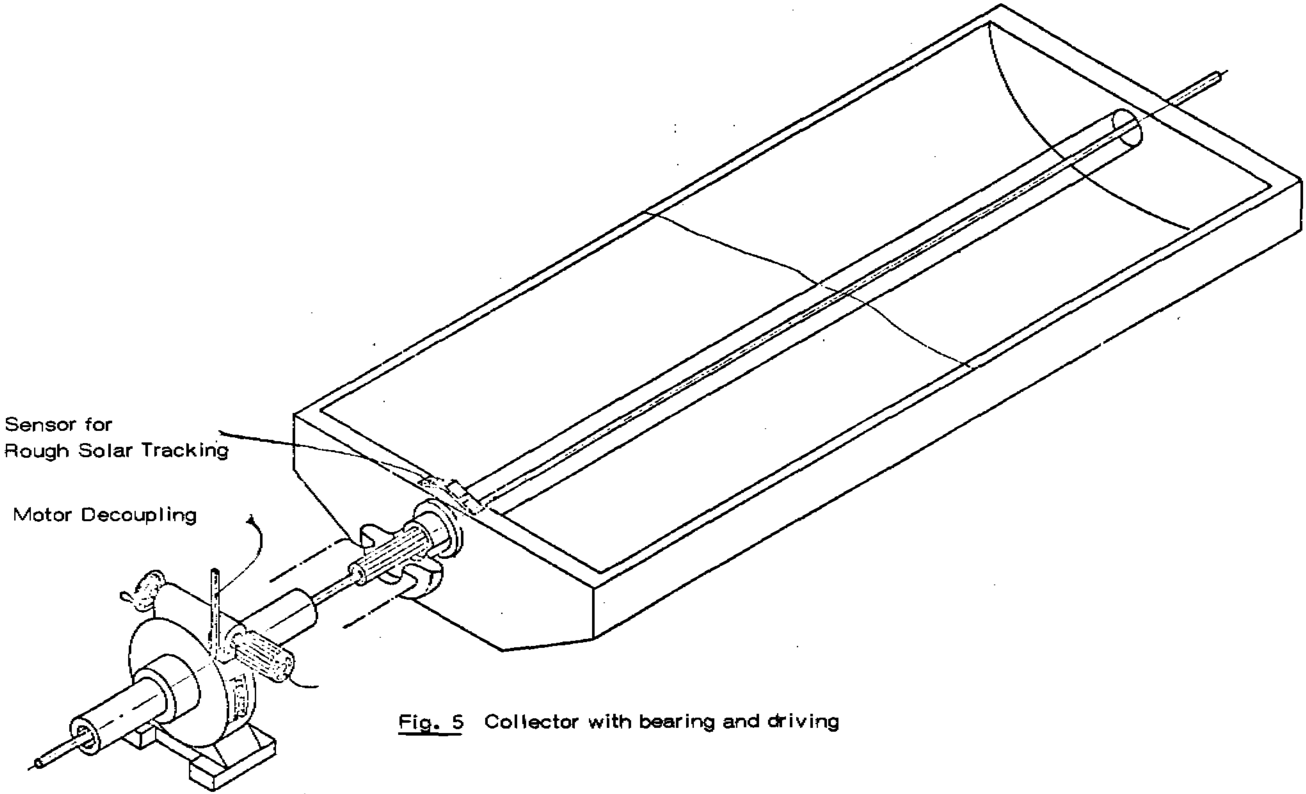
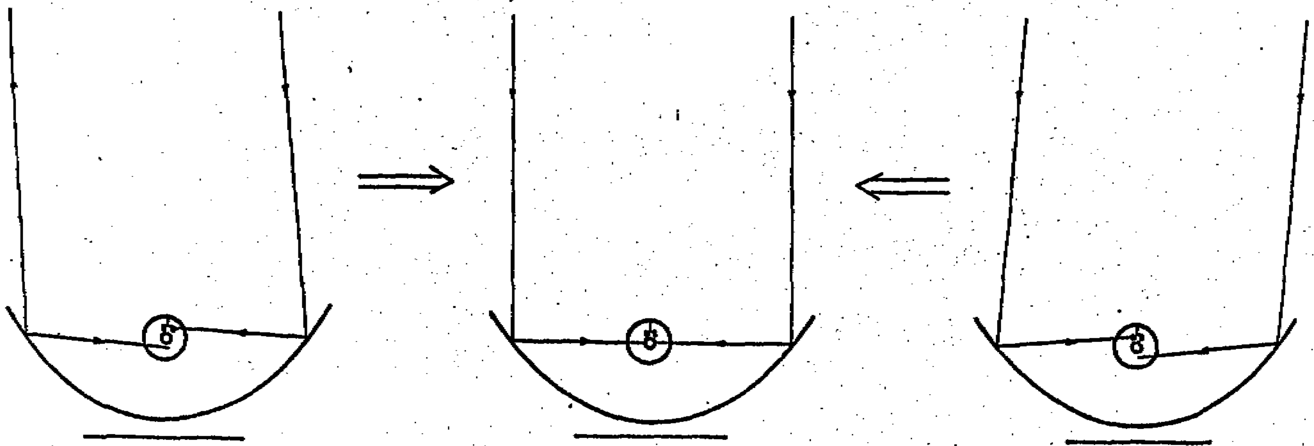


Fig. 5 Collector with bearing and driving



Sun gets to the left
Right sensor is responsive

Sun centered in the focus line

Sun gets to the right
Left sensor is responsive

Fig.6 Right-left decision with thermistors for fine tracking

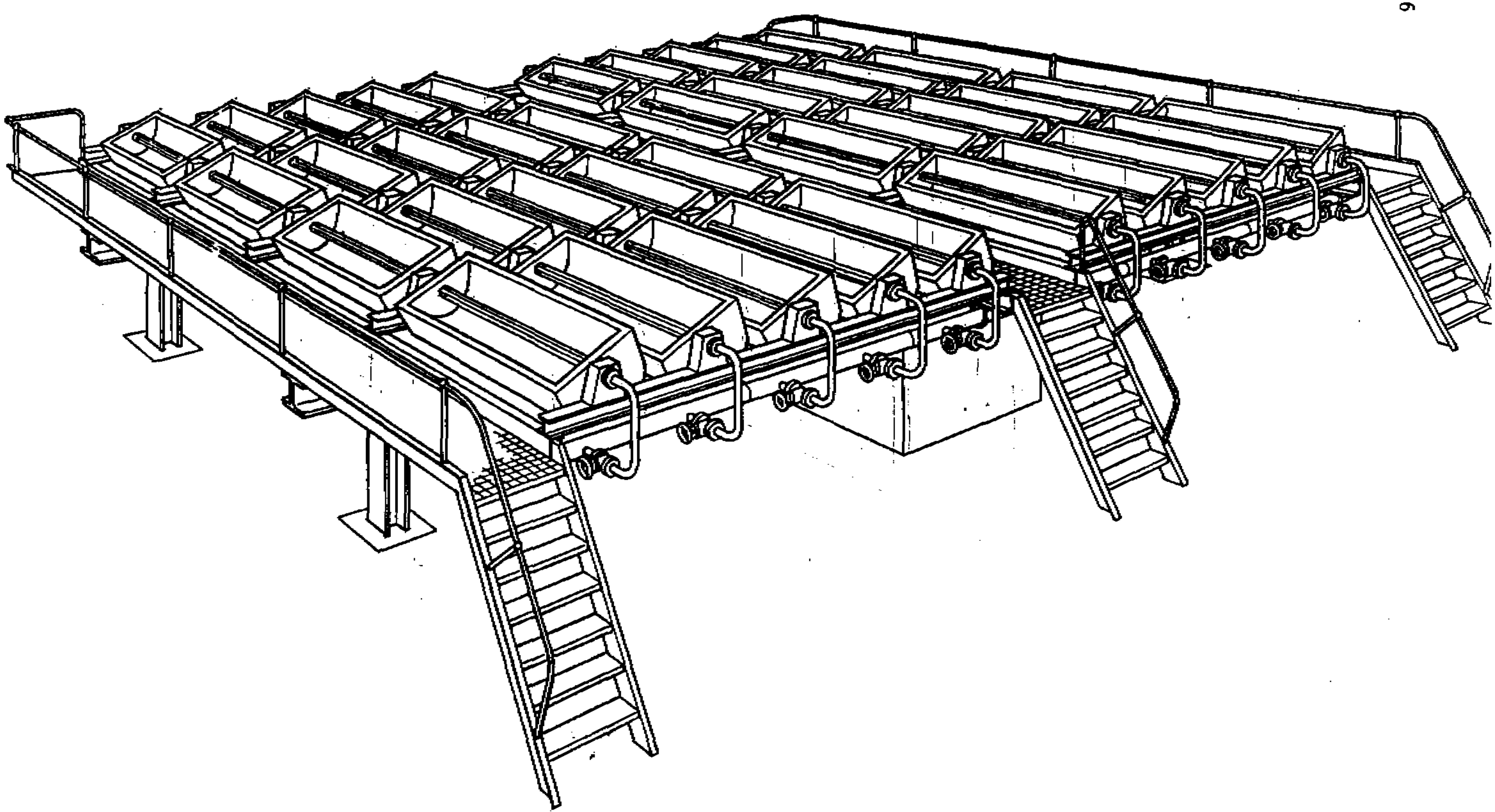
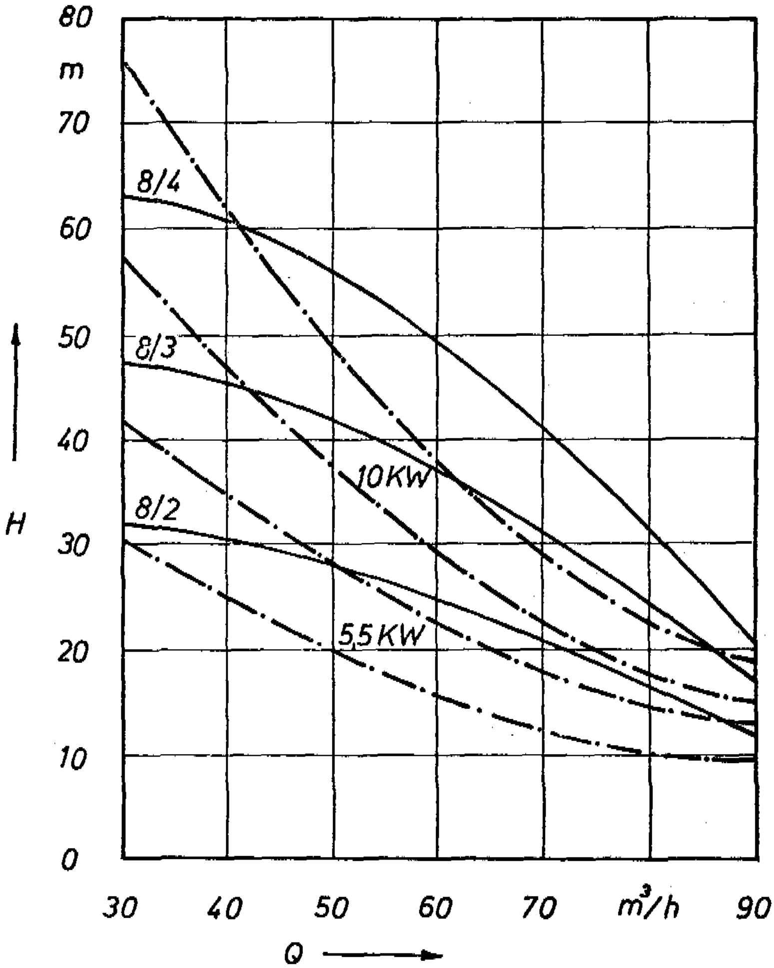


Fig. 7 Artist's/view of a 10 kW_e Solar Power Plant



Pumping Speed Q versus Head H

Parameter: Pumping Power —·—·—
Available Pump Size ———
(e.g. 8/3: Size 8, 3 Stages)

Fig. 11

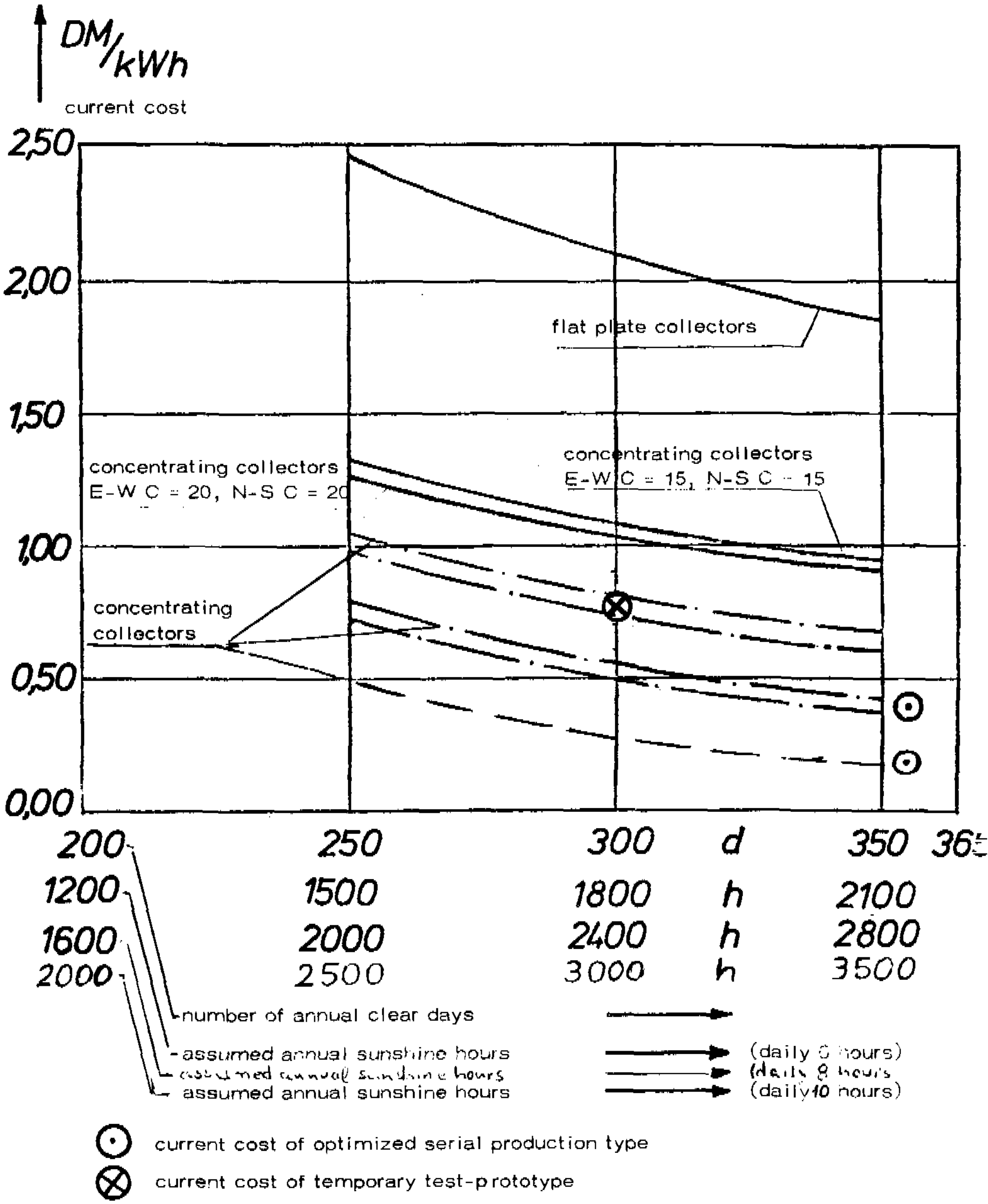


Fig. 12 Current cost including armortisation of investmentcost and maintenence cost versus operation time

(——————— daily time of operation 9.00 a.m. - 3.00 p.m.)

(——— · ——— daily time of operation 8.00 a.m. - 4.00 p.m.)

(— — — — daily time of operation 7.00 a.m. - 5.00 p.m.)

SPECIFICATION FOR 10 KW SOLAR ENERGY POWER PLANT

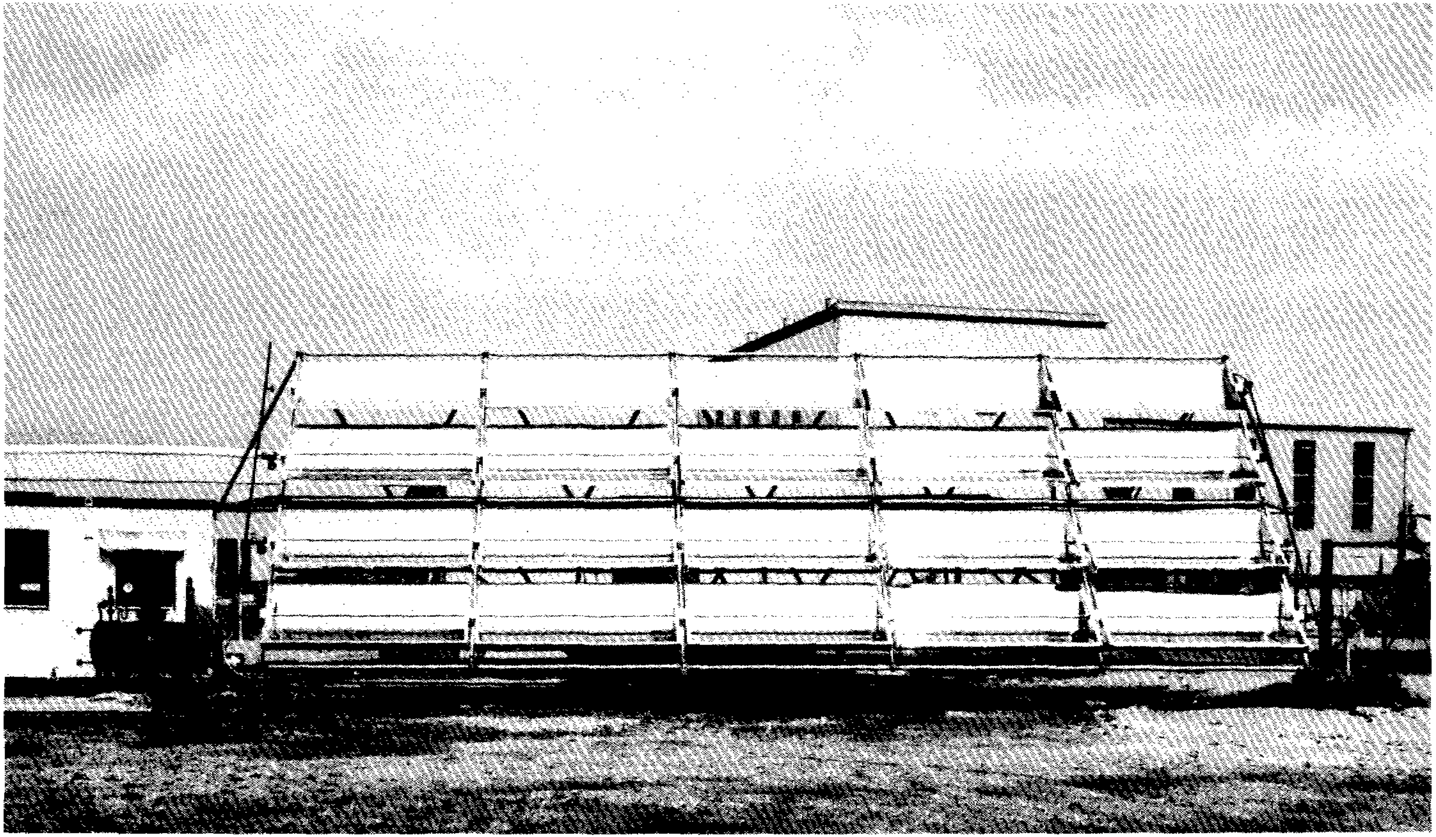
A) Temporary test prototype

1. Electrical power output:	operation daytime 950 $^{W}/m^2$ 10 kW operation at night 1 kW
2. Collector area:	180 m^2 tracked concentrating collectors
3. Steam circuit: (t ≈ 200° C)	1-stage steam piston engine with electric generator 1000 rpm - 50 Hz
4. Storage system:	Steam storage 17 bar, ca. 30 m^3
5. Electrical energy output:	300 solar days (2,400 available solar hours per year) 21,000 kWh
6. Current cost:	ca. 0.70 - 0.90 DM/kWh
7. Fabrication cost for prototypes: (ca. 30 St.)	ca. DM 137,000
8. Cost for fabrication in series:	lower than DM 100,000

B) Aim of development for optimised serial production type

1. Electrical power output:	operation daytime: long duration 10 kW can be extended to 40 kW operation at night: long duration 2 kW short time 10 kW
2. Collector area:	ca. 100-120 m^2 tracked concentrating collectors
3. Steam circuit: (t ≈ 250° C)	1-2-stage steam piston engine with electric generator 1500 rpm - 50 Hz
4. Storage system:	Hot water storage, ca. 4 m^3, ca. 25 bar
5. Electrical energy output:	300 solar days (3,000 available solar hours per year) 23,000 kWh/pa
6. Current cost:	ca. 0.30 - 0.70 DM/kWh
7. Cost for fabrication in large series:	ca. DM 50,000 - DM 70,000

Fig. 13



Testing of a first pilot plant

THE UTILIZATION OF SOLAR ENERGY FOR PUMPING WATER IN DEVELOPING COUNTRIES

M. Vergnet

Following the work of Professor Masson of Dakar University, our group of researchers have for about 15 years now been investigating the possibilities of harnessing solar energy to solve energy production problems in isolated tropical regions.

The Pierre Mengin Establishment and the Société Française d'Etudes Thermiques et d'Energie Solaire work in close collaboration with a number of African research institutes, in particular: the University of Dakar, L'Ecole Inter-Etats de Ouagadougou, The University of Chad, the Laboratoire d'Energie Solaire du Niger, the Laboratoire d'Energie Solaire de Bamako.

In view of the recent developments in this field of technology, the Atomic Energy Commission, la Société Renault, le Groupe total, and la Société Gaz Océan have decided to assist us in this research.

Solar Energy

Solar radiation is a free source of energy available in large quantities everywhere, in particular in the arid regions of the developing countries. It can amount to as much as 1 kW/m^2 at ground level. This advantage, however, is in part offset by a few drawbacks, which explain why this form of energy has not yet been fully exploited.

All sources of energy are required without exception to function 24 hours a day, solar energy, however, is cyclic. During cloudy weather this form of energy is considerably reduced, diffused radiation representing only 30 to 40 per cent of direct energy. It is available regularly and in quantity only in generally underindustrialized tropical regions. Having analyzed these difficulties we decided for purposes of efficiency on certain basic options.

Basic Options

a) Since solar energy is cyclic, we were looking for an application which would simplify energy storage. Water pumping, which is one of the most common forms of energy application in tropical countries, fulfilled this condition.

b) Simplicity of operation and reliability. In order to adapt the equipment to practical conditions in these isolated regions, it was necessary to design robust machinery which did not require maintenance by qualified personnel.

   Although they produce only small thermal energy yields, it was decided to use flat-plate captors which, being stationary, do not follow the path of the sun.

   Particular care was taken in the design and construction of the thermomechanic and thermoelectric converters in order to ensure that they were as reliable as the rest of the solar equipment.

Operating Principle of Solar Pumps with Flat-Plate Captors

We elected to use solar energy to drive a water pump by means of a low-temperature thermal cycle between the hot source fed by solar radiation and the cold source, the pumped water.

1. Solar captors

A battery of rudimentary and entirely static solar captors collects the solar radiation and converts it into heat. This process requires the use of a blackened steel plate thermally insulated from the surrounding air and housed under glass to take advantage of the pressure effect. This plate passes on the heat to a heat conductor, generally water circulating inside the captors.

2. Thermal Converters

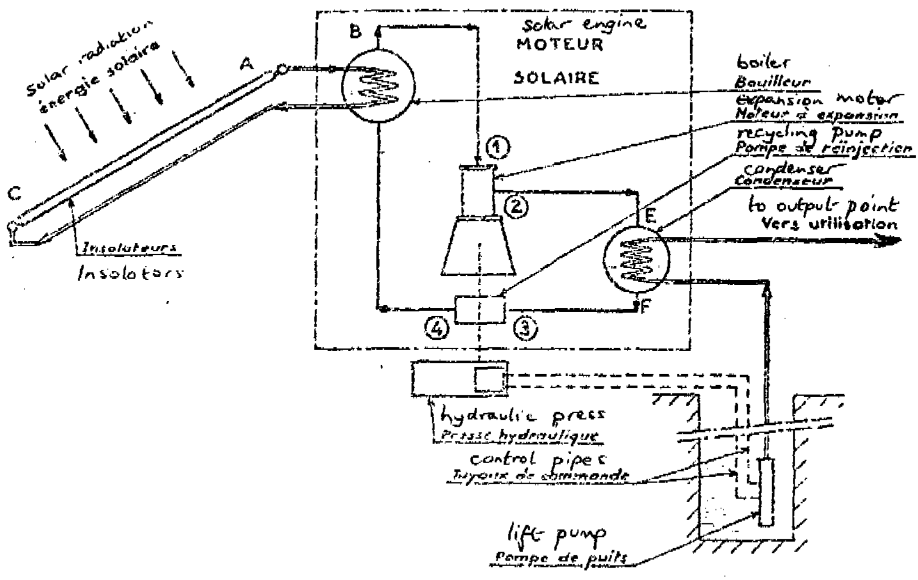
This radiation, which has been transformed by the captors into calorific energy, must be turned into a usable form of energy, in this case a thermodynamic potential, by means of a converter. The process is as follows: The heat conductor collects the thermal energy produced by the captors and passes it on to an organic liquid gas, thereby bringing the liquid gas to the evaporating point. The pressure obtained by the evaporation of this fluid actuates the converter, either a thermomechanic expansion engine, a piston engine, or a turbine.

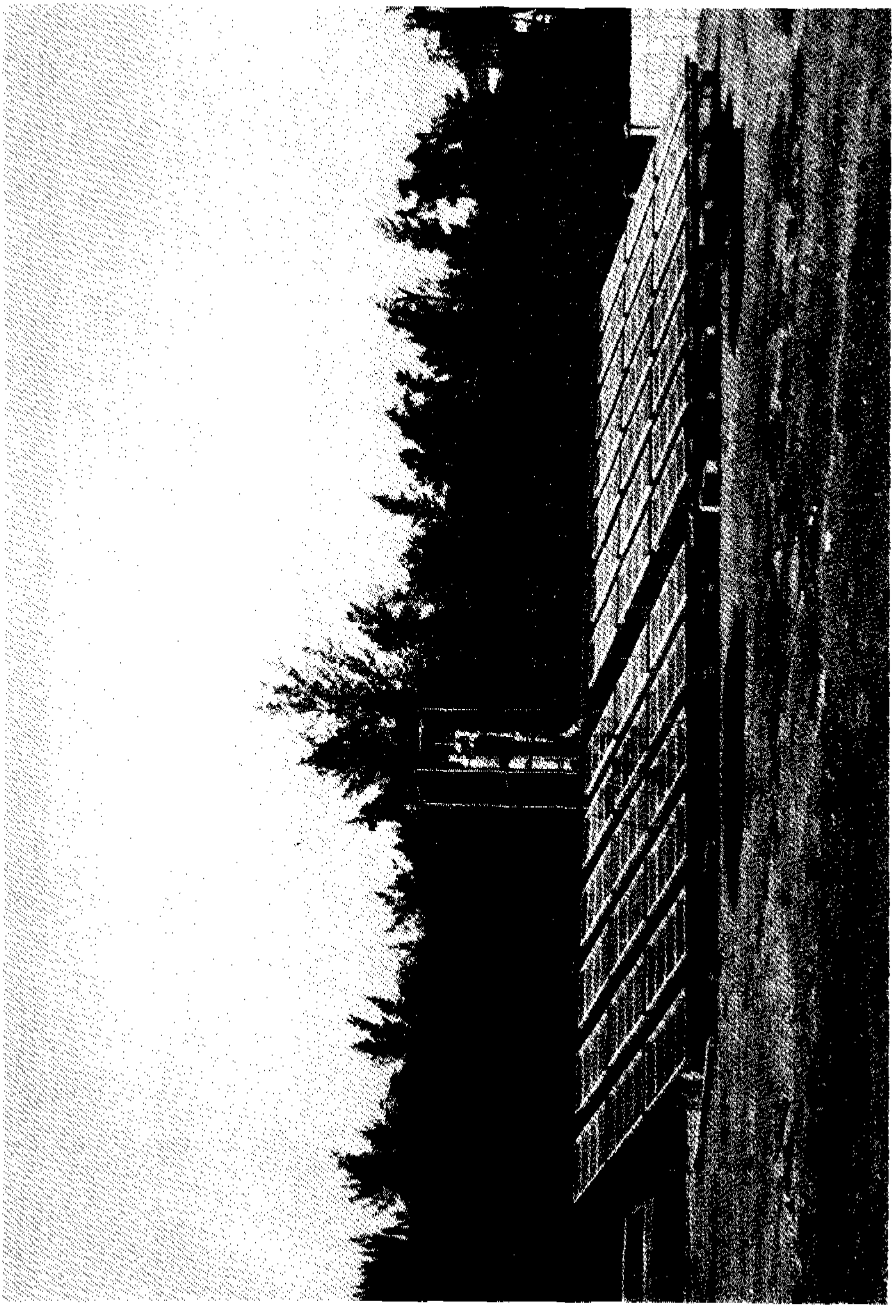
After passing through the converter, the gas is again liquified by a condenser, the heat being removed by the water pumped through the installation.

3. Pumping

A water pump actuated either directly by the main shaft via a piston engine or by a centrifugal pump fed by a generator engaged on the turbine discharges the fluid in a borehole or in an intake downstream.

The elements comprising a 1 kW pump and the solar turbo-generators are represented in the diagram below:



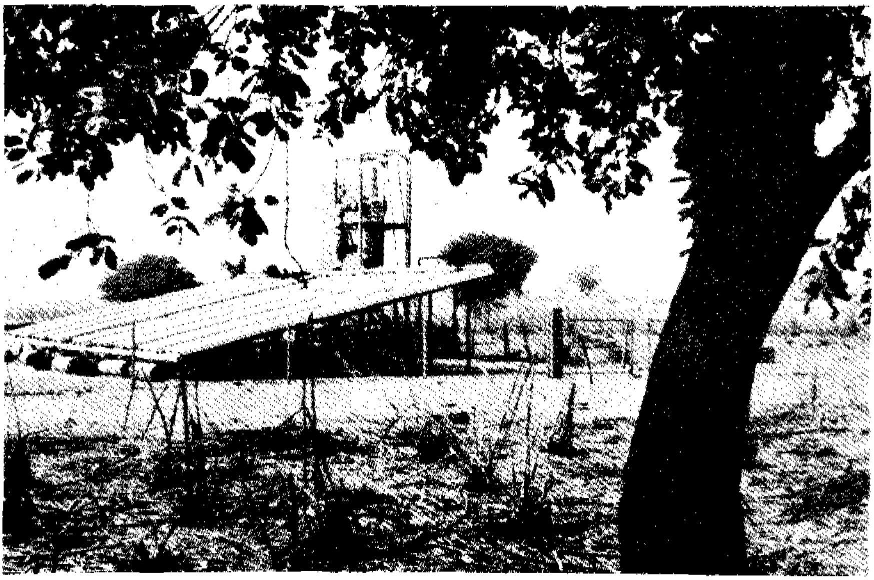


Current Projects

Apart from various prototypes being tested in laboratories, mainly at Dakar University, several different pumps are currently in operation. Relevant statistics are given below:

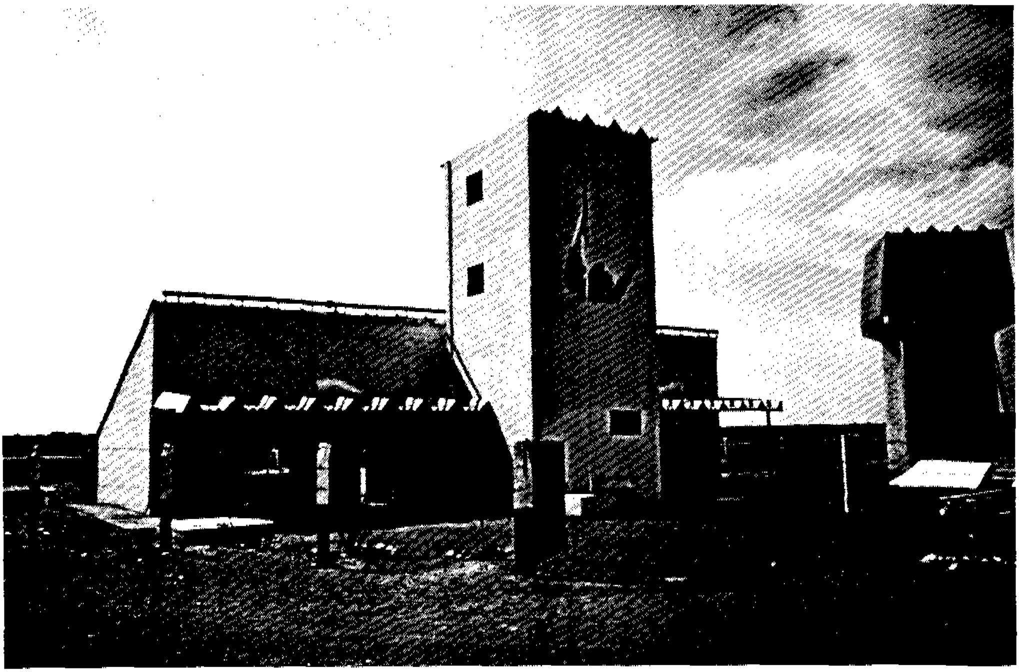
Segal Pump

Surface area of captor......................	88 m^2
Output.......................................	6 m^3/h
Total manometric lift........................	25 m
Operating time...............................	5 to 6 hrs
Date of entry into service...................	1968
Location.....................................	Institut de Physique Météorologique de Dakar



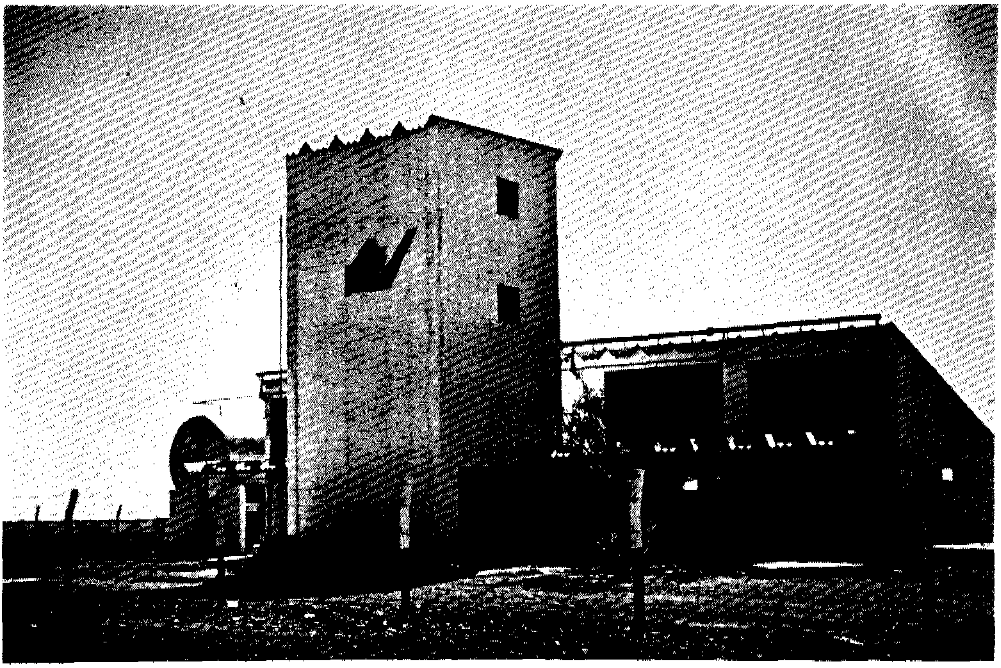
Onersol Pump

Surface area of captor......	60 m^2
Output......	6 to 7 m^3/h
Total manometric lift.......	12 m
Operating time....	4 to 6 hrs
Date of entry into service..	1969
Location.....	village of Bossey-Bangou (Niger)



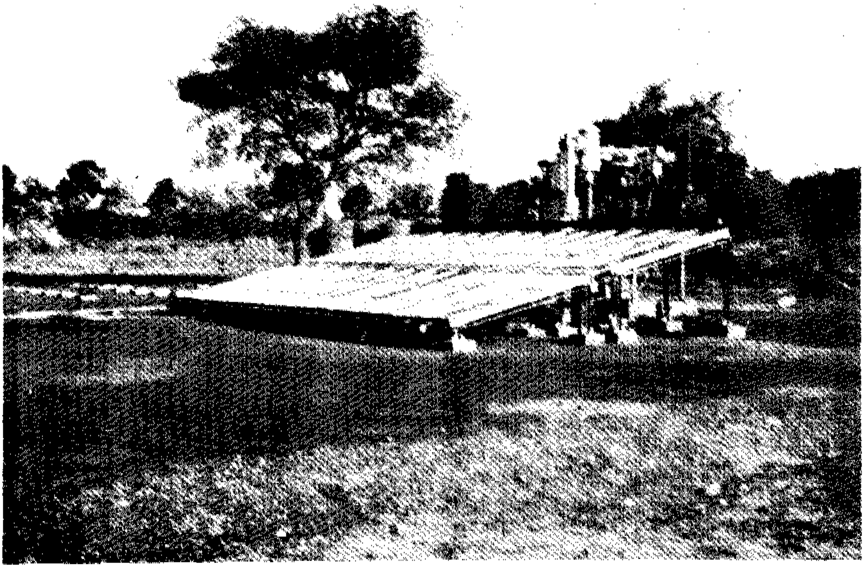
Caborca Pump

Surface area of captor....	90 m^2
Output....	3 m^3/h
Manometric lift	45 m
Operating time....	5 to 6 hrs
Location....	Caborca (Mexico) 1974



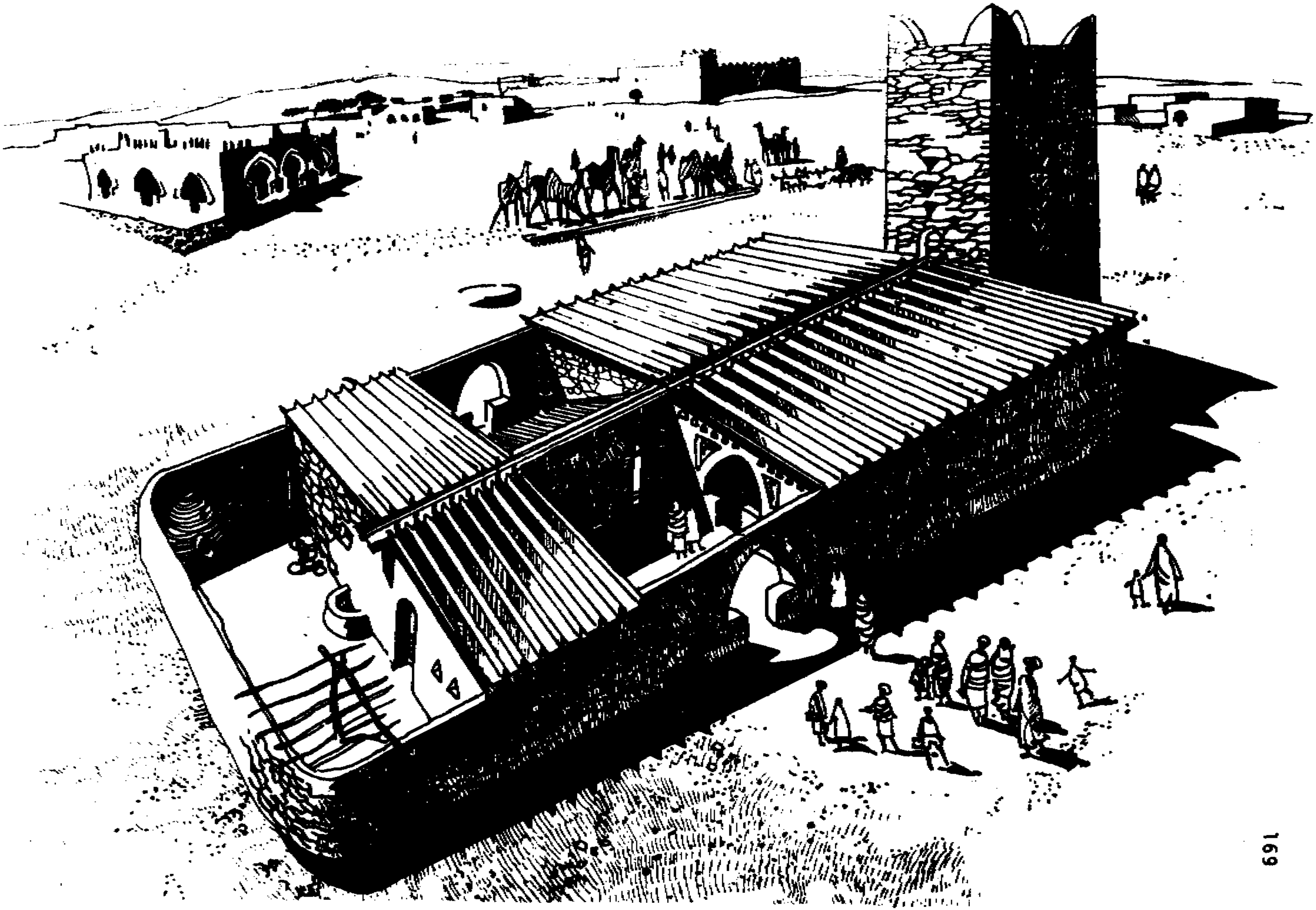
Ceballos Pump

Surface area of captor....	90 m^2
Output....	4 m^3/h
Manometric lift....	35 m
Operating time....	5 to 6 hrs
Location....	Ceballos (Mexico) 1974



Ouaga Pump

Surface area of captor......	30 m^2
Output......	2 m^3/h
Total manometric lift.......	20 m
Operating time....	4 to 6 hrs
Date of entry into service..	1971
Location.....	Ecole Inter-Etats de Ouagadougou



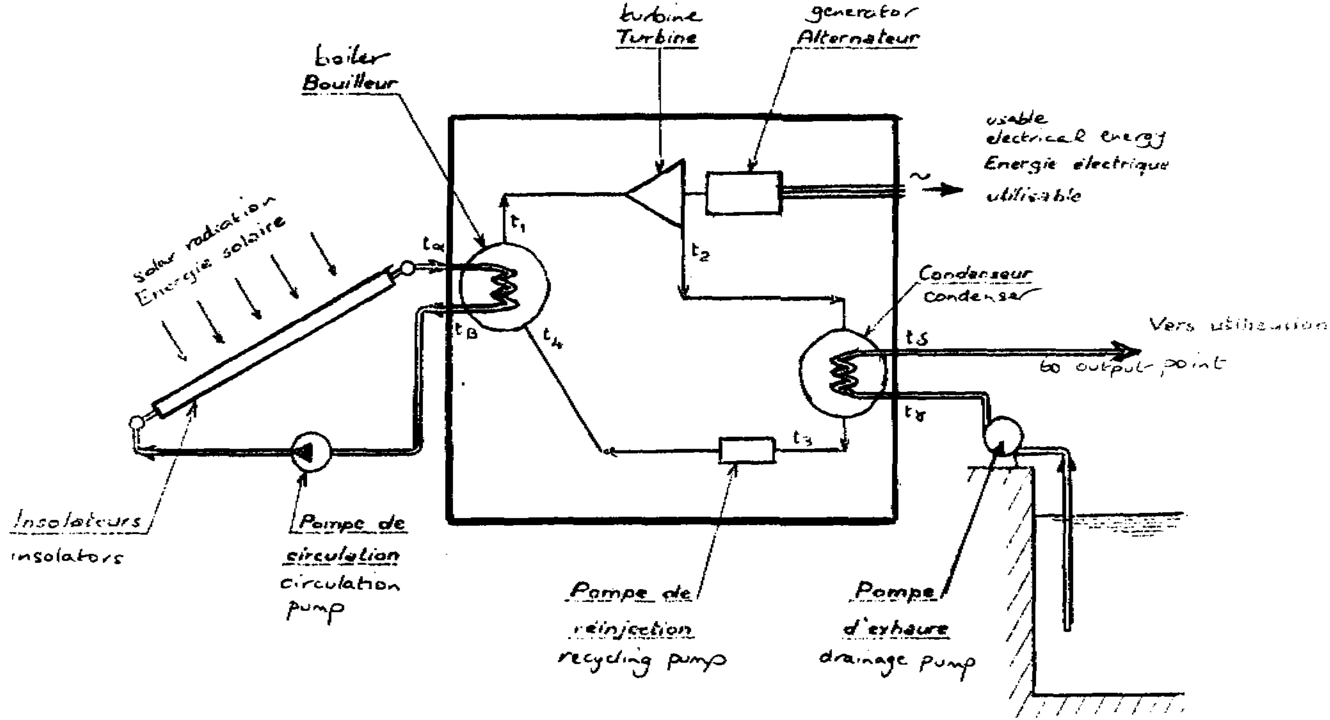


Diagram of 50kW Solar Turbo-Generator

Représentation schématique du Turbo alternateur solaire de 50 KW

Current Fields of Development

These technologies are being developed in three different fields:

Village water supply

In locations where we are competitive, our task is to solve the problems of supplying water to small agglomerations of 1,000 to 2,000 inhabitants and at the same time to integrate solar pumping processes into the social process by combining the solar pump with local facilities such as a school (Chinguetti, Ceballos, etc.), a dispensary centre (Dioila), or an administrative building.

Thus the process of supplying water also initiates ancillary development processes.

Water supply for grazing ranges

In order to fully exploit the stock-rearing potential of the tropical regions, in particular the Sahel zone, a number of waterpoints to serve 1,000 head of cattle, must be established.

In our view, solar pumps are one method of solving this problem. To prevent overgrazing, the stations should be kept down tc reasonable size. Ideally there should be a series of sma, stations producing about 50 m^3 per day, situated in intervals along the cattle tracks. This would also help prevent the major weight losses and deaths which frequently occur when livestock are moved along the transhumance and marketing routes.

Irrigation

Energy is required in the order of 25 to 50 and 100 kW for irrigation purposes. The Mexican Government commissioned us with the first project of this type. A series of project tests was commenced in June 1975 and the project is due to come into operation in October 1975. In this field of solar energy application the reliability of the installations is of fundamental importance. The use of stage gas turbines guarantees reliability over a period of at least ten years. As regards investment cost, the cost price per cubic metre calculated on the basis of a twenty-year repayment period is in the order of 0.10 to 0.15.

Since the surfaces of the captors must be quite large, plans exist to construct along with the plant a whole village to house the people working in the area. For this ambitious project we are receiving assistance from the Atomic Energy Commission via the Groupement Prométhée, which latter is particularly involved in these problems.

Future Programme

In all our activities we have always attempted to take into consideration the conditions in the developing countries, which is why we always refer simply to projects and parallel theoretic studies.

Many countries throughout the world have now become interested in this technology, and we have been commissioned with the establishment of about thirty stations of this type. Upper Volta, Chad, Senegal, Brazil, Mauritania, Cameroon, and Mexico have demonstrated particular interest.

The Mexican Government was the first to consider the large-scale introduction of solar pumps. We are at present involved in an initial programme for ten stations, five of which are currently in operation. We are in charge of a 25 kW station providing irrigation for San Luis Potosi, and the Mexican Government plans to initiate a programme for approximately 1,000 solar pumps and 25 to 50 50 kW turbines.

Lower costs made possible by this programme will make solar energy directly competitive with current sources of energy in all the tropical zones.

Future Possibilities

At present we are interested only in the most urgent problem, that of water supply. It is possible to establish refrigeration plants to preserve drugs in hospitals and to supply cold stores in the agricultural field. The first such projects are to be carried out this year at the Dioila and Koupela dispensaries. An interesting study could be undertaken later on the possibilities of using this technique for the purposes of air-conditioning. We will shortly be building Aramon houses in France, and there is no doubt that solar energy will soon be applied also to air condition tourist centres, small hotels, etc.

The longer term objective, however, is to supply electricity 24 hours a day from small independent power stations of between 25 and 100 kW. Before this is possible, however, we will have to solve problems of storing heat, the research into which remains as yet inconclusive, despite optimism in this field.

This has been a description of the work of a small group which is interested not only in the technical aspects but also in all the human aspects of solar projects and which has always sought to integrate development considerations in their work and to bear in mind the possibilities of technology transfer to interested Third World countries.

SOLAR CELLS FOR TERRESTRIAL USE

G. H. Hewig and W. H. Bloss

Introduction

Solar energy can be converted directly into electricity. The device for this conversion process is the so-called solar cell. Solar cells are the most important power source for space applications and they have proved their reliability in more than 1000 spacecrafts. The costs per kW of the installed generator for terrestrial applications will be the main problem. Therefore, the different possibilities for the structure of the solar cells will be outlined and compared with each other under the aspect of large area production.

Solar Irradiation on the Earth

There exist some data on the solar insolation on the earth. These data correspond to the total insolation and include the direct solar irradiation and the scattered light of the atmosphere and perhaps of clouds. Fig. 1 shows the total irradiation of sunlight on the earth. The lines in it connect points with the same total irradiation, the magnitude of which is indicated in kcal per cm^2 which corresponds to the total solar energy per year irradiated on a horizontal area of 1 cm^2. From fig. 1 it can be seen that the irradiation in the Sahel zone is about 200 kcal/cm^2 per year. This corresponds to an energy of 2400 kWh/m^2 per year. In Germany the total irradiation is smaller by a factor of two. So the semi-arid areas have a lot of solar energy but a large lack of water, so it would be the best thing to use solar energy for the water supply. As the photovoltaic effect is one possibility to use solar energy, this effect and the possibilities to be expected will be outlined.

Different Solar Cells

The photovoltaic effect is based on the separation of different sorts of charge carriers in a boundary, especially the separation of photogenerated electrons and holes in semi-conductor p-n junctions. As n and p materials can be of the same or different kinds, there are a lot of materials which can be used for solar cell construction and it looks as though a different type of solar cell will be suitable for the different applications. For space application the silicon solar cell seams to be the best solution as the reliability is of most important interest. But for terrestrial applications the CdS solar cell will probably be the cheapest and therefore the best solution. Therefore, the production processes of these cells and a few others which were developed in the last years are described shortly to get some ideas of the production costs for large-scale producing.

Si

The silicon solar cell, which is of great success in space application, is a single crystal solar cell. The p-type single crystal which was grown out of the melt is cut in wafers with a thickness of 300μ. A n-type layer at the surface is created by diffusion. The front layer is contacted by an evaporated grid structure. To avoid reflection losses an antireflective coating is evaporated, which causes the blue appearance of the surface.

The solar cells are produced with efficiencies up to 20 per cent [1/]. Nevertheless, a good standard process yields cells with efficiencies of 12 per cent without using a highly sophisticated technology. The area of one cell is 20 cm^2, which results in a power output of the cell of 0.24 W per cell [2/]. Therefore, a solar cell area of about 8 m^2 produces in bright sunshine a power output of 1 kW. The degradation of silicon solar cells is negligible for terrestrial use.

Cu_2S-CdS

The Cu_2S-CdS solar cell is a polycrystalline cell. The n-type CdS layer is evaporated under high vacuum conditions on a metallized substrate. The thickness of the n-type CdS is about 20 to 50μ [3/]. The p-type Cu_2S layer is generated by a dipping process in a cupreous chloride solution. The front contact consists of a photoetched gold-plated copper grid by using a proper adhesive material between the Cu_2S layer and the grid. Cu_2S-CdS solar cells show efficiencies up to 8 per cent, but there exist some problems in the reproducibility and the degradation of this cell. Due to the lower efficiency a solar cell area of 12 m^2 produces in bright sunshine a power output of 1 kW. The single cells can be produced with an area up to 100 cm^2.

Other Compounds

Some other types of solar cells show good results: the GaAs, the InP-CdS and the Cu In Se_2-CdS solar cells. The GaAs solar cell is produced by liquid phase epitaxy technique. The efficiency of this cell reaches 20 per cent [4/], but material and production costs are very high.

The InP-CdS [5/] and the Cu In Se_2-CdS [6/] solar cells are produced with efficiencies up to 12 per cent. But the base material is a CdS single crystal which is very expensive. Only if it is possible to use polycrystalline CdS-layers can the cell become a serious competitor to Si and Cu_2S-CdS solar cells.

In fig. 2 to 4 there are shown some solar cell generators, available commercially, in the power range of 1 to 8 Watt corresponding to an irradiation of 100 mW/cm^2 which correspond to bright sunshine on a clear day. In fig. 5 there is shown a CdS solar cell which was produced at our Institute.

An advantage of the CdS cell is the rectangular shape also for cells with a sensitive area of 40 cm^2. The silicon cell has the advantage of high conversion efficiency up to 14 per cent. But the large area CdS solar cell has a very good filling factor, this means a good proportion between the light sensitive solar cell area and the area of the total generator.

Applications

The main advantage of the solar cell generators is the fact that they are electronic devices without moving parts. This results in a service-free operation for years, as it can be seen by some applications of solar cell generators as power supply for electric equipment, for example for educational purposes (TV) in Niger.

Automatic Measuring Stations

The lack of correct meteorological data is a great difficulty for all projects in semi-arid areas. Therefore, automatic measuring data stations should be installed. The problem of the power supply for these stations can be solved by using a solar cell generator combined with a proper battery. A solar cell area of 1 m^2 produces an electrical power output of about 50 W, which will be sufficient for a lot of purposes. A plotter with 5 to 10 different channels, which can record all needed meteorological data, can be supplied by this arrangement.

Power Supply for Water Pumps

Another possibility for the application of solar cells will be the usage of solar cell generators as power supply for water pumps. This application depends on the occurrence and availability of underground water. In the following it is outlined what can be expected from a solar cell generator in combination with a water pump.

It is assumed that the solar irradiation in one year amounts to 2400 kWh per m^2 (see fig. 1). If solar cells with an efficiency of 5 per cent are used, a solar cell generator with an area of 1 m^2 yields an electrical energy of 120 kWh per year. As the efficiency of the water pump is about 75 per cent, a mechanical energy of 90 kWh per m^2 solar cell area and per year can be reached. The underground water is assumed to have a depth of 30 m, in this case the waterpump which is supplied by 1 m^2 solar cell generator with an efficiency of 5 per cent will pump 1080 m^3 water from a depth of 30 m to the surface in each year. In fig. 6 the magnitude of the pumped water in m^3 is plotted as a function of the depth in which the underground water occurs.

Cost Analysis

Si solar cell generators are available for about 50 $ per Watt 7/, but there are some new technologies, e.g. ribbon technique and polycrystalline Si solar cells, which will probably be cheaper. Projected costs for Si solar cells are in the range of 0.3 to 1 $ per W 8/9/10/. Cu_2S-CdS solar cells will be producible with costs projected in the range of 0.3 to 0.7 $ per W 11/, but first of all, the existing problems of reproducibility and degradation have to be solved. A panel with a power output described above amounts to 1000 $, the water pump to about 400 $. The costs for the installation of the water pump are very difficult to estimate and depend largely on the depth in which the pump has to be installed. Neglecting these installation costs for the pump, the total costs for the equipment with today's technology should be about 1500 $, which means a magnitude of 1080 m^3 water, pumped from a depth of 30 m to the surface each year. So the installation costs for 1 m^3 pumping capacity each year are about 1.4 $. If the equipment is not destroyed mechanically, an operation lifetime of more than 15 years can be expected. Further cost reductions can be expected by using CdS solar cells when the technology for the production process is developed entirely.

References:

1/ R. A. Arndt et. al.: 11th Photovoltaic Specialists Conference (PVSC). Phoenix, Arizona, 1975

2/ H. Fischer: AEG-Telefunken, Heilbronn, W-Germany

3/ G. H. Hewig et. al.: 11th PVSC. Phoenix, Arizona, 1975

4/ H. J. Hovel et. al.: J. Electrochem. Soc. 120, 1246, 1973

5/ S. Wagner et. al.: Appl. Phys. Lett. 26, 229, 1975

6/ S. Wagner et. al.: Appl. Phys. Lett. 25, 434, 1974

7/ J. Lindmayer: 11th PVSC. Phoenix, Arizona, 1975

8/ P. H. Fang: Proc. of the UNESCO Congress on the Sun in the Service of Mankind, Paris, 1973

9/ G. G. Currin et. al.: 9th PVSC. Silver Springs, Maryland, 1972

10/ E. L. Ralph: 9th PVSC. Silver Springs, Maryland, 1972

11/ K. W. Böer: 9th PVSC. Silver Springs, Maryland, 1972

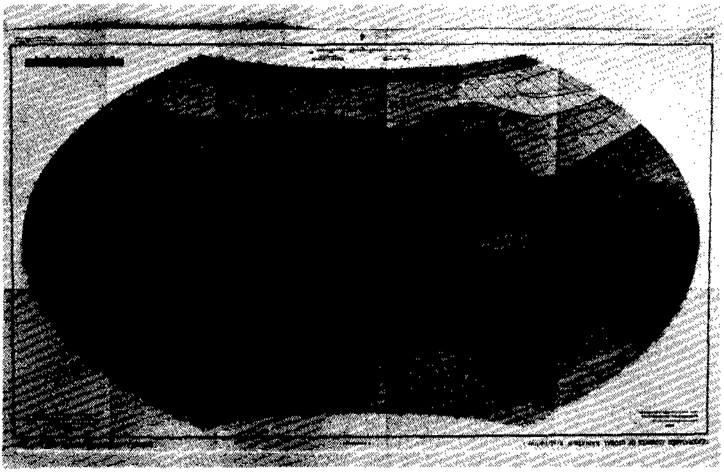


Fig. 1: Local distribution of the
irradiation on the earth

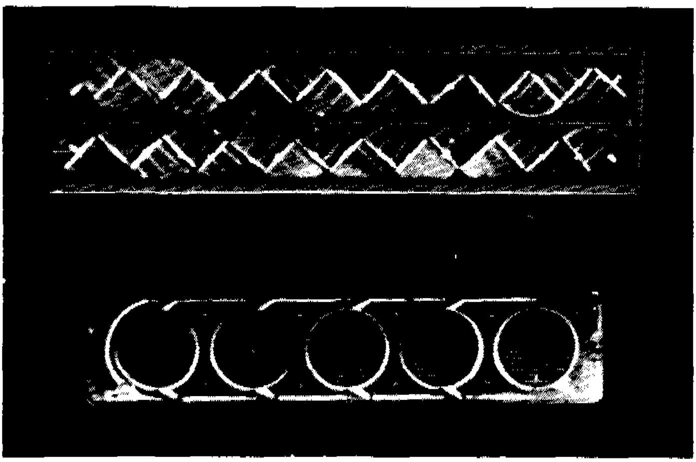


Fig. 2: Silicon solar cell generator (USA)

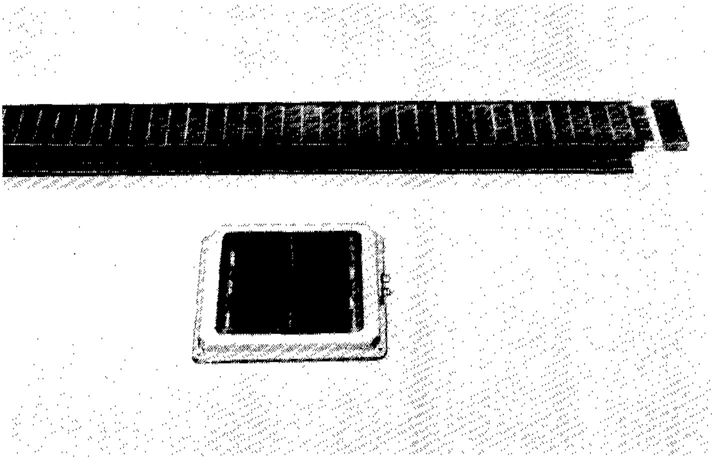


Fig. 3: Silicon solar cell generator (USA)

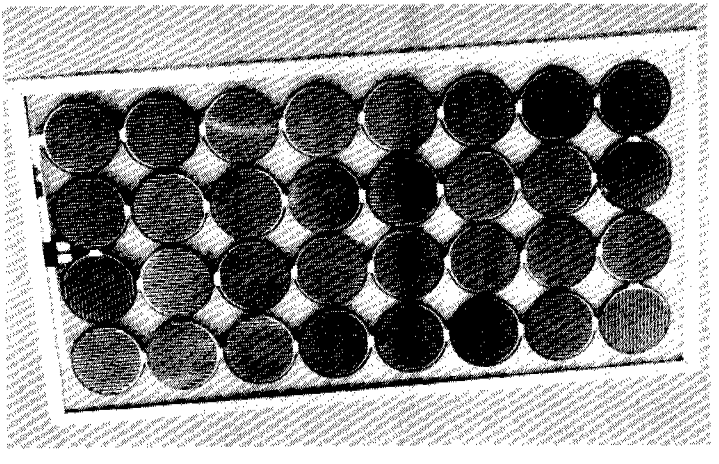


Fig. 4: Silicon solar cell generator (Germany)

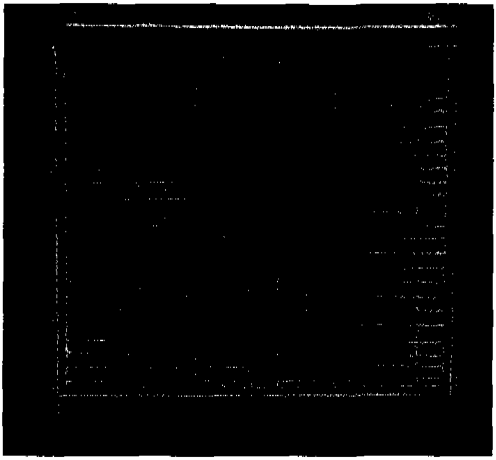


Fig. 5: CdS solar cell

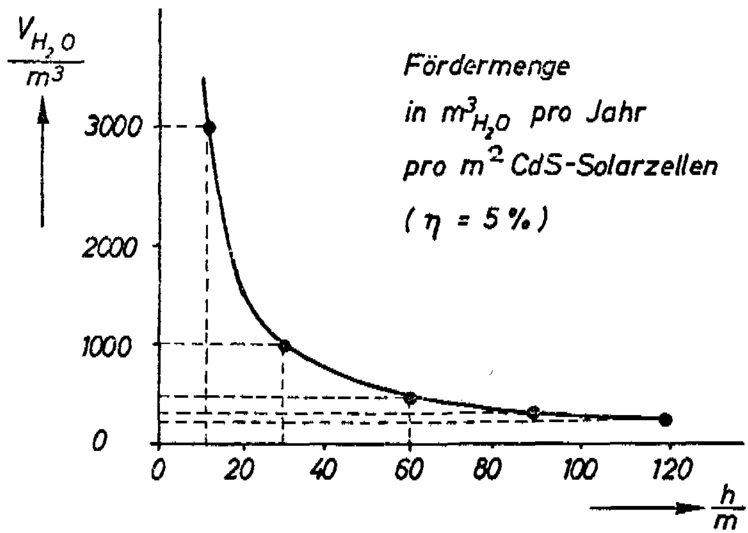


Fig. 6: Pumped water (in m^3) as a function of the depth the underground water occurs

THE GEOMETRY OF THE GUIDANCE OF SOLAR REFLECTORS

Dipl.-Phys. Klaus Kuhnke and Dipl.-Ing. Friedrich von Bismarck

For the guidance of a solar reflector according to the position of the sun, two different movements of the sun with regard to the surface of the earth must be taken into account, namely:

a) the daily orbit of the sun from east to west according to the revolution of the earth, and

b) the seasonal variation in height of the position of the sun according to the ecliptic incline with regard to the earth's axis.

When designing solar reflectors by means of appropriate technology, the obvious way is to adjust the seasonal movement (b) daily by hand (for example by means of a set-screw) whereas a simple automatic device should be designed for the daily east-west revolution (a).

Although the daily apparent movement of the sun (a) holds two components for the observer on earth (i.e. the vertical up-and-down and the horizontal east-west components) one single degree of freedom, i.e. revolution around one single axis, will be sufficient for a device (such as a solar reflector) to follow this movement (see Appendix). For this purpose the axis of revolution must be parallel to the axis of the earth. This principle applies to all geographical latitudes and does not depend on the deviation of the geoid from the spherical or ellipsoid shape.

The position of the axis of revolution does not depend on the seasonal position of the sun (b). That is to say, models such as shown in Figure 1 where the position of the daily revolution axis (a) would have to be adjusted daily by means of the seasonal regulator (b) must not be adopted. One must instead look for models corresponding to the principle represented in Figure 2 where the daily revolution axis (a) is situated in a permanent angle β with regard to the surface of the earth (i.e., parallel to the axis of the earth) and where the seasonal mechanism (b) revolves daily around the axis (a). It is easy to determine the correct angle β, for this angle is always equal to the geographical latitude of the place where the device is located (see Appendix).

A *construction* according to Figure 1 would be possible if linear-focused paraboloidal reflectors are used (such as in the figures). When directed towards the sun, these reflectors will always focus the light on the focal line, whatever the angle ϑ may be (Figure 1). But as the totality of the radiation collected by the reflector is proportional to cos ϑ, and therefore decreases according to the cosinus if $\vartheta \neq 0$, the model according to Figure 1 should be avoided, if possible, also for linear focussing reflectors. The loss of energy would amount to approximately 8 per cent if the reflector is aligned with a vertical deviation of $\pm 23.5^{o}$ with regard to the position of the sun. This deviation corresponds to the incline of the terrestrial orbit, i.e., to the seasonal maximum height variation of the sun's position.

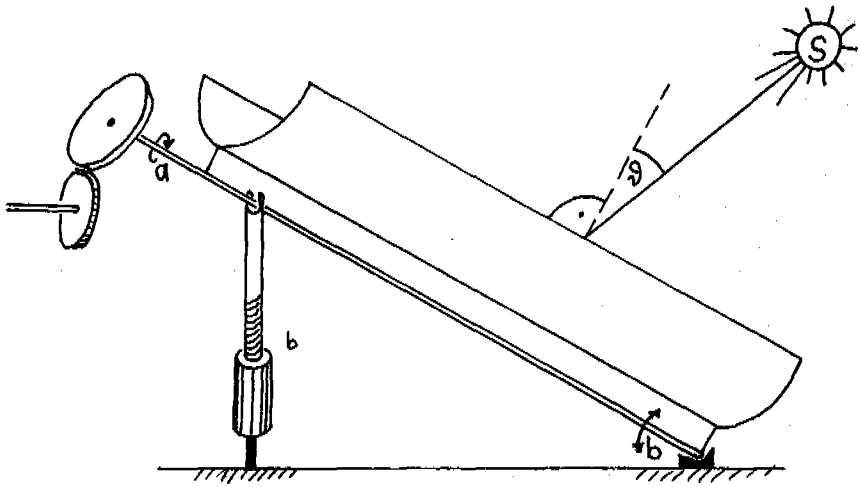


fig.1

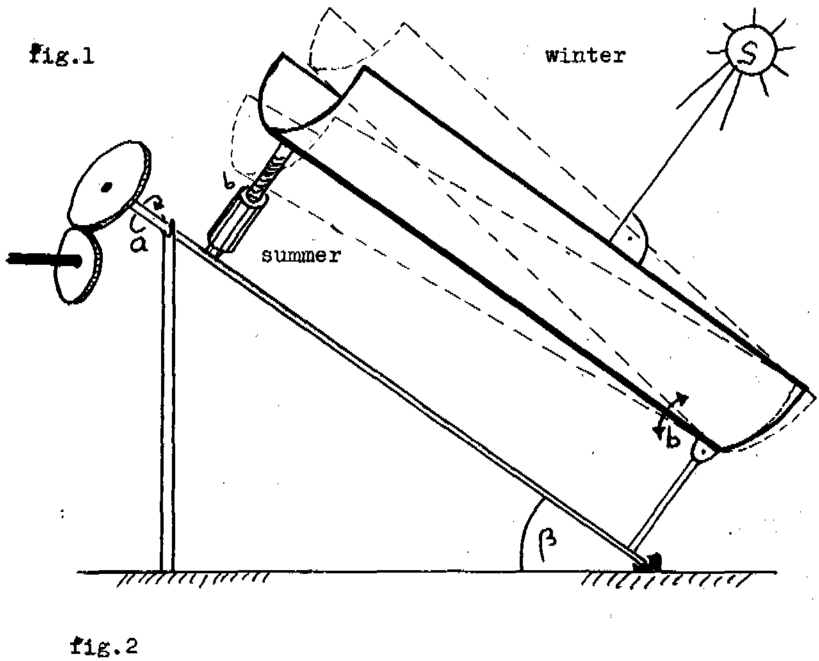


fig.2

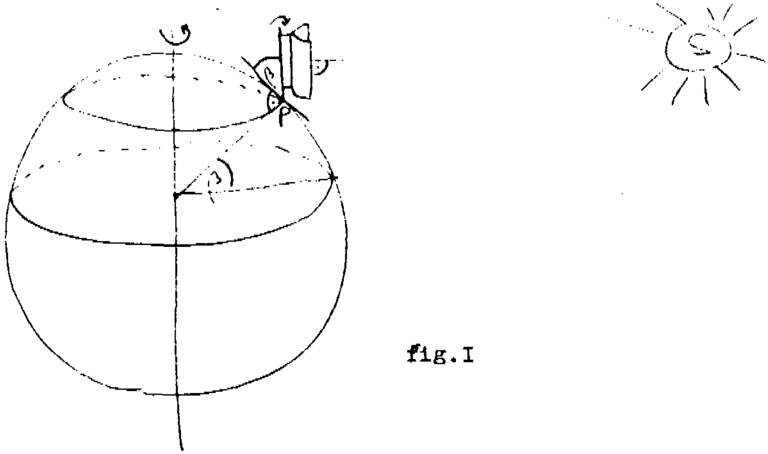


fig.I

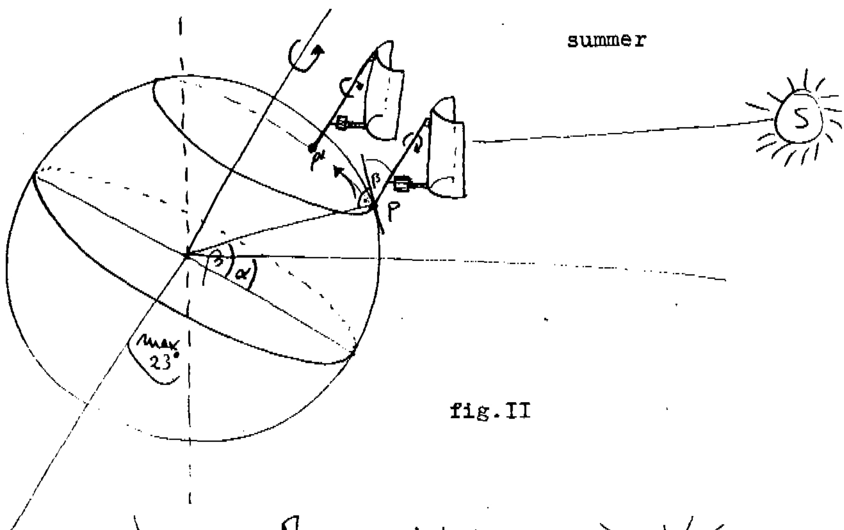


fig.II

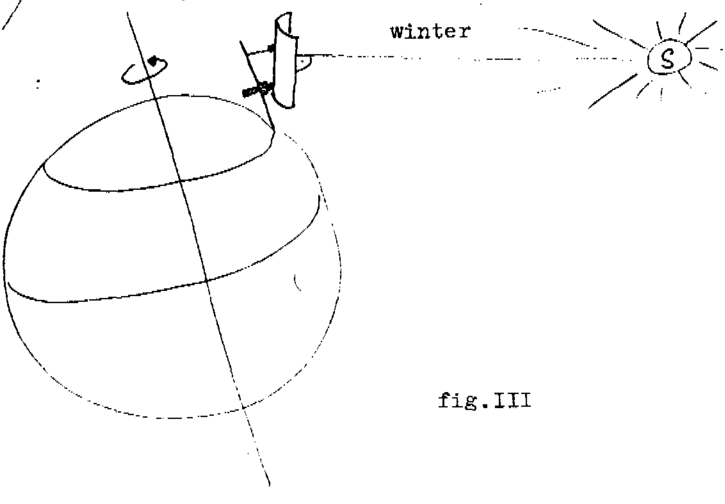


fig.III

Appendix I

Geometrical Nature of the Guidance Movement According to the Orbit of the Sun

For the sake of simplicity let us assume a vertical axis of the earth in space, so that the earth orbit would not be inclined and the sunlight would fall in laterally in a right angle (Figure I). In this case the place P where the reflector is located will turn horizontally in a circular movement.

During this circular movement the reflector should always be directed toward the sun so that the sunlight will reach it in a right angle. This is obtained by making the reflector turn in the reverse direction (east-west) around a fixed axis that is parallel to the axis of the earth. In this way the revolving movement of the reflector is eliminated; what remains is a circular translation movement of the place P where the reflector is located on the earth's surface.

The constant angle between the earth's surface and the revolution axis of the reflector is equal to the geographical latitude β because of the right angle between the normal line (radius) and the tangent (the pyriformity of the earth having been already taken into account).

Nothing is changed with regard to this principle when the earth's orbit is inclined with regard to the earth's axis so that the sunlight does not fall in to the earth in a right angle to its axis, i.e. in the equatorial plane, but in an angle α $(-23.5^{\circ} \leq \alpha \leq +23.5^{\circ})$ (Figure II). It is again sufficient to turn the reflector in the east-west direction according to the height of the sun around the axis of revolution parallel to the axis of the earth; what remains is again only a circular translation movement of the place P where the reflector is located on earth.

The difference between Figures II and III shows clearly that the revolution axis of the reflector is not subject to seasonal changes but must remain rigidly parallel to the earth's axis. The seasonal variation consists in a change of the position of the reflector with regard to its locally fixed revolution axis.

Appendix II

Non-Electrical Automatic Guidance

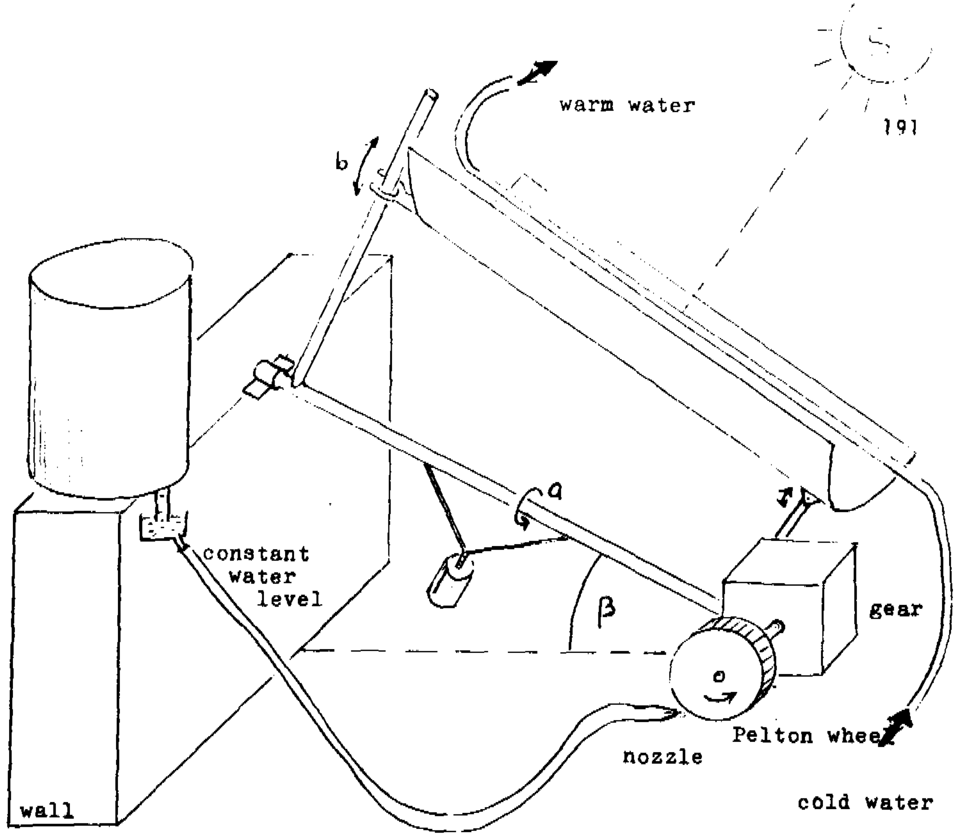
The solar reflector is balanced by means of an adjustable counterweight and can thus be easily moved around the rotation axis. It is driven by means of water power according to the Pelton turbine principle. A simple water wheel is driven at 6 revolutions/sec, the height of fall being 1 m and the nozzle opening 0.9 mm^2. A reduction of 518 400: 1 causes the reflector to rotate with the sun(1 revolution/ day). The constancy of the height of fall of the turbine water is guaranteed in line with the principle of a "Hühnertränke" (watering tank for chickens): A container which is tightly sealed at the top and holds 150 l (the amount of water is sufficient for one day) is provided with an outlet at the lower end and placed in a small basin from where the water flows to the turbine. The lower end of the outlet determines the level of water in the basin. The level remains constant, regardless of the flow of water.

In a developing country the entire device can either be screwed or welded using section iron and sheet metal. Some bearings and possibly the nozzle for the turbine may have to be imported. The worm gear and the water wheel can be manufactured by local craftsmen. Additional electronic photocell devices need not be imported; they would be too complicated for a layman to understand or repair.

Energy Output

If, taking into consideration the unstable weather and a medium efficiency in Central Europe during the day, a conversion of available solar energy of 580 W/m^2 = 500 $kcal/m^2h$ is assumed, 150 l of water per hour per 1 m^2 of solar projection area can be heated by 5^oC (swimming pool) or 25 l of water per hour can be heated from 20^oC to 50^oC (desalination of seawater).

In arid areas the energy output will be twice as high.



Bismarck/Kuhnke: Automatically guided sun reflector without electronic device to heat water

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP III (A): SOLAR PUMPING AND ELECTRICITY SUPPLY

It may at first glance appear to be illogical to deal with these two problems separately. However, the importance and scope (economic and social) of solar pumping and electricity supply as well as methodological reasons led the Working Group first to successive discussions of the two problems and then to a discussion of possible simultaneous solutions.

I. Solar Pumping

1. Meeting water requirements by means of solar pumping in developing countries

Whatever the method of pumping, water requirements can be subdivided into the following three categories:

- water requirements of the population in urban and rural areas;
- water requirements for cattle;
- water requirements for agriculture: sprinkled and irrigated cultures.

a) Water requirements of the population

Large agglomerations with more than 5000 inhabitants are mentioned only for the sake of completeness. The meeting of such large-scale water requirements (50,000 and more cubic metres per day) poses different and complex problems which cannot in the near future be solved by solar pumping.

In the rural areas the population is generally dispersed over numerous villages of various sizes (50 to 5000 inhabitants). Distance from the sea and/or watercourses (rivers, lakes or ponds) make necessary water supply through wells, the number of which depends on the size of village communities and the local hydrological characteristics.

The water requirements range from 30 to 50 m^3 per day to

100 to 250 m^3 per day. The wells have varying depths: 10 to 20 m near the sea or watercourses and 20 to 30 m and 60 to 100 m in the interior of the country. The wells exploit the fossil strata and sometimes reach a depth of 150 m and more. The amount of water obtained ranges from less than one m^3 to 20 m^3 per hour for wells supplied by groundwater and 50 to several hundred m^3 per hour for wells supplied by fossil layers.

b) <u>Water requirements for cattle</u>

In many countries situated in arid or semiarid regions animal husbandry plays an important role in the national economy. The watering points intended for the watering of cattle are generally dispersed over large areas and periodically used by the cattle. Taking various factors into consideration (average distance which cattle can cover, conservation of pastures, environment, etc.), the water requirements to be met by watering points (wells, borehole-well, or borehole) are within the range of 5 to 50 m^3 and, in exceptional cases, of 200 to 250 m^3 per day.

Two other characteristics (depth, output) of the watering points (wells, borehole-wells, boreholes) are the same as a) above.

c) <u>Water requirements for agriculture</u>

The developing countries are making efforts to expand different types of sprinkled and irrigated cultivation: vegetables, fruit, staple crops (rice, maize, sorghum), and export crops (cotton). Water requirements, which vary from plant to plant and from region to region (type of soil, significance of evaporation), are enormous.

On the average, water requirements are as follows for the different types of crops:

35 m^3/ha/day	for vegetables and fruit
60 to 100 m^3/ha/day	for sugar cane and cotton
30 to 65 m^3/ha/day	for rice.

This corresponds to a range of 30 to 100 m^3/ha/day.

The application of special techniques of water utilization (sprinkling, dripping) could bring about an economization of 30 to 35 per cent, but the costs are high (excess pressure in the case of sprinkling, pipe network in the case of dripping). Economical solutions must still be found.

In view of the large water requirements in the sector of agriculture hydraulics, recourse must be taken to the use of surface waters (rivers, dams, ponds) or, in exceptional cases, of large-scale groundwater resources at a depth of 2 to 5 metres. The order of the manometric height of pumping (5 to 10 metres) is a favourable factor with a view to the possible use of solar pumping.

d) Power ranges required for pumping

The preceding data permit calculation of the power required for pumping installations in each specific case. In the case of agricultural hydraulics the size of area to be sprinkled or irrigated is determinative: values of 30 ha, 100 ha, and 1000 ha and manometric heights of 5 to 10 m have been applied.

Whatever the type of pumping installation used, the range of power used is as follows:

2 kW (medium-size villages, regular watering points, small hydro-agricultural installations)
5 kW (large villages, regular watering places connected to deep wells, medium-size hydro-agricultural installations)
10 kW (very large villages, much frequented watering places connected to deep wells, medium-size hydro-agricultural installations for crops requiring irrigation)
25-100 kW (large hydro-agricultural installations).

II. Electricity Supply

It can be said that the present situation in most developing countries is such that priority must be accorded to the solution of the water supply problems as examined above. The supply of electricity for a limited range of requirements must be emphasized in view of the socio-cultural importance of the requirements in question. The solar installations chosen should be combined with a storage device.

1. Electricity supply for communal institutions: dispensaries, maternity hospitals, schools, educational centres

In rural areas the lack of electric energy considerably reduces the effectiveness and social performance of a number of communal institutions: the health centres can operate only during the day, vaccines and certain medicaments cannot be stored; the pupils and adults attending educational centres have disadvantageous conditions for studying.

In accordance with the size of the village, a power station of 500 W to 1 kW operating three to four hours per night represents considerable progress.

2. Supply for communications devices

The communities of the rural areas are in general quite isolated. Electricity supply for small radio stations (20 to 40 W), stations for educational television (10 to 20 W), and radio sets to be used by the whole community (some 100 W) contribute to overcoming the isolation of the inhabitants and permit at the same time the development of socio-cultural activities.

3. Power range required

The electricity required to meet the requirements mentioned above ranges between 500 W and 1 kW. In view of the fact that energy utilization is not continuous, it could be reduced by half, if an appropriate storage device would be coupled to the chosen solar installation.

III. Selection of Type of Installation, Possibility of Simultaneous Satisfaction of All Requirements, Economic Aspects

1. Whether pumping or electricity supply is concerned, the selection of the type of installation (conventional, thermomechanical, photovoltaic, thermo-electric, etc.) must be based on an analysis and an evaluation which take into consideration both economic factors (investments, recurring costs) and utilization conditions (length of life, maintenance problems, etc.). A comparison of classical and solar solutions is not reasonable if, in view of the anticipated progress of the technology of solar installations and their average life, the evaluation does not cover a period of at least ten to twenty years.

2. The problem of simultaneous satisfaction of a number of requirements (pumping, electricity supply) by one solar device apparently cannot be solved by one solution applicable to all cases. Only a thorough examination and an evaluation of advantages (and disadvantages) of all possible alternatives will facilitate decision-making.

IV. SOLAR DISTILLATION

SYSTEMS FOR SOLAR DISTILLATION

Tom A. Lawand

I. INTRODUCTION

Solar distillation is not really a new process. Its principle was known to the ancients. Although there may be others, the first mention of solar distillation known to the author was reported by Mouchot who stated that the Arabs "se servaient de vases de verre pour opêrer certaines distillations au soleil". He then elaborated on their method as follows: "Au dire des alchimistes, les Arabes pour opêrer certaines distillations au soleil, se servaient de miroirs concaves, poli, fabriquêes ã Damas". In l'Histoire Naturelle, published in 1551, Adam Loncier depicted by means of an illustration a similar procedure for distilling, amongst other items, the essential oils of flowers.

The next report on solar distillation comes in the excellent historical review of desalination by Nebbia and Menozzi. They quote the work of Della Porta, published in 1589, whose apparatus was described in detail, for the distillation of herbs.

Obviously, the distillation capabilities of solar energy were well understood although no specific reference to water desalination was made. It must be noted, however, that Della Porta published several other books on desalination experiments.

The first specific reference to the possibilities of solar distillation were made by an Italian, Nicolo Ghezzi, who wrote a short treatise in 1742 where he proposed the following which has been freely translated from the original Italian script:

> "Perhaps placing a cast iron vase containing sea water in such a manner that the sun's rays will strike it (and during mild days and seasons, not an insignificant amount of vapour will be formed) and if the spout of the vase is shaded from the sun, it will result in a more copious and more extended flow of fresh water".

The next reference to solar distillation was given by Harding who reported on a 4,800 square metre still erected near Las Salinas, Chile. This unit was of the greenhouse or roof type solar still. No mention is made of what inspired the builder, a Mr. Wilson, regarding this design. It is known that the productivity of the still in summer was of the order of five kilograms of fresh water produced per square metre of evaporating surface per day. It is an interesting reflection on the simplicity of the process that productivities reported from solar stills recently built are of the same order of magnitude.

For a while after this, few reports of solar stills appear to have been published. In the decade following World War I, interest was renewed in solar distillation. Many publications have followed with reports on the process in general, often accompanied by descriptions of small stills of the roof type, V-covered, tilted-wick, inclined tray, suspended envelope, tubular, or air-inflated design.

In order to increase the productivity, several workers have tried forced circulation systems to condense the water vapour externally from the still. Others tried to recapture the latent heat of evaporation through multiple-effect systems or humidification systems.

Several large solar distillation schemes have been proposed while others have considered combination plants which generated power as well as desalting saline water.

Alternative uses besides desalination were also found for solar stills, such as regenerating solutions, and obtaining fresh water from the ground.

There are a number of plans and specifications for the building of solar stills which have been published.

Quite a few patents have also been issued in this field. With a few exceptions, they generally deal with small solar stills, etc.

It goes without saying that small stills of under fifty square metres in area, as have been described, are most useful for individual family units in isolated areas. Stills of this type have been extensively tested, particularly at the University of California, Berkeley, as reported in 1961 by McLeod, et al. They give results of productivity of a small solar still for seven years, 1952-1959. The Las Salinas still in Chile was reputed to have run for 40 years but records do not appear to have been published.

Work on larger solar stills was initiated through the efforts of the Office of Saline Water, US Department of the Interior, reported mainly by Lof and the Battelle Memorial Institute. This work was carried out chiefly at the Solar Research Station, Daytona Beach, Florida.

These stills were glass-covered units, and one was 250 square metres in area. Although primarily designed as deep basin evaporators with a depth of sea water up to 30 centimetres, there was continuous experimentation in solar still operation, which was excellently reported in the publications of this series.

Concurrently, several other designs of stills were tested, including the air-inflated plastic and tilted wick stills. The former were tested for the Church World Service who were instrumental, in 1964, in the installation of the first large plastic solar still on Symi, a small Greek Island in the Dodecanese. Subsequently, several other stills were built on small Greek Islands.

This work was taken over by the Hellenic Industrial Development Bank which financed some of the largest and longest operating solar stills in the world.

Other significant activities have resulted in solar still installations in Spain and Australia. In both countries, glass-covered stills have been favoured. The Australians have built a large still, 3,800 square metres of evaporator area at Coober Peby, South Australia. In Pakistan, an even larger solar still has been built in Gwadar.

The important work of Howe, Tleimat et al. in this field must be mentioned. In particular, their collaborative efforts with the South Pacific Commission in the testing and installation of solar stills on small islands in the Pacific Ocean have been most informative and useful in resolving problems effecting fresh water provision to small communities. These installations are not quite so large as the others, having been designed mainly for family use. One unit on Fiji was nearly 30 square metres in area. The work of this group in stressing the importance of rainfall collection and storage in combination with solar stills clearly parallels the present study

The Brace Research Institute has been associated with the construction testing and operation of several large solar stills in the West Indies at Petit St. Vincent (230 square metres) and in a rural application in Haiti (300 square metres). Both units are combined with rainfall collection.

One of the better overall assessments of this field is Solar Distillation of Saline Water, prepared by the Battelle Memorial Institute, June 1970 for the United States Department of the Interior. This manual reviews the whole subject and lists the different units, both experimental and practical, which have been built during the last few decades.

The short rêsumê given above is indicative of the very nature of solar distillation technology. It is by no means stagnant. Improvements are continuously being made which hopefully will reduce the costs and increase the productivity of solar stills. With this in mind, further advances in technology should make the future use of solar distillation even more feasible.

II. Experiences with Operating Solar Stills

The Manual of Solar Distillation of Saline Water is the most complete document to date describing the different solar stills which have been built to date in different parts of the world. The situation is constantly changing due to the variable conditions under which these units are tested and installed.

Delyannis at the 1973 Fresh Water from the Sea Conference in Heidelberg prepared a more up-to-date list given in Table I, and illustrated in Figures 1 to 7.

It is evident from this list that solar distillation technology has been tried on a fairly extensive basis in a number of different areas and climatic regions. Obviously notall these units will represent success stories. This is because by their very nature, they will be of a pilot plant nature as various organizations and research teams acquire increased operating knowledge. Nonetheless in order to ensure that this technology is adequately treated, it will be necessary to compile a comprehensive assessment of different systems and how they have performed in practice. It is equally important that the socio-cultural aspects of each of these installations also be monitored so that it will be possible to ascertain whether these have been given sufficient attention in the preparation of these projects. It is apparent that solar distillation is often an appropriate technology. The question that must be raised however is whether this technology has been effectively and appropriately applied.

Many organizations have published details of operating experiences and productivity. The Hellenic Industrial Development Bank in Greece has monitored the performance of the solar still at Nissyros in the Aegean and these figures are given in Figure No. 8. What this does show is a reduction of production of roughly 12 to 15 per cent during the summer months over a period of five years. What has caused this reduction? It is essential to determine these factors in order to illustrate the effectiveness of this type of technology. This in addition underlines the necessity for global assessment of the various components of these systems in order to ascertain their short- and long-term appropriateness.

A series of photographs illustrate the different solar distillation units listed in Table I. In addition, some smaller individual basis solar stills have also been shown.

It is essential to realize that one of the prime advantages of solar distillation is its flexibility. It is exceedingly easy to increase the capacity of these solar stills by adding additional units. On the other hand, solar stills can be used in very small-scale operations by providing freshwater for individual needs in units adjacent to residences or integrated directly into the roof of buildings. A number of commercial firms now exists which provide hardware either in the form of installations on a turnkey basis or in the form of prefabricated units.

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
	Mahdia	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

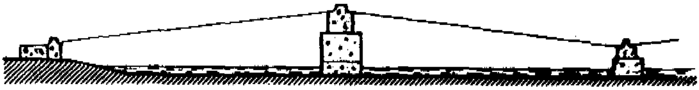


Fig. 1. Battelle-Löf design

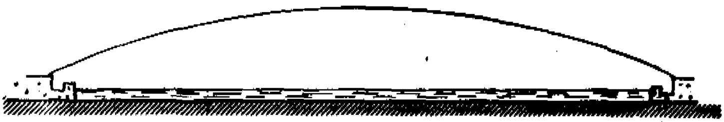


Fig. 2. Inflated plastic cover design

Fig. 3. V-shape plastic cover design

Fig. 4. Stretched plastic or inclined glass cover design

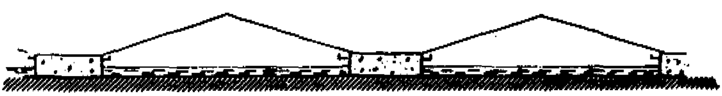


Fig. 5. C.S.I.R.O. - Australia design

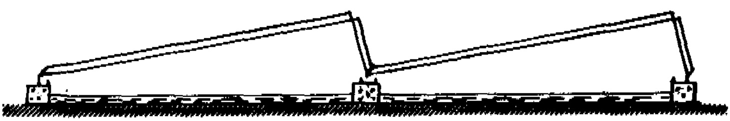


Fig. 6. Delyannis design

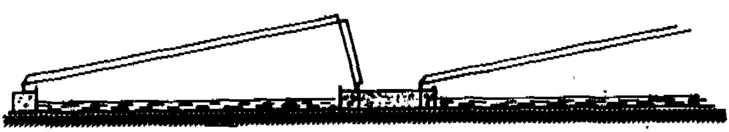
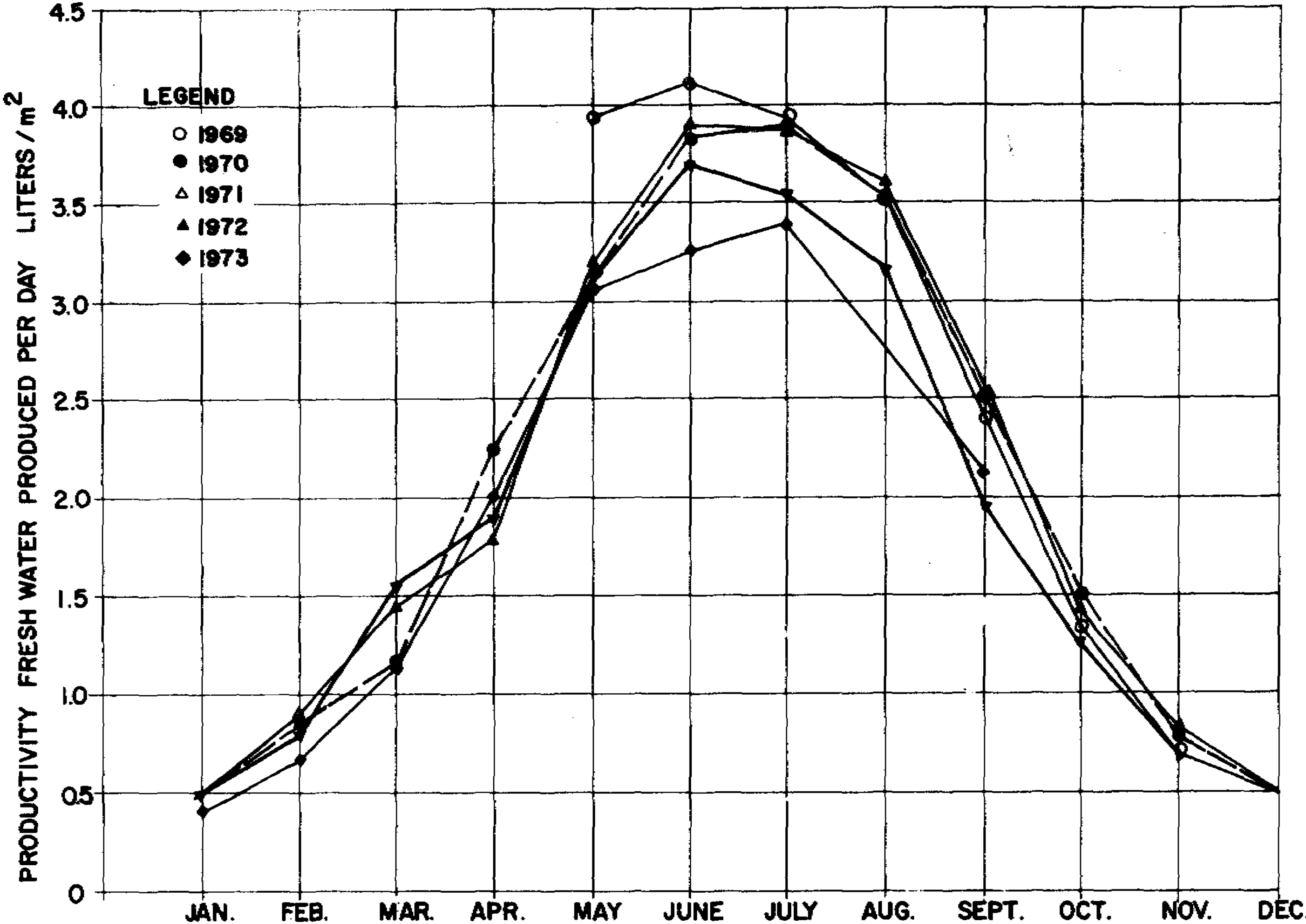


Fig. 7. Delyannis modified design



VARIATION OF PRODUCTIVITY WITH TIME OF

[illegible]

Components of Solar Distillation Systems

There are many ways in which solar distillation systems can be built. It is generally agreed that it would be most advantageous for these systems to have a long life. At the same time full appreciation and use must be made of locally available materials and technologies. In this manner, truly appropriate systems can be developed and maintained by the local population.

Specifications for Solar Still Components

Many designs of solar stills exist. One aim of this study is to evaluate and adapt various materials for use in still construction.

Hence, it has been decided to split up the material requirements in relation to their function within the unit. These are listed below:

1. General Specifications of Solar Stills
2. Transparent Cover
3. Evaporator Liner
4. Solar Still Frame
5. Sealants
6. Insulation
7. Auxiliaries - Piping, Pumping and Reservoirs.

1. General Specifications of Solar Stills

There are certain basic requirements which must be met. In general, the unit

a) must be easily assembled in the field.

b) materials imported to the region should be packageable so that transportation costs will not prove excessive. (This is particularly true not only for shipment from one country to another, but especially for internal movement within a given area, i.e. from the port to final destination.)

c) should be lightweight for ease of handling and shipping.

d) must have an effective life, with normal maintenance, of ten to 20 years.

e) must have access ports for ease of maintenance.

f) should not require or depend upon external power sources.

g) should serve as a rainfall catchment surface.

h) should be able to withstand the effects of severe storms.

i) must be manufactured of materials which will not contaminate the collected rainwater or the distillate. (It must be continuously stressed that solar stills constitute the water supply systems for the communities served and hence must be nontoxic in every respect to the freshwater produced.)

j) must be fabricated so that the maximum size of solar still components can be directly related to economic shipping dimensions as specified by freight carriers.

k) in general must make use of as many local resources, whether material or labour, as possible.

In summary, the solar stills must meet standard civil and structural engineering standards.

2. Transparent Cover

This serves to cover the distillation segment and permit access of the solar radiation to the interior.

Properties required are listed below:

a) The material must withstand the effects of weather - wind, sunshine, rain, dust, etc.

b) The material must have a transmissivity for short-wave solar radiation (between the limits of 0.3 and 3.0 microns) of over 85 per cent and preferably higher.

c) Essentially, it must be nearly opaque to long-wave (over 3.0 microns) radiation.

d) It should not have a high water absorptivity, both from its use as a rainfall catchment surface on the outside and its probable use as a condenser on the inside.

e) The solar reflectivity at normal incidence should not exceed ten per cent where possible.

f) The solar absorptivity of the material should be low, especially if the cover is also to be used as a condenser.

g) The heat capacity should be high in order to reduce the cover temperature.

h) The material properties should not alter with age.

i) The material should not possess electrostatic properties which would concentrate dust particles on the outside surface.

j) If the cover is to be used as a condenser, then the material must withstand temperatures of up to 80° C. In addition, one side will experience extremely high relative humidities (up to 100 per cent), while the other surface must concurrently withstand the low humidities prevalent in arid regions.

k) The cover must be able to withstand the ravages of small animals.

l) The cover must be able to withstand a wind load of up to 45 metres per second.

3. Evaporator Liner

.The evaporator of basin liner serves as the absorbing surface for solar radiation as well as a container for the saline water. Materials used for this purpose should have the following properties and characteristics:

a) The liner must be impervious to water.

b) The liner must have a solar absorptivity of the order of 0.95. Generally, black materials are used.

c) The surface should be fairly smooth so as to discourage the deposition of scale from the saline water. It also becomes easier to clean when this is necessary.

d) As liners are often placed directly on the ground, the material *should not deteriorate* or decompose on contact with normal soils.

e) The material must withstand the effects of continuous immersion in hot, saline water. Temperatures should not exceed 80^{0} C to 100^{0} C upon being heated.

f) The basin liner should not emit any gases or vapours which could taint the taste of the freshwater distillate.

4. Solar Still Frame

This section refers to materials which are used to form the frames of the evaporators.

Any materials used in this fashion should possess the following characteristics:

a) They should be resistant to attack from the saline water or atmosphere.

b) In case they are exposed to the evaporator, they should be covered with a protective coating.

c) They should be sufficiently heavy so as to anchor the stills to the ground during periods of high winds.

d) Solar stills vary in width from one to three metres and are generally up to 50 metres in length. Frame components should be available in a series of sizes, which could be easily disassembled for shipping and erection on the site. In situ construction must also consider logical sizing.

e) The frames should be made of such materials as to permit ease of working or attachment.

f) These materials should not be affected by direct contact with the ground or exposure to normal weather conditions.

g) As the frames separate different evaporator bays, they will more often than not be used as a walkway and must be able to withstand usage in this capacity.

h) Any sections of the frame exposed to the exterior will invariably serve as part of the rainfall catchment surface. In this regard, the material should neither absorb too much of the incident rainwater nor contaminate it.

5. <u>Sealants</u>

This section includes materials used to seal transparent cover materials to one another as well as to the other components of the distillers. In addition, it includes any members used to support the superstructure of the distillation units as they will invariably come in contact with the transparent cover.

a) The materials should not be adversely affected by exposure to the weather on one face and by their possible exposure to the interior of the evaporator on the internal face.

b) If the transparent cover is to be used as a condenser, then the sealants and structural components should intercept a minimum amount of solar radiation in order to keep the efficiency high. In addition, all heat inputs to the cover area increase its temperature and reduce the evaporation potential of the system.

c) A minimum number of sealants should be utilized. Preferably the same sealant should be employed to bond the transparent cover materials as well as to seal other materials used in the solar still construction.

d) The sealants must be easily applicable under extreme field conditions, as it is likely that they will be utilized during erection phases on the site.

e) If structural cover supports are not used, the transparent cover material sealants must withstand the effects of winds of up to 45 metres per second.

6. Insulation

The insulation used in solar distillation units is used beneath the seawater evaporator basins in order to reduce ground heat losses. The materials used for this purpose require the following properties:

a) They must be lightweight and structurally self supporting.

b) They must be waterproof and basically water-impermeable.

c) They should insulate the edges as well as the base of the evaporator.

d) The insulation must withstand temperatures of up to 80^{o} C and must not warp or change shape.

e) The insulation must withstand the effects of the ground on which it is placed.

f) Insulation materials could also serve as basin dividers in large solar still bays.

7. Auxiliaries - Piping, Pumping and Reservoirs

This section includes all fluid systems - gutters for rainfall and condensate collection, piping for feed and rain lines, and reservoirs for saline and fresh water. In addition, some form of pumping mechanism should be provided for water transfer.

a) All auxiliaries in contact with either fresh or rain water should have a protective coating of inert material in order to avoid contamination or damage to the system.

b) All internal gutters or piping systems must be of continuous, single-piece construction so as to avoid internal joints which are difficult to maintain.

c) All joints which must be made to piping or gutters must be easily undertaken under field conditions.

d) All auxiliaries and reservoirs must be so fabricated as to meet general shipping dimension regulations.

e) Where conventional power sources do not exist, the pumps should be manually operated or wind-powered units.

f) The distillate reservoir should exceed at least the maximum daily production capacity by a factor of three.

g) The rainwater reservoirs should be rated to existing short-term rainfall intensities.

8. Note on the Use of Windmills for Providing Water for Solar Stills

As longer solar stills are considered, it becomes necessary to pump large quantities of water. There are several modes of operation that can be envisaged.

a) The continuous flow of water through solar stills - this type of operation has been followed in Australia. The amount of saline water generally fed into solar stills is of the order of 0.5 kg/hr per sq. metre of evaporating area. A reservoir is needed to permit gravity feed of the water into the solar still. Water must be pumped from a well, salt lake, the sea etc. into this reservoir. In this case a smaller reservoir can be envisaged because of the continuous nature of the operation. Experience has indicated that the buildup of algae etc. can be considerable with this system.

b) Water can be flushed through the solar still periodically, i.e. every one, two or three days, removing all of the concentrated saline solution, and replacing this with fresh brine. This method requires a longer reservoir than method (a) but it is more suited to manual operation, and results in less sealing within the solar still basins. If wind speeds are variable, then this method has greater advantage, as the larger capacity reservoirs can insure that some water can be replaced in the solar stills.

Selecting a proper windmill for these applications depends on the following conditions:

a) the availability of the saline water,

b) the volume of water to be pumped per unit time and the total head through which the pump must work,

c) the availability of wind during the periods of operation of the solar still,

d) the suitability of this equipment under the somewhat severe climatic conditions prevailing in locations where solar stills are often used.

The careful selection of a windmill-pump system is an integral part of a solar still system for remote locations. Some backup pumping system whether manual or conventional should be provided to ensure the continuous operation.

If electricity or diesel power is available on the site, its use should be considered, provided the cost and operations can be absorbed by the local authorities. In all cases, all the alternatives must be explored.

9. Note on Freshwater Reservoirs

In all cases, freshwater collection reservoirs should be provided. This will permit the measurement, collection and storage of water from these sourses. Generally, separate collection systems should be provided to avoid contamination from

a) dirt, dust, animal and bird droppings in case of the rainwater collection,

b) saltwater overflow in case of the distillate production

The freshwater should be carefully handled and possibly sand-filtered if the need arises.

It is obvious that these specifications do not cover all types of applications of solar stills. Rather, they should be viewed as criteria which should be adhered to, if we wish to develop appropriate technology in solar distillation.

III. Costing Procedure for Solar Stills

In 1970, A. Delyannis proposed the establishment of a standardized procedure for costing, applicable to all designs of solar stills and to all countries. This procedure was designed to allow the comparison of the cost of the various solar stills at a given locality, as well as the calculation of the cost of a given design in various localities. Therefore, such detailed information must be provided for each case to make this aim possible and any comparison reliable. A modified version of this procedure is given below.

A principal item of equipment for this comparison should be the distillation plant proper, as representing a particular design. Auxiliaries, more or less not directly dependent on the specific solar still design, e.g., site preparation, fencing, storage facilities, pumping, piping, etc., must be quoted as well in detail, but as separate or independent items.

Units of necessary materials and total amounts needed must be reported separately for each item. Cost of materials and labour in the currency applicable to the proposed site must be given.

A description of the proposed mode of operation, including continuous or batch feed, brine evacuation and renewal, necessity of cleaning cover or basin, etc., should be given.

Special mention should be made if rainfall is to be collected. Only additional cost for this purpose, on top of the conventional solar distillation plant, should be included in this item.

1. PLANT DESCRIPTION

(a) Location: Place..................Country..................
Latitude...............Longitude................
Elevation..............m over sea level

(b) Feed: Type of water...........
Salinity................mg/l NaCl
Total hardness..........meq/l CaO
Carbonate hardness......meq/l CaO
Permanent hardness......meq/l CaO

(c) Plant Area: Water evaporating surface............m^2
Cover projected area.................m^2
Area inside boundary of the still....m^2

(d) Available area for future enlargement...........m^2

(e) Number of distilling units:
Water evaporating surface............m^2 per unit
Cover projected area................m^2 per unit
Dept of brine in basin..............mm
Cover material......................

(f) Mean daily output per year............l/m^2 day or l/day
Maximum output.......................l/m^2 day or l/day

2. CONSTRUCTION OF DISTILLATION UNITS

(a) *Basin structure per unit:*

Gravel and sand	........m^3 X ...... = ...
Cement	........kg X ...... = ...
Concrete Mix	........m^3 X ...... = ...
Precast concrete beams (No. of dimensions)	........pieces X .... =........
Precast concrete posts (No. of dimensions)	........pieces X .... =........
Steel for reinforcement	........kg X ..... = ...
Other materials	.... X ..... = ...

(b) Lining:

Butyl rubber sheet	........m^2 X ..... = ...
Asphalt mats	........m^2 X ..... = ...
Polyethylene, sheet	........m^2 X ..... = ...
Others - specify	........m^2 X ..... = ...

(c) Sealing materials:

Silicone rubber	........tubes X ..... = ...
Asphalt cement	.... X .... = ...
....	.... X .... = ...

(d) Gutters and weirs:

Stainless steel strip	........m X .... = ...
Aluminum Channel	........m X .... = ...
Plastic channel	........m X .... = ...
Asbestos - cement angles	........m X .... = ...
Asbestos - cement strips	........m X .... = ...
Other specify	........m X .... = ...

(e) Insulation:

Polystyrene	........m^2 X .... = ...
Other materials specify	.... X .... = ...

(f) Labour for:

1. Basin:	concrete skilled	.....mh X ..... = ...
	unskilled	.....mh X ..... = ...
	other work	.....mh X ..... = ...
2. Lining:	skilled	.....mh X ..... = ...
	unskilled	.....mh X ..... = ...
3. Sealing:	skilled	.....mh X ..... = ...
	unskilled	.....mh X ..... = ...

(f) Labour for:

4. Gutters: skilled ......mh X ...... = ...
unskilled ......mh X ...... = ...

5. Insulation: skilled ......mh X ...... = ...
unskilled ......mh X ...... = ...

(g) Any other (specify)

(h) Total cost of basin:

Cost .... per m^2 evaporating surface

Cost .... per m^2 of cover projected area

3. COVER CONSTRUCTION

(a) Materials used:

Concrete curbs (dimensions) ..... pieces X ...... = ...
Aluminum angles (dimensions) ..... kg X .... = ...
Aluminum T-ees (dimensions) ..... m X .... = ...

Cover: glass ..... m^2 X ..... = ...
Tedlar ..... m^2 X ..... = ...
Other plastics ..... m^2 X ..... = ...

Sealing Materials:

Silicone rubber ..... tubes X ..... = ...
Silastic ..... tubes X ..... = ...
Other sealants ..... X ..... = ...
Primer ..... lit. X ..... = ...

(b) Labour for:

Cover structure skilled ... mh X ... = ...
unskilled ... mh X ... = ...
Cover material skilled ... mh X ... = ...
unskilled ... mh X ... = ...

(c) Total cost of cover:

Cost ... per m^2 evaporating surface
Cost .... per m^2 cover projected area

4. COST OF DISTILLATION UNITS (total of 2 and 3)

(a) Basin ....
(b) Cover ....
Total of distillation units ....

Cost ..... per m^2 of evaporating surface
Cost ..... per m^2 of cover projected area

5. SITE PREPARATION

Minimum area required for projected output ....m^2

Cost .... m2 X ..... = ...

Removal and relocation of -

(a) Earthen materials ..... m^3 X ...... = ...

(b) Rocky materials ..... m^3 X ...... = ...

Type of mechanical means used:

....

Machine hours .... h X .... = ...

Labour, skilled .... mh X ... = ...

Labour, unskilled ... mh X ... = ...

Any other special

. . . .

. . . .

. . . .

Total cost of site preparation ....

Cost .... per m^2 of evaporating surface

Cost .... per m^2 *of cover projected area*

6. PIPING AND PUMPS

(a) Salt water:

.... m pipe ..... mm Ø X ..... = ...

.... m pipe ..... mm Ø X ..... = ...

.... m pipe ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

..... fittings ..... mm Ø X ..... = ...

..... fittings ..... mm Ø X ..... = ...

..... fittings ..... mm Ø X ..... = ...

(b) Distillate

.... m pipe ..... mm Ø X ..... = ...

.... m pipe ..... mm Ø X ..... = ...

.... m pipe ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

.... valves ..... mm Ø X ..... = ...

...... fittings ..... mm Ø X ..... = ...

...... fittings ..... mm Ø X ..... = ...

...... fittings ..... mm Ø X ..... = ...

(c) Pumping (specify HP per pump)

...... salt water pumps ... mm Ø X .... = ...

...... distillate pumps ... mm Ø X .... = ...

...... windmill pumps ... capacity, cost.

(d) Total cost of piping and pumping:

Cost .... per m^2 evaporating surface
Cost .... per m^2 cover projected area

7. STORAGE

Capacity for salt water ....m^3
Capacity for distillate ....m^3

(a) Materials used
(specify by item) ....

(b) Labour, skilled ... mh X ... = ...
unskilled ... mh X ... = ...

(c) Total cost of storage

Cost ..... per m^3 of storage capacity
Cost ..... per m^2 of evaporating surface
Cost ..... per m^2 of cover projected area

8. FENCING

Total area included inside fencing .... m^2

(a) Materials used
(specify by item) ....

(b) Labour, skilled ... mh X ... = ...
unskilled ... mh X ... = ...

(c) Total cost of fencing

Cost .... per m^2 of area included
Cost .... per m^2 of evaporating surface
Cost .... per m^2 of cover projected area

9. OTHER ITEMS OF INVESTMENT COST

(a) Facilities for pretreatment of salt water (specify by item) ....

(b) Facilities for post-treatment of distillate (specify by item) ....

(c) Transportation of materials to the site (specify by item) ....

(d) Engineering and design ....

(e) Supervision of construction ....

(f) Testing ....

(g) Brine disposal ....

(h) Power supply ....

....

(i) Total cost of other items

Cost .... per m^2 of evaporating surface

Cost .... per m^2 of cover projected area

10. RECAPITULATION

Cost of distillation units	.....
Site preparation	.....
Piping and pumps	.....
Storage	.....
Fencing	.....
Other items	.....
Total	.....
Contingencies, 10% of total	.....
Insurance	.....
Interest during construction	.....
Grand total	.....

Cost ..... per m^2 of evaporating surface
Cost ..... per m^2 of cover projected area.

IV. Why Consider Solar Distillation

The need for water in arid areas of the world is taking on increasingly large proportions as the population of the world increases. There are 35,000 kilometers of coastal deserts located in some of the most favored climatological regions of the world. The time will come when it will be necessary to make use of the areas not only for habitation but also for increased agricultural production. Given these conditions, technology which by large makes use of locally available resources will obviously be favoured and decidedly more appropriate. The use of solar distillation could therefore be considered not only for the provision of water, but also for the production of agricultural produce when combined with structures like greenhouses which can control the often harsh natural climatological conditions experienced in these areas.

One would consider the use of Solar Distillation if the following conditions are met:

a) The availability of saline water.

b) Small populations living in arid areas where inexpensive conventional sources of energy are not readily available.

c) No natural sources of freshwater under the control of the local population are easily exploitable.

d) For extended periods of time, there is adequate level of solar radiation intensity and reasonably high ambiant air temperatures.

e) Areas where the annual rainfall generally does not exceed 600 millimeters.

f) Land is available and has little opportunity cost.

It must be pointed out that generally Solar Distillation should only be provided in quantities less than 20 cubic metres per day. Even this constitutes an exceedingly large size of installation. It can be that the cost will be excessive and the size relatively unmanageable in attempting to build installations close to this upper level. This does not necessarily mean, however, that only small populations need be supported. Given that man can survive easily on 10 litres of freswater per day for his basic needs, approximately 2 000 persons per community could be supported in a 20 cubic metre per day plant. In this method of operation, however, all other forms of water would be derived from saline water sources.

What criteria should the decision makers in the developing arid areas utilize in considering solar distillation as an option for freshwater provision for rural communities. The prime advantages of Solar Distillation are that

1. The units can be built to a large extent using locally available material or materials from manufacturers in the country or the general region.
2. The local labour force can undertake all the principal jobs in the construction, installation, operation, and maintenance of the system.
3. Generally, apart from the amortization of the capital investment the cost of the operation is not high if the unit has been appropriately constructed in the first instance.

No desalination process should even be envisaged until full exploitation has been made of all natural freshwater sources - surface, ground and rain water. This applies as equally to solar desalination as to other conventional processes. In the solar case, the energy cost is nil but the cost of collecting this "free" energy is not without value.

SUGGESTED READINGS IN SOLAR DISTILLATION

1. Nebbia, G. and G. Menozzi. "A Short History of Water Desalination". Acque Dolce Dal Mare, IIa Inchiesta Internazionale, Milano, April 1966, pp. 129-172.

2. Della Porta, G.B. Magiae Naturalis Libri XX. Napoli, 1589. Libro X, p. 183.

3. Harding, J. "Apparatus for Solar Distillation". Proceedings of Institute of Civil Engineers, Volume 73, 1883, pp. 284-288.

4. Barasoain, J.A. and L. Fontan. "First Experiments in the Solar Distillation of Water". Revista de Ciencia Aplicade, Madrid Vol. 72, 1960, pp. 7-17.

5. Battelle Memorial Institute. Study and Field Evaluation of Solar Sea-Water Stills. United States Department of the Interior, Office of Saline Water, R & D Report No. 50, September 1961, pp. 1-82.

6. Battelle Memorial Institute. Second Two Years' Progress on Study and Field Evaluation of Solar Sea Water Stills. United States Department of the Interior, Office of Saline Water, R & D Report No. 147, July 1965, pp. 1-86.

7. Baum, V.A. Solar Radiation, Experience, Possibilities and Prospects of its Exploitation. Proceedings of the New Delhi Symposium on Wind and Solar Energy, UNESCO, /NS/AZ/191/ANNEXE 23, Paris, 1956, pp. 1-14.

8. Baum, V.A. and R. Bairamov. "Prospects of Solar Stills in Turkmenia". Solar Energy, Vol. X, No. 1, 1966, pp. 38-40.

9. Bjorksten Research Laboratories Inc. Development of Plastic Solar Stills. United States Department of the Interior, Office of Saline Water, R & D Report No. 24, 1959, pp. 1-25.

10. Bjorksten Research Laboratories Inc. Weathering Tests of Plastics and Design of Suspended Envelope Stills. United States Department of the Interior, Office of Saline Water, R & D Report No. 30, 1959, pp. 1-40.

11. Cillie, G.G. Solar Distillation of Saline Water. South African C.S.I.R. 1955, pp. 1-26.

12. Coanda, H. "Pour changer l'eau salée en eau douce". Science et Vie, D. Vincendon, Paris, Vol. 86, No. 443, August 1954, pp. 146-151.

13. Cooper, P.I. The Maximum Efficiency of Single-Effect Solar Stills. Solar Energy, Vol. 15, No. 3, 1973-74, pp. 205-219.

14. Cooper, P.I. and W.R.W. Read. Design Philosophy and Operating Experience for Australian Solar Stills. Solar Energy, Vol. 16, No. 1, August 1974, pp. 1-9.

15. Daniels, Farrington. Construction and Tests of Small Solar Stills. Solar Energy Laboratory, University of Wisconsin, Proceedings of Solar Energy Society Annual Meeting, Phoenix, Arizona, March 1965, pp. 1-18.

16. Daniels, Farrington. "Direct Use of the Sun's Energy". American Scientist, Vol. 55, No. 1, March 1967, pp. 15-47.

17. DeJong, T. "An Introduction to Solar Distillation". Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Paper No. 1704, Sa-4, July 1958, pp. 1-39.

18. Delyannis, A.A. and E. Piperoglou. Solar Distillation in Greece. Proceedings of First International Symposium on Water Desalination, Session C, Paper No. SWD/87, Washington, October 1965.

19. Fitzmaurice, R. and A.C. Seligman. Some Experiments on Solar Distillation of Sea Water in Cyprus during the Summers of 1954 and 1955. Trans. Conference on the Use of Solar Energy, Vol. III, Part II, Tucson, Arizona, 1955, pp. 109-118.

20. Fontan, L. and J.A. Barasoain. Quelques expériences sur la distillation solaire de l'eau à petite échelle. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 34/S/73, Rome, August 1961, pp. 1-6.

21. Garret, C.R. and E. Farber. Performance of a Solar Still. ASME Publication, Paper No. 61-SA-38, 1961, pp. 1-8.

22. Gomella, C. "Le problème de la déminéralisation des eaux saumâtres par distillation solaire". Terres et Eaux. E. Nouel, Paris, 2e Trimestre, Vol. 6, No. 25, 1955, pp. 4-31.

23. Gomella, C. PracticalPossibilities for the Use of Solar Distillation in Under-Developed Arid Countries. Trans. of the Conference on the Use of Solar Energy, Vol. III, Part II, Tucson, Arizona, 1955, pp. 119-133.

24. Gomella, C. Solar Distillation Developments in the Eastern Mediterranean. Proceedings of Symposium on Saline Water Conversion, Publication No. 568, National Academy of Sciences, National Research Council, Washington, pp. 131-136.

25. Gomella, C. Use of Solar Energy for the Production of Fresh Water - Small and Large Scale Distillers. U.N. Conference on New Sources of Energy, Session III E, General Report, E/CONF. 35/Gr./19(S), Rome, August 1961, pp. 1-42.

26. Gomella, C. Possibilités d'extension des dimensions des distillateurs solaires. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/107, Rome, August 1961, pp. 1-16.

27. Hafez, M.M. and M.K. Elnesr. Demineralization of Saline Water by Solar Radiation in the United Arab Republic. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/63, Rome, August 1961, pp. 1-10.

28. Hay, H.R. "V-Cover Solar Stills". Sun at Work, 2nd Quarter, 1966, Vol. II, No. 2, pp. 6-9.

29. Herlihy, J.T. and F. Daniels. Solar Distillation of Sea Water in Plastic Tubes. Solar Energy Research, University of Wisconsin Press, 1961, pp. 125-126.

30. Hirschmann, J.G. Evaporateur et distillateur solaire au Chili. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/23, Rome, August 1961, pp. 1-30.

31. Hobbs, W. The Design and Construction of a Solar Heater for the Distillation of Water. Haile Selassie I University, Dire Dawa, Ethiopia, Publication 7, June 1965, pp. 1-5.

32. Howe, E.D. Solar Distillation Research at the University of California. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/29, Rome, August 1961, pp. 1-22.

33. Howe, E.D. "Solar Distillation on the Pacific Atolls". South Pacific Bulletin, Sydney, Australia, April 1964, pp. 57-59.

34. Howe, E.D. "Pacific Island Water Systems Using a Combined Solar Still and Rainfall Collector". Solar Energy, Arizona, Vol. X, No. 4, 1966, pp. 175-181.

35. Khan, E.U. "Practical Devices for the Utilization of Solar Energy". Solar Energy, Vol. VIII, No. 1, 1964, pp. 17-22.

36. Khanna, M.L. and K.N. Mathur. Experiments on Demineralization of Water in North India. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/115, Rome, August 1961, pp. 1-11.

37. Khanna, M.L. Solar Water Distillation in North India. Proceedings of International Seminar on Solar and Aeolian Energy, Sounion, Greece, September 1961, Plenum Press, New York, pp. 59-63.

38. Lappala, R. and J. Bjorksten. Development of Plastic Covered Solar Stills for Use in the Large Scale, Low-Cost Demineralization of Saline Water by Solar Evaporation. *Trans. Conference on the Use* of Solar Energy, Tucson, Arizona, Vol. III, Part II, 1955, pp. 99-108.

39. Lawand, T.A. A Description of the Construction of Solar Demineralization Still No. 1. Brace Research Institute, McGill University, Montreal, Canada, Technical Report No. T-1, February 5, 1962, pp.1-11.

40. Lejeune, G. and J. Savornin. "La distillation solaire de l'eau en Algérie". Journal de Physique, M. Blodin, Paris, 15: 52S, June 1954.

41. Lejeune, G. Avoiding Crystallization in Solar Stills. Trans. Conference on the Use of Solar Energy, Tucson, Arizona, Vol. III, Part II, 1955, pp. 142-144.

42. Lof, G.O.G. Demineralization of Saline Water with Solar Energy. United States Department of the Interior, Office of Saline Water, R & D Report No. 4, August 1954, pp. 1-80.

43. Lof, G.O.G. Solar Distillation of Sea Water in the Virgin Islands. United States Department of the Interior, Office of Saline Water, Progress Report No. 5, 1955, pp. 1-39.

44. Lof, G.O.G. Design and Cost Factors of Large Basin Type Solar Stills. Proceedings of Symposium on Saline Water Conversion, National Academy of Sciences, National Research Council, Washington, D.C., Publication No. 568, 1958, pp. 157-174.

45. Lof, G.O.G. Design and Operating Principles in Solar Distillation Basins. Saline Water Conversion, Advances in Chemistry, Series No. 27, American Chemical Society, Washington, D.C., 1960, pp. 156-165.

46. Lof, G.O.G. "Solar Distillation of Saline Water". Southwest Waterworks Journal, B. Greshan, Temple, Texas, July 1960, pp. 1-4.

47. Lof, G.O.G. "Solar Distillation". Journal of American Waterworks Association, Vol. 52, No. 8, 1960, pp. 1-7.

48. Lof, G.O.G. Fundamental Problems in Solar Distillation. Proceedings of Symposium on Research Frontiers in Solar Energy Utilization, National Academy of Sciences, Washington, D.C., April 1961, pp. 35-46.

49. Headley, O.St.C. Cascade Solar Still for Distilled Water Production, Solar Energy, Vol. 15, No. 3, pp. 245-259.

50. Howe, E.D. and B.W. Tleimat. Twenty Years of Work on Solar Distillation at the University of California. Solar Energy, Vol. 16, No. 2, pp. 97-107.

51. Hirschmann, J.R. The Cosine Function as a Mathematical Expression for the Processes of Solar Energy, Solar Energy, Vol. 16, No. 2, pp. 117-125.

52. Gomkale, S.D. and R.L. Datta. Some Aspects of Investigations on Solar Stills. The Sun in the Service of Mankind, UNESCO House, Paris, 2-6 July 1973, E-101, 12 pages.

53. Bahadori, M.N. and F.E. Edlin. Improvement of Solar Stills by the Surface Treatment of the Glass. Solar Energy, Vol. 14, No. 4, pp. 339-353.

54. Gomkale, S.D. and R.L. Datta. Some Aspects of Solar Distillation for Water Purification. Solar Energy, Vol. 14, No. 4, pp. 387-393.

55. Hay, H.R. Plastic Solar Stills: Past, present and future. Solar Energy, Vol. 14, No. 4, pp. 393-405.

56. Frick, G. and J. Hirschmann. Theory and Experience with Solar Stills in Chile, Solar Energy, Vol. 14, No. 4, pp. 405-415.

57. Kokkaliaris, P.P. International Research Center for Distillation, Solar Energy, Vol. 14, No. 4, pp. 423-427.

58. Masson, H. "Solar Stills". South Pacific Commission, Quarterly Bulletin, January 1957, pp. 33-37.

59. McCraken, H. Performance of Natural Convection Stills. Sea Water Conversion Laboratory, University of California, Internal Report, 1960, pp. 1-10.

60. McLeod, L.H. and H. McCracken. Performance of Greenhouse Solar Stills. Sea Water Conversion Programme, University of California, Series 75, Issue 26, Contribution 46, 1961, pp. 1-57.

61. Malik, M.A.S. and V.V. Tran. A Simplified Mathematical Model for Predicting the Nocturnal Output of a Solar Still, Solar Energy, Vol. 14, No. 4, pp. 371-387.

62. Mullik, S.Ch. and M.S. Gupta. A Simple Method for the Desorption of Water using Solar Radiation for Heating the Absorbing Solution, Solar Energy, Vol. 10, No. 3, pp. 69-75.

63. Nebbia, G. "Le richerche sui distillatori solari". Bollettino Della Camera di Commercio Industria e Agricoltura di Bari, Anno XXXVII, No. 11/12, 1953, pp. 1-7.

64. Nebbia, G. "Some New Studies on Solar Distillation". La Chimica e l'Industria, Milano, Vol. XXXVI, 1954, pp. 1-22.

65. Nebbia, G. "Un nuovo tipo di distillatore solare". La Ricerca Scientifica, Roma, Anno 25, No. 6, June 1955, p. 6.

66. Nebbia, G. "Esperimento con un distillatore solare tubolare di materia plastica". Macchine e Motori Agricoli. Vol. XVI, No. 7, 1958, p. 5.

67. Nebbia, G. "La transformazione della acque salmastre in acque dolce". Bollettino Scientifico Della Facolta di Chimica Industriale. Bologna, Vol. XVI, 1958, pp. 44.

68. Nebbia, G. and E.M. Pizzoli. "Research on a Vertical Solar Still". La Ricerca Scientifica, Roma, Vol. 29, No. 9, September 1959, pp. 7.

69. Nebbia, G. Present Status and Future of the Solar Stills. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/113, Rome, August 1961, pp. 1-12.

70. Nebbia, G. The Experimental Work on the Solar Stills in the University of Bari. Proceedings of International Seminar on Solar and Aeolian Energy, Sounion, Greece, September 1961, pp. 19-27.

71. New York University. Research on Methods for Solar Distillation. United States Department of the Interior, Office of Saline Water, R & D Report No. 13, December 1956, pp. 1-65.

72. Richard, J. "Extraction de l'eau douce des eaux salées et de toutes substances aqueuses au moyen de la chaleur solaire". Recherches et Inventions. 1928, pp. 18-19.

73. Richard, J. "Sur un procédé simple pour extraire l'eau douce de l'eau de mer, des eaux salées ou polluées, de toutes les substances aqueuses et même de l'atmosphère, au moyen de la chaleur solaire". Bulletin de l'Institut Océanographique, No. 535, Monaco, April 1929, pp. 1-27.

74. Sakr, I.A. Portable Solar Water Distiller. Second European Symposium on Fresh Water from the Sea, Athens, Greece. Preprints of Papers, Vol. 7, Paper No. 142, May 1967, pp. 142-1 - 142-5.

75. Salam, E. and F. Daniels. "Solar Distillation of Salt Water in Plastic Tubes using a Flowing Air Stream". Solar Energy, Arizona, Vol. 3, No. 1, 1959, pp. 19-22.

76. Savornin, J. Efficiency of Various Types of Solar Stills. Trans. Conference on Use of Solar Energy, Vol. III, Part II, Tucson, Arizona, 1955, pp. 134-137.

77. Savornin, J. and G. Lejeune. "Essais de perfectionnement des appareils à distillation solaire". Comptes Rendus de l'Académie des Sciences, Paris, 2e semestre (T 243, No. 1) 1956, pp. 32-34.

78. Selçuk, K. "The Role of Solar Distillation in the Saline Water Conversion Processes". COMPLES, Marseille, Bulletin No. 8, May 1965, pp. 70-78

79. Selçuk, K. and V.V. Tran. Solar Stills for Agricultural Purposes, Solar Energy, Vol. 17, No. 2, May 1975, pp. 103-111.

80. Satcunanathan, S. Remarks on "Cascade Solar Still for Distilled Water Production". Solar Energy, Vol. 17, No. 1, April 1975, pp. 81.

81. Satcunanathan, S. and H.P. Hansen. An Investigation of Some of the Parameters Involved in Solar Distillation, Solar Energy, Vol. 14, No. 4, 1972, pp. 353-365.

82. Szulmayer, W. Solar Stills with Low Thermal Inertia. Solar Energy, Vol. 14, No. 4, 1972, pp. 405-415.

83. T lkes, M. Distilling Water with Solar Energy. Report to the Solar Energy Conversion Committee, Massachusetts Institute of Technology, 1943.

84. T lkes, M. Solar Distiller for Life Rafts. United States Office of Science, R & D Report No. 5225, P.B. 21120, 1945.

85. Telkes, M. "Fresh Water from Sea Water by Solar Distillation". Industrial and Engineering Chemistry, Vol. 45, No. 5, 1953, pp. 1108-1114.

86. Telkes, Maria. Distillation with Solar Energy. Proceedings of World Symposium on Applied Solar Energy, 1955, Phoenix, Arizona, pp. 73-79.

87. Telkes, Maria. Improved Solar Stills. Trans. Conference on the Use of Solar Energy, Tucson, Arizona, Vol. III, Part II, 1955, pp. 145-153.

88. Telkes, Maria. Solar Still Theory and New Research. Proceedings of Saline Water Conversion Symposium, 1957, Publication No. 568, National Academy of Sciences, National Research Council, Washington, D.C., published 1958, pp. 137-149.

89. Telkes, Maria. Solar Still Construction. United States Department of the Interior, Office of Saline Water, R & D Report No. 33, August 1959, pp. 1-14.

90. Telkes, Maria. New and Improved Methods for Lower Cost Solar Distillation. United States Department of the Interior, Office of Saline Water, R & D Report No. 31, August 1959, pp. 1-38.

91. Telkes, Maria. Flat, Tilted Solar Stills. Proceedings of International Seminar on Solar and Aeolian Energy, Sounion, Greece, September 1961, Plenum Press, New York, pp. 14-18.

92. Telkes, Maria. The Inflated Plastic Stills. Proceedings of International Seminar on Solar and Aeolian Energy, Sounion, Greece, September 1961, Plenum Press, New York, pp. 28-30.

93. Tleimat, B.W. and E.D. Howe. Comparison of Plastic and Glass Condensing Covers for Solar Distillers. *Proceedings of Solar Energy Society* Annual Conference, Phoenix, Arizona, March 1967, pp. 1-12.

94. Touchais, M. "Un nouveau distillateur solaire à exposition directe; Le distillateur Jean Mary". COMPLES, Marseille, Bulletin No. 12, July 1967, pp. 64-65.

95. United States Army Air Forces. Sunshine-Operated Stills and Rainfall as Sources of Water for Life Rafts. Weather Information Branch, Publication SS-18, P.B. 38657, 1943, pp. 1-17.

96. United States Bureau of Aeronautics. Still, Drinking Water, Solar, Mark 1, Model O. NAVAER Specification M-663, January 1945, Amendment 2, August 1946.

97. Umarov, G.Ya., Achilov, B.M., T.D. Zhuraev, R. Akhtamov. Water Distillation by Solar Energy and Winter Cold. Solar Energy, Vol. 8, No. 6, 1973, pp. 62-66.

98. Vardiyashvili, A.B. Experimental Investigation of the Optical and Technical Characteristics of a Through-Flow Solar Still. Solar Energy, Vol. 4, No. 2, 1968, pp. 49-53.

99. Vannucci, S.N. Sea Water Distillation using Solar Energy with a Solar Proheater. The Sun in the Service of Mankind, UNESCO House, Paris, 2-6 July 1973, E102.

100. Whillier, A. "Prospects for the Engineering Utilization of Solar Energy in South Africa". South African Mechanical Engineer, Kelvin Publications, Johannesburg, October 1956, pp. 59-90.

101. Wilson, B.W. Solar Distillation in Australia. Trans. Conference on the Use of Solar Energy, Vol. III, Part II, Tucson, Arizona, 1955, pp. 154-158.

102. Wilson, B.W. Solar Distillation Research and its Application in Australia. Proceedings of Saline Water Conversion Symposium, 1957, Publication No. 568, National Academy of Sciences, National Research Council, Washington, D.C., published 1958, pp. 123-130.

103. Weihe, Henrik. Fresh Water from Sea Water: Distilling by Solar Energy, Solar Energy 1972, Vol. 13, pp. 439-444.

104. Xogler, X. and M. Kubler. Sea Water Desalination by Solar-Heated Heat-Pipes. The Sun in the Service of Mankind, UNESCO House, Paris, 2-6 July 1973, E-104.

105. Blanco, P. "Distillateur multi-étage 'RM' ". COMPLES, Marseille, Bulletin No. 8, May 1965, pp. 66-69.

106. Battelle Memorial Institute. Solar Distillation of Saline Water, Office of Saline Water, United States Department of the Interior, 30 January 1970.

107. Battelle Memorial Institute. An Investigation of Multiple-Effect Evaporation of Saline Waters by Steam from Solar Radiation. United States Department of the Interior, Office of Saline Water, R & D Report No. 2, December 1953, pp. 1-58.

108. Cooper, P.I. and J.A. Appleyard. "The Construction and Performance of a Three Effect, Wick Type, Tilted Solar Still". Sun at Work, Vol. 12, No. 1, First Quarter, 1967, pp. 4-8.

109. Dunkle, R.V. "Solar Water Distillation". The Roof Type Still and a Multiple Effect Diffusion Still". International Developments in Heat Transfer, ASME, Proceedings of International Heat Transfer Conference, 28 August to 1 September 1961, pp. 895-902.

110. Grune, W.N. and I. Zandi. "Improved Solar Still Process for Desalting Sea and Brackish Water". Journal of American Water Works Association, New York, Vol. 52, No. 8, 1960, pp. 993-1005.

111. Grune, W.N. and T.L. Thompson, R.A. Collins. Forced Convection, Multiple Effect Solar Still for Besalting Sea and Brackish Waters. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/14, Rome, August 1961.

112. Grune, W.N., R.B. Hughes, T.L. Thompson. "Operating Experiences with Natural and Forced Convection Solar Stills". Water and Sewage Works, Chicago, October 1961, pp. 378-382.

113. Grune, W.N., R.B. Hughes, T.L. Thompson. "Natural and Forced Convection Solar Still". Journal of the Sanitary Engineering Division, Proceedings of the ASCE, Vol. 88, P + I, Paper No. 3036, January 1962, pp. 1-24.

114. Hodges, C.N. and R. Kassander. Distillation of Saline Water Utilizing Solar Energy in Multiple Effect System Consisting of Separate Collector, Evaporator and Condenser. Solar Energy Laboratory, University of Arizona, Introductory Report, April 1962, pp. 1-20.

115. Hodges, C.N., T.L. Thompson, J.E. Groh. Separate Component, Multiple Effect Solar Distillation. Solar Energy Laboratory, University of Arizona, Interim Report No. 1, November 1962, pp. 1-48.

116. Hodges, C.N. Separate Component, Multiple-Effect Solar Distillation. Solar Energy Laboratory, University of Arizona, Interim Report No. 2, March 1963, pp. 1-49.

117. Hodges, C.N., T.L. Thompson, J.E. Groh, W.D. Sellers. "The Utilization of Solar Energy in a Multiple-Effect Desalination System". The Journal of Applied Meteorology, Vol. 3, No. 5, October 1964, pp. 505-512.

118. Hodges, C.N. et al. Final Report - Solar Distillation Utilizing Multiple-Effect Humidification. Solar Energy Laboratory, University of Arizona, January 1966, pp. 1-155.

119. Selçuk, K.M. Design and Performance Evaluation of a Multiple-Effect, Tilted Solar Distillation Unit. Brace Experiment Station of McGill University, St. James, Barbados, May 1963, pp. 1-29.

120. Sharafi, A.Sh. "Continuous Solar Still". Geliotekhnika, Vol. 1, No. 2, pp. 38-40. (Translation, Applied Solar Energy, Faraday Press, Vol. 1, No. 2, March, April 1965, pp. 37-39).

121. Brice, D.B. Saline Water Conversion by Flash Evaporation Utilizing Solar Energy. Saline Water Conversion II, Advances in Chemistry Series 38, American Chemical Society, Washington, D.C., 1960, pp. 99-116.

122. Caufourier, P. "L'utilisation de la chaleur solaire par l'emploi d'appareils auto-évaporateurs". Le Génie Civil, Paris, Vol. LXXXII, No. 14, Avril 1923, pp. 327-329.

123. Hirschmann, J. "Planta Piloto par Utilisar la Energia Solar en Producir Agua Potable de Agua Selada Generando Simultaneamente Energia Electrica". Scientia, Valparaiso, Chile, Vol. 25, December 1958, pp. 195-200.

124. Hummel, R.L., D.F. Rudd. A Solar Distillation Design for the Economic Production of Fresh Water from the Sea. University of Michigan, 1960, pp. 1-19.

125. Hummel, R.L. New Concepts in Solar Stills Leading to Low Cost Fresh Water from Sea Water. American Chemistry Society Meeting, St. Louis, Missouri, March 1961, pp. 1-23.

126. Hummel, R.L. A Large Scale, Low Cost, Solar Heat Collector and its Application to Sea Water Conversion. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/28, Rome, August 1961, pp. 1-19.

127. Hollands, K.G.T. "The Regeneration of Lithium Chloride Brine in a Solar Still". Solar Energy, Vol. VII, No. 2, 1963, pp. 39-44.

128. Jackson, R.D., C.H.M. van Babel. "A Simple Desert Survival Still". Sun at Work. Vol. 2, No. 4, Fourth Quarter, 1966, pp. 4-6.

129. Kobayashi, M. "A Method of Obtaining Water in Arid Lands". Solar Energy, Vol. VII, No. 3, 1963, pp. 93-99.

130. Brace Research Institute, McGill University. Do-It-Yourself Leaflet No. 1, How to Make a Solar Still (Plastic Covered). Brace Research Institute Publication List. January 1965.

131. CSIRO. How to Make Solar Still. Melbourne, Australia, Diagrams, Steps 1-8, 1954.

132. Edson, L., H. McCracken, J. Weldy. How to Build a Solar Still. Sea Water Conversion Laboratory, University of California., 1959, Series 75, Issue 13, pp. 1-10.

133. Edson, L., H. McCracken, J. Weldy. How to Build a Solar Still. Sea Water Conversion Laboratory, University of California, 1962 revised edition, Series 75, Issue 13, pp. 1-7.

134. Pretoria, P.W.D. Drawings for Solar Still. CSIR, No. CR 789, 1954.

135. Ramsay, N. Suggestions for Solar Distillation of Saline Water. Nairobi Kenya, unpublished, 1954, pp. 1-10.

136. Abbot, C.G. Solar Distillation Apparatus. U.S.A. Patent 2,141,330, 27 December 1938.

137. Altenkirch, E., H. Behringer. Improvements in or Relating to a Process of and Apparatus for Separating Water Contained in a Liquid. British Patent 454,558, September 1936.

138. Barnes, W.S. Solar Water Still. U.S.A. Patent 2,383,234, 21 August 1945.

139. Bimpson, H.S. and E.J. Palmer. Solar Salt Water Distilling Apparatus. U.S.A. Patent 2,424,142, 15 July 1947.

140. CSIRO. An Improved Diffusion Still. Australian Patent No. 65,270/60, October 1960.

141. Delano, W.R.P. Process and Apparatus for Distilling Liquids. U.S. Patent 2,402,737 - 25 June 1946.

142. Delano, W.R.P. Collapsible Distillation Apparatus. U.S. Patent 2,398,291 - 9 April 1946.

143. Delano, W.R.P. Solar Still with Nonfogging Window. U.S. Patent 2,413,101 - 24 December 1946.

144. Dooley, G.W. Means for Purifying Water. U.S. Patent 1,812,516 - 30 June 1931.

145. Dornig, M. and A. Belloni. Apparecchiatura per la produzione di acqua distillata o simile utilizzante il calore solare. Italian Patent 448,833. Ddp: Nov 8, 1948; Dcs: Maggio 27, 1949.

146. Edlin, F.E. Air Supported Solar Still. E.I. du Pont de Nemours. U.S. Patent No. 3,174,915, 23 March 1965, Filed July 1962. Serial No. 211, 942.

147. Engisch, O. Improvement in or Relating to Evaporators. British Patent 344,125 - March 1931.

148. Gandillon, P.A. and L.A. Garchey. An Improved Method of Utilizing Solar Energy. British Patent 229,211, February 1925.

149. Ginnings, D.C. Multiple-Effect Solar Still. U.S. Patent 2,445,350. 1948.

150. Gordon, A. Applying Solar Heat to the Evaporation of Fluids, Generation of Steam, etc. British Patent 1044. May 1856.

151. Graham, F.A. Distilling Apparatus. U.S.A. Patent 1,302,363. 29 April 1919.

152. Kain, S.C. Distillation Device. U.S.A. Patent 2,342,201 - 22 February 1944

153. Merz, F. System and Apparatus for the Utilization of Natural Thermal Energy. British Patent 152,753 - October 1920.

154. Miller, W.H. Inflatable Floating Solar Still with Capillary Feed. U.S.A. Patent 2,412,466. December 1943.

155. Miller, W.H. Improvements in or Relating to Solar Distillation Apparatus. British Patent 594,131. November 1947.

156. Schenk, T.C. Device for Producing Potable Water from Sea Water. U.S.A. Patent 2,342,062. 15 February 1944.

157. Snyder, R.E. Solar Heated Vacuum Still. U.S.A. Patent 2,490,659. December 1949, Filed April 1944, Serial No. 532,386.

158. Ushakoff, A.E. Inflatable Solar Still. U.S.A Patent 2,455,834. 7 December 1948.

159. Ushakoff, A.E. Inflatable Solar Still. U.S.A. Patent 2,455,835. 7 December 1948.

160. Ziem, T. Process and Apparatus for Utilizing Solar Heat for the Distillation of Volatile Liquids, for Recovering Substances Dissolved in such Liquids, and for Obtaining Water in So-Called Waterless Localities. British Patent 12,402. February 1889.

161. Bloemer, J.W., R.A. Collins and J.A. Eibling. Field Evaluation of Solar Sea Water Stills. Saline Water Conversion, Advances in Chemistry. Series No. 27. American Chemical Society, Washington D.C., 1960, pp. 166-177.

162. Bloemer, J.W., J.A. Eibling, J.R. Irwin and G.O.G. Lof. Development and Performance of Basin-Type Solar Stills. Proceedings of Solar Energy Society Annual Meeting, Phoenix, Arizona. Solar Energy, Vol. 9, No. 4, March 1965. pp. 197-200.

163. Bloemer, J.W., J.A. Eibling and J.R. Irwin. Solar Distillation - A Review of Battelle Experience. Proceedings of First International Symposium on Water Desalination. Session C, Paper No. SWD/84, Washington, D.C., October 1965.

164. Battelle Memorial Institute. Design of a Basin-Type Solar Still. United States Department of the Interior, Office of Saline Water, R & D Report No. 112, 1964, pp. 1-26.

165. Lof, G.O.G. Design and Evaluation of Deep-Basin, Direct Solar Heated Distiller for Demineralization of Saline Water. United States Department of the Interior, Office of Saline Water, 1959, pp.1-60.

166. Lof, G.O.G. Application of Theoretical Principles in Improving the Performance of Basin-Type Solar Distillation. U.N. Conference on New Sources of Energy, Session III E, E/CONF. 35/S/77, Rome, August 1961, pp. 1-17.

167. Battelle Memorial Institute. Final Three Years' Progress on Study and Field Evaluation of Solar Sea Water Stills. United States Department of the Interior, Office of Saline Water, R & D Report No. 190, May 1966, pp. 1-87.

168. Delyannis, A.A. "Solar Stills Provide an Island's Inhabitants with Water". Sun at Work, Vol. 10, No. 1, First Quarter, 1965, p. 6.

169. Eckstrom, R.M. "Design and Construction of the Symi Still". Sun at Work, Vol. 10, No. 1, First Quarter, 1954, p. 7.

170. Eckstrom, R.M. "New Solar Stills in Greek Islands". Sun at Work, Vol. 11, No. 2, Second Quarter, 1966, p. 13.

171. Howe, E.D., B.W. Tleimat and A.D. Laird. Solar Distillation. University of California, Sea Water Conversion Laboratory, Report No. 67-2. Water Resources Center, Desalination Report No. 17, pp. 1-52.

172. Blanco, P., C. Gomella and J.A. Barasoain. Pilot Plant of Solar Potabilization at "Las Marinas" (Spain). Proceedings of First International Symposium on Water Desalination. Session C, Paper No. SWD/116, Washington, D.C., October 1965.

173. Blanco, P., C. Gomella and J.A. Barasoain. "Installation pilote de potabilisation solaire de Las Marinas (Espagne)". COMPLES, Marseille, Bulletin No. 9, December 1965, pp. 29-41.

174. Blanco, P., C. Gomella and J.A. Barasoain. "Installation de potabilisation d'eau de mer et d'eau saumâtre à Las Marinas (Espagne)". COMPLES, Marseille, Bulletin No. 11, December 1966, pp. 32-38.

175. Blanco, P., C. Gomella and J.A. Barasoain. "Projet de distillateur solaire pour l'Ile de Nueva Tabarca (Alicante)". COMPLES, Marseille, Bulletin No. 12, July 1967, pp. 47-55.

176. CSIRO, (Australia). Solar Energy Progress in Australia and New Zealand. No. 5, July 1966, pp. 9-10.

177. CSIRO (Australia). Division of Mechanical Engineering, Annual Report, 1966-67, pp. 11-12.

178. Morse, R.N. The Construction and Installation of Solar Stills in Australia. Second European Symposium on Fresh Water from the Sea, Athens, Greece. Preprints of Papers, Vol. 7, Paper No. 101, May 1967, pp. 101-1 - 101-8.

179. Morse, R.N. and W.R.W. Read. "The Development of a Solar Still for Australian Conditions". Mechanical and Chemical Engineering Transactions of the Institution of Engineers, Australia, Vol. MC3, No. 1, May 1967, pp. 71-80

180. Read, W.R.W. A Solar Still for Water Desalination. Australian CSIRO, Division of Mechanical Engineering, Report No. 9, September 1965, p. 23.

181. Edlin, F.E. Water, Food and Solar Energy. Proceedings of Energy and Power Conference, Rockefeller Foundation, New York, July 1967, pp. 1-19.

182. Alward, R., A. Acheson and T.A. Lawand. The Integration of Solar Stills into Minimum Cost Dwellings for Arid Areas. Proceedings of the International Congress "The Sun in the Service of Mankind". Paris, Palais de l'UNESCO, 2-6 July 1973, 12 pages.

183. Thierstein, G.E. Solar Still Design for Anguilla. Brace Research Institute Publication Report No. CP6, 25 pages, May 1968.

184. Richardson, W.G. Nocturnal Production of Solar Distillation Units , Brace Research Institute Publication, Report No. CP7, 10 pages, May 1968.

185. Lawand, T.A. The Engineering and Economic Evaluation of Solar Distillation for Small Communities, Proceedings of the Solar Energy Society Annual Meeting, Palo Alto, California, Brace Research Institute Report No. R.30, 21-23 October 1968.

186. Lawand, T.A. Description of a Large Solar Distillation Plant in the West Indies, Solar Energy, Vol. 12, No. 4, pp. 509-512, Brace Research Institute Report No. R.40, December 1969.

187. Lawand, T.A. Experiences with Solar Stills used by Developed and Primitive Societies in the West Indies, Paper No. 5/12, presented at the 1970 International Solar Energy Society Conference, Melbourne, Australia, 6 p., 2-6 March 1970, Brace Research Institute Report No. R.41.

188. Lawand, T.A. The Technical Evaluation of a Large Scale Solar Distillation Plant, Paper No. 69-WA/Sol-8, presented at the ASME Winter Annual Meeting, Los Angeles, California, 16-20 November 1969. Transactions of the ASME: Journal of Engineering for Power, Vol. 92, No. 2, pp. 95-102, April 1970. Brace Research Institute Report No. R.49.

189. Lawand, T.A. Experiences with Solar Stills used by Developed and Primitive Societies in the West Indies, presented at the 1970 International Solar Energy Society Conference, Melbourne, Australia, Paper No. 5/12. Brace Research Institute Report No. R.53.

190. Oztoker, U. and M.K. Selçuk. Theoretical Analysis of a System Combining a Solar Still with a Controlled-Environment Greenhouse. Paper No. 71-WA/Sol-9, presented at the ASME Winter Annual Meeting, Washington, D.C., 28 November to 2 December 1971, 12 pages, Brace Research Institute Report No. R.59.

191. Lantagne, M. and R. Alward. Thermodynamic Analysis of a Double-Effect Basin-Type Still, Paper No. 71-WA/Sol-8, presented at the ASME Winter Annual Meeting, Washington, D.C., 28 November to 2 December 1971, 11 pages, Brace Research Institute Report No. R.60.

192. Tran, V.V. and M.K. Selçuk. Solar Still Greenhouse - A Proposal for using Desalinated Water for Agricultural Purposes, presented at the Rencontre Générale de la Coopération Méditerranéenne pour l'Energie Solaire, Athens 4-9 October 1971, 17 pages. Brace Research Institute Report No. R.61.

193. Lawand, T.A. Description of the Construction of a 50 Square Ft. Wooden Roof-Type Solar Still in Barbados, 21 pages, February 1962, Brace Research Institute Report No. T.1.

194. Lawand, T.A. and R. Alward. Plans for a Glass and Concrete Solar Still, 9 pages, December 1968. Brace Research Institute Report No. T.58.

195. Malik, M.A.S., and V.V. Tran. Nocturnal Production of a "Multi-Stage" Solar Still, 41 pages, April 1969, Brace Research Institute Report No. T.61.

196. Lawand, T.A. Specifications for a Prefabricated Solar Saline Water Distillation Unit, 4 pages, September 1970, Brace Research Institute Report No. T.65.

197. Lawand, T.A. and Henri Boutière. Solar Distillation: Its Application in Arid Zones in Water Sypply and Agricultural Production. Presented to the First World Symposium on Arid Zones, Mexico, 9-12 November 1970, 5 pages, Brace Research Institute Report No. T.66.

198. Selçuk, M.K., M. Shariat and N. Toraman. The Analysis and Performance of a Solar Still Greenhouse, September 1971, 18 pages, Brace Research Institute Report No. T.71.

199. Lawand, T.A. Feasibility of Converting Some of the Salinas on Grand Turk, Turks and Caicos Islands into Solar Distillation Plants for the Production of Fresh Water, submitted to the United Nations, New York, March 1972, 59 pages. Brace Research Institute Report No. T.77.

200. Lawand, T.A. Summary of Discussions on Solar Distillation during the Visit of Mr. W.R.W. Read, CSIRO, Australia, 6 pages, May 1968. Brace Research Institute Report No. I.41.

201. Lawand, T.A. Summary of Discussions on Solar Distillation with Mr. Wilson Radway, Church World Service, New York, 3 pages, May 1968, Brace Research Institute Report No. I.42.

202. Lawand, T.A. Proposal for the Installation of a Solar Distillation Plant on Ile de la Gonave, Haiti, 8 pages, October 1968, Brace Research Institute Report No. I.46.

203. Thierstein, G.E. Anguilla Solar Still Project, 12 pages, October 1968. Brace Research Institute Report No. I.47.

204. Lawand, T.A. Review of the Activities of the Brace Research Institute in the Field of Solar Distillation, 6 pages, October 1968, Brace Research Institute Report No. I.48.

205. Lawand, T.A. Proposal No. I: Three Small Solar Sea Water Distillation Plants in the Eastern Caribbean, 4 pages, April 1969, Brace Research Institute Report No. I.57.

206. Alward, R. Installation of a Solar Distillation Plant on Ile de la Gonave, Haiti, May 1970, Brace Research Institute Report No. I.67.

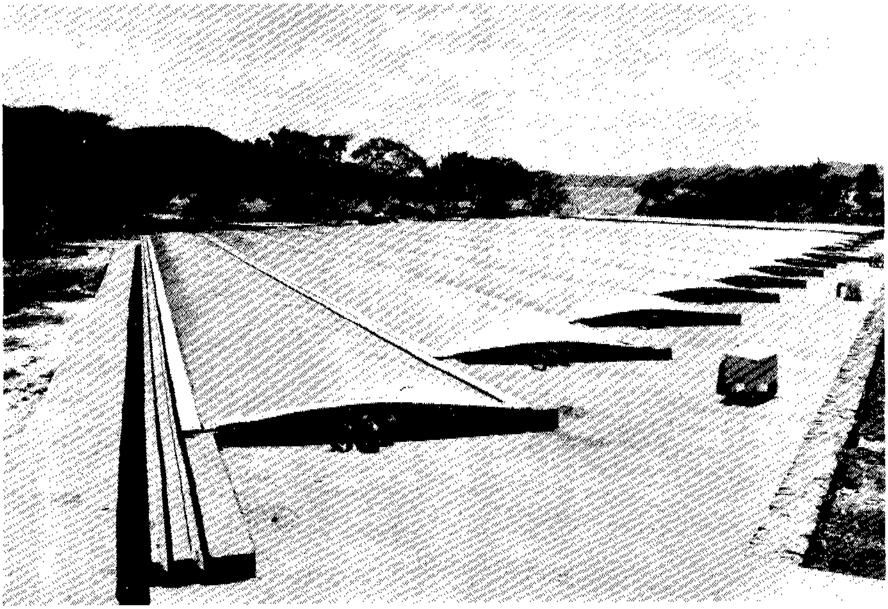
207. Tran, V.V. Nocturnal Production of a Solar Still. M.Sc. Thesis, Department of Agricultural Engineering, McGill University, 187 pages, June 1970, Brace Research Institute Report No. MT.11.

208. Lantagne, M. The Study of a Double-Effect Basin-Type Solar Still. M.Sc.Thesis, Department of Agricultural Engineering, McGill University, 200 pages, September 1971, Brace Research Institute Report No. MT.14.

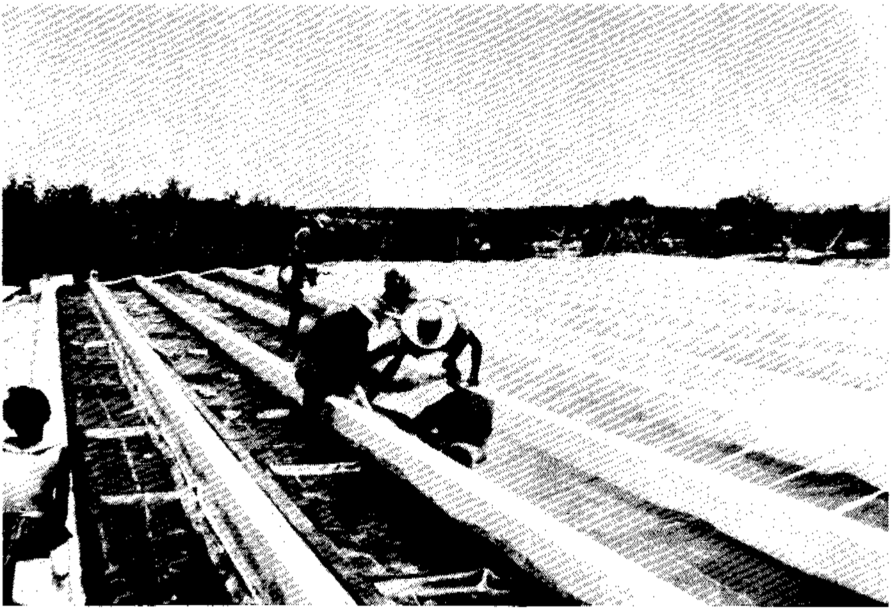
209. Selçuk, M.K. Design and Performance Evaluation of a Multiple Effect, Tilted Solar Distillation Unit, 52 pages, May 1963, Brace Research Institute Report No. DT.1.

210. Lantagne, M. Theorie de la Distillation Solaire, 47 pages, October 1969, Brace Research Institute Report No. CP.50.

PHOTOS OF SOLAR STILLS



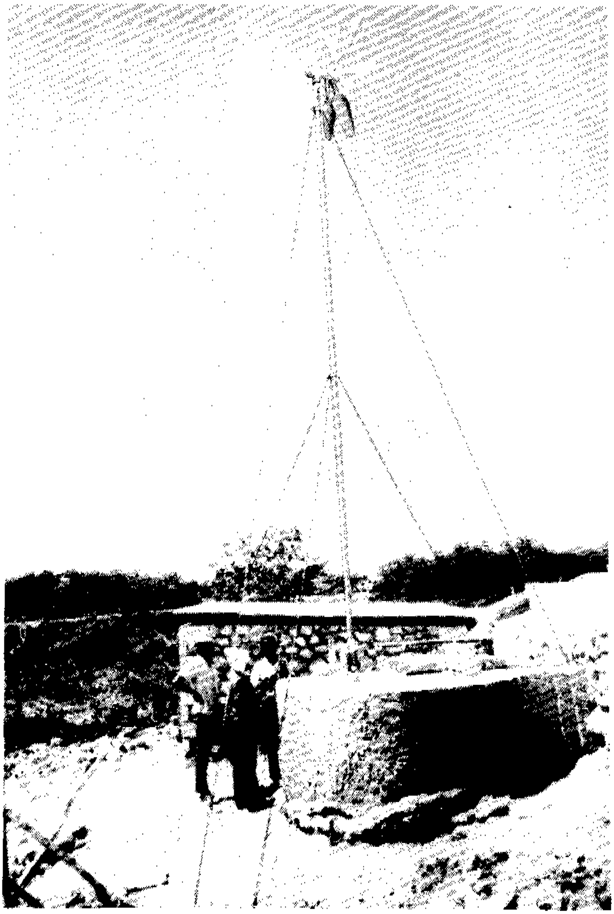
Stills in Petit St. Vincent, West Indies (plastic covered)



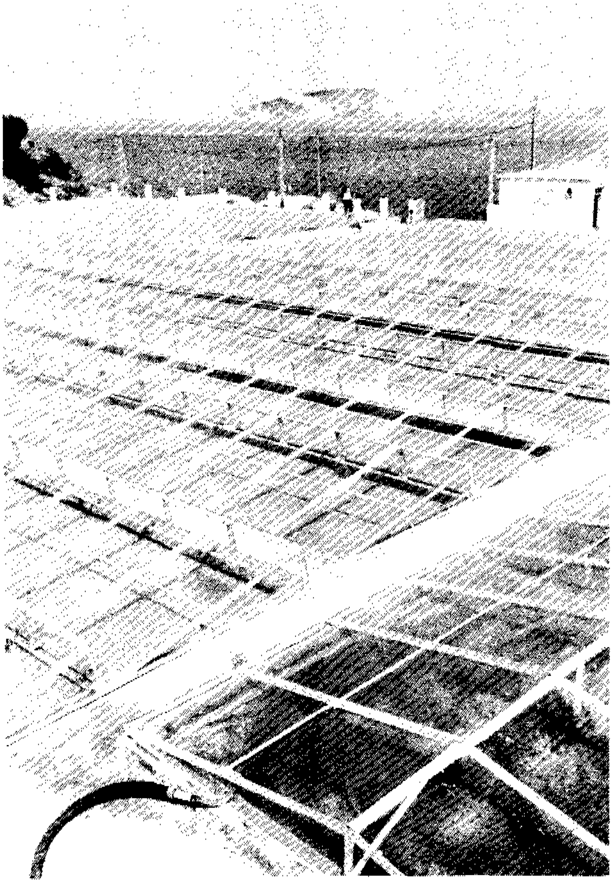
Construction of Still in Haiti

Solar Stills in Haiti

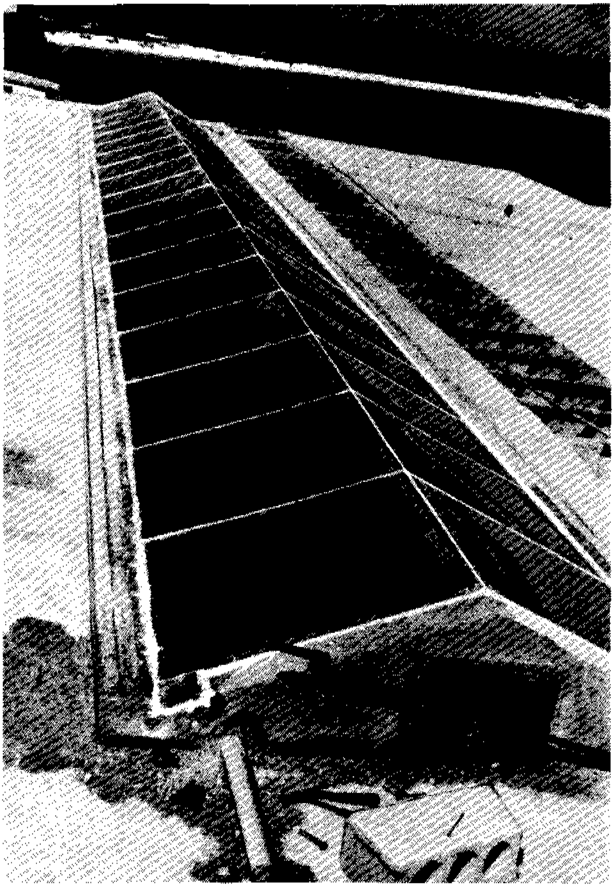
Individual Still



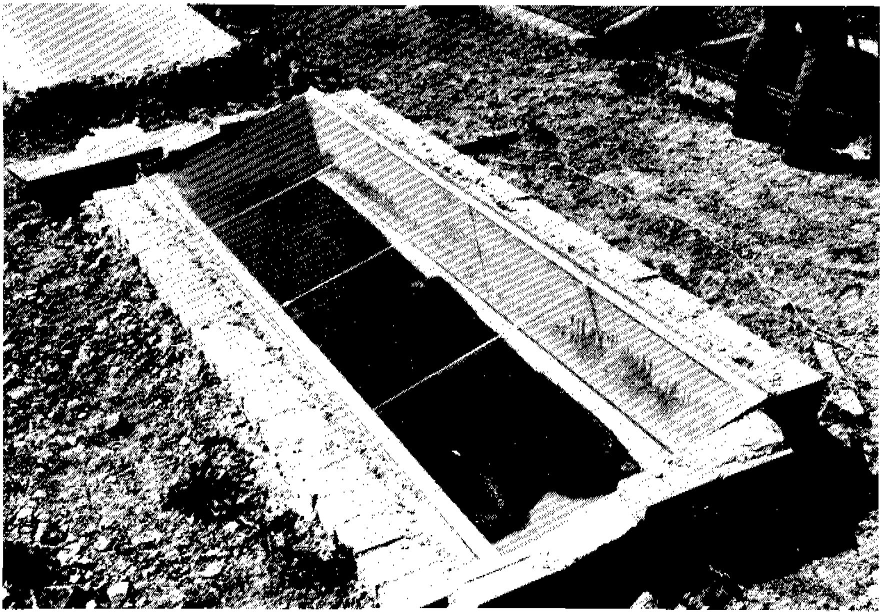
Still Windmill Pump in Haiti



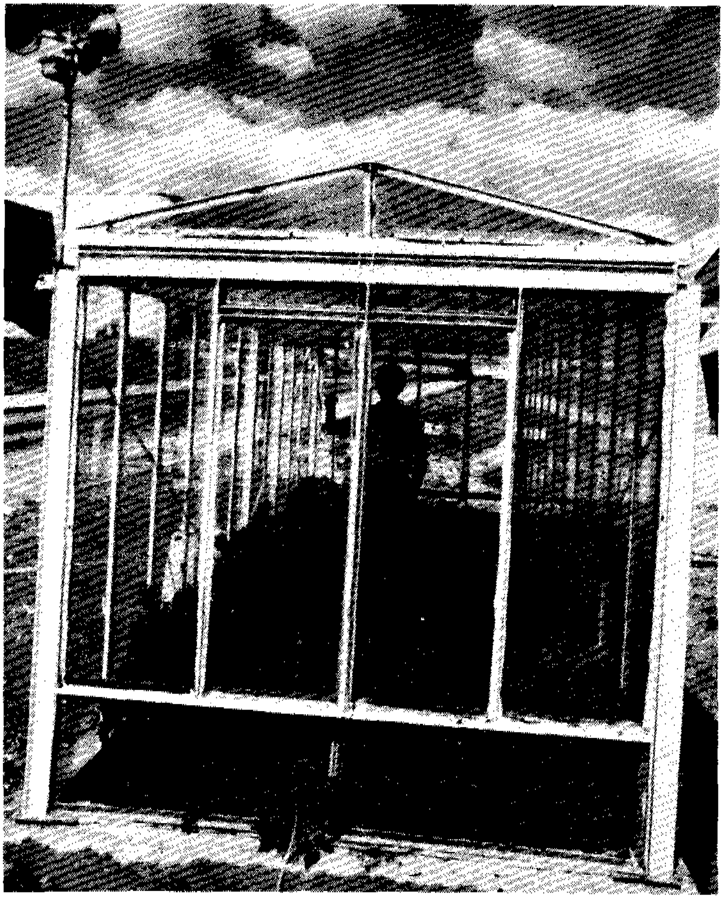
Solar Still-Greece



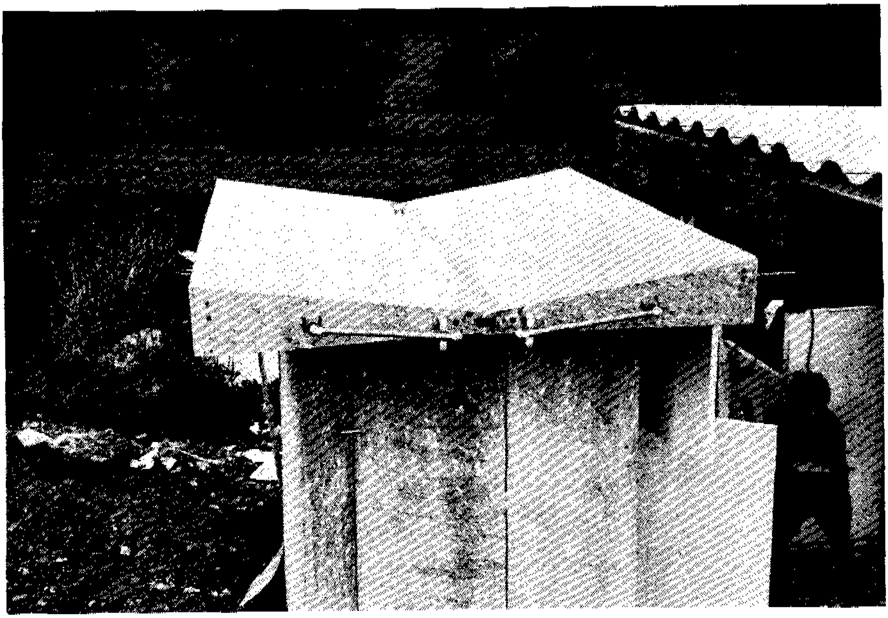
Solar Still--Anguilla



Brick Frame Solar Still



Solar Still-Greenhouse, Turkey



Solar Still Integrated into Roof

SOLAR DISTILLATION USING DISTILLING TANKS AND EVAPORATION CLOTH

Professor Dr.-Ing. A. Beckers

Various forms and methods of producing evaporation and condensation have been investigated for the development of solar distillers. This paper deals with solar distillation using tanks and solar distillation using evaporation cloth.

As a rule the tanks are made from asbestos cement, but in recent tests glass fibre was used since it has certain advantages, to be mentioned later. The distillers with evaporation foil are made from galvanized lead, but here again new possibilities are being investigated in order to avoid the problem of lead corrosion.

In both cases the surface exposed to solar radiation is constructed from glass. So far trials with plastic materials have proved relatively unsuccessful. Because of its good capillary properties, jute has been successfully used for the distillers with evaporation foil. The most crucial point is the blackening, which has to withstand the solar radiation.

In designing solar distillers it is necessary to define a few important parameters determining the thermal properties of these devices. The two most important are 1) the energy balance of the distiller, and 2) the thermal inertia of the distiller.

The first definition identifies thermal efficiency as the ratio of output in the form of condensate to input in the form of absorbed solar energy.

Thermal inertia is the time between the points of maximum radiation and maximum distillate production. This definition is important, since it provides the possibility of comparing various methods of distilling water by means of solar energy. Certain devices—tanks or evaporation cloth—need more time to effect evaporation than do others; that is to say, there is a longer wait until water is produced, and less use is made of the variable amount of solar radiation at any given moment.

Figure 1 demonstrates these factors in mathematical terms. The useful energy is the evaporated mass times evaporation heat

$$Q_e = m_3 \cdot r$$

The energy balance is used to calculate further energy flows:

- to heat the excess water,
- to heat the water which is to be evaporated,
- losses due to reflection and heat emission through the walls,
- heat given out as a result of the condensing of the distilled water.

Q_{rad} represents the heat absorbed by the surface exposed to the solar radiation. In the case of a tank, this value is measured vertical to the earth's surface. In the case of a distiller with evaporation cloth, which is inclined at an angle, the energy must be measured vertical to the evapora-ting surface.

Hence the thermal efficiency is given by

$$t = \frac{m_3}{Q_{rad}}$$

Figure 2 shows measurements taken from a distiller with evaporation cloth at the Technical University of Santa Maria in Valparaiso. The top left of the figure represents in diagram form the apparatus with the evaporation cloth, in-take and outlet, and the mean values for the temperatures of intake, condensate, and outlet, 23^o C, 31^o C, and 58^o C. The mean radiation measured was 1 cal/min cm^2 and the mass flows 40.1, 8.3, and 31.8 ml/min. These values were used to draw the energy flow diagram on the right of Figure 2.

With regard to thermal inertia, the more sensitive the device, the quicker it adapts to fluctuations in solar energy and the greater the amount of distillate produced. On the other hand the distillate yield is more irregular.

It is more important in the case of distillers with evaporation cloth to ensure that the cloth is kept moist. This means that the water throughput must be relatively large. As a result of the high temperature, the energy loss from the excess water is relatively great. Since moreover, the salt concentration is relatively low, it is practical to use this preheated water to directly supply the tanks as shown in Figure 3.

When designing solar distillers geographical factors also have to be taken into account, as described below:

1) Danger of earthquakes

Earthquakes are an important factor in, for example, the Chilean desert regions, since the asbestos cement tanks rest directly on the ground and therefore risk being fractured.

2) Oxidation

As far as possible it is essential to use materials which withstand corrosion over long periods of time.

3) Climate

The extreme temperature fluctuations which often occur must be carefully observed, since they produce thermal tension in the elements. The wind is also important since it removes condensation heat and creates the danger of the glass covers being soiled by flying sand.

4) Fauna

Experience has shown that plants situated in locations with high temperatures, fresh water, and hence a large number of animals must be built with corresponding precautions.

On the basis of many years of preliminary study in the Laboratory for Solar Energy Utilization at the Santa Maria

Technical University in Valparaiso, a pilot project has been initiated in collaboration with CIDDA (Centre for the Research and Development of the Atacama Desert) in Quillagua. Results are available for the first year of operation from April 1974 to March 1975.

Quillagua is a village in the desert with 600 inhabitants who live primarily from the cultivation of alfalfa grass and maize. The River Loa, which runs through the village, is highly saline, making water supply problematic. At present the water, which is of very poor quality when judged by the standards set by the World Health Organization, has to be transported 200 km by rail.

The test plant consists of 30 asbestos cement tanks of 1.8 m^2 surface area, of which the evaporation area amounts to 1.64 m^2. There are also six reserve units, none of which was needed during the first year.

Water for the system is supplied from River Loa. Every morning twice the amount of saline water is let in from a storage tank as distillate was produced in the previous 24 hours. The water is let into groups of six units each connected in sequence one after the other. Naturally some heat is lost with the excess water, thus reducing efficiency, but this method prevents salt accumulating and making cleaning necessary.

With a total evaporation surface of 49.2 m^2, the annual mean per radiation period was measured at 5.11 kWh/m^2 per day, producing an annual average of 2.7 l/m^2 d of distillate. The distribution throughout the year is given in Figure 4. the following table gives information on costs:

	cost per unit US $	service life years	cost per unit per year US $
asbestos cement open tank	15.11	15	1.01
glass cover	15.14	20	0.80
rubber gaskets	3.21	5	0.64
costs of installation per tank (based on 36 units	17.13	15	1.14
pump, tank, pipes	1.12	20	0.06
interest at the rate of 6 % on capital costs	52.51		3.15
servicing and maintenance	6.98		6.98
total cost per unit per year			13.78

For annual production of 1621 l per unit, the costs of the produced distillate are calculated at 13.78/1621 = 0.0085 US $/l.

By way of comparison, the transport costs to Quillagua amount to 0.0023 US $/l, whereas the cost of the transported water is 0.013 US $/l. The distillation plant therefore proves an economic proposition, since production costs amount to about half of the cost of the transported water.

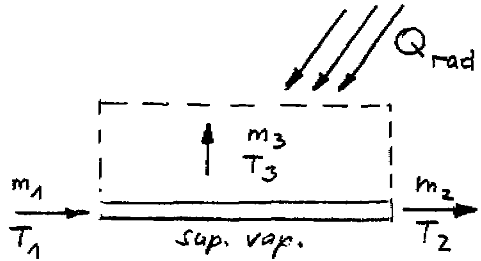
It is interesting to note that efficiency can be increased, as was shown in the preliminary tests. When the surface area is covered with a layer of fine gravel (about 1 cm deep), efficiency is increased by 18 per cent.

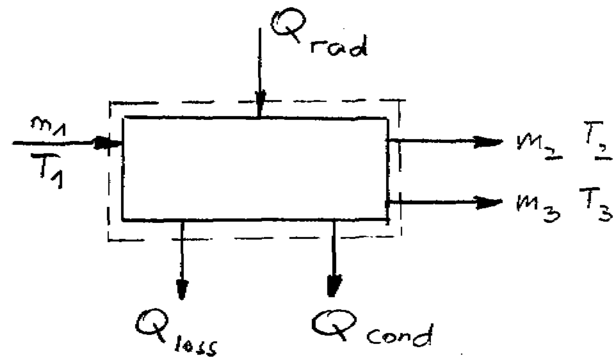
If the amount of excess water is reduced, the amount of distillate produced can be increased by ten per cent. This would indicate that the costs of a larger installation could be still lower. Taking the example in question, the installation costs for a plant of 10,000 m^2, as is needed to supply Quillagua, could be an estimated 15 per cent lower.

Since a pure distillate is not ideal drinking water, further processing proves necessary. Chemical processing is generally very expensive and unfeasible on economic grounds. Investigations should therefore be made to ascertain whether it is possible to add a very small amount of raw water in order to make the quality of the drinking water acceptable.

For other uses of fresh water, e.g., cultivation under plastic tents, the amount of raw water added could be considerably increased, thus appreciably increasing water production. Experiments up to now have shown that the cultivation under plastic tents of fresh vegetables to supply small settlements in arid regions is a very promising project. The amount of water needed is far less than in the case of open irrigation and therefore could be met by the supply produced by solar distillation.

There are already several working models for the application of solar distillers to produce fresh water, in particular for supplying small settlements. Whilst requirements will naturally vary for each situation, there is every reason to be optimistic that this process will prove economically feasible in many cases.





$$Q_e = m_3 \cdot r$$

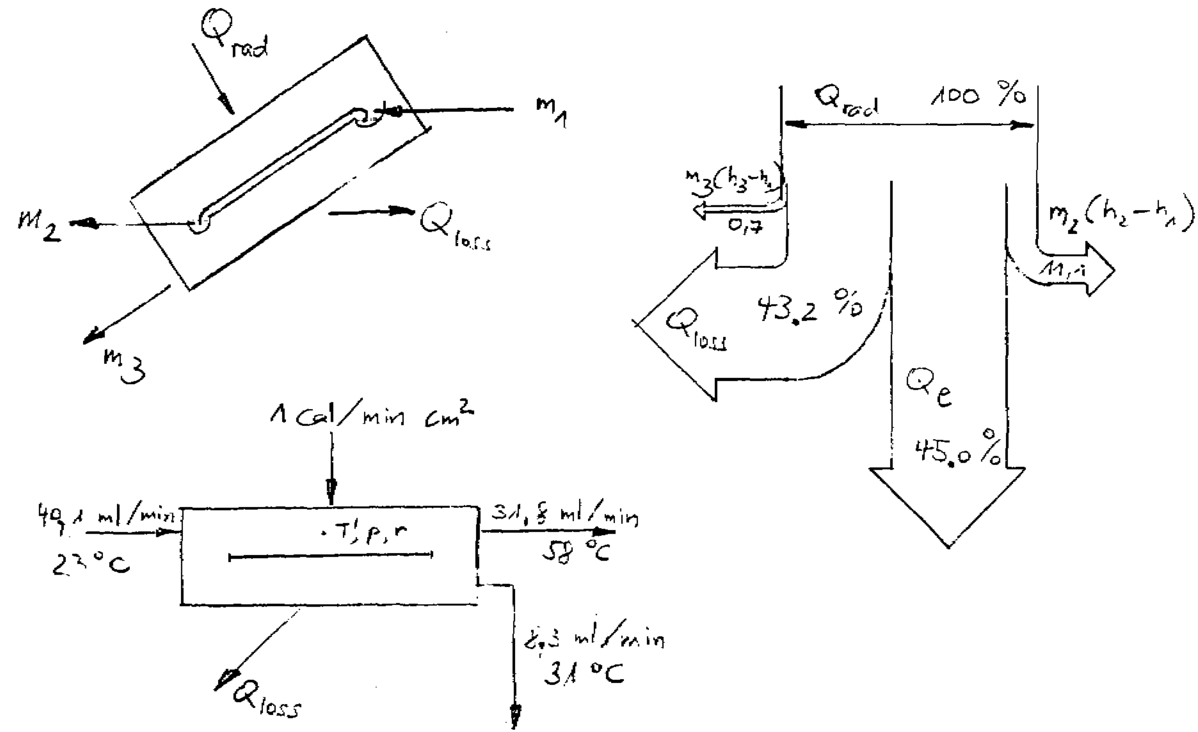
1rst law $\quad m_1 h_1 + Q_{rad} = m_2 h_2 + m_3 h_3 + Q_{loss} + Q_{cond}$

mass res. $\quad m_1 = m_2 + m_3$

$$Q_{rad} = m_2 (h_2 - h_1) + m_3 (h_3 - h_1) + Q_{loss} + Q_{cond}$$

$$\eta_t = \frac{m_3 \cdot r}{Q_{rad}}$$

fig. 1



Qrad
m1
m2
Qloss
m3
1 cal/min cm²
49,1 ml/min
22°C
T, p, r
31,8 ml/min
58 °C
8,3 ml/min
31 °C
Qloss
Qrad
100 %
m3(h3−h1)
0,7
m2(h2−h1)
11,1
43,2 %
Qloss
Qe
45,0 %

fig. 2

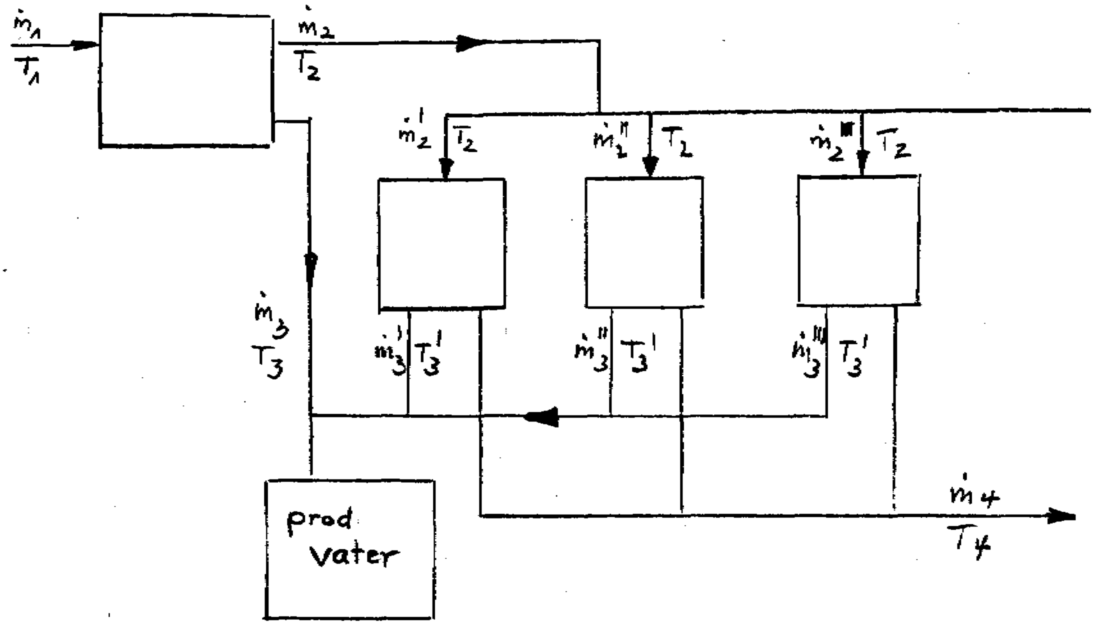


fig. 3

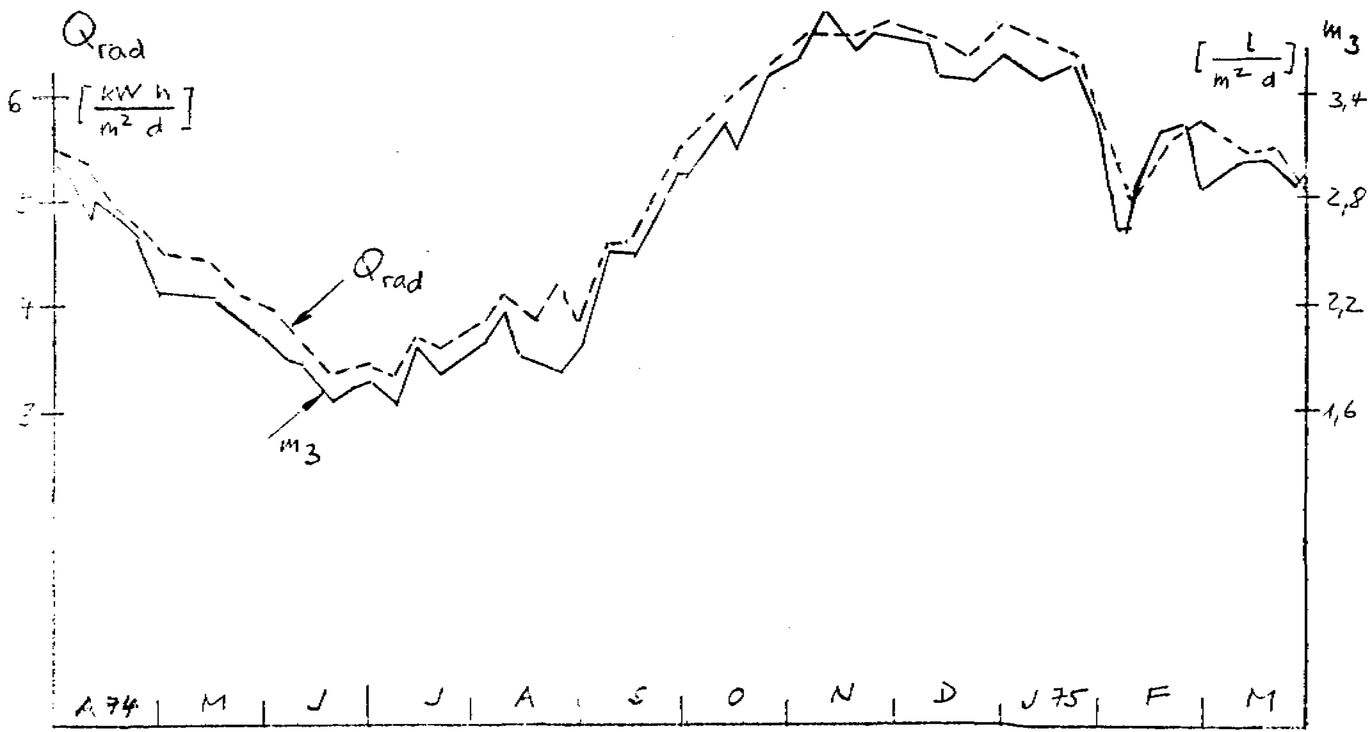


fig. 4

AN EXPERIMENTAL SOLAR STILL DESIGN FOR THE SUDAN +/

Yahia H. Hamid ++/

This is a general note on the economic and technical features of a solar still developed for use in the Sudan with no details of cost or construction. This design is being tested in the laboratory and may eventually be adopted for the construction of solar desalination plants connected with, presently, over 200 rejected high salinity underground boreholes.

Solar desalination of brackish underground and seawater is a practice which has been known to man for many centuries. The economics of the process, mainly those of initial charges, were so unfavourable that solar desalination stood no chance of meaningful competition with other desalination processes. However, recent advances in the technology and design of the solar still using modern and more durable materials, as well as the thorough understanding, resulting from intensive research, of all the factors influencing the still performance, have already led to a cheaper product from the still and may soon tip the balance in favour of solar desalination.

By its very nature, solar desalination is suited for application in the arid hot regions of the world. Large areas of many of the Northern and Western African countries fall in this category, i.e. mainly arid. A realistic economic

---

+/ A publication of the Institute of Solar Energy and Related Environmental Research, National Council for Research, Khartoum, Sudan, presented at the 1st Conference of the Federation of African Organizations of Engineers, Cairo, Egypt.

++/ Lecturer, Mechanical Engineering Department, Faculty of Engineering and Architecture, University of Khartoum

study of the capital cost of the solar still in these countries should consider the following alternatives:

1. The use of local materials in place of imported materials. This is dictated by the foreign exchange limitations confronting developing countries.
2. The types and standards of skills of the local workers and the technological level of the local industries. These factors should be considered as early as the design stage and hence carefully weighed, particularly when the still is to be installed far from urban centres with minimum attention.
3. The generally abundant and low cost manual labour available in these countries. Labour is probably the most important single factor which leads to the relatively high cost of presently accepted solar still designs.[1/]

Consideration of these factors as applied to developing countries favours designs of the still which are labour-intensive and adapted to local materials and skills. As the solar still is generally a very simple single-effect apparatus, suitable alternatives could be arrived at without jeopardizing the performance of the still.

Recent development research on solar still designs at the Faculty of Engineering and Architecture, University of Khartoum (in progress since 1969) has proceeded with the following economic constraints:

1. Low overall cost of the unit.
2. Minimum foreign currency expenditure on materials, equipment, and expertise.

Techno-economic factors such as the durability of the materials, performance of the still, operation and maintenance problems, and simplicity of construction operations were also carefully considered and analyzed in the case of each design. Designs were then tested in the laboratory on full-scale models. Guided by our experience and the experience of pioneering groups in this field such as SCIRO

(Commonwealth Scientific and Industrial Research Organization), Division of Mechanical Engineering in Australia, it became evident that low capital cost, durability and high performance of the still are the main features which would put solar desalination in a competitive position with other desalination processes.2/ Minimum technical requirements of construction, operation and maintenance are an extra feature of the still for the technologically underdeveloped countries.

On these bases an experimental solar still suitable for the Sudan has been developed. The research project was initially supported by the Ministry of Cooperation and Rural Development, so that the developed designs would be field-tested at some of the Ministry's rejected underground boreholes. Plans for the construction of two 1,000 m^2 pilot plants, one in Khartoum province and one in Kordufan province, are under way. In 1971 the program received the support of the National Council for Research after the creation of the Institute of Solar Energy and Related Environmental Research.

Two versions of a single design of the still have emerged. The first version represented an earlier stage of the experiment and was tested on a full scale 6 m^2 laboratory model. Test results over the last 7 months, summarized in table 1, indicate better performance data than the typical data quoted from reference1/ for similar operating conditions.

Table 1

Month	Average yield litres/m^2/day	Yield from a typical solar still-similar operating cond. litres/m^2/day
April	4.24	3.88
May	4.28	3.90
June	3.90	3.57
July	4.14	3.80
August	3.87	3.54
September	3.91	3.58
October	3.66	3.35

The second version of the design, which has possibilities of considerable reductions in capital cost, has not been fully tested but preliminary test results are favourable.

General features of the design are a ten meter long glass-covered bay. The bay's main structure is made of masonry brick with a bed of straw or dry sand for insulation. The brine basin is covered with heavy gauge black polythene lining (0.013" thick). Silicone rubber is used exclusively for the sealing and the structural joining of the glass cover. The bay and cover are set horizontally for batch fill and discharge of the brine and mid-bay collection of distillate. The cover has glass ends with silicone-hinged flaps for the purpose of cleaning the still. The only variation in the two versions of this design is in the distillate collection arrangement. The first version incorporates a silicone sealed glass trough, details of which are shown in figure 1. The second version is simpler as a water seal is used. The distillate trough, lined with white polythene sheeting, is actually part of the masonry structure. Details of this are shown in figure 2.

Favourable technical features of the design may be classified under construction features, operation features and maintenance features, as detailed below:

a) *Construction features*: On the whole the design was meant to be simple and easy to construct. The brick structure of the still is laid horizontally with minimum secondary jobs such as preparation of site, finishing, etc. There are no fittings for filling or discharge of brine. The ends are simplified and require the same type of skill as that for the glass covers. The distillate troughs are easy to construct and the brine basin ends are removeable. Wider glass cover panes may be considered to reduce cost of silicone and on-the-job labour.

b) Operational features: Batch fill and discharge are adapted. The filling and discharge of the brine require no skill. The collection of distillate midway across the bay reduces revaporation loss and improves the drainage efficiency.

c) <u>Maintenance features</u>: The proposed ten metre bay length provides for easy cleaning from the ends. Periodic dumping (weekly) of brine from the basin as a result of the batch filling minimizes cleaning and reduces the chances of salt and algae formation.

Subsequent publications will contain details of the design in the form of working drawings as well as layout plans of the proposed pilot plants. Detailed construction procedures will also be delineated.

References

1/ R.U. Morse, W.R. Read & R.S. Trayford. Solar still Operation in Australia. 1970 International Solar Energy Conference Paper No.5/34

2/ P.I. Cooper, The Maximum Efficiency of Single Effect Solar Stills, submitted for presentation at the 1973 International Solar Energy Conference. Private communication.

3/ Y.H. Hamid, A.A.R. El Agib, O.B. Abu Haraz; Prospects of Solar Desalination of Saline Underground Water in the Sudan, published by the Department of Mechanical Engineering, Faculty of Engineering and Architecture, University of Khartoum, 1971.

4/ A Solar Desalination Experiment-Training Report, an I.S.E.R.E.R. publication, 1972.

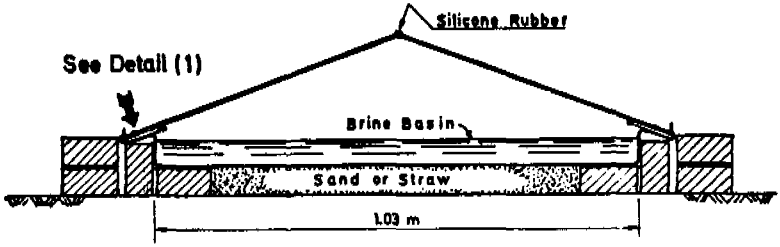


Fig. (1)

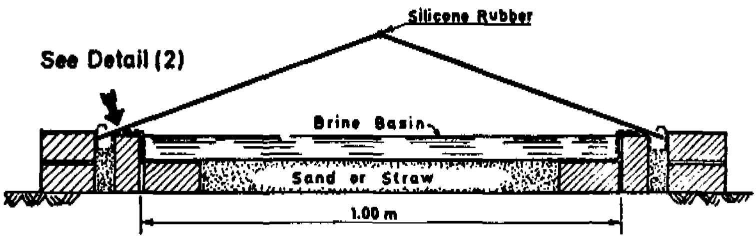
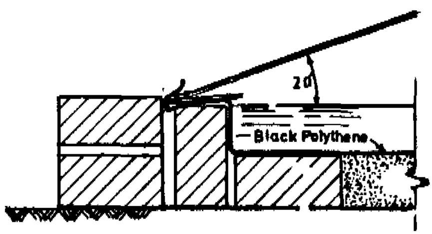
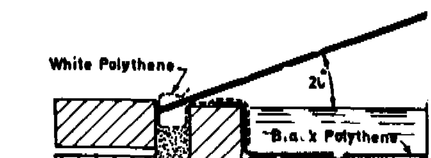


Fig. (2)



Detail (1)



Detail (2)

UTILIZATION OF SOLAR ENERGY FOR DESALINATION IN INDIA

Professor N. Majumder

India lies within the latitudes 7^{o}N and 37^{o}N with an annual average intensity of solar radiation of nearly 600 cal/cm^2/day, the yearly average being more in arid and semi-arid regions and some southern parts of the country. Our country stands 113th in the ladder of per capita energy consumption which is in the range of 100 to 150 KWh. A look at the present 'Indian energy scene' which is typical of most of the developing countries shows an urgent necessity to explore and exploit newer energy sources such as nuclear energy, solar energy, geothermal energy, etc.

Rainwater constitutes the only practical major natural source of water deposited on the earth's surface by the spontaneous cycle of operations of evaporation and condensation occurring in nature. Due to rapid industrialization, growing population and improved standard of living, many developing countries including India are facing the problem of water shortage. In the absence of alternative water resources to meet the increasing demands, desalination is gaining importance day by day.

Solar energy utilization and desalination have been coupled together for the production of fresh water from sea as well as brackish water sources. 'Solar Distillation' offers fruitful opportunities for producing drinking water for household purposes.

The earliest experiments in our country on the 'Solar Stills' were conducted at NPL.[±/] Two stills systems namely, 'concentrator' and 'Telke's' type stills were experimented upon. In the concentrator type stills reflectors were employed for concentrating the radiations at the bottom of a still. An indigenous metallic still was mounted with its

±/ NPL - National Physical Laboratory; New Delhi.

bottom at the focus of the reflector. A thermal efficiency of 17 to 20 per cent was realized. Improvements in the thermal efficiencies were obtained to the range of 30-35 per cent using plane glass mirrors. The cost of such stills is very high and the efficiency very low, hence the work on this type was discontinued for obvious reasons. The work on Telke type of stills was also initiated at the NPL in early 1950's. Five different sizes of Telke's type stills were fabricated using indigenously available material. The maximum yield of distilled water obtained was 0.066 to 0.073 gal/sq.ft./day, from different stills. The TDS in product water was 10 PPM. On the basis of price index of 1952 installation cost per sq.ft. was estimated to be 2 to 4 rupees. Thus cost of setting up a unit of 1 gal. of distilled water/day works out to be Rs. 80, which is approx. 250/- rupees based on the present price index.

In 1964, CSMCRI,+/ Bhavnagar started working on Solar distillation after the discontinuation by NPL. Optimum parameters were evaluated regarding the design of solar stills, essentially the Telke's type. The standardized unit using black polythylene tape lining to the tray has the external dimensions of 2.36 x 1.22 m. with a double sloped glass cover placed at an angle of 20^{o}. Data collected throughout the year indicates that the average productivity of the unit ranges to 2.51 l/m^2/day yielding an efficiency of 28 per cent with solar energy isolation of 550 cal/cm^2/day. In the year 1974 the laboratory has reported some improvements in the field. The reported efficiency is 30 per cent with a productivity of 3 l/m^2/day. Pilot plant studies are undertaken by this laboratory and have set up 10 stills covering an area of 350 m^2. The experiments regarding use of plastic covers as roof did not show a success owing to the life of the plastic. Other improvements in the still are the use of an ashphalt/concrete combination for the base of the tray and precast parts for use in rigid top, bottom support combined with thin water gutter, for collection of product wa-

---

+/ CSMCRI - Central Salt and Marine Chemical Research Institute, Bharnagar.

ter. This technique has been standardized and is available with NRDC. The efficiency of solar still is improved further in modified process of humidification-dehumidification.

In this technique as shown in Fig. 1 saline water heated by solar energy in solar collectors or by any other source is pumped countercurrent to atmospheric air in a humidifier (normally a packed tower) whereby the air gets humidified. This humidified air then enters a surface condenser and gets dehumidified releasing water as product. Cold saline water is circulated as a coolant in the surface condenser and that preheated water circulates through solar collectors. Research and development work on this technique was undertaken in 1965 by CSMCRI.

Earlier experiments have been on a very small unit comprising of a packet tower made of 5 cm dia glass tube and packed to a height of 30 cm with 6 mm x 6 mm Raschig rings. The dehumidifier of surface condenser has a total cooling area of 0.225 m^2 provided by 5 mm O.D. and 46 cm long 32 copper tubes fitted inside a G.I. pipe shell of 10 cm I.D. having 75 per cent segmental baffles. Experimental runs have shown that the unit has a capacity of about 140 ml/hr with brine temperature of 60°C, and liquid/gas ratio (L/G) of about 3 is suitable. In these runs the unit is fed with hot brine heated in an electrical heater.

Another unit of 130 litres/day has been fabricated and experimented upon. This unit has the packed tower made of mild steel (20.3 cm dia) and has 98.5 cm height packed with 12 mm x 12 mm porcelain Raschig rings. Surface condenser has a shell fabricated with mild steel plates having 20.3 cm D and accommodating 96 copper tubes of 1.3 cm O.D. and 92 cm long. The shell side is provided with five 75 per cent segmental baffles. The experiments on these units have confirmed (L/G) optimum of 2.03. The actual output from this unit has been less than theoretical due to less condensation area available in the condenser. This unit has been operated most of the time with electrically heated seawater and a few runs have been taken with solar collectors.

With the experience gained and on the basis of the data collected a pilot plant of 4500 litres/day capacity has been designed, constructed and operated.

This pilot plant has been operated with solar collectors but without satisfactory performance. For operation of the plant steam-heated seawater has been used as preliminary to the use of waste heat of industries. The successful operation of this technique is based on the performance of solar collectors if solar energy is to be used as the source of energy. Available plastics used in collectors have a life of about four months. Glass appears to be better in this respect.

The pilot plant has been provided with 9 solar collectors covering an area of 344 m^2. They are 91 cm wide and 40 cm long. But their performance on this large scale has been very poor. Heavy leakages of saline water have been observed in the collectors. Moreover only PVC and polythene films are indigenously available in the country, hence solar energy based operation of this technique has not been considered promising.

The cost of solar still is dependent on the type of still and the maximum efficiency is assumed to be 30 per cent, and with the value of average annual incidence of solar energy, the calculated productivity is taken as the basis for calculation of surface area required for solar stills. Usually 2 per cent cost goes for maintenance of the stills under Indian conditions. Today in our country a 30 l capacity still with 10 m^2 area will require an investment of 1,000 to 1,200 rupees approximately. It is also evident that the output is not dependent on the feedwater salinity and upscaling cost is linear. Hence, by putting up a large scale community plant there is not going to be a saving of cost as the scaling up cost is almost proportional to the product yield.

In a comparative assessment of economics of solar still it is found that this will become economical to piped water supply only when the still has a capacity of 15,000 l/day to pipe water up to a distance of 3 km. This preposition is impracticable as this will need an area of 200 m^2, which reflects on the increase in the efficiency of solar still.

In spite of this economics in certain situations solar stills offer fresh water on comparative basis. Apart from use in arid regions, lighthouses can use this with good results. The Department of Lighthouse and Lightships, Ministry of Transport, Government of India, spends Rs. 80 to 100/m^3 of water for supply of fresh water to small group of workers in lighthouses. CSMCRI has installed a still on Navinar Lighthouse having an area of 57.2 m^2 with a capacity of 130 l/day. The construction cost as estimated in 1973 was 5400/- with assured life of 20 years. The cost of water becomes roughly 75 to 78/m^3. CSMCRI has installed about 40 stills till 1972.

The above analysis under Indian conditions clearly indicates that the cost of construction of solar still (as of today) is Rs. 150/m^2 area yielding fresh water 3 l/day. The capital investment on solar stills/l/day of water is Rs. 30/-. This has to be decreased five times or so to make a large scale installation economical. This can only be possible by increasing the efficiency of solar energy utilization and reducing the cost of materials used to fabricate the solar still.

List of References

(1) How to Use Present Day Technology of Desalting of Saline Water in solving Fresh Water Shortages in India. M.L. Khanna. Indian Chemical Manufacturer, Vol.VI, No. 5-6, May-June, 1968. P.52

(2) Solar Stills as Source of Drinking Water for Isolated communities and for Distilled Water Production. S.D. Gomkale, Indian Chemical Manufacturer, Vol.VI, No. 5-6, May-June, 1968. P.53.

(3) Some Aspects of Civil Engineering in Water Desalination. H.D. Ghogri and S.D. Gomkale. Indian Chemical Manufacturer, Vol.VI, No. 5-6, May-June, 1968. P.59.

(4) Report of the NCST Expert Panel on Solar Energy (NCST), New Delhi, April, 1974. Published by Department of Science and Technology, Govt. of India Chapter 5-2-2.

(5) Report of the NCST Expert Panel on Solar Energy (NCST), New Delhi, April, 1974. Published by Department of Science and Technology, Govt. of India Chapter 4-25, P.88.

(6) Experience in the Operation of 'Humidification Dehumidification' Pilot Plant of Sea Water Desalination. S.K. Garg, M.H. Mehta. S.D. Gomkale, R.L. Datta. Indian Chemical Manufacturer, Vol.VI, No. 5-6, May-June, 1968. P.61.

(7) H.D. Technique - A solution for Industrial Water needs. Indian Chemical Manufacturer, Vol.VI, No. 5-6, May-June, 1968. P.69.

(8) Jain, T.S., Shaikh, S.G. and Dabadghaonkar, S.M., Studies on Solar Stills for Production of Water for Small Communities in Arid Zone. Proceedings, Symposium on Community Water Supply and Waste Disposal, Nagpur. Dec. 19-21, 1966, Vol.1, P. 155-64.

(9)+/ Design and Operating Principles in Solar Distillation Basins. George O.G. Adv. In Chem.Ser. No. 27, P. 156, 1960.

(10)+/ Field Evaluation of Solar Sea Water Stills. J.W. Blomer, R.A. Collins and J.A. Eibling. Adv. in Chem.Ser. No. 27, P. 156, 1960.

+/ These articles contain information on solar stills from countries other than India.

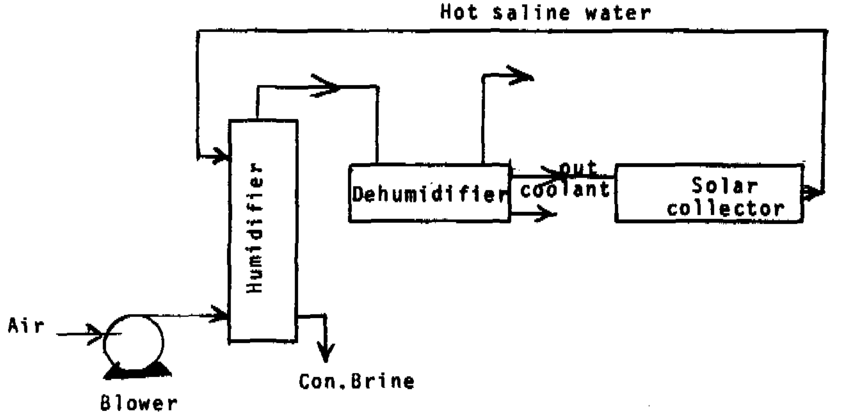


Fig. 1 : Principle of H.D. Technique

WATER DISTILLATION PLANT

Dipl.-Ing. R. Owsianowski

1.0 Physico-chemical principles

The purpose of this plant, which is described here, is to gain desalted water out of seawater, or other undrinkable water. The salty compounds have to be eliminated. This is done by converting water into vapour and condensing it again. The conversion from water into vapour needs very much energy, the so-called evaporation energy. The same amount of energy is regained by condensing the vapour, the so-called condensation energy. The radiation energy of the sun serves as the energy source. Two physical facts are united in this plant.

1) Sunlight is transformed into heat when falling on a black surface, it is absorbed and converted. By cooling the black surface with water, the water becomes warm and a certain amount gets transformed into vapour. When the surface is covered with glass or GPR one will have a greenhouse effect.

2) The amount of vapour which can be absorbed by a certain quantity of gas is a function of its temperature. The higher the temperature, the more vapour can be absorbed. When the gas is cooled, the vapour is condensed to water. The following is the idea of the construction: to transform solar energy into heat, to transform water into vapour.

To make this simple idea efficient one has to use several processes:

1) While water runs down the inclined plane, the air ascends and is saturated with vapour.

Dipl.-Ing. R. Owsianowski is scientific assistant in the Institute for Civil Engineering Hydraulics and Water Management at the Technical University of Berlin, and member of the Adapted Technology group there.

2) The evaporation of thin layers

A thin water layer covers the declined plane, while running down; here the ratio of surface to volume is very good.

3) Recycling principle

Air as well as water can be recycled in the apparatus.

4) Heat pumps

The condensation energy is absorbed by a heat pump and brought back to the reservoir from which the water starts running down the declined plane.

1.1 Energy flow

To heat water from 0^{o} C to 100^{o} C only 100 kcal are needed, but to evaporate water from 100^{o} C, 540 kcal are needed, which means that one needs 600 kcal to evaporate water with a temperature of 40^{o} C.

1000 ml H_2O_{fluid} (100^{o} C) $\longrightarrow$ 1000 ml H_2O_{vapour} (100^{o} C) = 540 kcal.

One can expect in arid or semiarid regions about 600 kcal/ hm^2, which means that one can gain 1000 ml (1 liter), if all the sun energy is converted into heat and the apparatus is very well insulated. Under the condition that heat pumps are used, the yield will be much higher.

2.0 The construction

When water flows down the black inclined plane, some of it will be transformed into vapour. The rest is collected in the bottom basin. The warm water is pumped into the top basin and starts trickling down again. During this process air is gently pressed in the system, starting from the bottom basin, ascends and is saturated with vapour. This saturated air has to pass two funnels. One of them is connected with the storage tank, the other is combined with a heat pump. The condensed water is collected separately, while the cooled air is pressed into the system again. The quantity of condensed water has to be replaced by water which is coming from the big storage tank. The flow of water is regulated by a simple valve.

2.1 Supplementary apparatus

As shown, the main energy is needed to evaporate the water and not to heat it. Therefore, supplementary energies in the range of 100° C or slightly above are very useful.

2.1.1 Sun mirror

A sun mirror has the big advantage to be adjustable, while the distillation plant has a fixed location. Water can be heated in the focal line.

1) With temperatures around 100° C this water can be brought into the distillation plant, or
2) evaporated and then brought into the plant; the hot steam would heat the water in the tank, or
3) could be recycled in a closed pipe.

It would be best to recycle a liquid such as meta-, ortho- or para-xylol, the xylols having a boiling point around 140° C.

2.1.2 Use of heat pumps

To get higher temperatures of water it is useful to take advantage of heat pumps as pointed out under 1.0. When sustaining a cold store one could use a heat pump, which gives its energy to the distillation plant.

3.0 Materials used for the construction

The materials which are used should be inexpensive and durable; if possible, one should try to use local materials as much as possible.

The structure should be built in such a way that it can easily be extended and repaired.

Sheets of the inclined plane

1) Particularly suitable is trapeze sheet metal of aluminium or steel. Here it is used for façades and roofs. Their drawback is that they are very expensive.

2) However one can buy metal sheets and can edge them by oneself.

3) Corrugated metal or corrugated asbestos cement is quite useful, but one has to position it in such a manner that the water flows across and not downward.

4) The plane can be made out of concrete; its natural roughness disturbs the water layer, but it has the drawback of being rather heavy.

3.1 Covering of the inclined plane

1) For covering one can use glass plates. The disadvantages of glass is that it is too heavy and fragile.

2) GPR has the disadvantage of being less penetrable for light, it scratches easily and becomes murky. Meanwhile there are many sophisticated techniques to treat glass and plastic, which cannot be discussed here.

3.2 Insulation

To minimize the loss of energy it is necessary to insulate the tanks and the inclined plane.

3.3 Water tanks and water storage tanks

The volume of the tanks at the bottom and the top has to be large enough to guarantee that the water is not saturated with salt while the plant is working the whole day. (Saturated sodium chloride solution: 360 g NaCl/1000 ml water, by 30^{o} C).

The tanks can be smaller when the water is not recycled. The water storage tank has to be fairly large. It has to be large for two reasons:

1) The water should be pumped from the sea level to the tank by means of a flapping-vane wind machine. As wind is an irregular energy source, there should be always enough water for windless days.

2) The water in the storage tank serves as cooling agent. The tank is connected with one of the chambers at the top of the inclined plane. So the hot vapour is con-

densed to a certain amount when passing this chamber in pipes. The water in the storage tank is heated. Therefore warm water passes the valve filling up the tank at the bottom to replace the distilled quantity.

3.4 Pumps used in the plant

As described above the high storage tank will be filled with water by means of a windmill. The air which is moved in the distillation apparatus must be pumped. A lot of types are available. The water which is recycled in the plant must be pumped. Well adapted for this task is the so-called "Mammutpumpe". In such a pump, which can be easily prepared from a variety of materials and which contains no mobile parts, an air water mixture is generated. With such a pump 1 m^3 water can be pumped 5 to 15 m high, by using 2 to 3 m^3 of air.

4.0 The distillation plant as integral part of a project

4.1 Windpower

Wind is used in windmills to pump water into the storage tank.

4.2 Sun mirrors

The energy of the sun is utilized by means of sun mirrors to generate temperatures slightly above 100^0 C.

4.3 Heat pumps

The condensation energy is brought back into the system by means of a heat pump, but heat from coldstores can be used in the plant as well.

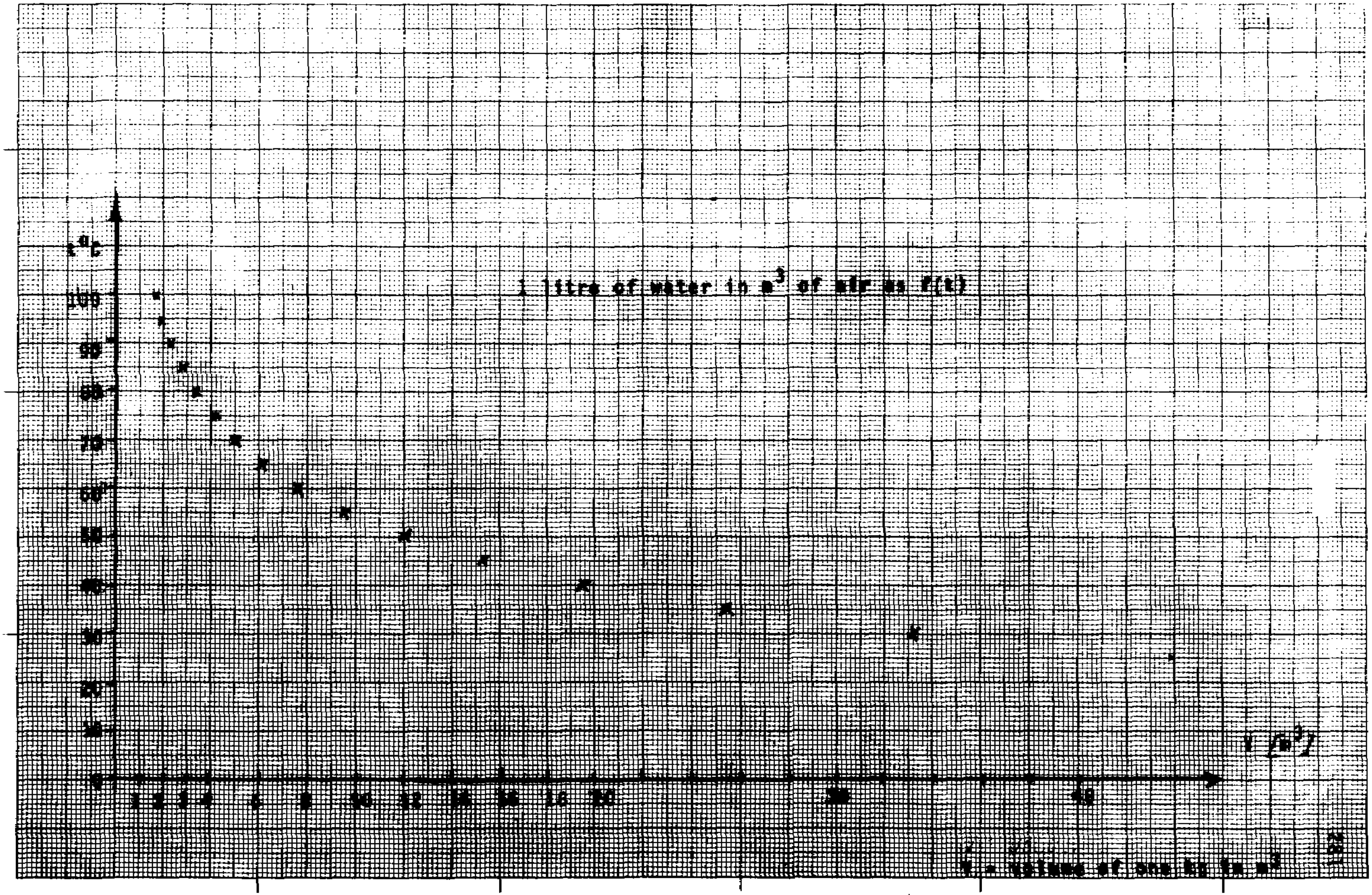
4.4 Distillation plant and gardening

The inclined planes are arranged in such a way that agricultural work is possible to be done under them and between them. The space between the planes is sufficient for direct and indirect light to penetrate.

4.5 Water from the plant

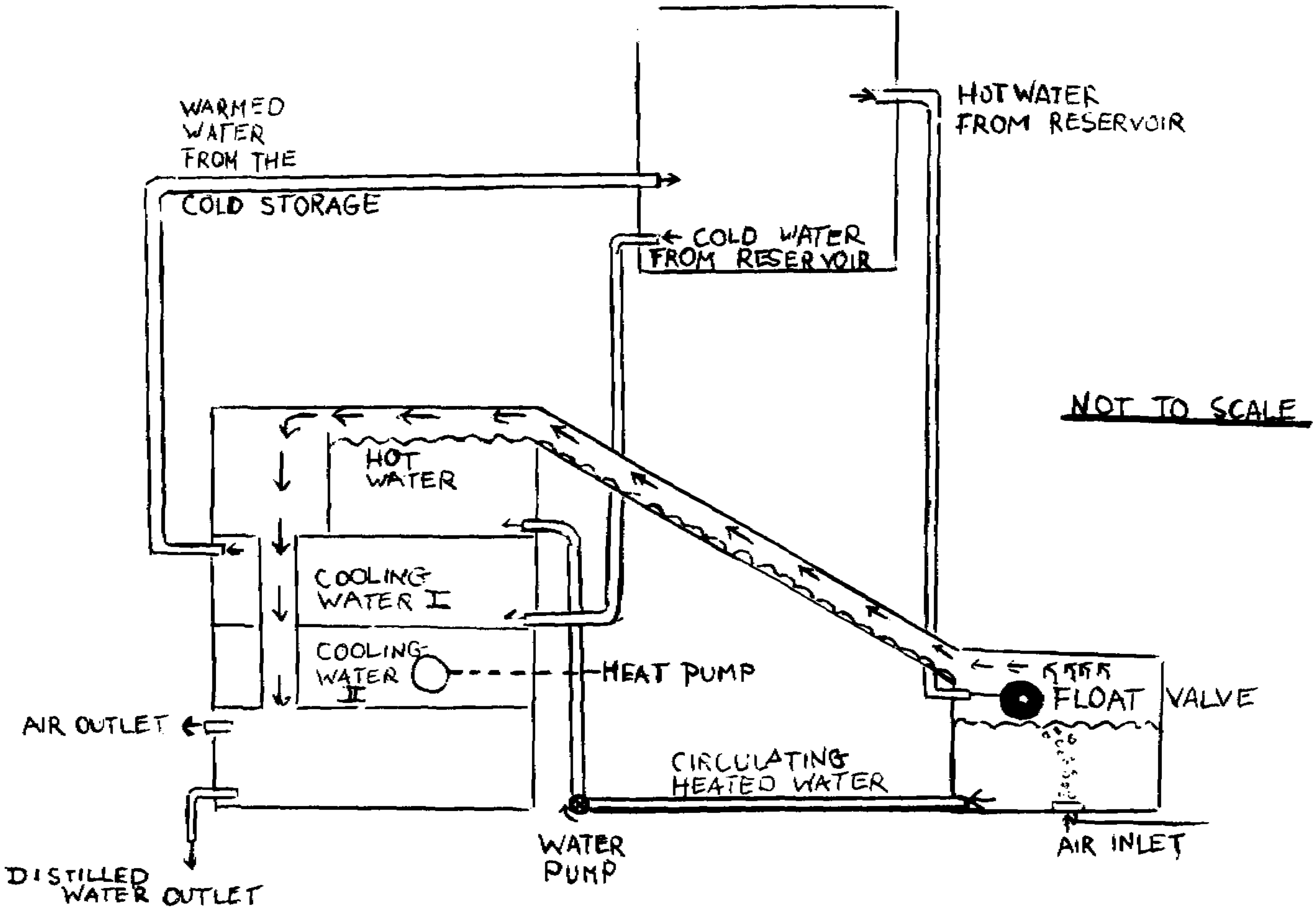
The water must be mineralized before it can be used. This can be done by adding the needed chemical compounds, or by filtering it with mineral materials.

Patent application has been filed.



t °C
1 litre of water in m³ of air as f(t)
100
90
80
70
60
50
40
30
20
10
0
V (m³)
v = volume of one kg in m³

WATER DISTILLATION PLANT



A RESEARCH AND DEVELOPMENT PROGRAM ON SEA WATER DESALINATION PLANTS

Dr. K.-P. Schubert

Two methods of sea or brackish water desalination are discussed:

- solar distillation,
- reverse osmosis combined with a solar powered rankine cycle.

Solar Distillation

A desalination plant using solar energy for water distillation is being developed and tested by Dornier System. A joint research and development program with the Royal Scientific Society of Jordan is under way. A desalination plant of 400 m^2 solar collector area will be erected in Aqaba.

The aim of this program is

- test of the plant under arid conditions,
- automization of plant operation,
- optimization of plant operation.

The base line of the development is shown in Figure 1. A highly efficient solar collector, using heat pipes for the collection of solar energy, is combined with a greenhouse.

The advantages are

- highly efficient collector for optimum energy gain,
- high water temperature in the distiller and therefore high vapor pressure and condensate output,
- small heat capacity of the plant,
- heat flux only in one direction as the heat pipes operate as thermal diodes,
- no corrosion and fouling problems, as the brine is separated by a thin plastic foil from the heat pipes and can easily be removed.

Figure 2 shows a scheme of the plant. During operation of the plant, finned aluminium heat pipes collect the incoming solar energy. The heat flux is concentrated at the upper end and conducted to the brine. The brine is separated by a thin plastic foil from the heat pipes. On top of the brine channel a flat plate with cooling channels is arranged, at which the evaporated water condenses. The distillate is collected and stored in a storage tank. The heat of condensation is transported to the cooling water.

Figure 3 shows two modules of the plant at the test area of Dornier System.

In Figure 4 the production of useful water is shown as a function of the solar intensity and the brine temperature. Due to the increasing vapor pressure of the water, the mass flow of the distillate increases.

Reverse Osmosis Combined with a Solar Powered Rankine Cycle

In Figure 5 the scheme of a small solar power plant, combined with a reverse osmosis apparatus, is shown. Although this arrangement is much more complicated than a solar still, it can be shown that due to the high efficiency of the reverse osmosis, an attractive amount of water can be desalted or cleaned. In addition, electric power is available.

Dornier System is now involved in the development of this plant. The first phase is directed towards an output of 10 kW of electric power. If this power is used to operate the high pressure pump of the reverse osmosis plant, an output of 2 to 3 cubic meters of useful water per hour is expected. The water output is highly sensitive to the salt concentration or pollution of the raw water.

The working machine of the power plant is a small radial turbine arranged at the same shaft as the synchronous generator, delivering a frequency of 666 Hz by 40,000 revolutions per minute of the turbine. The high frequency current will be transformed to direct current of 110 V and alternating current of 220 V and 50 Hz due to power demand.

Advantages of this system are

- high water production,
- power supply for additional consumers.

Technical and Thermodynamic Aspects

Solar Distillation

- Relative simple design, therefore low maintenance but moderate useful water output,
- Concentration of salt for energy demand negligible,
- High energy needs for water vaporization, which is wasted to the cooling water or ambient air.

Solar Powered Reverse Osmosis

- Sophisticated technique, various auxiliary devices necessary,
- Membranes for reverse osmosis still in the development phase,
- Desalination of water with respect to energy consumption and development only up to 1 per cent of salt concentration attractive.

Conclusions

For water desalination both systems can be considered, due to the boundary conditions at the place of plant operation. But the solar distillation plants are being much more investigated than the solar reverse osmosis plants. The relative small water production of the solar still is a compromise for its simplicity. Two years of research and development will now be undertaken to investigate how this compromise can be optimized. Especially the desalination plant developed by Dornier System is well suited for the adaptation of a multi-stage vaporation unit, increasing the usable water output considerably.

The solar powered reverse osmosis plant can be seen as a future option, if additional energy for other purposes is demanded. The electrical part of this plant will operate in about two years.

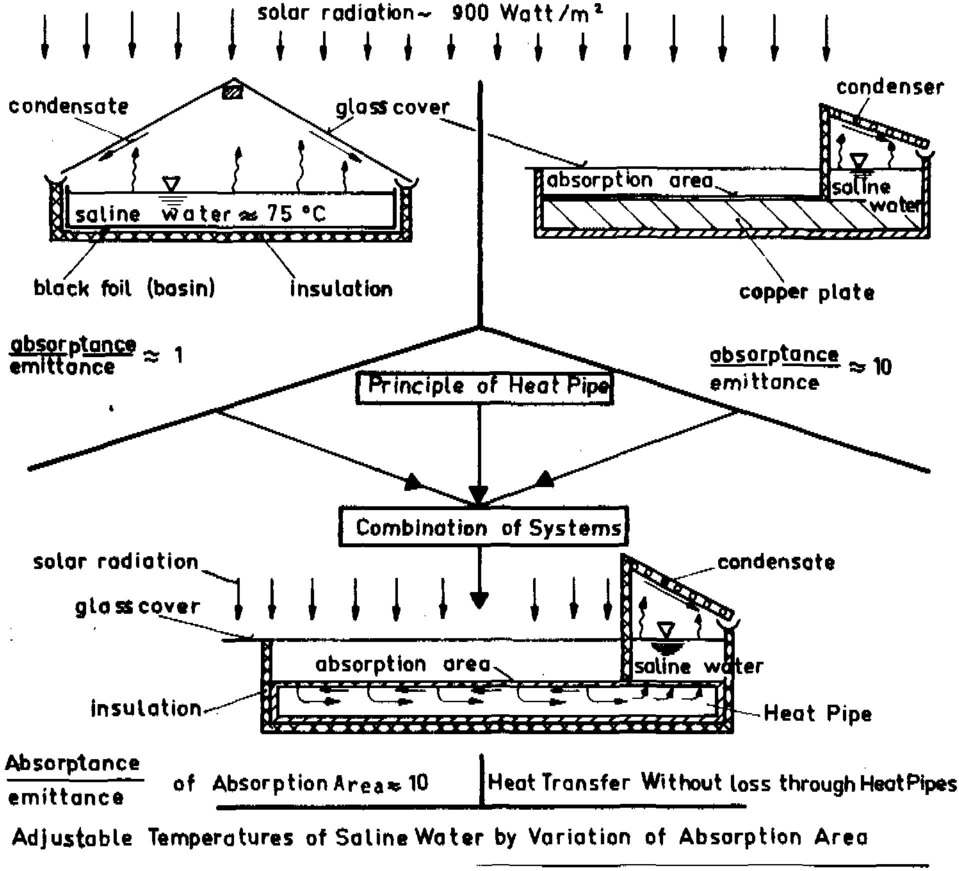

solar radiation ~ 900 Watt/m²
condensate
glass cover
saline water ≈ 75 °C
black foil (basin)
insulation
condenser
absorption area
saline water
copper plate
absorptance / emittance ≈ 1
absorptance / emittance ≈ 10
Principle of Heat Pipe
Combination of Systems
solar radiation
glass cover
condensate
absorption area
saline water
insulation
Heat Pipe
Absorptance / emittance of Absorption Area ≈ 10
Heat Transfer Without loss through Heat Pipes
Adjustable Temperatures of Saline Water by Variation of Absorption Area

FIGURE 1

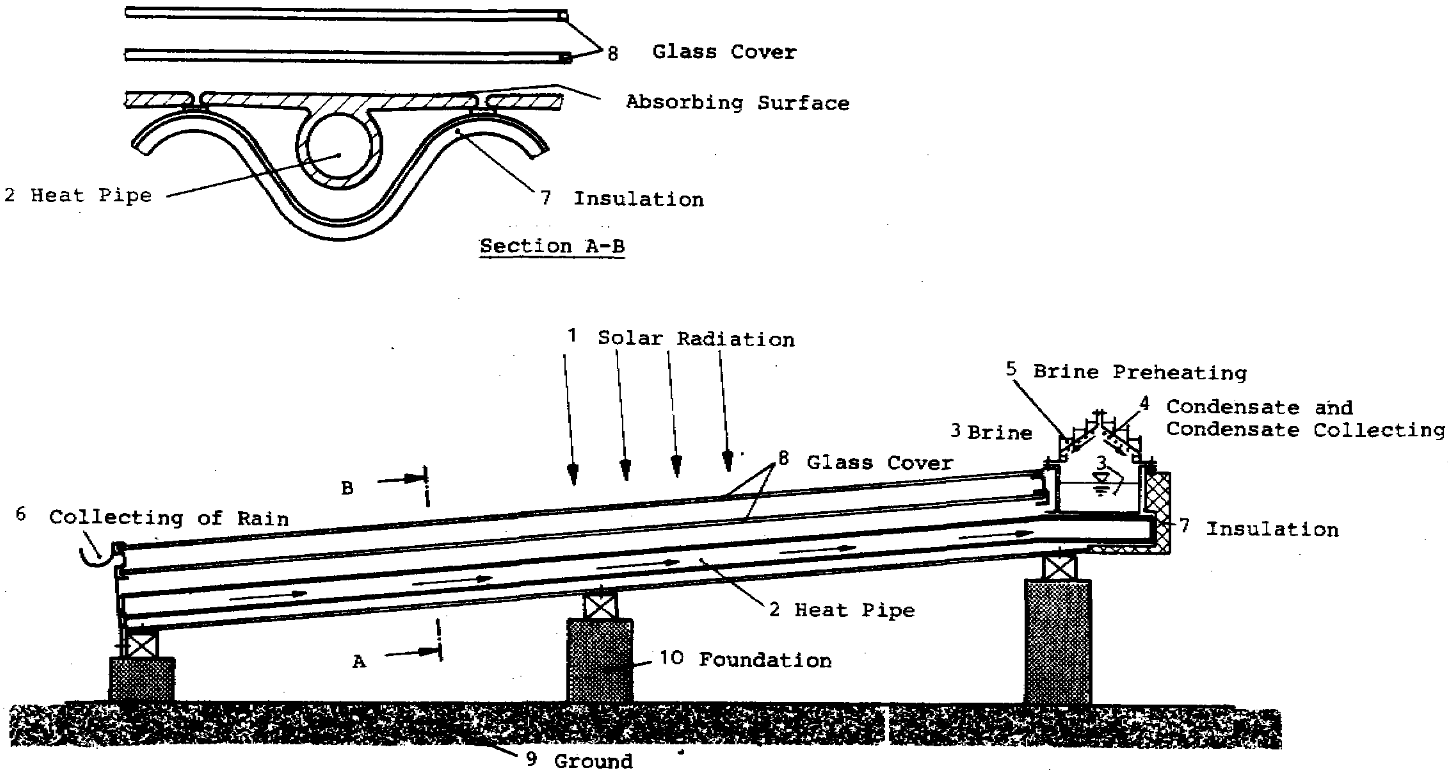


FIGURE 2 : SCHEME OF THE SOLAR DESALINATION PLANT

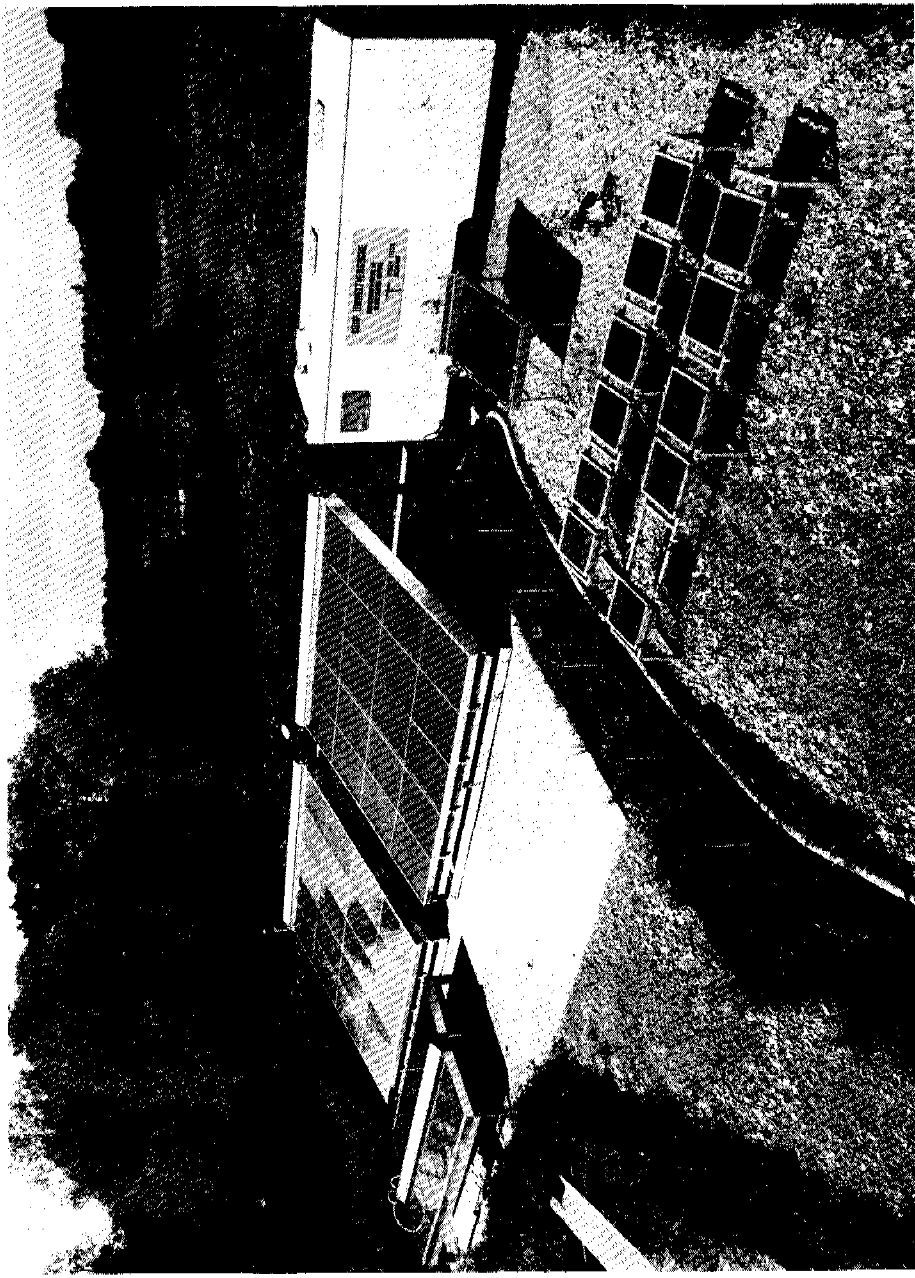


Figure 3

VERSUCHSWERTE

TEST RESULTS

RESULTATS EXPERIMENTAUX

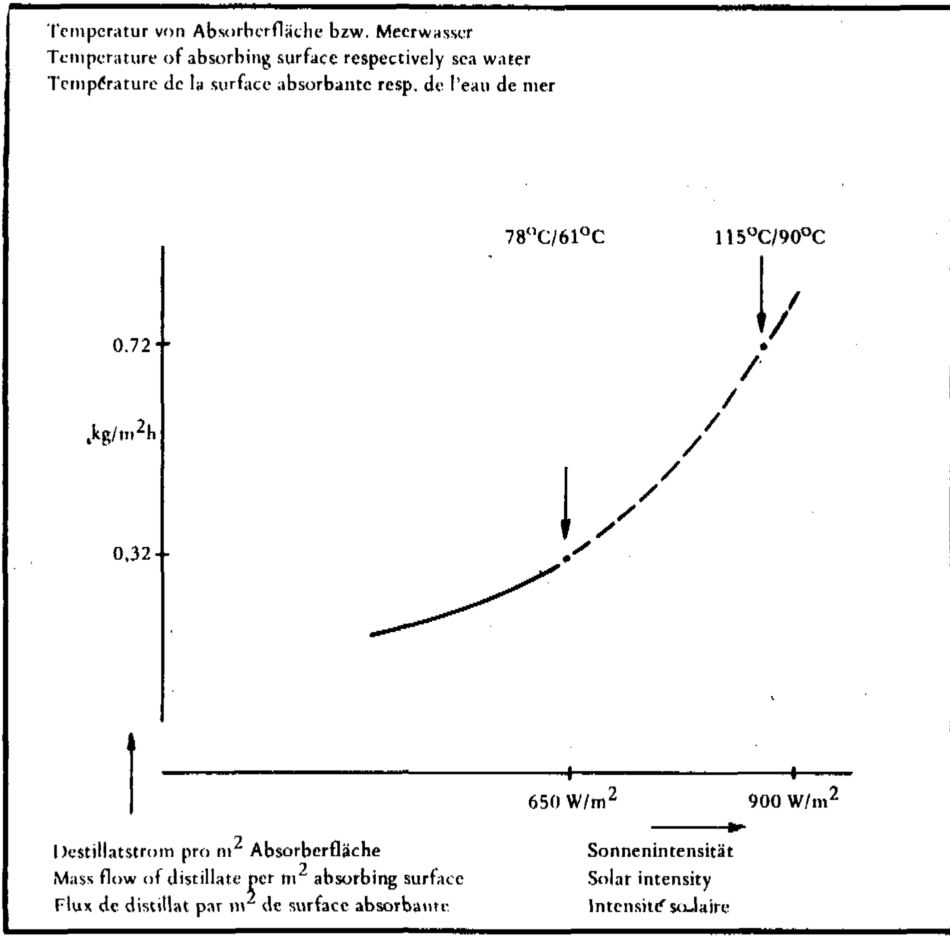


FIGURE 4

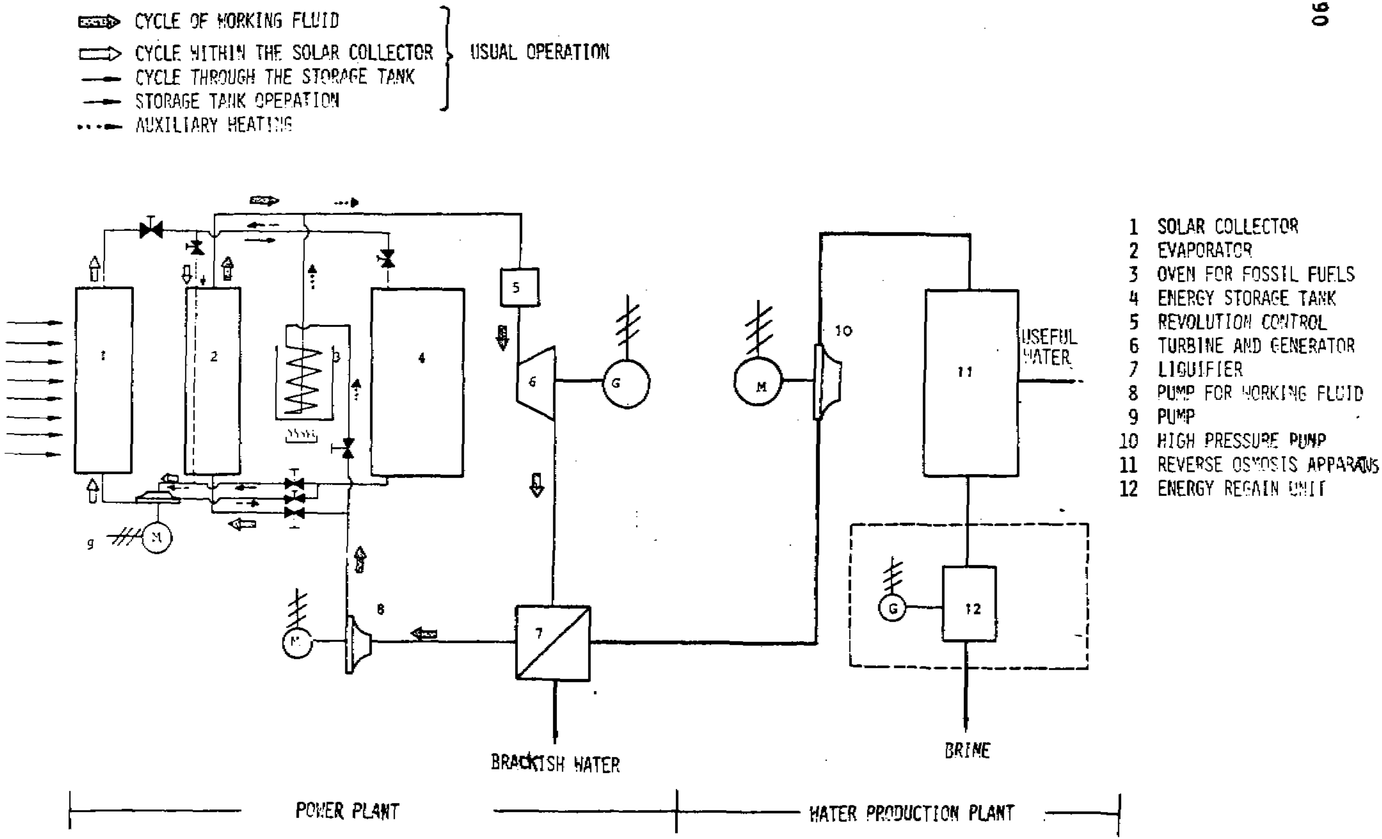


FIGURE 5 SCHEME OF A SOLAR POWER PLANT FOR WATER DESALINATION BY REVERSE OSMOSIS

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP IV: SOLAR DISTILLATION

Discussions started after setting the agenda of the meetings based on questions and inquiries raised by members of the Working Group in a free session. The items suggested for discussion were generally categorized as relating to one of the following main headings:

1. The present state of solar still technology;
2. The choice of a technology of a solar still for application in a certain locality;
3. Cooperation programmes between developed and developing countries in the field of solar distillation.

Elaborate discussions followed the setting of the agenda. A paper on the present state of solar still technology, prepared by Dr. Sakr, and a document summarizing scientific and technical factors influencing the solar still performance were circulated. Discussion on the technical aspects of solar distillation proceeded along the following lines:

- the simple greenhouse still: typical performance, limitations, etc.;
- other improved designs: reported gains in efficiency and yields;
- new trends, including the heat pipe still.

Various aspects of solar still technology were also touched upon, including optimal size and dimensions of components, reuse of latent heat of condensator, types of saline water, relative performance of tilted verus classical greenhouse solar stills, determination of solar still efficiencies, etc.

There was considerable discussion on the economics of solar stills, and the need to develop low-cost, long-life, robust solar stills. The use of concentrating solar collectors for solar stills was discounted for a number of reasons, including the often high percentage of diffuse radiation in arid areas and the dangers of overheating the saline water and thus causing precipitation.

As a specific case study in connection with the question of choice of technology, there was detailed discussion on the need for a portable solar still which nomads could take with them on their travels. It was generally decided that although surface saline was available in some parts, the need to pump the saline water from wells indicated that permanent solar distillation plants along the path of the nomads would be the best solution to consider.

Considering the present state of development, it was concluded that the simple greenhouse still represented the best choice for application in developing countries.

In considering the question of choice of solar still technology for a particular locality, three levels of technology were identified:

- the highly sophisticated technology of the developed countries;
- the local technology of a developing country;
- a technology dictated by
  - technical factors peculiar to solar distillation systems,
  - techno-economic factors pertaining to the region where the system is to be installed.

It was agreed that the third level constituted the appropriate level of technology for a region. A team of trained scientists and engineers with sufficient knowledge of the region would be in a position to choose the proper technology of a solar distillation system for installation in the particular region. Since the solar distillation system is generally a simple system, the choice of a technology can be influenced to a greater extent by the level of local technology.

Furthermore, it was stressed that a total system approach to the choice of technology is necessary. This requires that principles of choice of appropriate technology must be applied to the individual components of the solar distillation plant, e.g., the pumping facility, etc.

Discussion of cooperation programmes between developed and developing countries in the field of solar energy drew a variety of proposals aimed at enhancing the long-term impact of such programmes on the recipient countries. The proposals centered around training and development of research facilities prior to the implementation of full-scale projects:

1. Initiation of a summer school for solar distillation in which young engineers and scientists would be exposed by experts to the technology;
2. Creation of research centres for solar distillation incorporating data-taking and testing facilities;
3. Training of a core of researchers from the receiving countries to ensure continuity of research and development in this area.

V. RESEARCH AND DEVELOPMENT

APPROPRIATE TECHNOLOGY AND THE CHOICE OF SOME RESEARCH PROJECTS

Cornelis Daey Ouwens

This paper deals with the possibilities of doing research in the field of energy supply for developing countries, considering especially wind and the sun as energy sources. As the main subject of this Conference is the application of wind and solar energy for semiarid regions, the examples will be directed to this subject. We will outline what our philosophy is in doing research for developing countries; in this the ideas of appropriate technology are very important.

In looking at the needs of developing countries it is clear that energy is fundamental to their development. Now there are several advantages of using the sun and wind as energy sources, for instance: no, or hardly any, environmental problems; no exhaustion; no dependence on other countries. Further, the decentralized aspects are often important, because generally there is no effective system for the distribution of energy.

What do we think of when developing the sun and the wind as energy sources for developing countries? Huge fields of solar energy collectors or relatively small decentralized systems? Pumps made of advanced materials or locally available materials? Systems made by labour-intensive processes or not? What is the amount of money which is available for a product?

When answering these questions, one must keep clearly in mind that there is not much enthusiasm about the results of the aid to developing countries during the last one or two decades. An analysis of the reasons has led to the conclusion that many projects failed because the system introduced (from complete factories to machinery for agriculture), was not appropriate, did not fit, did not suit the community which had to work with it. People must be able to work with a machine, maintain it, repair it and even after a while make a new one themselves. But it is not only the technical aspects which are important, since the system must also be acceptable from an economic viewpoint. At the same time the new system must be socially appropriate. If it does not fit into the local culture, there is no point in introducing it.

So, in our opinion, one has to look at the system from more than just a technical point of view. Many of these ideas can be found in the articles and books about appropriate technology.

Here we want to emphasize that appropriate technology is not an answer to all problems. Of course advanced projects can also be undertaken, for instance in the field of space research. But a lot of this research is already going on, and appropriate technology is at the least a very attractive completion of our help. We must never forget that 80 to 90 per cent of the people in developing countries are still living in rural areas, and appropriate technology is intended to concentrate on their problems.

Let us try to get two things clear. Firstly, what are the implications of this philosophy when we talk about systems for pumping water in semiarid regions, and secondly what is the role of western institutions, such as universities, in this context.

To answer the first question, let us say there is water available and we want to pump it by a windmill. First, we need a lot of information not only about the climatological conditions but also about the peoples' way of living, about the possibilities of maintaining and repairing a windmill. What materials are locally available, and if new materials are to be introduced, can they be handled. In the context of appropriate technology it would be most desirable if, after introducing the first windmill and testing it, the community could maintain it and local industry could make more. Of course a training period in a western country for some of the local people might be necessary. Know-how has to be transferred. But as soon a possible they have to take over.

Now the second question concerning the role of institutions. The information given is based on practical experience within our university. First, what we call "micro projects." We receive many technical inquiries from developing countries about completely different subjects. If possible, the question is given to somebody who has experience on the specific subjects.

Two examples: how can I prevent scum in a methane digester; what is the best way to store potatoes? The answer is mostly in the form of a description or reference to the literature. Sometimes there is some follow-up after the question is answered, but normally micro projects are just incidental and without continuity.

Often, however, the question has wider aspects. If somebody asks for a windmill and we know enough about the local conditions and about the man who has to work with it, we can send drawings of a certain type of windmill. But if it should be a prototype of a windmill with wide application, then it is not a micro project any more. Then we have to be careful. In the first place we need a windmill which will be foolproof. If a system is introduced in those countries on a big scale, the system must not fail. Further, the windmill has to be optimized, the best type of windmill for a certain application. It is certain that a detailed research program will be needed before the best system can be presented.

Let us put it another way. How can we introduce appropriate technology on a wide scale if the technology does not exist. We often need to develop completely new constructions. This holds also for pumping equipment in semiarid regions.

If we would like to use the sun as an energy source instead of the wind, the same questions as mentioned above will come up. By analyzing all possible solar pumping systems, we will be able to decide which systems are most appropriate and then we must look at those parts of the system which can be improved by doing research. One problem is on what basis do we choose our research projects. On the one hand we must be sure that there will be applications for the research and on the other hand there must be some expertise on the subject at the institute. Also the person or group of people must be really motivated about the project. So it is difficult to give general rules. If a group really wants to do research for developing countries, there is normally no problem about the subject.

In doing research one must always keep in mind the ultimate application, namely the community where it has to be applied. If the research is successful we have to transfer the knowledge to the country so that they can take over. The problem is difficult because one has to look at all aspects.

We can give many examples where systematic research could give useful results. For instance cheap solar cells might have a great influence on the energy use in developing countries. One can think of selective surfaces which are so important for solar thermal systems. There are also many applications for simple intermittant cooling systems. Development of appropriate machinery for agriculture is also a challenge. Also there are still possibilities of optimizing methane digesters.

What I have tried to say is that much research for developing countries can be done, but from our point of view it is very important that other aspects should be taken into consideration when choosing research projects.

PROMOTION OF APPROPRIATE TECHNOLOGIES FOR DEVELOPING COUNTRIES BY THE GERMAN FEDERAL GOVERNMENT

The German Federal Government regards the transfer of technologies as an important contribution towards the economic and social advancement of these countries. In its view, it is necessary to make the technical procedures evolved in the industrial countries more easily available to the developing countries and to remove the obstacles hampering the transfer of technical knowledge.

To prevent the developing countries from becoming unilaterally dependent on technology transfer from abroad and to make the best of the potential for innovation of that technology in production structures in the recipient countries, it is necessary to promote technological research and development in these countries. Therefore, the German Federal Government cooperates with developing countries by setting up pilot projects for the opening up of unconventional sources of energy, for the utilization of local raw materials and for the development of economically viable irrigation methods. In addition, the developing countries are given assistance in setting up and expanding centres for the development and dissemination of technologies in the developing countries, and cooperation between these centres and corresponding German institutions is encouraged.

In particular, the German Federal Government supports for use in rural areas those technologies which are labour-intensive, help save capital and foreign exchange, help make use of untapped raw material deposits and energy sources, ensure small-scale production at low-cost, and are simple enough to allow easy maintenance and repair of production requisites.

Pilot Projects

It did not prove possible to carry out the German Federal Government's initial plan to promote the development of appropriate technologies by setting up an institute for technologies for developing countries. Instead, attention was turned to practical projects in the field, especially to pilot projects. The object of these projects is to find technological solutions to economic or social problems occurring in several countries rather than just one. In a pilot project, an institution in a developing country, in close cooperation with a German counterpart possessing the know-how, tries to work out an appropriate technological approach to the problem. The necessary finance is provided in part or in full by the Federal Republic of Germany out of technical assistance funds.

The Federal Ministry for Economic Cooperation and the Federal Ministry for Research and Technology cooperate closely in the planning and execution of their activities in the area of technology. On the scientific-technological side (handled by the Ministry for Research and Technology) a number of cooperation projects with developing countries are already under way. Close scientific collaboration with several more developing countries is being prepared. In these cases, cooperation means mainly an exchange of scientists and the joint utilization of research installations. Coordination agencies on the German side are the international offices of the Nuclear Research Centres in Jülich and Karlsruhe.

On-going Pilot Projects with a Bearing on the Subject-matter of this Conference

As far as the use of solar energy is concerned, the German Federal Government has started cooperation with developing countries, through the technical assistance programme of the Ministry for Economic Cooperation, in the following areas: purification of water for drinking purposes, desalination of sea-water, refrigeration and production of mechanical energy for operating water pumps. Under the scientific-technological cooperation programme handled by the Ministry for Research and Technology, preparations are under way for joint development work to use solar energy for supplying remote regions with electricity.

Brief Description of Pilot Projects

1. Solar heat pipe procedure for purifying water (SOHP)

   The system was developed by the firm Dornier, and a prototype was tried out at Lake Constance. In the SOHP procedure, solar energy is absorbed by specially-treated glass surfaces. Brackish water is heated in a system of tubes arranged beneath the glass surfaces and piped in to evaporators. The further procedure is conventional. The steam condenses, producing water (which has the properties of rain water) which is stored. The SOHP procedure is particularly suited to supply small consumer units such as hospitals or schools.

   Advantages of the procedure: purification of sea water and brackish water; easy maintenance as there are no moving parts; drinking water is obtained at low costs; substantial desalination effect: up to 5 litres drinking water per square meter of absorption surface are obtained per day.

2. Use of greenhouse effect for obtaining drinking water

   Sea water is desalinated and evaporated in a glass-covered building. The procedure yields about 3 litres of drinking water per square metre per day.

3. Use of SOHP procedure for solar cooling

   The system is based on the aqua-ammonia absorption cycle. The heat necessary for evaporation is obtained from solar collectors. The system is suitable both for stationary and mobile units. It is intended to be used for the cold storage of vegetables, meat and fish, and for the production of ice.

4. Solar-operated pump

   Object of the pilot project is the development of a prototype of a pump which would permit the tapping of underground water reserves with the help of solar energy. The pump is driven by a sort of piston which in turn is moved by the expansion of a medium heated by solar collectors. At a later stage, it is hoped to build the pumps locally. The pumps are intended for use mainly in rural areas.

Scope of the German Research Programme in the Field of Solar Energy

Over the next five years, funds amounting to about DM 110 million will be available for research work on solar energy in the Federal Republic of Germany. Research will be concentrated on the use of solar heat.

Where to Obtain Additional Information

During the Conference, please contact Mr Kühn from the Ministry for Economic Cooperation for further information. After the Conference, write to

Federal Ministry for
Economic Cooperation
- Referat 300 -

D 53 B o n n 12
Postfach 120322

WIND ENERGY IN DEVELOPING COUNTRIES: A RESEARCH PROGRAMME IN THE NETHERLANDS

P. T. Smulders

The energy crisis in 1973 brought about a renewed interest in the use of sun and wind as energy sources. In the western world wind energy systems well over the megawatt range are being considered in a number of countries as one of the means of solving future energy needs and environmental problems inherent to high per capita energy consumption. In developing countries the situation is completely different. Per capita energy consumption is a factor 10 to 100 lower. Also 80 per cent of the population lives in the decentralized rural areas. In some cases distances between communities are so great that centralized energy distribution networks are out of the question.

What then are the potentialities of wind power for these areas, what are the social, cultural and economic constraints to introduce wind power and what kind of technical research is needed as one of the links in a program to put the wind to work.

In my opinion the utilization of wind energy will (for the coming years) be most effective on the small scale, say related to the needs of one or more farmers, (1 hectare = 10,000 m^2 = $2\frac{1}{2}$ acres). In India, for example, the average plot of a farmer is between 1/3 and 1 hectare. Water needs for a variety of crops is on the average 50 m^3 water/day/hectare.

Depending on the pumping height H, the energy needs are small; e.g. for 50 m^3/day at H = 1, 10 and 100 m the theoretical power requirements are about 5,50 and 500 W respectively.

Requirements for drinking, cooking and washing for a family are of the order of 100 l/day. Water consumption for beasts varies between 10 l/day (a sheep or 100 chickens) to 70 l a day for a cow.

So very roughly we can say: the energy requirements (pumping over the same height) for

irrigation of 1 hectare	are
domestic needs of 500 families	equivalent
water needs of 1 000 beasts	

We should therefore consider in the first place windmills with an average power of 1 kW and less. In general that will mean mills with diameters less than 10 m. (E.g., calculations for a site in India with a (low) annual average wind velocity of approximately 2.5 m/s were made, assuming a pumping height of 10 m. With a mill of 6.2 diameter the annual average capacity was 100 m^3/day, assuming normal efficiencies for mill and pump.)

Commercial mills are available on the market, but at a cost of $ 500 or more. There should be a relation however between capital investment and the yearly earnings of a farmer, which in many cases will be between $ 200 and $ 500. That fixes limits: wind energy investments per farmer should probably be well below $ 100. This implies that mills be made in the country itself, preferably for the major part in the villages, and that repair and maintenance is simple.

Where now does research come in, especially research at institutes in western countries? I believe we should concentrate on doing those things

a) for which we have the ability, are well equipped, have the information (e.g., literature access) and the money;

b) which for various reasons are difficult or impossible to do at the moment in the developing countries themselves or are just not done.

At the same time we should concentrate less on doing those things where developing countries have the expertise: in defining needs, evaluating social and cultural implications, and setting up extension programmes.

As an example, an outline is given below of a research program, which has just started in the Netherlands on the utilization of wind energy in developing countries. Participant are members from the Organisation for Applied Scientific Research TNO, The University of Groningen, and The Eindhoven University of Technology.

I. 1. a) A number of different conceptual designs will be evaluated and if necessary tested, leading to hardware prototypes with known characteristics, which can be used as a starting point for local adaption. Variables are: tip speed ratio, mills with vertical versus horizontal axis materials (sails, wood, metals, etc.) transmission, etc.

b) Different conceptual designs of water pumps will be evaluated and if necessary tested.

c) Evaluation of windmill pump systems for different situations.

d) Long term: possibilities of generation of electricity and other applications, maybe in combination with water pumping.

e) Long term: integration of wind energy systems with other systems, e.g. solar.

2. Evaluation of sites. As power is related to the cube of the wind velocity, it is absolutely necessary that wind data in situ are available. This implies

a) availability of simple and inexpensive wind measuring equipment for in situ measurements. To this end evaluation of existing equipment and maybe design of new equipment is necessary;

b) simple evaluation methods of existing wind data. Often scanty, these must be devised.

3. Evaluation of inexpensive storage systems: pumped storage, compressed air storage, etc.

II. In principle the program aims at transfer of knowledge and know-how, primarily in such a way that wind energy can become effective at the village level. We believe there is a great need for a handbook on windmill technology for the worker in the field, explaining basic principles but also giving information on construction, etc. Such a handbook could be invaluable in adapting windmill systems to local conditions. Another method of transferring knowledge could be by exchange of students.

III. In addition to the parts of the program described above in I and II, which may seem rather abstract or academic, projects with parties from developing countries are being initiated. One example is participation in an agricultural project on the Cape Verde Islands, where there is incidentally a lot of wind.

As a conclusion I would say that projects aiming at making wind energy effective will in general only succeed if as well as institutes from both developed and developing countries there are organizations involved which work at the village level. All our 1975 ingenuity will be necessary to construct simple and inexpensive, reliable systems. From there, in the long run, more complex and sophisticated systems, utilizing solar and other reliable sources, may evolve in such a way that a number of developing countries may by-pass the fossil-fuel stage which is typical of western history.

THE ACTIVITIES OF MESSERSCHMIDT-BÖLKOW-BLOHM GMBH IN THE APPLICATION OF SOLAR ENERGY

Dr. rer. nat. Knut Berndorfer

Messerschmitt-Bölkow-Blohm GmbH (MBB) has been developing solar energy systems in its Space Division for several years. All these systems could be applied in developing countries and most of them have been designed specifically for this purpose.

The following activities are being pursued at present:

1. Development of house heating and cooling systems.
2. Building a 10 kW_e solar power supply.
3. Preliminary design of 100 kW_e power station.
4. Preliminary design of 1 MW_e power station and equivalent pumping station.
5. Comparative analysis of designs of solar power stations in the range 100 W_e to 10 MW_e.

A brief description of the activities follows below:

1. Solar House Heating and Cooling

Modular solar house heating systems have been developed since 1974, based on a flat plate collector of very simple design which is being subjected to long term tests at the present time. The heating systems are expected to be on the market within 18 months; combined heating and cooling systems are being projected in cooperation with firms specializing in cooling installations.

2. 10 kW_e Power Supply Prototype

This work is being sponsored by the German Ministry for Research and Technology (BMFT) and is aimed at producing a prototype by the end of 1976. The power supply is intended for use in developing countries and appropriate technology has been used throughout. Water is heated to 95^{o} C in MBB's flat plate collector and transfers heat to a simple and reliable heat engine which drives a generator. The heat engine could be used similarly to drive a pump.

3. Preliminary Design of 100 kW_e Power Station

This is an experimental power station which is being developed within the framework of a cooperative agreement with the Italian firm Ansaldo, with the technical guidance of Prof. Francia and J. Gretz of Euratom. It uses a single parabolic reflector of about 30 m diameter to heat water in a boiler at the focus of the paraboloid. The plant will be erected in Italy where in the presence of an electricity grid no energy storage is foreseen.

The design of the paraboloid, with its tracking system, is sufficiently simple and reliable to consider applying it to pumping stations in developing countries.

4. Preliminary Design of 1 MW_e Power Station and Equivalent Pumping Station

This is being carried out by the same consortium as 3. The design is based on the central tower concept first demonstrated by Prof. Francia in Genoa and preferred by E.R.D.A. in the US for 100 MW_e plants. An area of 15,000 m^2 would be required and a tower about 30 m high which would produce steam at 450^o C and 60 atm.

The same plant could pump 6 m^3/s of water through a height of 10 m for about seven hours a day and also provide 100 kW of electricity for auxiliary services. An area of 1,500 hectar could be irrigated in this way.

5. Comparative Analysis of Various Designs of Solar Power Stations in the Range 100 W_e to 10 MW_e.

This study is sponsored by the BMFT and was started recently. Different system designs for producing electric power will be compared on the basis of criteria derived not only from technical and economic considerations but also from the requirements and resources of developing countries. India, where MBB has built up close connections in this respect, has been foreseen as a typical case, though with necessary modifications the results will also apply to other developing countries.

Similarly the results may be applied with little modification to systems for pumping water either with mechanical or electric pumps. Energy is conveniently stored in this case in a water reservoir.

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP V: RESEARCH AND DEVELOPMENT

Following preliminary discussions, the following agenda was agreed upon:

I. State of the Art and Research Programmes in Developing Countries Represented at the Conference

II. Methane Digesters

III. Concentrating and Flat Plate Solar Collectors

IV. Uncovered Areas for Research and Development

V. General Recomendations.

I. State of the Art and Research Programmes in Developing Countries Represented at the Conference

In order to place the discussions of the Working Group in their proper perspective, it was decided that each representative undertaking research in a semiarid area would present a resumè of his research and development activities in the field of solar and wind energy. This was done by representatives of Egypt, Sudan, Niger, Mali, and Senegal. It was interesting to note that there was certain commonality in their activities, as most addressed themselves to the problems of solar distillation, solar heating, solar cooking, solar drying, etc. In several institutions work was also carried on in film technology and on the important problems of the use of solar and wind energy for the pumping of water. Solar pumping experiments have been undertaken utilizing flat plate collectors for the operation of Rankine cycle engines as well as concentrating collectors for the production of higher temperatures. It is significant to note that a wide variety of research activities of good quality are currently in progress. In summing the total number of personnel currently involved in the countries, it was evident that more than a hundred researchers are actively working in nearly twenty institutions.

The wind energy work to date has been directed towards the development of small-scale water pumping units as well as the evaluation of commercially available units imported from abroad.

II. Methane Digesters

In view of the considerable amount of attention accorded to methane digestion, it was decided to review the potential of this system in view of its ultimate dependency on solar energy. Discussions were held on the principal operation techniques as well as some areas of research. It was pointed out that the direct use of solar energy could be profitably exploited through research and development programmes for maintaining the optimum maintaining temperature. Recent studies have indicated that it is possible to generate up to twenty per cent of basic power requirements of a typical African village. Methane gas can be used to power a modified diesel engine.

III. Concentrating and Flat Plate Solar Collectors

Following a brief review of the state of the art of the principal features of both systems, areas of research and development in concentrating collectors were examined. This was done principally because of the growing realization that in order to increase operating efficiencies while at the same time cutting down on the size of installations, concentrating systems have some validity. The potential of using concentrators on a village level was also discussed. Some of the general areas of technology needing further development were identified.

1. Simple tracking systems should be further developed.
2. There needed to be significant attention paid to fundamental research, in particular with regard to properties of component parts of systems.
3. In view of the apparently large amount of measured diffused radiation, it was agreed that there should be

only one definition of diffused radiation. The data obtained from around the world could then be intercompared.

4. In view of the considerable number of concentrating power systems developed for use in the semiarid areas in the world, it would be important to undertake a global assessment of the potential for power generation in different parts of the world.
5. This would necessitate the development of an accurate, robust, inexpensive, diffuse radiation measuring sensor which could be installed in conjunction with an inexpensive, low-cost recorder or integrator.
6. There should be some international support.
7. It was suggested that solar concentrating collectors more suited to low-attitude areas as well as their ancillary controls be developed.

IV. Uncovered Areas for Research and Development

A novel type of solar pump recently developed in India using the principle of expanding vapour in a reservoir was described.

The tower type of solar energy concentrator was also discussed in some detail. These solar power systems could possibly produce a variety of outputs.

A non-tracking concentrating system was also discussed. In the field of wind power there is a similar lack of robust inexpensive measuring equipment to monitor wind speed and direction.

There also appeared to be the need for a low-speed windmill for water pumping which could generate one to two horsepower at approximately 15 km/hour wind speed.

V. General Recommendations

It is essential to recognize that there is a significant amount of research and development that still must be carried out in both developed and developing areas in order to come up with appropriate and economically viable technologies.

In some instances, bilateral cooperation was very positive in promoting research and development activities. A detailed discussion was held on the role that the international organizations of the UN could play in furthering the technology of solar and wind energy. There was general agreement that much more effort should be put into this field by the UN agencies, especially regarding information exchange and the support and coordination of activities.

It was stressed that the semiarid areas should do as much as they can on their own. Additional funds are required for further research and specific projects. There is a great need for technical information exchange in these fields.

However, it was not possible to come to a consensus of opinion as to the methodology that might be followed in implementing these programmes.

It was pointed out that UNESCO is seriously considering the establishment of a Committee to handle this technology.

In view of the multiplicity of technical meetings in the field of solar and wind energy, it would be advisable if there were some form of international coordination. It would facilitate the attendance of delegates from the developing countries.

There appeared to be a need for the exchange of information between the various institutions doing research in the field of solar and wind energy as applied to pumping water.

It was recommended that given the fact that most representatives from the semiarid countries present at the Conference are here in their official capacity representing their governments, the DSE should circulate the general conclusions of this Conference to the different international organizations.

DISCUSSIONS AND RECOMMENDATIONS

WORKING GROUP VI: TRANSFER OF TECHNOLOGY - PRODUCTION AND MAINTENANCE

The Working Group discussed the different aspects of technology transfer in developing countries. The principal concept is that of the promotion of research and of existing projects in order to achieve industrial development in these countries in this sector.

After a far-reaching discussion, the following main points were elaborated:

1. Appropriate technology relates primarily to the rural environment. Therefore machinery must be found which is effective, can be handled easily and is easily understood by the rural population.

Before the rural population is contacted by extensionists, an intermediary group must be considered which plays an important, even indispensable role in the development of these technologies: the researchers (at national or regional institutes of applied research), the responsible national politicians (governments) and the technical services working in the field (hydraulics, public works, agricultural engineering, agriculture, etc.).

2. Regarding the modalities of technology transfer, it is of importance that the rural population and the above-mentioned institutions are familiarized with the new techniques. To achieve this,

a) the complete confidence of the rural population must be gained;

b) a conscientization and training programme covering pilot farms or experimental stations, scholarships, conferences, exchange of documents, etc., must be initiated. This exchange of information should take place not only between industrial and developing countries but also among the developing countries themselves;

c) regional centres for wind and solar energy must be established or extended in order to coordinate the activities of existing organizations (ONERSOL in Niger, IPM in Senegal, EIER in Upper Volta, DFVLR in the Federal Republic of Germany, Laboratory of Solar Energy in Mali, SOFRETES in France, Canadian Institute, etc.) and to permit the rational development of research in semiarid regions.

All activities and institutions could be coordinated by an international organization such as the UN (for example, the UN could establish a special section which could cooperate with existing UN organizations dealing with energy problems in certain fields: FAO, UNIDO, UNESCO).

Until such an organization has been established the UN could publish practical manuals on wind and solar energy which could be distributed free of charge to all countries.

3. As far as maintenance is concerned, the Working Group was of the opinion that an efficient organization would have to be established which could be in charge of organizing and controlling activities.

4. With regard to the concept of cooperation, the principal idea was that of the existing technologies some are satisfactory and others need to be improved.

In all cases they have to be promoted and developed locally. To achieve this there must be mutual and multilateral cultural and technical exchange in the form of exchanges of ideas and visits of technicians and experts of all countries.

The formula of cooperation should be: "You do it yourselves, and then we do it together."

A N N E X

LIST OF PARTICIPANTS

Arab Republic of Egypt	Professor Dr Nayel BARAKAT Dean of Faculty of Science Ain Shams University Abbassia Cairo
	Professor Dr Ibrahim Ahmed SAKR Head of Solar Energy Laboratory National Research Centre (NRC) Dokki Cairo
Ethiopia	Ato TAMENE TEFERRA;BSc; MA A/Head of Department of Water and Soils Study National Water Resources Commission POB 1008 Addis Ababa
India	Professor Nityananda MAJUMDER BE; SM (Harvard) Director National Environmental Engineering Research Institute Nehru Marg. Nagpur-440020
Iraq	Natheer Jibrael YOUSIF; BSc Geologist responsible for development and hydrogeolog- ical studies Administration of Groundwater Exploitation Ministry of Agriculture and Agrarian Reform Sadoon Street Baghdad

<u>Jordan</u>

Dipl.-Ing. Mohammed BALAWI
Head of R & D Section in M.E.D.
Royal Scientific Society
POB 6945
Amman

<u>Mali</u>

N'to DIARRA
Ingênieur des sciences appliquées
Ingênieur de recherches
Laboratoire de l'Energie Solaire
du Mali
B.P. 134
Bamako

<u>Niger</u>

Professor Dr Abdou MOUMOUNI
Directeur de l'Office de l'Energie
Solaire (ONERSOL)
B.P. 621
Niamey

<u>Senegal</u>

Moussa DIENG
Ingênieur hydrogéologue
Directeur gênéral de l'Hydraulique
et de l'Equipement Rural
Ministêre du Dêveloppement Rural
et de l'Hydraulique
B.P. 4021
Dakar

Souleymane NDIAYE
Ingênieur Chimiste
Directeur des Relations Extêrieures
Primature/Délégation Gênérale
à la Recherche Scientifique
et Technique
(DGRST)
B.P. 3218
61 Bd Pinet Laprade
Dakar

<u>Somalia</u>

Dr Abdulaziz S. ALI MOHAMUD
Adviser
Ministry of Mineral and Water
Resources
Mogadiscio

Sudan

Dr Yahia Hassan HAMID
BSc; MSc, PhD
Director
Institute of Solar Energy and
Related Environmental Research
National Council for Research
Khartoum

Professor Dr Ahmed Abdel Rahman
ELAGIB
Chairman
Scientific and Technological
Research Council;
National Council for Research
Faculty of Engineering
and Architecture
University of Khartoum
Khartoum

Syria

Muhammed KHALAYLI
Civil engineer
Director
The General Administration
for the Development of the
Euphrates Basin
(GADEB)
Daria
Raqqa

Turkey

Dr Mustafa Özcan OLTANIR
Assistant Professor
Faculty of Agriculture
Power Machinery Department
University of Ankara
Cengiz Sotah No 119/3 Yeninahalle
Ankara

Upper Volta

Charles TIAO
Ingènieur
Directeur de l'Hydraulique
et de l'Amênagement de l'Espace
Rural
Service de l'Hydraulique et
de l'Amênagement Rural
Ministére du Plan et du
Dèveloppement Rural, du Tourisme
et de l'Environnement
B.P. 7025
Ouagadougou

Upper Volta (contd)

Hado Paul ZABRE
Ingénieur de l'Equipement Rural
Chef de Service de l'Equipement Rural
Direction de l'Hydraulique et de l'Aménagement de l'Espace Rural
(HAER)
B.P. 330
Ouagadougou

Canada

Tom LAWAND; BEng; MSc
Director
Field Operations
Brace Research Institute
Macdonald College
McGill University
POB 900
Ste Anne de Bellevue 800
Québec

Federal Republic of Germany

ORR Dr ARNOLD
Bundesministerium für Forschung und Technologie
(BMFT)
D-5300 Bonn

Dipl.-Ing. Peter BADE
Institut für Wasserbau und Wasserwirtschaft
Technische Universität Berlin
Straße des 17. Juni 135
D-1000 Berlin 12

Professor Dr.-Ing. Arno BECKERS
Institut für angewandte Thermodynamik
Technische Hochschule Aachen
D-5100 Aachen

Dr rer.nat. Knut BERNDORFER
Messerschmitt-Bölkow-Blohm
(MBB)
Postfach 80 11 69
Ottobrunn
D-8000 München 80

Federal Republic of Germany

Dipl.-Ing- Firedrich VON BISMARCK
Technische Universität Berlin
Straße des 17. Juni 135
D-1000 Berlin 12

Dipl.-Ing. Heiner DÖRNER
Assistent
Forschungsinstitut Windenergie-
technik
Universität Stuttgart
Pfaffenwaldring 31
D-7000 Stuttgart 80

H. FRIEDRICH
Bundesministerium für
Forschung und Technologie
(BMFT)
D-5300 Bonn

Dr.-Ing. Dipl.-Ing. Hans GEHRKE
Dornier System GmbH
Postfach 648
D-7990 Friedrichshafen

Professor Dr Dietrich GOLDSCHMIDT
Direktor am Max-Planck-Institut
für Bildungsforschung
Lentzealle 94
D-1000 Berlin 33

Dr.-Ing. Gert HEWIG
Diplom-Physiker
Institut für physikalische
Elektronik
Universität Stuttgart
Böblinger Straße 70
D-7000 Stuttgart 1

Professor Dr Ulrich HÜTTER
Forschungsinstitut Windenergie-
technik der Institutsgemeinschaft
der Universität Stuttgart e.V.
(FWE)
Pfaffenwaldring 31
D-7000 Stuttgart 80

<u>Federal Republic of Germany</u> (contd)

RD Dr Helmut KLEIN
Diplom-Physiker
Bundesministerium für
Forschung und Technologie
(BMFT)
Stresemannstraße 2
D-5300 Bonn

Dr.-Ing. Rainer KÖHNE
Diplom-Physiker
Deutsche Forschungs- und
Versuchsanstalt für Luft-
und Raumfahrt e.V. (DFVLR)
Pfaffenwaldring 38-40
D-7000 Stuttgart

Dipl.rer.pol. Bernhard KÜHN
Bundesministerium für
wirtschaftliche Zusammenarbeit
(BMZ)
Karl-Marx-Straße 4-6
D-5300 Bonn

Dipl.-Phys. Klaus KUHNKE
III. Physikalisches Institut
Bürgerstr. 42
D-3400 Göttingen

Dipl.-Ing. Rolf-Peter OWSIANOWSKI
IAAC
Technische Universität Berlin
Straße des 17. Juni 135
D-1000 Berlin 12

Dr Richard PATZAK
Kernforschungsanlage Jülich (STE)
D-5170 Jülich

Dr.-Ing. Dipl.-Ing. Klaus-Peter SCHUBERT
Dornier System GmbH
Postfach 648
D-7990 Friedrichshafen

Dr Ing. U. SPRENGEL
Deutsche Forschungs- und
Versuchsanstalt für Luft-
und Raumfahrt e.V. (DFVLR)
Linder Höhe
5000 Köln 90

Federal Republic of Germany (contd)	Dipl.-Ing. Michael SIMON Abteilungsleiter M.A.N. (Neue Technologie) Abt. EPM Dachauer Straße 667 D-8000 München
	Ingo WALLNER Arbeitsgemeinschaft Solarenergie e.V. Kruppstraße 5 D-4300 Essen
France	M. VERGNET Sociêtê Française d'Etudes Thermiques et d'Energie Solaire (SOFRETES) B.P. 163 45203 Montargis
Netherlands	Cornelis DAEY OUWENS Assistant Professor Eindhoven University of Technology Eindhoven
	Paul SMULDERS Assistant Professor Physics Department Eindhoven University of Technology Eindhoven
Switzerland	Dipl.-Ing. Paul DUBACH Lehrbeauftragter ETH Zürich Weinbergstraße 17 Ch-8623 Wetzikon
United Kingdom	Simon WATT; BSc Intermediate Technology Development Group Parnell House 25 Wilton Road London SWI

United States of America	Louis DIVONE; MSc Chief, Wind Energy Systems Branch Energy Research and Development Administration 1800 G St Washington, D.C. 20545
	Marcus SHERMAN Director Wind Power Research New Alchemy Institute - East POB 432 Woods Hole, Massachusetts 02543
	Jack PARK President Helion POB 4301 Sylmar, California 91342
FAO	Wiekert J. VAN GILST Agricultural engineer Food and Agriculture Organization of the United Nations Via delle Terme di Caracalla 00100 Rome, Italy
UNICEF	Alan ROBINSON Chief, Food Engineering and Technology Section United Nations Children's Fund 866 United Nations Plaza New York 10017, USA
UNIDO	Dr. oec. Dipl.-Ing. Milan DELOS United Nations Industrial Development Organization Rathausplatz 1 1010 Vienna, Austria
WHO	Ir. T. Kien TJIOOK International Reference Centre for Community Water Supply Nw. Havenstr. 6 Voorburg, The Hague

PROGRAMME

Monday, 15 September

9 to 10.30 a.m.	Arrival and registration of delegates
11 a.m.	Opening of the Conference by Mr R. Bühling, MP, President of the Board of Trustees of the German Foundation for International Development (DSE) and Dr Gerhard Fritz, Director General of DSE
11.30 a.m. to 1 p.m.	Plenary session Presentation of technical papers Wind Energy "Wind Energy Converter Systems for Water Pumping and Electricity Supply" (with films and slides) Professor Hütter, Stuttgart
1 p.m.	Lunch
3 to 4.30 p.m.	"Flapping-Vane Wind Machine and Rod-Piston Pump, An Integrated Delivery System for Large Well Depth and Small Flow Rates" P. Bade, Berlin "Efficiency and Economic Comparison of Different Wind Energy Converter Systems" Dipl.-Ing. Doerner, Stuttgart "Simple Anemometric Equipment" Dipl.-Ing. Dubach, ETH, Zürich "The Design and Construction of an Appropriate Waterpumping Windmill for Agriculture in India" M. Sherman, USA
4.30 to 5 p.m.	Coffee break

Monday, 15 September (contd)

5 to 6.30 p.m.	Solar Distillation
	"Systems for Solar Distillation"
	T. A. Lawand, Canada
	"Solar Distillation Using Distilling Tanks and Evaporation Cloth"
	Professor Beckers, Aachen
	"A Research and Development Programme on Seawater Desalination Plants"
	Dr K.-P. Schubert, Dornier System, Federal Republic of Germany
	"An Experimental Solar Still Design for the Sudan"
	Y. Hamid, Sudan
6.30 p.m.	Dinner

Tuesday, 16 September

9 to 10.30 a.m.	Promotion of Appropriate W & S Technology
	"Appropriate Technology and the Choice of Some Research Projects"
	C. Daey Ouwens, The Netherlands
	"Wind Energy in Developing Countries: A Research Programme in The Netherlands"
	Professor Smulders, The Netherlands
	"Approaches to Water Pumping in Semiarid Lands and a Description of the Cretan Sail Windwheel"
	S. Watt, Silsoe, UK

Tuesday, 16 September (contd)

	"Promotion of Appropriate Technologies for Developing Countries by the German Federal Government" H. Kühn, Federal Ministry for Economic Cooperation, Bonn Dr Klein, Federal Ministry for Research and Technology, Bonn
10.30 to 11 a.m.	Coffee break
11 a.m. to 1 p.m.	Solar Pumping Electricity Generation "The Utilization of Solar Energy for Pumping Water in Developing Countries" M. Vergnet, SOFRETES, France "A R & D Project for 10 KW Solar Power Station" Dr Kleinkauf and Dr Köhne, DFVLR, Stuttgart Dr Simon, MAN, Munich "Solar Cells for Terrestrial Use" Dr Hewig and Professor Bloss, Stuttgart Additional related papers by Dr Berndorfer, MBB, Munich
1 p.m.	Lunch
3 p.m.	Formation of working groups
3.30 p.m.	Working Group I: Conditions and Constraints for W & S Technology in Water Supply Working Group II: Wind Energy Working Group III (a): Solar Pumping and Electricity Supply Working Group III (b): Solar Distillation

Tuesday, 16 September (contd)

6.30 p.m.	Dinner

Wednesday, 17 September

9 a.m.	Working groups, contd
10.30	Coffee break
11 a.m. to 1 p.m.	Final meeting of working groups I to III
11 a.m. to 1 p.m.	Press conference
	(Between 9.30 a.m. and 12 noon a representative of Lufthansa German Airlines will be available at the Conference Secretariat to book return flights.)
1 p.m.	Lunch
2.30 p.m.	Departure by bus for sightseeing tour of Berlin (West)
6.30 p.m.	Dinner

Thursday, 18 September

9 to 10.30 a.m.	Plenary session
	Findings of working groups I to III
11 a.m. to 1 p.m.	Panel discussion with representatives from developing countries: Perspectives of Development and Dissemination of W & S Technology for Water Supply in Developing Countries
1 p.m.	Lunch

Thursday, 18 September (contd)

3 p.m.	Formation of working groups
	Working Group IV: Choice of Technology
	Working Group V: Research and Development
	Working Group VI: Transfer of Knowhow, Production, etc
3.30 p.m.	Working groups in session
4.30 to 5 p.m.	Coffee break
5 to 6.30 p.m.	Working groups, contd.
6.30 p.m.	Dinner

Friday, 19 September

9 to 10.30 a.m.	Working groups, contd
10.30 to 11 a.m.	Coffee break
11 a.m. to 1 p.m.	Final meeting of working groups
1 p.m.	Lunch
3 to 4 p.m.	Plenary session
	Reports of working groups
4 to 4.30 p.m.	Coffee break
4.30 to 6 p.m.	Panel discussion: Tasks of R & D, Problems of Communication, Organization and International Assistance for W & S Technology in Developing Countries
7 p.m.	Reception and dinner given by the Director General of the German Foundation for International Development

Saturday, 20 September

9 a.m.	Final session Evaluation and recommendations for future collaboration
10.30 a.m.	Coffee break
1 p.m.	Lunch
Afternoon	Departure

DOK 803 A/a
III – IT 8/75