中美再生能源研討會

ROC-USA WORKSHOP ON RENEWABLE ENERGY

PROCEEDINGS

Jointly Sponsored By:

Committee for Scientific and Scholarly Cooperation with the United States
Ministry of Education
Republic of China

Board on Science and Technology for International Development
Office of International Affairs
National Academy of Sciences/National Research Council
United States of America

Co-sponsored By:

National Science Council, ROC
Energy Commission, Ministry of Economic Affairs, ROC
Energy Research Laboratories, ITRI, ROC

May 12-14, 1982
Taipei, Taiwan,
Republic of China

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FOREWORD

Energy, the lifeblood of modern industry and hence the underpinning of economic we being of mankind, has been the focus of world attention since the first oil crisis. We are increasin ly concerned about the energy problem not only because the price of crude oil, the princip fossil fuel, has risen from less than three dollars to well over 30 dollars per barrel in the last eig years, but also because fossil fuels in general are expected to run out of supply by the beginni of the next century. The problem is particularly serious in the Republic of China because we ha to import nearly 80 percent of our energy supply. This being the case, The Republic of Chi Committee for Scientific and Scholarly Cooperation with the United States, Academia Sini and the U.S. National Academy of Sciences decided in 1979 to sponsor a series of worksho with energy as the topic issue.

The ROC-USA Workshop on Renewable Energy represents the second in the series of plann workshops. It is held to enable energy scientists of the two countries to compare notes on state-of-the-art development in this field and explore the potential for further research in Taiwa The theme is particularly pertinent because, as stated above, Taiwan is extremely poor in ener resources of the traditional type and the island is handsomely endowed in terms of other for of energy which are "renewable". While they are not expected to replace a part of fossil fuels, should know the extent to which we should be involved in research and development on t topic. Hopefully, certain specific fields of renewable energy can be identified at this Workshop guidance for our continued efforts in the months and years ahead.

The topics discussed at this Workshop included anaerobic digestion, photovoltaics, so salt ponds, solar cooling, photosynthesis, mini-hydro devices, Stirling engines and geothern energy. Experimental work in some of these fields has been in progress in Taiwan for some tin But most of them are entirely new disciplines to local scientists and engineers. The deliberatic and recommendations from this Workshop are expected to become a tremendous boost in c efforts to harness the renewable forms of energy identified.

As the Chairman of the ROC Committee for Scientific and Scholarly Cooperation w USA, I feel greatly indebted to Dr. William Hughes and Dr. Hsuan Yeh, the co-chairman of t Workshop, whose dedicated work was largely responsible for the success of this Worksh My gratitude goes particularly to the prominent energy scientists of the United States wh lectures provided the "blood and flesh" for the deliberations. I must also say "Thanks" to those who have contributed in one way or another to the fruitful meeting.

K. T. Li
Chairman
ROC Committee for Scientific
and Scholarly Cooperation
with USA, Academia Sinica

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OPENING REMARKS AT ROC-USA WORKSHOP ON RENEWABLE ENERGY

by
Dr. Chien Shih-liang
President, Academia Sinica
May 10, 1982, Taipei

Messrs. Co-Chairmen, Former President Yen, Distinguished Participants, Honorable Guests, Ladies and Gentlemen:

On behalf of the Republic of China Committee for Scientific and Scholarly Cooperation with the United States, Academia Sinica, I warmly welcome you all to this "Workshop on Renewable Energy Resources." I would like to express our appreciation to all the participants who are taking time out of their busy schedules to attend this Workshop, particularly to our American friends who have travelled half the globe to Taipei to deliberate in and contribute to this Workshop.

For the benefit of those who participate in the programs of our Joint Committees on Sino-American Science Cooperation for the first time, perhaps I should say a few words about the program of our Joint Committees.

The program of Sino-American Science Cooperation, sponsored by the U.S. National Academy of Sciences and Academia Sinica, was established in 1964. Therefore, our joint program has had a history of eighteen years. Our program was launched at the time when Dr. Fred Seitz was the president of the U.S. Academy of Sciences, and we have all been very happy to see that some fifteen years later, he became the Chairman of the U.S. Committee, and he plays an active role in the planning of the program of our Joint Committees. The major activity of the program of our Joint Committees has been the organization of one or two workshops or conferences each year on subjects related to either the economic development of the nation or the welfare of the people of the Republic of China.

For instance, in 1980, the "ROC-USA Joint Workshop on Industrial Energy Conservation" was convened in Taipei; and in 1981, we had the "Joint Sino-American Workshop on Food Safety in Taiwan" in Washington, D.C. and the "Special Seminar on Strong Motion Seismic Instrument Arrays" in Taipei. All three workshops yielded very fruitful results.

The subject of the current workshop—Renewable Energy Resources— is indeed a very important and timely subject. I am sure that this workshop on energy will be as successful as the ones we had in 1980 and 1981. In this connection, I would like to express my thanks to Dr. Hughes, Dr. Hurley, Dr. Yeh, and their colleagues for their efforts in the preparation and organization of this workshop.

The recommendations derived from this workshop may not produce immediate benefit to the nation, but I am sure that it will be of great value in the future planning of the development of the energy resources of this country.

Finally, I wish this workshop a great success, and I wish all our American friends a pleasant stay in this Country. Thank you.

OPENING ADDRESS TO
ROC-USA WORKSHOP ON
RENEWABLE ENERGY

by
His Excellency C.K. Yen
Former-President of the Republic of China
May 10, 1982

Dr. Hughes, Dr. Yeh, Mr. Hurley, Distinguished Participants, Honorable Guests,
Ladies and Gentlemen:

It is a great pleasure for me to meet you today and to say a few words to you at the opening of the Sino-American Workshop on Renewable Energy. The workshop has focused on a most timely topic. For about 10 years now, energy has been a serious problem of [illegible]al concern. We all realize that conventional resources are finite in nature, and the world is rapidly running out of conventional energy resources. The American National Academy of Sciences and our Academia Sinica therefore decided in 1979 that we should have a series of workshop projects focused on the energy issue. About one and a half years ago, the first workshop was convened in Taipei with industrial energy conservation as the theme. The result was significant. In 1981, energy consumption in this country registered its first negative growth in history. In that year, consumption was down 4.56 percent compared with that of 1980, despite the growth of 5.5 percent in GNP. Much of the energy saved was derived from conservation measures taken on the recommendations of our American friends.

The current workshop on renewable energy represents the second phase of our collaboration. I understand a third one, a workshop on energy economics and energy policy will take place again in Taipei in late fall this year. I am sure both of these workshops will yield fruits as bountiful as the first one.

The definition of "renewable energy resources" poses many interesting questions. Philosophically speaking, renewable energy resources may not mean indefinite cycling of energy. In the nuclear age we have already succeeded in converting matter into energy, but we are not yet able to convert energy back into matter. Therefore, renewable could not mean at this time indifinite converting back and forth.

Some people might argue that, if we could harness solar energy in some way, we could make energy resources infinitely renewable through photosynthesis. But this again has its limitation. Solar energy in fact comes from the conversion of matter into energy in the sun. And the sun, as one of the numerous cosmic bodies, does have a finite, though exceedingly long, life time. While the sun might outlive man, it is theoretically possible that, when it finally burns up, there will be no longer any solar energy for man. On the opposite end, people might argue that the finite resource, fossil energy, may be renewable also over a long span of time. We know that oil, gas and coal were formed in the earth during prehistoric times. It is at least theoretically possible that the earth may convert organic matter into oil gas and coal again millions of years from now. When that happens, fossil fuels will be renewed.

Since human knowledge of the universe is really quite primitive even in these days of enlightenment, we could not ask for logical purity. We live in a practical world, and we must deal with the enrgy problem as a practical one and in a pragmatic way. It seems to me that we ought to think about the energy problem in its short-term, intermediate-term and long-term aspects. The short-term issue is clearly conservation. Through conservation we can make the presently available energy resources, particularly fossil fuel resources, stretch out much longer. In the intermediate term, there probably will be two directions where we should address our efforts. On the one hand, there is nuclear power through fission. On the other hand, there are efforts to find what we call renewable energy resources. In the long run, we look forward to the day when fusion power will become a reality, or in some way we can harness solar energy that can lead to a hydrogen economy. While these efforts will not last forever because the life of the solar system is a finite one, for all practical purposes this ought to give us a long lasting solution to the energy problem.

In very practical terms, we could then see that the definition of "renewable energy resources" takes shape because of its many characteristics. The definition obviously does not apply to fossil fuels. Nor does it apply to nuclear energy. It refers to diverse energy resources that can be tapped for use in the not too distant future and may last for decades, or even centuries or millenia.

Another characteristic of renewable energy resources seems to be that they do not have the capacity to fully replace conventional, traditional energy resources. What we now work on are energy resources known to man for a long time. They have not drawn much attention until very recently because making use of them was either inconvenient or uneconomical, or both. We are increasingly aware of their potentiality only because we have waken up to the fact that fossil fuels are dwindling rapidly, and that what used to be uneconomical has become worthwhile. In this manner we think about renewable energy resources as diverse forms of energy that require ingenuity in their exploitation so that they can substantially substitute conventional energy resources. In this manner they have become particularly technology-dependent.

For the present workshop eight forms of renewable energy are singled out for discussion. They are anaerobic digestion, photovoltaics, solar salt ponds, solar cooling, photosynthesis, mini-hydro devices, Stirling engines, and geothermal energy. This list does not exhaust all renewable energy resources that man can tap, but they do point to the major renewable energy resources available for explotiation in the Republic of China. Other forms of renewable energy resources are not included partly because we do not have time to deal with all of them and partly because their economic value to this country still remains to be ascertained. For still another reason, you decide not to include wind energy. This is a variant form of solar energy and is quite promising in Taiwan. For this reason considerable progress has already been made here. There are also renewable energy resources connected with the ocean. In this category we find tidal energy, ocean thermal energy conversion, energy derived from ocean current and energy derived from wave physics. These energy forms either require certain physical settings which do not lend themselves to attention here or may require so much heavy investment in fiscal and human resources that the people here can ill afford to experiment with at this time.

As I mentioned a little earlier, the eight topics you have carefully selected for discussion

at this workshop represent areas where we have certain conditions conductive to development and exploitation. To begin with, you have listed anaerobic digestion. This is a process by which agricultural wastes can be converted into energy. Even though this is a country where industrialization marches in strides, still we are determined to retain a substantial share of farming in our national economy. Active agricultural activities in a subtropical climate naturally will lead to agricultural wastes, including animal wastes. We have already experimented with, through anaerobic digestion, the conversion of pig wastes. The future for this type of undertaking is bright. It can serve a two-fold purpose: On the one hand, it is a good subsidiary energy source. On the other hand, it helps the disposal of agricultural wastes. In some intances it could also help pollution abatement.

The second topic you have listed on your program deals with photovoltaics. The southern part of Taiwan may be an ideal place to use photovoltaic cells because of the weather conditions, but the nothern part of the island is not as favorable for it does not have many clear days. Nevertheless, photovoltaic cells can contribute a great deal to our energy picture, especially in isolated locations not immediately accessible to the transmission facilities of the power network Whatever energy solar cells may generate will at least be complementary to our total electricity generation pattern. Photovoltaic cells are active only during daytime and therefore the electricity they generate will take off some of the power needs during the peak hours of the day. Besides, we have an exporting economy, and the making of quality photovoltaic cells may give birth to a new industry in the Republic of China.

We all know that for photovoltaic cells the real problem is how to make them cheap enough while maintaining an adequate rate of conversion. If we could attack the problem from the viewpoint of material science and engineering and produce the kind of materials cheap enough and yet serviceable as required, then photovoltaic cells will become eminently practical.

Our National Science Council has already started a silane project with a view to developing silicon materials of sufficient purity but at lower cost. Should our efforts in this direction be successful, not only can we use some of the solar cells ourselves but also supply such cells for countries where the conditions are far more favorable for the utilization of energy in this manner.

Solar salt pond is unique in that it not only collects solar energy but also stores it for a long period of time, sometimes for many months. The collected energy can reach a temperature of 90°C or more and can be extracted for industrial or agricultural heating, or for coverting into electricity. Since many parts of Taiwan have abundant solar insolation, solar pond is a device that may become economically attractive in this part of the world.

Solar cooling is another aspect of solar energy that is particularly important to the Republic of China on Taiwan. Because we are situated in the tropics and subtropics, we have almost no need for solar heating. Solar cooling, theoretically speaking, should be more efficient than solar heating, because when you need cooling it is usually a time when the sun is up and the day is warm. If we could develop devices for solar cooling, we should be able to take off much of the load of the power company during the peak hours.

Photosynthesis, of course, is a very intriguing area of scientific endeavor. This opens up new

frontiers for biomass conversion. Alcohol, for example, may be fermented from materials produced by effective and accelerated processes of photosynthesis.

Mini-hydro devices are particularly suitable for the island of Taiwan, because locations for large-size hydroelectric installations on the island are more or less all taken up. The question about mini-hydro devices is naturally on their cost effectiveness. Many modern engineering ideas may be applicable in this connection.

The selection of Stirling engines in your discussion seems to be a fasciniating choice. The Stirling engine itself does not represent any particular energy resource. But a better developed, economical and practical Stirling engine can enable us to harness some renewable energy resources, much more efficiently than we now can. I firmly believe this is one item that may come of age in this century.

Last but not least, you will discuss the geothermal energy problem. We know quite well that Taiwan is an island with considerable geothermal energy resources. The question is: we must have some reliable assessment of each geothermal reservoir, how long it will last and how much it will yield, before investment is made to build a geothermal plant. I am sure you will deal with this question and many related ones in depth.

All the items listed in your agenda represent more diversified and decentralized energy resources. Each of them may not amount too much. But when worked out into a system, when combined and coordinated, they may have a very substantial impact on our energy picture. Because these energy resources tend to be small, diversified and decentralized, we should study certain special requirements before they become practical. First and foremost, I would like to mention that these are exactly the kind of energy resources neglected so far because they have not been truly cost effective. To make them cost effective, it seems that a great deal of efforts at automation in manufacture and in operation should be considered. Through automation we could reduce the cost of energy generation. At the same time automation should be achieved at the lowest possible cost. This, then, becomes a great challenge to scientists and engineers.

Secondly, I would like to emphasize that these energy resources will not become viable unless a great deal of efforts are made to improve the management of such operations. We cannot consider only isolated, small energy resources. We have to be able to integrate the diverse energy resources into a large national grid of electricity generation. For example, when dealing with solar energy, we should think about how it can be harnessed so as to reduce peak-hour loads of our fossil fuel or nuclear power plants. At the same time, we ought to think about the management of our overall energy system. In the recent past we were thinking about bigger units and bigger networks. Economy was to be achieved through scaling up. But now we are confronted with a rather different picture in renewable energy resources. None of the devices or facilities we can build in this connection will be very large. These energy resources become highly valuable to our society only when they are combined and coordinated. This would call for renewed efforts in planning and in managerial techniques. Energy supplied as power for the public of public utility, and in this connection, we have to think about multitudes of legal as well as economic issues. Innovation will be needed in our thinking to handle renewable energy. When we are working on renewable energy it is perhaps quite advisable that we begin to think

small more than thinking big.

As you all know, the Energy Research Laboratory at our Industrial Technology Research Institute is one of the newest additions to our R & D endeavor. I am sure the deliberations at this workshop will have a far-reaching impact on the program to be developed by the Energy Research Laboratory. We look forward to your candid and constructive recommendations as to what in general we in this country can profitably pursue and what in particular the Energy Research Laboratory can appropriately take up.

In this connection, I must compliment the program of cooperation between the American National Academy of Sciences and our Academia Sinica. We can always depend on the good recommendations from our American friends, not only in technical fields but also in policy recommendations. We have benefited much by this type of recommendations in the past. I am sure at this workshop many valuable suggestions on pros and cons will be forthcoming. I wish to thank all participants of this workshop, and my gratitude goes particularly to our American friends who have traveled around half of the world to be with us here. I wish to assure them that we would give our most serious consideration to their suggestions. We will follow up on all of these suggestions with our best efforts. Only in this way can we make their visits to the Republic of China a satisfying and rewarding experience.

Thank you.

OVERVIEW OF RENEWABLE ENERGY

by
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Dr. Yeh Distinguished Colleagues from the Republic of China and America:

First I would like to express for my colleagues and myself how appreciative we are of the opportunity to interact with you of the Republic of China on our various specialties related to the overall technology of renwable energy. The purpose of this meeting is twofold:

1. to learn of the latest development status of the several renewable energy technologies that show the greatest promise for Taiwan.

2. to recommand a renewable energy program to be pursued by the Republic of China which shows the most likelihood of being technically successful in actual field practice, and economically viable in short term.

It would be presumptive of me, in the few minutes I have, to try to present an overview of the many areas of renewable energy for each of which we will hear from some of the top experts in the field. I therefore will address myself to the major factor that underlies all of them and which is the real reason really more than that, because it relates to our relative economic national security and industrial future.

The energy crisis is, for the Republic of China, (and the U.S. too, for that matter) first keyed to the immediate need to drastically reduce the international currency drain related to the ever increasing cost of imported oil. Secondly it is keyed to the problem of generating increasing amounts of electricity while simultaneously using less imported fuel to do it. Thirdly, it is keyed to an equally crucial problem those of us advocating alternative energy substitutes are so prone to forget, that is the ever increasing capital costs for equipment, and if that equipment must be imported, again the drain on available international currency is paramount.

Thus to simply look at the dollar cost of a renewable energy source vis-a-vis the dollar cost of a conventional source is much too simplistic a view.

The truth of the matter is, almost all of the renewables I know of (be if geothermal, solar, biomass, wind, or what have you hydroelectricity perhaps excepted) are even at todays conventional fuel prices, usually more expensive than conventional sources. The prevailing idea among some renewable advocates is that since renewable energy often comes free from nature, all you have to do is to pay for the physical facilities and everything is solved. Nothing could be further from the truth.

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On a cost alone basis, most renewables are either highly questionable from an economic point of view or in some cases, downright unfavorable economically. In remote villages that are not on an electrified national grid and have little hope of becoming so, the issue is still not necessarily clear cut. While much of the capital cost of a renewable energy source might be in local inexpensive labor, one still has to ask the question as to whether or not that labor is best spent to the maximum benefit of the laborer and those around him by developing a renewable energy source, or in some other endeavor.

Nor is this situation likely to be changed in the future by simply increased oil, gas, or coal prices.

The thing we must remember is that much of the hardware used for renewable resources are manufactured by energy intensive processes, and that energy comes from conventional, not renewable sources, at least for now and the intermediate future.

Thus to take advantage of renewables, we must continue to have conventional energy sources at least for some considerable time in the future.

Why then do we so vigorously pursue the renewables we do it for several basic reasons:

1. Because of the extreme world instability, we will ultimely probably have to run our economies on something besides imported oil. Our critical issues are liquid fuels for transportation electricity, and both are critically dependent on a world political stability over which none of us- not R.O.C., not U.S. have any real control.

2. Even if such a disruption does not occur and even if cost of oil remains below the cost of renewables, the fundamental issue is that foreign oil will always require world currency for which we may be in very short supply where as much of the capital burden of renewables can often be shifted to local currency and local labor. Balance of trade becomes less of a constraint and a country's destiny is somewhat more under its own control.

I would like to suggest that this is what the energy crisis is all about for the R.O.C., the U.S. and for just about every other country with which I have been involved at least.

So as we deliberate on the technical aspects of geothermal, amorphous silicon photovoltaics, anaerobic digestion, alcohol, etc. let us all continually ask ourselves these questions.

1. Does what we propose lessen the crisis impact of a probable oil disruption.

2. Does what we propose reduce the need of foreign expeditures, substituting, rather local currency, labor & materials.

3. Does what we propose reduce our critical dependency on those over whom we have little or no control.

In short are the high costs of renewable energy offset by the benefits of reduced depenency. Finally, we should ask if what we propose to do does any permanent changing of environ-

mental conditions such as — condition of soil, does it affect erosion, does it expend precious and irreplaceable minerals etc.

I would like to suggest that any program that doesn't meet at least one of these criteria (and perhaps more than one) we should examine very carefully whether we want to recommend it.

As former President Yen so clearly pointed out, our objective is not to immediately replace oil & gas, it is to preserve those resources for those tasks which can only realistically be bandied through their use.

We have a heavy schedule of work in the next four or five days, and we had best be getting at it.

Thank you for listening to these comments.

ANAEROBIC DIGESTION

by
Dr. Donald L. Day
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My speech this morning is going to be a slide show of installations of anaerobic digestions on farms in the US and the foreign countries. So I want to start with the slides and go through this presentation.

The subject is the anaerobic production of biogas. I am not a microbiologist, I am an engineer. I just want to remind you that it is a biological process of recent times. The biologists that I think of are in agreement that it is a 3-stage process. We used to talk about the two stages of acid fermentation and fermentative production but now we include the hydrogen part. This is well documented and I am not going to dwell on it. (Figure 1)

What I want to dwell on is how to do it. We take organic matter with proper carbon to hydrogen and nutrient ratios and put it in a liquid system and then get the bacteria to start fermentation. We can produce biogas which is about 60% methane. As you know, natural gas is nearly 100% CH_4 which was produced deep down in the earth at a century of a digesting organic matter that were covered up under pressure down the earth. We can repeat the process in the very short time like 2 weeks or less. We don't get a pure CH_4 like natural gas. It has CO_2, H_2S, but we can take that out if need to be. So what is required very simply is a tank. The raw material in an air tight tank, the food, bacteria and a fermentation going on inside here. The gas coming off as a gas not as a liquid and the effluent which we sometimes separate the liquids from and have concentrated sludge. (Figure 2)

There are some ways to connect this tank with the livestock growing facilities, as far as installations using livestock manure are concerned. Of course any other organic matter of proper nutrients can also be used and if desired, the gas clean-up facilities can also be added.

In cold climate we must supply heat to keep the digestion temperature up to ranges which it works best. Like any other biological system it is subjected to malfunction or poor production. So they must be treated with care and given a proper feeding daily as with any other biological system.

Now I want to start the show of a tour across the USA on example installations, and I want to, in this tour, to point out variety of tanks, vertical-horizontal materials that may be made

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from metal, plastics, rubber, fiber glass and clean up the gas and use of the effluent and sludge.

To just point out, I am from Illinois, with the University of Illinois which is about 130 miles south of Chicago on the Mississippi river. Most of the installations are in the Mid-West Illinois, Missouri, Iowa, Indiana, but I will also show some from Pennsylvania on the East Coast, Oklahoma, and South West and Southern California on the West Coast, plus some others I have visited that are not in the U.S.

1. Morrison Farm; Dewey, Illinois. Poultry, 20,000 caged layers.

The manure is mechanically scraped from beneath the caged layers and water is added to pump into the digester.

The digester is a rubber bag that was installed into a horizontal trench in the ground. The trench was insulated with spray-on insulation. The installation included a pre-built control room. The gas is used for producing electricity and the sludge is used for fertilizing crops. (Figure 3)

2. Leefer Farm; Carlinville, Illinois. Beef cattle, 1,000 head.

The finishing cattle are in a slotted floor building, the liquid manure is pumped to the digester.

The digester is an upright, glass-lined, metal tank with insulation sprayed on the outside.

The gas is used as fuel for an alcohol plant. By-products from the alcohol plant are fed to the cattle. Sludge is used for fertilizing crops. (Figures 4 and 5)

3. Nelson Farm; Rensslaer, Indiana. Swine, 3,000 hogs marketed per year.

Manure is mechanically scraped from beneath partially slotted floors and pumped to the digester.

The digester is a horizontal metal tank installed in a trench and covered with earth. The manure is pre-heated before entering the digester. The gas is used on the farm and the effluent is spread on crop land using semi-automatic irrigation equipment. (Figures 6, 7, 8 and 9)

4. Mason-dixon Farm, Gettysbury, Pennsylvania Dairy cattle.

The manure is flushed from the barns to a settling tank. Settleable manure is pumped to two digesters.

The digesters concrete trenches with rubber covers to collect the gas.

The gas is used in engine-generators to produce electricity. Some of the electricity is used on the farm and the surplus is sold to the utility company, especially during the peak demand time of each day. (Figure 10)

5. Panhandle Feedlot; Guymon, Oklahoma. Beef cattle, 100,000 head.

The cattle are in open-type feedlots. The manure is collected only between batches of cattle, about every four months. The manure had lost considerable nitrogen and organic matter, that had to be mixed with water to make a liquid manure.

The gas was to be cleaned and sold as natural gas. The project was abandoned for several reasons. (Figures 11 and 12)

6. Kershaw Feedlot; Brawly, California. Beef cattle.

The cattle are in open-type feedlots. The manure is collected infrequently. The two digesters are above-ground metal tanks, with spray-on insulation. One tank was operated as thermophylically and the other one mesophylically. Various studies were done with the sludge including solar drying. (Figure 13)

7. Farmers Cooperative; Gust, New Zeland. Poultry.

Manure form several poultry farms is hauled to the common site. The digester is an upright, insulation metal tank. The gas is cleaned and compressed into cylinders for use in automobiles. The effluent is used as fertilizer. (Figure 14)

8. University of Missouri; Columbia, Missouri. Swine and Beef.

Manure is flushed from swine and beef buildings into a settling tank. Settled manure is pumped into the digester.

The digestor is an upright concerete tank with a metal jacket. There is insulation between the jacket and the tank.

The gas is used in burners for heeting buildings, in an engine-generator, and as process fuel for an alcohol plant. Sludge is used as fertilizer. (Figures 15 and 16)

9. Iowa State University; Ames, Iowa. Beef Cattle.

Manure is flushed from the slotted floor building and pumped into the digester.

The digester is an upright fiber-glass tank insulated on the outside. Research is being done on mixing, heat exchangers, and gas utilization. (Figure 17)

10. University of Hawaii; North Shore, Hawaii. Swine.

Manure is flushed from the hog buildings and goes to the digester.

The digester is a RMP bag from Taiwan. Effluent goes to a pond that is gently mixed and aerated to promote bacteria and algae. The pond water is used to flush the buildings and thus the bacteria and algae an reed as substrate for further production of gas.

11. University of Illinois; Urbana-Champaign, Illinois. Swine.

Manure is mechanically scraped into a pump and pumped to the digester. (Figure 19)

The digester is a horizontal metal tank in a trench. The tank has spray-on insulation on the inside and outside. The tank also has a spray-on rubber liner. Research includes gas cleanup, gas utilization for heating and as a fuel for an alcohol plant. (Figure 20)

12. Meat Animal Research Center, USDA; Clay Center, Nebraska. Swine and Beef.

Manure is collected by flushing from buildings and hauled to the research digester.

The digester is an upright insulated metal tank. The manure is heated to thermophilic temperature upon entering the digester. Research includes digestion kinetics, and using the effluent as a feed ingredient.

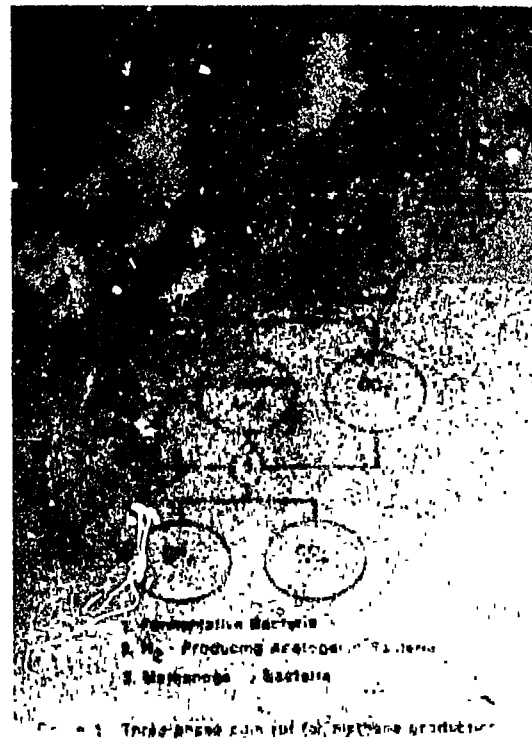


Fig. 1

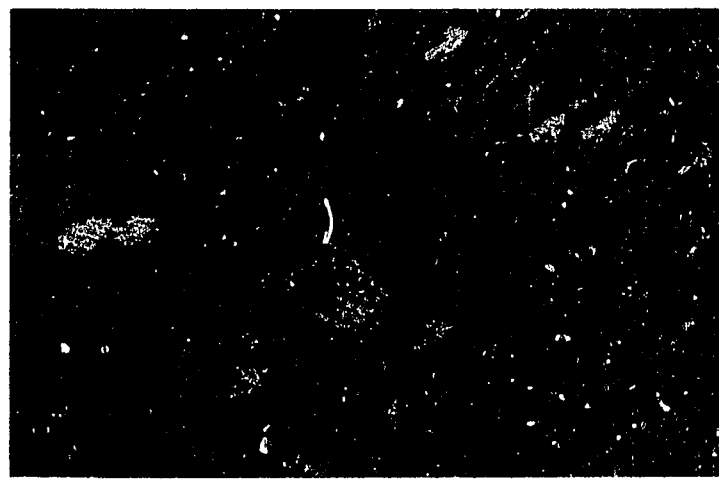
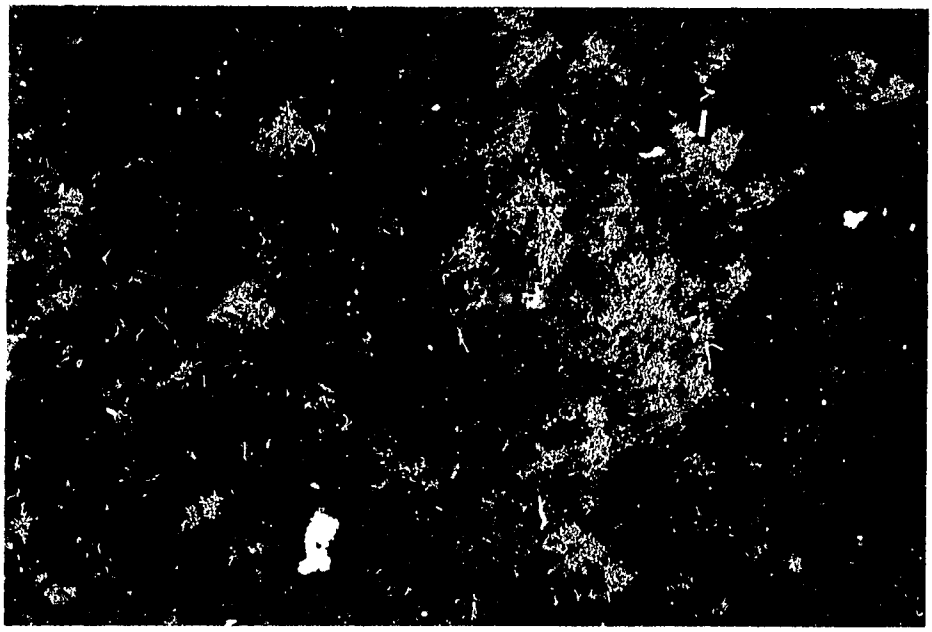


Fig. 2



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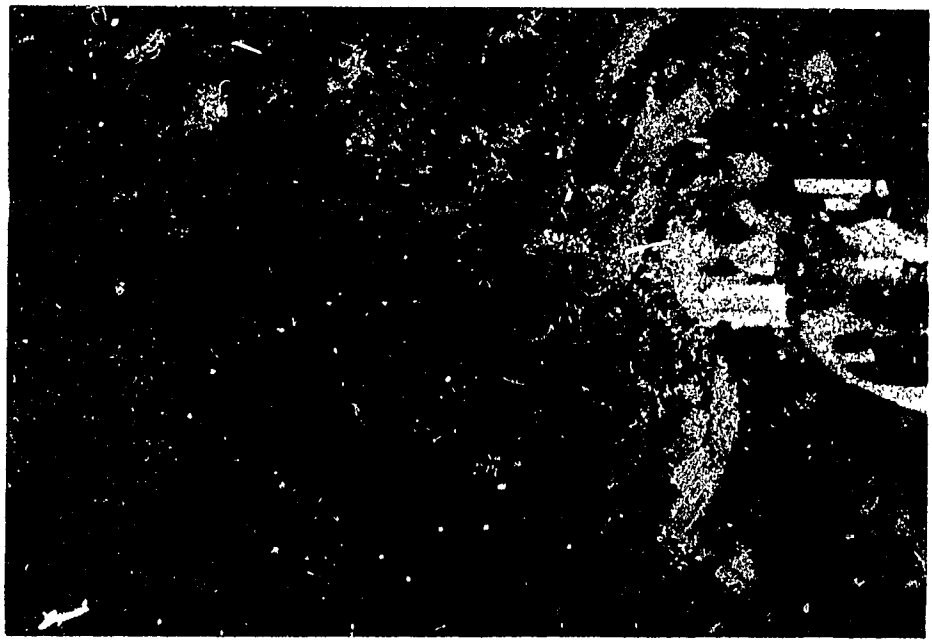

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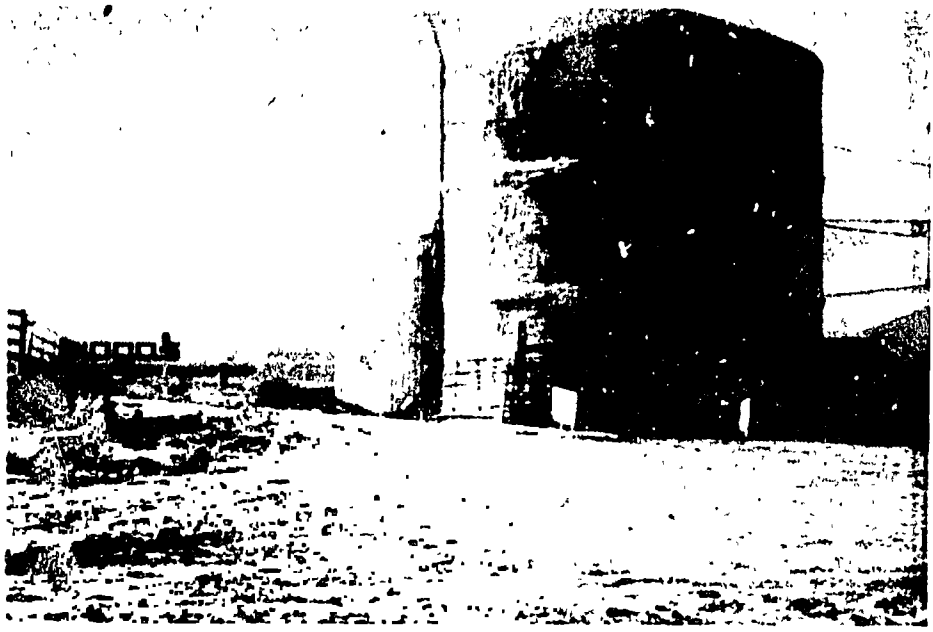

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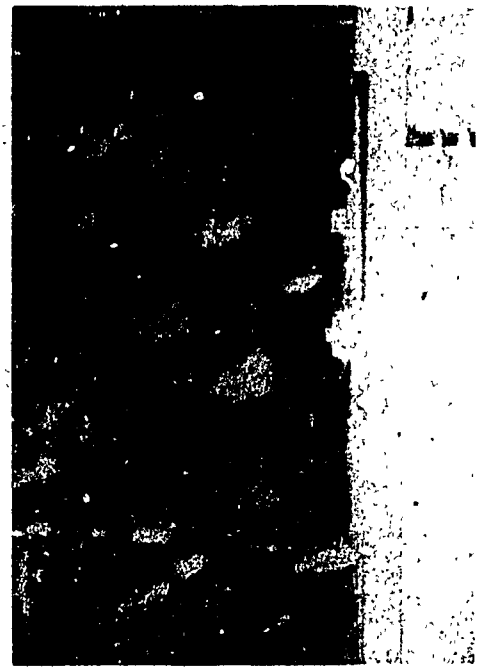

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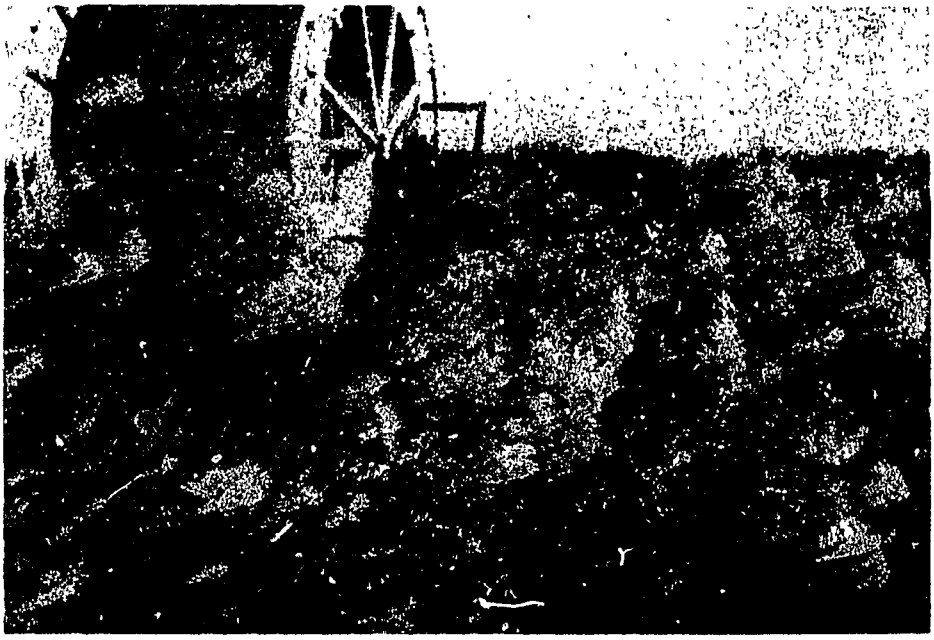

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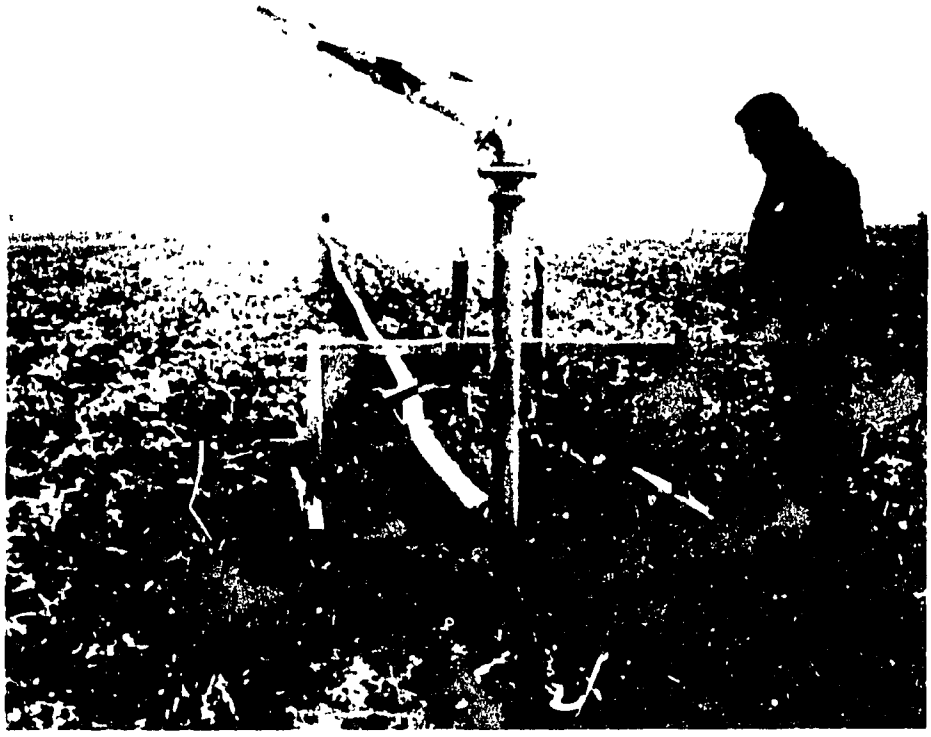
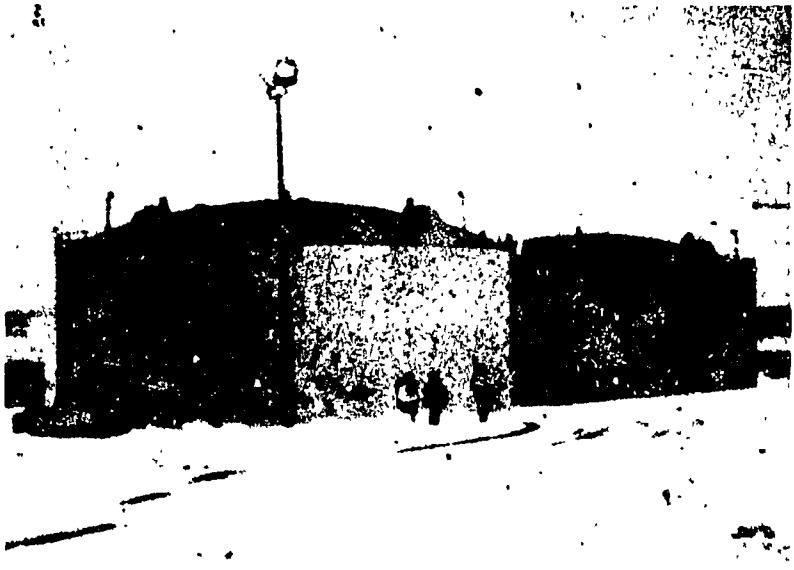


Fig. 9



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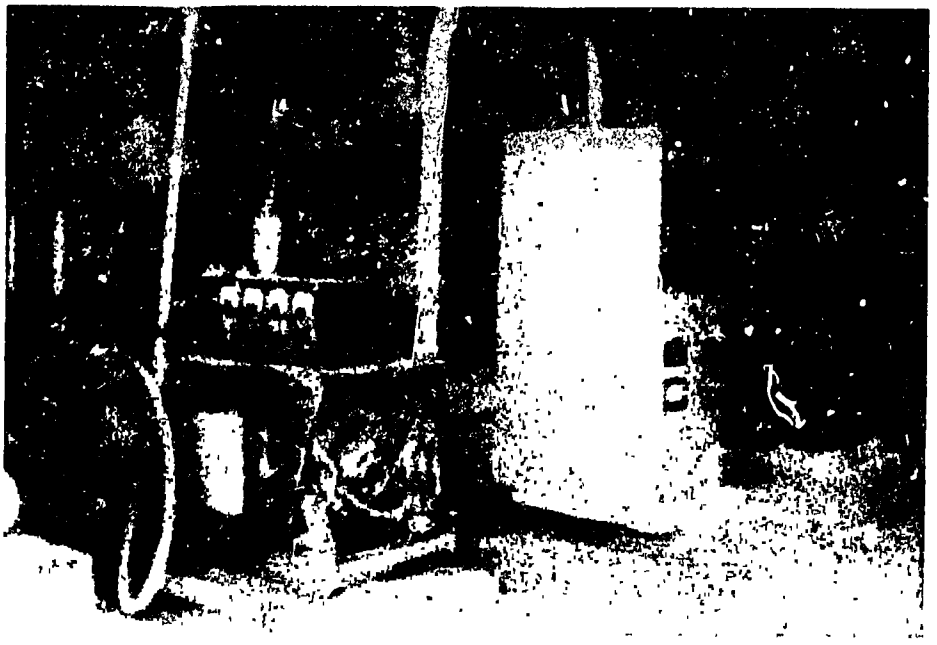

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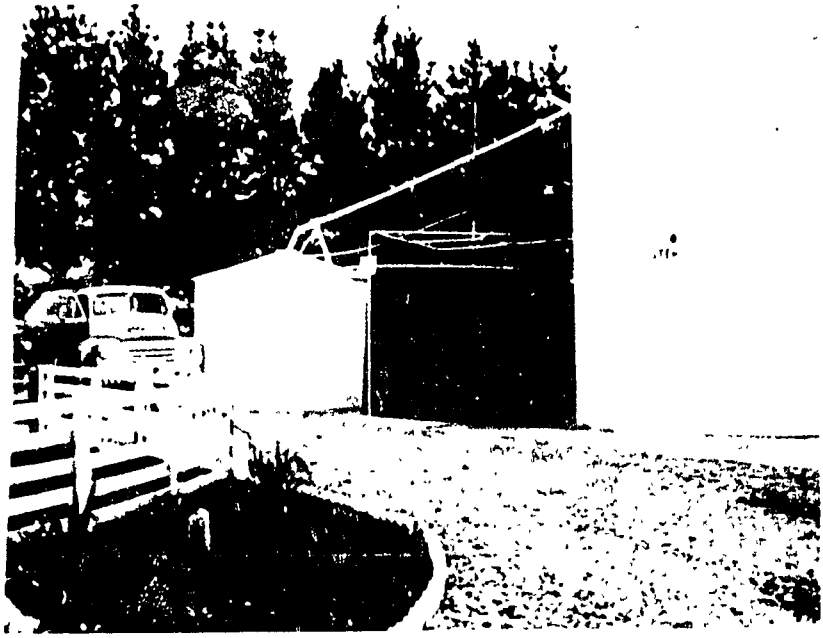

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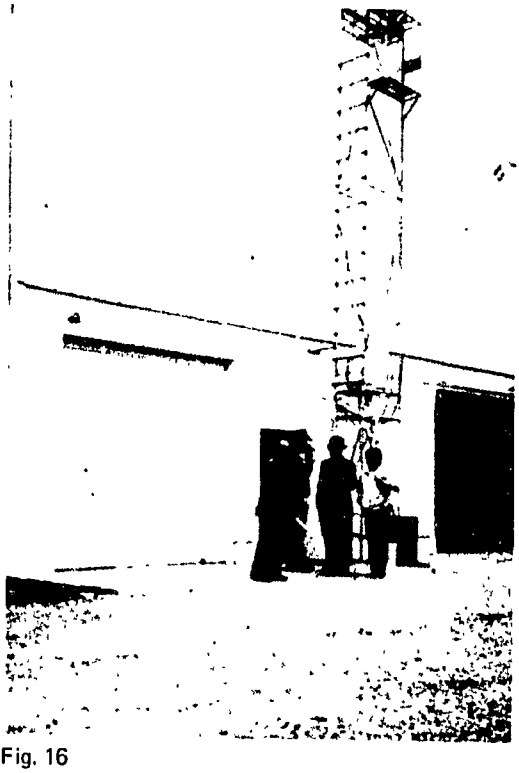

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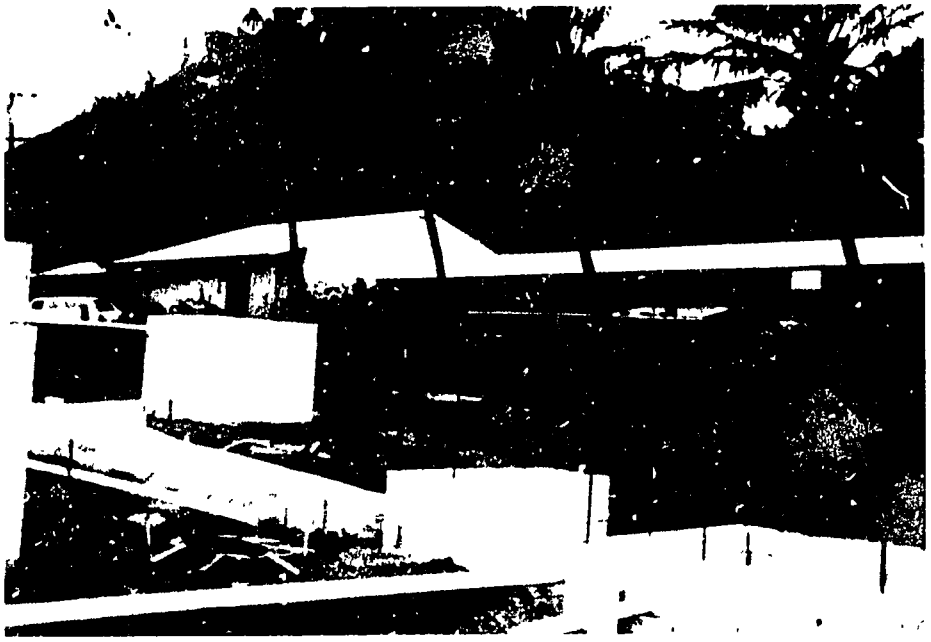

Fig. 18

Fig. 19

Fig. 20

REPORT OF ANAEROBIC DIGESTION GROUP

by
Dr. Donald L. Day

Introduction

In recent decades, the size of hog raising farms in Taiwan has rapidly increased and pollution problems caused by hog wastes are getting serious. In 1973, the government of the Republic of China placed restrictions on waste water effluents, limiting the biological oxygen demand (BOD) and suspended solids (SS) of waste water to 200 ppm (Hong et al., 1980)*. Treatment facilities are not available to meet these effluent requirements. Anaerobic digestion processes offer a solution to pollution control as well as being a source of biogas that is needed as a fuel. Another area of interest is the production of alcohol from agricultural by-products.

Recommendations for research on anaerobic digestion in Taiwan agriculture for production of biogas and alcohol

A. Production of biogas

1. Completion of anaerobic digestion laboratory at TLRI as soon as possible and be staffed with sufficient appropriate personnel.

2. Increased cooperation between the new laboratory at TLRI and ERL to utilize training and capabilities of ERL staff on anaerobic digestion subjects.

3. More fundamental research is needed. Microbiological studies of kinetics of anearobic digestion to get increased rates and higher efficiencies. Some possibilities are increasing reaction rates and reducing digestion process limitations. Some limitations are adherance of microbes to the substrate and insufficient supply of hydrogen.

4. Development of pilot plant scale facilities to be used to gather operational data. The first plant to be built at the Hsieng-Dai farm and the current project of ERL in Taiwan be continually supported.

5. Investigating various digester tank materials and configurations.

B. Biogas purification

1. Compare available methods including economic assessments in order to make recommendations for proposed uses of the gas.

Hong, C.M., M.T. Koh, T.Y. Chow, P.H. Tsai and K.T. Chung. 1980. Utilization of hog wastes in Taiwan through anaerobic fermentation. Proc., Integrated Crop- Livestock- Fish Farming. FFTC Book Series No. 16. pp. 119-133.

2. Install a preferred system for demonstrating the method. This should be funded by the government, not by the private sector.

C. Utilization of biogas

1. Investigate practical methods of selecting and operating engine-generator units. The electricity to be used on the farm and the potential for selling electricity to utility companies should be considered.

2. Investigate methods of utilizing biogas for operating farm vehicles such as iron water buffalo.

3. Investigate methods of utilizing biogas for freezing and air conditioning units.

D. Utilization of sludge and effluent

Futher investigation of using the anaerobic sludge and/or effluent is needed.

1. Sludge and/or effluent are used as fertilizer for field crops.

2. Sludge and/or effluent are used as substrate for single cell protein which can be used as a feed ingredients for ruminants (Day, 1980).

3. Cultivation of Rhodotorula yeast by using digester effluent, and extracting the yeast fat by rupturing the yeast cell is a potential method for using the digester effluent.

E. Algae production and utilization

1. Practical harvesting methods are needed such as use of a hydrocyclone.

2. Direct feeding of wet algae to hogs is feasible, but efficient drying methods are needed to store and use as a feed for other animals and fish. Solar drying should be further investigated.

F. More research to use biogas as the process fuel for alcohol plants in an integrated system. More cooperation is needed among TSC, ERL, TLRI, universities, and others.

G. Reduce transportation costs by building the fuel production systems near the biomass producer.

H. Multiple use of by-products will enhance interest in fuel production.

Conclusions

Taiwan is already very active in utilizing anaerobic digesters for waste treatment and production of biogas. There is potential for further improvement of present processes and also for

development of additional processes. This workshop is a mechanism for promoting and directing further research. Continued cooperation between USA scientific organizations and appropriate agencies in ROC is desirable.

PHOTOSYNTHETIC BACTERIA

by
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Urbana, Illinois 61801

The interest in my laboratory are primarily concerned with photosynthesis. Unfortunately, although the U.S. Government has spent a great deal of money over many years in agricultural research, it has not really spent very much money in the research of photosynthesis.

By photosynthesis, I mean not just the light reaction and dark reaction but in addition, the organization, and the structure of membrane system upon which photosynthesis takes place because it is there that this reaction is best characterized and best understood.

Photosynthesis is really a process involving molecule, enzyme, membrane, phospholipid and occasional electron. It is about those reactions and in particular structure of photosynethetic membrane that I'd like to talk about.

But I'd like to put it into somewhat new light. What we would be able to do is to examine the genetic make-up of photosynthetic system. What is there about between the organization which is permitted also lead to the formation of photosynthetic membrane. Those are the questions I'd like to address myself today and which our laboratory has been concerned for number of years.

Like any one else who works on the biological problem, you choose a model system. Because the models are easy to manipulate. You formulate the question and hope you can answer. From there you can further the condition you formulate and the question you can test.

The model system which I choose for my laboratory is a photosynthetic bacterium. It turns out that photosynthetic bacteria are the most versatile organisms on this planet. The organism which we choosed to work with are called *Rhodopseudomonas sphaeroides.*

Generally, there are two broad classes of photosynthetic bacteria. They are so called obligate photosynthetic bacteria which photosynthesis is in a anaerobic condition. This organism never experiences aerobic system, they use some inorganic electron delivers such as H_2S as a source of electron which they will metabolizes and use available high energy. It fixes CO_2 and grows as such making the high energy phosphate forms of ATP. On the other hand, the other group of photosynthetic bacteria, they are facultative photosynthetic bacteria. *Rps. sphaeroides* is a member of this particular group. This organism can grow in a number of ways, and because of this, the photosynthetic efficiency is exactly quite high.

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This organism as typical of most of the common members of the facultative photosynthetic bacteria is the most metabolically promiscuous organism known. This organism can grow aerobically as a typical chemoheterotroph in the presence of oxygen, oxidizing organic compounds including cellobiose, to CO_2 and H_2O employing the TCA cycle and a terminal respiratory electron transport system. This organism can also utilize H_2 with O_2 as a terminal electron acceptor. Under anaerobic conditions, in the absence of light this organism is weakly fermentative or when an external electron acceptor is present such as dimethylsulfoxide or trimethylamine oxide it can employ an anaerobic respiration. When light is present under anaerobic conditions, the organism will grow photosynthetically and if conditions are appropriate it can evolve large quantities of H_2 gas, utilize H_2 + CO_2 photosynthnetically and fix N_2 all under photosynthetic conditions. There is no other organisms or group of organisms so metabolically versatile. (See Table 1)

Table 1: Physiological Diversity of Rhodospirillaceae

1) Photoautotroph – Anaerobic/H_2, CO_2/light energy
2) Photoheterotroph – Anaerobic/Organic carbon source/light energy
3) Fermentative Anaerobe – Various sugars
4) Chemoheterotroph – Aerobic/Organic carbon source
5) Chemoautotroph – Aerobic/H_2 energy source.

When the organism grows photosynthetically it develops an entirely new membrane system which arises as invaginations of the cytoplasmic membrane. These invaginations house the entire photosynthetic apparatus for fixing light energy into chemical bond energy. (See Fig. 1)

In freeze-fracture preparations the invaginations can be viewed as small pits in the bacterial cell membrance. (See Fig. 2)

Despite the fact that these pits only cover a few percent of the cell membrane surface, the vesicular invaginations can double or triple the surface area exposed to radiant energy. In fact, depending upon light intensity the amount of photosynthetic membrane can represent from 10%-40% of the total cellular dry weight.

The photosynthetic membrane system can be isolated in pure form following cell breakage and consists of sealed-spherical vesicles approximately 50-60nm in diameter, called chromatophores, capable of carrying out primary photochemical activity. (See Fig. 3)

The absorption spectrum of either intact cells or isolated vesicles shows several interesting features. There are a number of bacterio-chlorophyll (BChl)-protein spectral complexes. The normal spectrum shows light harvesting or antenna complexes with absorption maxima at B800, B850 and B875. These comprise 95% of the cellular chlorophyll. (See Fig. 4)

The chlorophyll is same, it is the protein that is different, and it is the specific association of the chlorophyll with the protein that gives the chlorophyll molecul its unique absorption spectrum.

The reaction center (RC) complexes comprise only 5% of the cellular chlorophyll and show a spectral peak at P870. Importantly, note that it is the near-infrared region of the radiant

spectrum which these cells utilize.

Light is absorbed by the variable B800-B850 species, the electronic excitations are passed to the fixed B875 species which in turn passes the excitation to the RC complex where the business end of photosynthesis takes place. Up to this point the process is better than 99% efficient. It is the organization, structure and biosynthesis of the photosynthetic membrane system in which my laboratory is interested.

We also have numerous mutant organisms which lack various spectral species and these have provided us with tools for answering important biological questions. For example we have mutants lacking the B875 or the B800-850 spectral forms of BChl. If we compare the polypeptide SDS-Page profiles of these mutant organisms to the wild type organism we can see that these are single polypeptide differences. Therefore as one of our goals we have set about to purify these important chlorophyll-binding proteins. Because we intend to perform detailed chemical analyses of these proteins and to reconstitute BChl binding we developed techniques to purify these very hydrophobic proteins without using detergents. However, as a basis of comparison during our purification procedure we compared our isolated polypeptides to the active spectral complexes isolated from membranes by using detergents. During the initial stages of purification there are numerous polypeptide species, but finally we were able to isolate the B875, and B800-850 proteins in pure form.

What we would now be able to do is to restore the binding of the chlorophyll to the protein and to attempt to restore the spectral properties of this chlorophyll-protein molecules. This is very important. Because we know it is the protein which inparts upon chlorophyll its specific spectral forms.

Therefore, what we are now able to do automatically is to take chlorophyll from green plant and ask

(1) Can we take that chlorophyll und restore binding of the protein molecule from bacteria.

(2) If we can, what would be the unique spectral properties of that chlorophyll-protein compound.

As part of these studies we are interested in determining how these proteins arrive at their final destination and organize themselves together with other components to form the photosynthetic membrane. When we examined the synthesis of photosynthetic membranes in growing cells we were surprised to learn that the growing membrane system is formed in a rather unexpected fashion leading to some very interesting conclusions which I will summarize only briefly:

1. Protein and photopigments are inserted into preexisting photomembranes continuously throughout the cell division cycle.

2. Phospholipid synthesis and accumulation is continuous at the whole cell level but occurs only at the time of cell division for the photomembranes.

3. A "barrier" exists to the free movement of phospholipid from cell membrane to the

photomembranes.

4. Phospholipid is transferred from the cell membranes to the photomembrane only at the time of cell division.

5. The photomembranes go through a cyclical change in protein to phospholipid ratio which apparently serves to affect the rate of flow of electrons through the transport chain. So as the membrane becomes more protein enriched it becomes more crystalline and as it becomes more lipid enriched it becomes more fluid.

We would picture this process as resulting in an increase in the size or number or both of the photosynthetic units comprising the photomembrane. In order to visualize this process we would like to employ freeze-fracture electron microscopy of isolated photomembranes. Unfortunately these isolated vesicles whose diameter is 50-60nm are too small to perform good freeze-fracture analysis. To get around this problem we have taken the smaller vesicles and made them much larger by fusion of individual vesicles and now it is experimentally practical to perform freeze-fracture analysis. (See Fig. 5)

In order to facilitate further studies on the regulation and biosynthesis of BChl-binding proteins it became necessary to isolate those genetic regions containing the regulatory and structural information for these proteins. We went about this in the typical fashion and used an immunologic screening procedure (See Fig. 6) in order to recognize these proteins when made from cloned DNA using recombinant DNA techniques in *E. coli*. Although we were able to isolate such clones we determined that *Rp. sphaeroides* DNA is not expressed in *E. coli* and that the expression which we observed in a very few instances resulted from the fusion in phase of *Rp. sphaeroides* DNA with the gene of the plasmid cloning vector. We have subsequently demonstrated using λ-virus clone banks that *Rp. sphaeroides* DNA is not expressed in *E. coli*.

In order to offset these problems we have developed our own transformation system in *Rp. sphaeroides* so that we can now put plasmid DNA into *Rp. sphaeroides*. We have developed our own *in vitro* transcription/translation system where we can demonstrate that *E. coli* DNA is not expressed in *Rp. sphaeroides* and vice versa but also where we can synthesize *Rp. sphaeroides* specific gene-products to study the synthesis, control and localization of BChl-binding proteins. We have also developed techniques whereby we can isolate mutants of *Rp. sphaeroides*, described earlier and which have been derived via the insertion of a transposable genetic element into a particular gene now permitting us to clone that gene and either reintroduce it back into *Rp. sphaeroides* or study it *in vitro*.

Lastly, and quite unexpectedly we discovered that under appropriate growth conditions *Rp. sphaeroides* can be induced to make a new species of phospholipid, N-acylphosphatidylserine (NAPS) not previously described and which contains three fattyacyl residues instead of the usual two and which possesses important biological properties.

Many organisms are closely related to *Rps. sphaeroides* also possesses this particular phospholipid, and possess the ability to regulate in a very particular interested fashion. The one such organism that has phospholipid is a non-photosynthetic bacteria characteristic of nitrogen fixation. This organism is closely related because they have ATPase, cytochrome system almost

identical to that found in *Rp. spaeroides*. It also possess this phospholipid. With this, what permitted us to do with this organism is in fact compatible with *Rp. spaeroides*. It means that we have another system, in which we can introduce DNA from the *Rp. spaeroides* into a non-photosynthetic bacteria, that could then prevail us in fact to test various components of photosynthetic system.

We are now being able to use a phototraps that is worked down by molecular biologist for introducing specific mutational vector. This is involving using DNA element for transposon. This is a element of DNA that can jump one piece of DNA into another. Whenever they jump in, you get mutation.

We are now being able to adapt that system to *Rp. spaeroides* such that we can get very specific mutation in very specific gene which control specific photosynthetic membrane function.

In conclusion, studies of the photosynthetic bacteria have shed considerable "light" on the structure-function, control and biosynthesis of photosynthetic membranes. However, because these organisms are typical bacteria their experimental manipulation and investigation is facilitated.

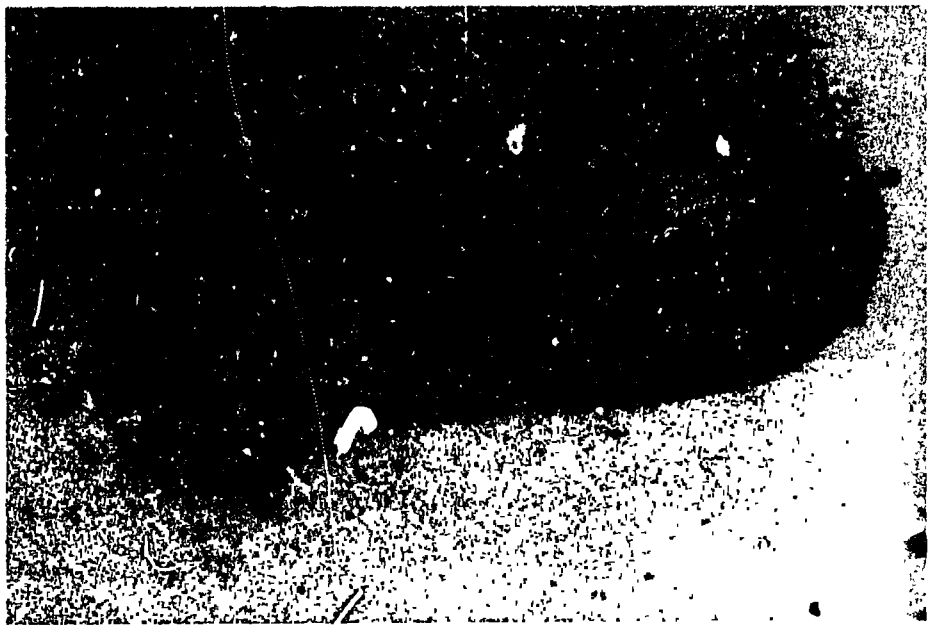

Fig. 1 Photosynthetic membranes exist as invaginations of the cytoplasmic membrane which are referred to as the intracytoplasmic membrane (ICM).

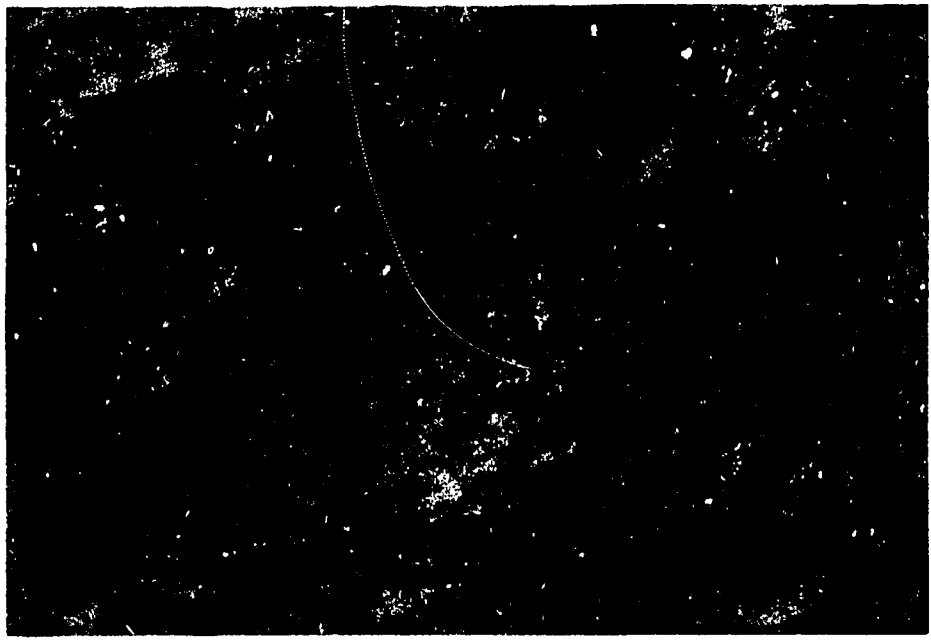

Fig. 2 Membrane invaginations can be viewed as small pits in the bacterial cell membrane. Freeze-etch electron micrograph.

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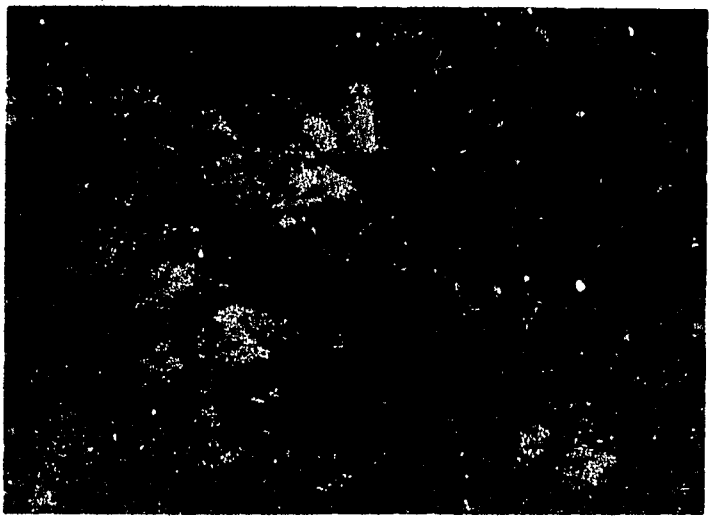

Fig. 3 Electron micrograph of purified chromotophores. Marker represents 0.1 um.

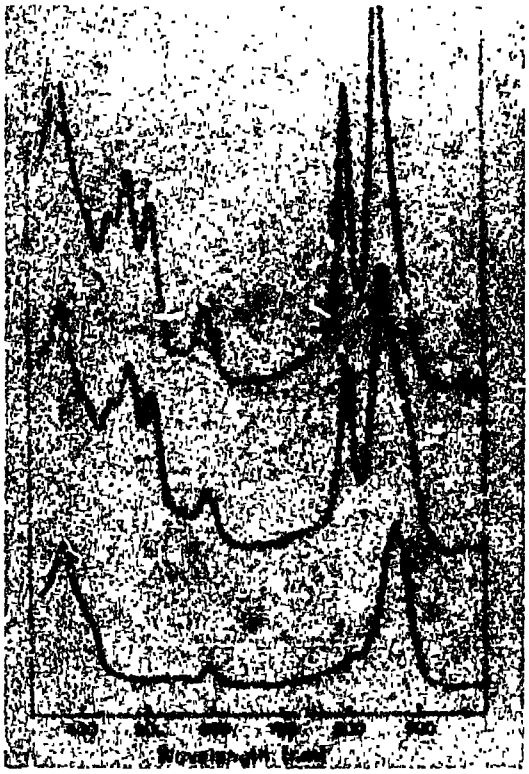

Fig. 4 The spectroum shows maximum light absorptions at 800, 850 and 875nm.

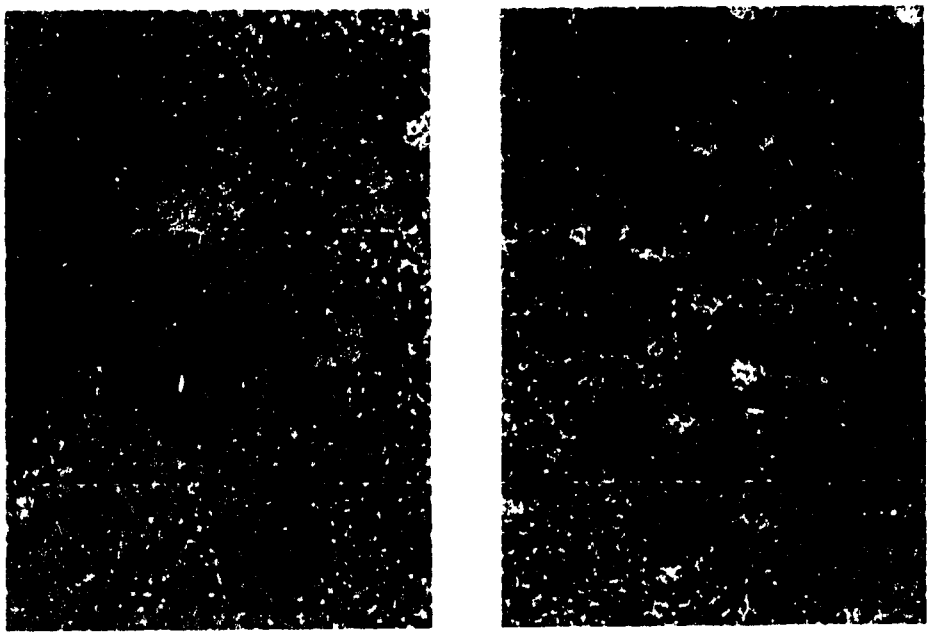

Fig. 5 Large vesicles made by fusion of small individual vesicles can be used to perform freeze-fracture analysis.

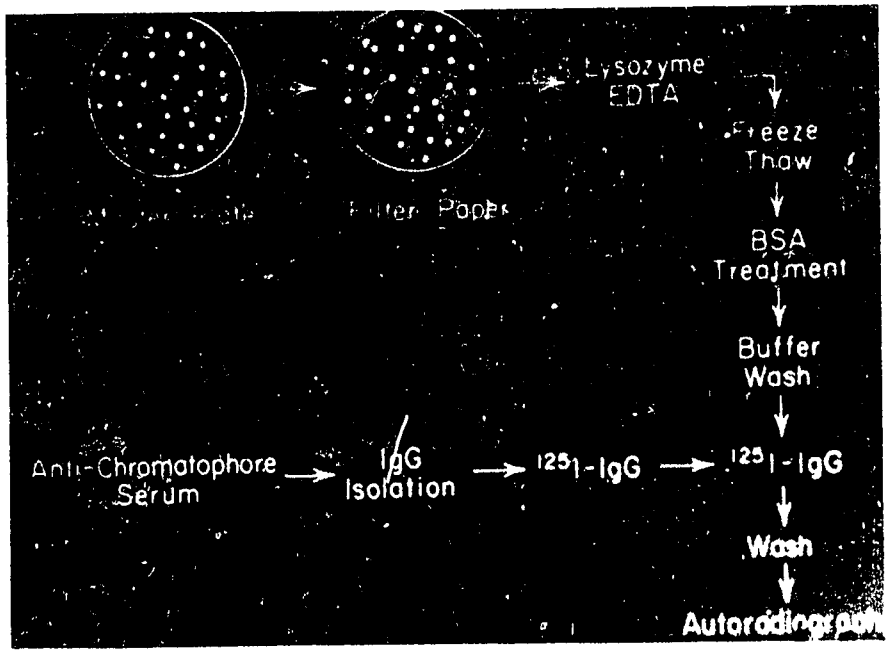

Fig. 6 Immunologic screening procedure used to recognize BCH1-binding proteins.

REPORT ON PHOTOSYNTHESIS
A Proposal and Recommendations Submitted

by
Dr. Samuel Kaplan
and
Photosynthesis Study Group

Objective

To improve the quality, diversity and yields of ROC agricultural production for application to biomass, and energy production and the utilization of all plant materials to these ends.

We view these objectives as having both traditional and well accepted approaches as well as newer or less well developed approaches.

1. Traditional

To continue programs already underway which provide the potential for crop growth thereby yielding a biomass base for conversion to energy yielding or energy supplanting hydrocarbon and fuel production. To continue to employ traditional or well-established methods of agricultural expansion, e.g. tillage programs, conservation, crop resistance, fertilizer use, plant breeding, etc. The ROC has in the past utilized these methods to great success and we anticipate continued success in these areas.

2. Newer Approaches

Because the land mass available is finite and the yield of crop production can not be expected to go beyond physiological limits, new approaches aimed at altering the basic physiology of photosynthesis is to be encouraged. It is within this area that we direct our remarks. Newer approaches involve the utilization of promising advances in the areas of molecular genetics and recombinant DNA technologies, photosynthesis research, research into nitrogen fixation, microbial activities and the application of these activities and plant cell culture techniques and biochemistry. We can not insure success in any or all of these areas but a lack of activity will certainly insure failure. Further, the introduction of these disciplines into the ROC must demand a high level of training. However, the knowledge gained can be utilized well beyond the focus of this proposal.

Proposal

1. To continue the traditional approaches discussed above. We will say no more about these areas.

2. To establish a research institute whose mission or focus deals with biomass production and energy conversion as well as the complete utilization of plant materials and products. By

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having this mission the focus of a single research institute we bring together the different approaches required to solve these problems in a coordinated fashion.

3. Some of the approaches described below are also encouraged to develop within the Universities. The Universities have a special responsibility for training future generations of graduates and undergraduates which is so important to continuing the progress in these areas once begun.

Application

1. The institute should consider representation by the five research areas described below, namely.

   a. Recombinant DNA technologies, methodologies and their applications.

   b. Microbial activities and their products for the production and utilization of plant materials.

   c. Photosynthesis research involving plants, algae, cyanobacteria, and photosynthetic bacteria.

   d. Nitrogen fixation research involving bacterial-plant interactions and free-living bacteria.

   e. Single-celled plant culture systems and plant biochemistry.

   We would consider the order presented above as a basis for priority implementation.

Some of the specific research topics which might be addressed can include the following but by no means should this list be considered exhaustive.

1. Increasing photosynthetic efficiency by understanding the structure-function interrelationships of the photosynthetic apparatus.

2. Problems in photorespiration or dark respiration involving investigations of Ribulose – 1, 5 bisphosphate carboxylase and plant mitochondria.

3. Increasing light availability by increasing the spectral diversity of plant chlorophyll-protein complexes.

4. Increasing salt tolerance by examination of the genetic and physiological mechanisms underlying this phenomenon.

5. Increasing tolerance to stress by examination of the genetic, physiologic and ecologic mechanisms underlying these phenomena.

6. Alternatives to field crop photosynthesis-e.g. the utilization of plant cell cultures growing in dispersion.

7. Utilization of bacteria or bacterial products for chemical conversions of plant materials, e.g. the breakdown of complex plant materials to simple, utilizeable products.

8. Transformation of radiant energy directly into gaseous products e.g. H_2 involving the diversion of photochemically derived energy containing reactants to the reduction of ^{+}H.

9. Single-cell production (plant bacterial, cyanobacteria) of useful compounds through the intervention of photosynthetic mechanism involving cell systems producing specific biochemical end-products.

10. Making available and utilizing microbial nitrogen fixation for non-symbiotic systems by investigations of the biochemical basis of microbial-root interactions.

Implementation

1. We would imagine somewhere between 4-6 laboratories conducting investigations in each of the five research areas cited above, involving a total of between 80-100 personnel.

2. We would suggest that following a decision to implement the above proposal a group of 5-6 distinguished scholars from outside of the ROC be assembled to advise upon the specific organization, personnel and research staff to be assembled and in what particular sequence.

3. We would further suggest that such an outside review body be assembled at appropriate intervals to follow the progress of the institute and make recommendations as necessary.

PHOTOVOLTAIC

by
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The performance of amorphous silicon solar cells has improved in the last years, currently several laboratories are reporting conversion efficiencies in the range of 7%-9%. This increase in performance is partially due to the improved quality of the undoped material. Diffusion lengths on the order of one micrometer and depletion width of several micrometers have been measured in films under one sun illumination. Another factor leading to improved performance has been the development of better doped layers such as the wide bandgap P type, amorphous silicon-carbon-hydrogen (a-Si : C : H) alloys. Another significant achievement is the recent development of relatively efficient stacked or multi-junction solar cells utilizing amorphous silicon-germanium-hydrogen (a-si : Ge : H) alloys.

The most efficient amorphous silicon solar cells are usually made in one of the two structures: either ITO/n-i-p/stainless steel, or glass/SnO_2/P*-i-n/Al where P* layer is boron-doped a-Si : C : H. In the first case the ITO (indiumtin-oxide) is usually deposited onto the n layer (phosphorus-doped) by electron-beam evaporation. For both structures, the top doped layer is very thin (~10nm), and the undoped or intrinsic layer is 0.5-1.0nm thick.

The transport properties as well as the composition and microstructure of amorphous silicon films are strongly dependent on deposition conditions. Films grown in silane are dependent on deposition conditions. For films grown in silane (SiH_4) glow discharges, the hydrogen content and the Si-H bonding configurations can vary with substrate temperature, discharged power, pressure, flow rate, etc. Impurities such as oxygen, carbon and nitrogen also influence electrical properties and appear to give to metastable defects that can degrade device performance during prolonged illumination.

Several sources have predicted that the cost of amorphous silicon solar cells will fall down US$0.50 per peak watt once large scale manufacturing occurs. Moreover, the pratical efficiency of amorphour silicon solar panels may eventually exceed 12%, especially for stacked junction structures.

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AMORPHOUS SILICON SOLAR CELLS

by
D.E. Carlson

Introduction

In the last few years, more than 100 million dollars (U.S.) has been spent by private industry in the development of amorphous silicon solar cells. In this talk, I will review the techniques used to deposit films of hydrogenated amorphous silicon (a-Si : H), the properties of the materials, the fabrication of solar cells and the characteristics of these devices.

Discussion of Illustrations

Fig. 1. A schematic of an rf capacitive discharge system. Discharge conditions are typically: pressure ~ 10-100m Torr of SiH_4 power density ~0.1W/cm^2, Ts~200-300°C, flow ~20-200 sccm.

Fig. 2. A schematic of a dc proximity discharge system. Discharge conditions are typically: pressure ~0.3-1.0 Torr of SiH_4, current density ~0.1-0.3mA/cm^2, Ts~200-300°C, flow ~20-200 sccm, cathode screen-substrate spacing ~ few cm.

Fig. 3. Positive ion spectra obtained with a line-of-sight mass spectrometer for an rf capacitive discharge at two different pressures. The first peak corresponds to monosilane species ($SiHx^+$), the second to disilane species (Si_2Hx^+), etc where x = 0, 1, 2, etc.

Fig. 4. A compositional profile of a boron-doped a-Si : H film deposited at four different substrate temperatures. The profile was obtained by SIMS (secondary ion mass spectroscopy). The film was grown in a dc proximity discharge (1.3% B_2H_6 in SiH_4).

Fig. 5. A compositional profile of a phosphorus-doped a-Si:H film deposited at four different pressures (~4% PH_3 in SiH_4).

Fig. 6. The optical absorption coefficient vs. photon energy for undoped a-Si:H films grown at Ts≅200°C (●), Ts≅300°C (▼), Ts≅400°C (■). The bottom curve is for crystalline Si.

Fig. 7. The Hall mobility of electrons in undoped a-Si:H (slightly n-type) as a function of $10^3/T$. The thermally activated motion at higher temperatures argues against simple extended state condution at room temperature.

Fig. 8. The Hall mobility of holes in boron-doped a-Si:H as a function of $10^3/T$. The conductivity type is p-type at low temperatures and n-type at high temperatures from the sign of the Hall effect. Thermopower measurements indicate p-type conduction at all temperatures.

Fig. 9. A plot of I_{sc}^{-1} as a function of α^{-1} where I_{sc} is the short-circuit current for the photo-electromagnetic effect and α is the absorption coefficient. The intercepts give the diffusion

length for illumination through the top surface of the a-Si:H (DIRECT) and through the glass substrate (REVERSE).

Fig. 10. The density of states as a function of energy for a-Si:H films. The data shows a wide discrepancy between the field effect and DLTS techniques possibly due to surface states influencing the former.

Fig. 11. Photon flux as a function of α^{-1}. This data is acquired by maintaining a constant surface photovoltage while changing the intensity of monochromatic light at various wavelengths. The intercept gives the diffusion length (0.54μm).

Fig. 12. A compositional profile of an undoped a-Si:H film (Lp≅0.55μm). Thus, a diffusion length of 0.55μm can be obtained even with impurity levels in the range of $\sim 10^{18}$-10^{20} cm^{-3}.

Fig. 13. The infrared absorption spectrum of an undoped a-Si:H film (Lp≅0.55μm). There is no evidence of a mode at 2100cm^{-1}, and the modes at 840 and 890cm^{-1} are small. These modes are associated with SiH_2 and $(SiH_2)n$ groups.

Fig. 14. The common p-i-n solar-cell structures. SnO_2 is often used in place of ITO (indium-tin-oxide) and a cermet (co-sputtered pt and SiO_2) for cells fabricated on glass. Al alone may be used as a back contact in this case if the cell is not heated above ~100°C.

Fig. 15. A compositional profile of a p-i-n cell deposited on stainless steel. This cell exhibited a conversion efficiency of 5.5%, and was fabricated in one system without terminating the discharge between layers.

Fig. 16. An I-V plot of a p-i-n cell deposited on SnO_2/glass where the p layer is alloyed with carbon. Similar recent cells at RCA have exhibited conversion efficiencies as high as 7.9% for 1.09cm^2.

Fig. 17. The spectral response of a p-i-n cell deposited on stainless steel. The dashed curve was taken with a white light bias of ~100mW/cm^2. Recent p-i-n cells deposited on SnO_2 glass and using a carbon alloyed p layer exhibit a much better response in the blue (collection efficiency is ~0.65 at λ≅400nm).

Fig. 18. The open-circuit voltage (V_{OC}) and short-circuit current density as a function of the thickness of the top n layer in a p-i-n cell fabricated on stainless steel. The optinum efficiency occurred at a thickness of ~8nm.

Fig. 19. A schematic of a p-i-n cell on steel that was fabricated with a thick n layer. The bottom figure shows the surface photovoltage obtained by sputtering through the device and using a vibrating Kelvin probe in the presence of light.

Fig. 20. Conversion efficiency as a function of white light exposure for a relatively stable p-i-n cell grown on steel and for an unstable cell.

Fig. 21. Conversion efficiency as a function of time on a log-log plot for p-i-n cells grown on

steel. No degradation occurs in the dark, but a gradual degradation is observed under prolonged illumination. This degradation is reversed by heating the cells for several minutes at 200°C.

Fig. 22. Surface photovoltage profiles for a relatively efficient p-i-n cell (TOP) and for a poor p-i-n cell (BOTTOM). The effect of prolonged illumination is often similar; i.e. initially the field is relatively uniform across the cell but prolonged illumination creates space charge that leads to a quasi-neutral region in the center of the cell.

Fig. 23. The fractional change in efficiency often light soaking (48 hours at AM1) as a function of an air bleed admitted during the deposition of the i-layer. The p-i-n cells were deposited on steel and exhibited efficiencies of ~4-4.5%.

Fig. 24. The electron trap density as determined by DLTS as a function of oxygen concentration for the same cells as characterized in Figure 23. The nitrogen concentration was ~ 10X less than the oxygen concentration in each case.

Fig. 25. The fill factor as a function of i-layer thickness for p-i-n cells before and after light soaking. The cells were fabricated on cermet/ITO/glass using an rf discharge. The data shows good stability for thin cells.

Fig. 26. Diffusion length data as determined by the constant surface photovoltage method for an undoped a-Si:H film before (a), and after light soaking (b). These data shows that light-induced centers can reduce the lifetime in some films. Stable films show no change in diffusion length and the density of metastable centers is less than 10^{15} cm^{-3}.

Fig. 27. A brief outline of how the theoretical efficiency limit for a-Si:H cells is determined. Recent work by T. Tiedge (Appl. Phys. Lett.) on band tail recombination is used for estimating the limit for V_{OC} and FF.

Fig. 28. Conversion efficiency as a function of time for 1cm^2 p-i-n cells. The most recent cells utilized a carbon-alloyed p-layer.

Fig. 29 Projected efficiencies for a-Si:H solar cells.

Fig. 30. A schematic of a two-stack a-Si:H solar cell. The first p-i-n cell may utilize a carbon-alloyed p layer while the second cell might utilize a a-Si:Ge:H undoped layer (i*).

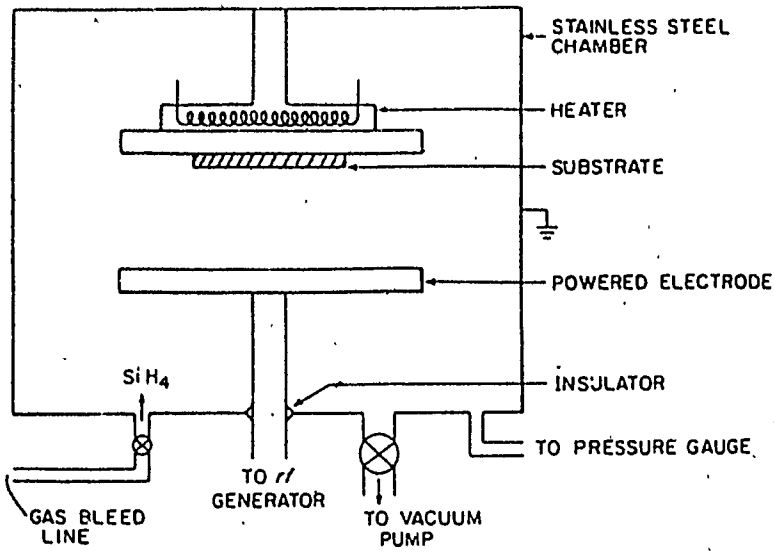

Fig. 1 A schematic of an rf capacitive discharge system.

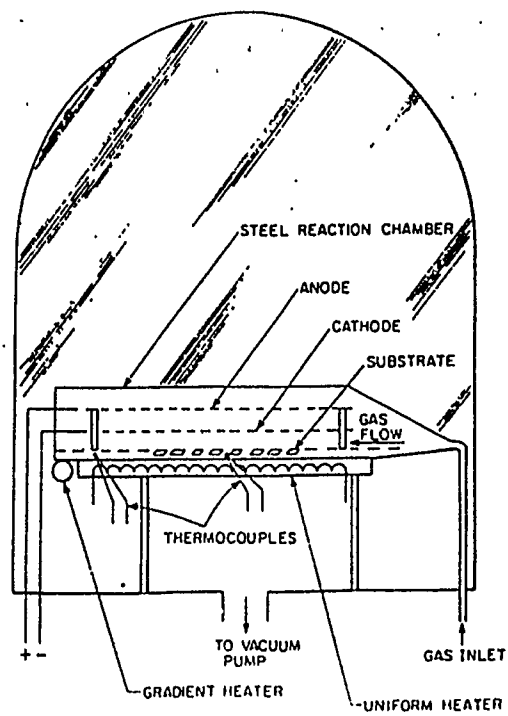

Fig. 2 A schematic of a dc proximity discharge system.

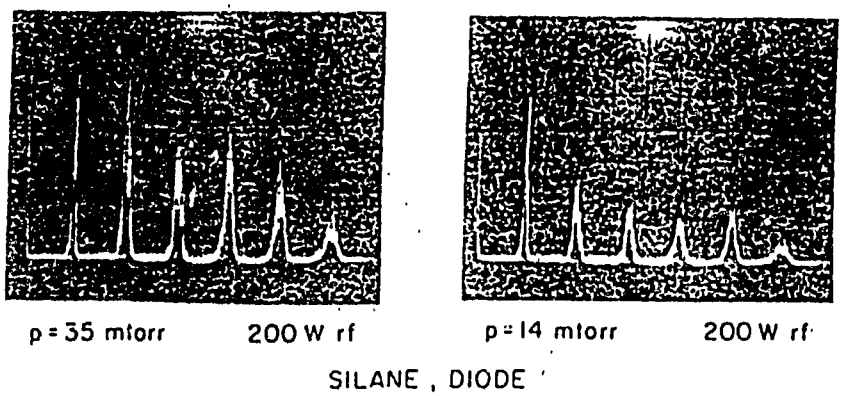

Fig. 3 mass spectrometer for an rf capacitive dischar at two different pressures.

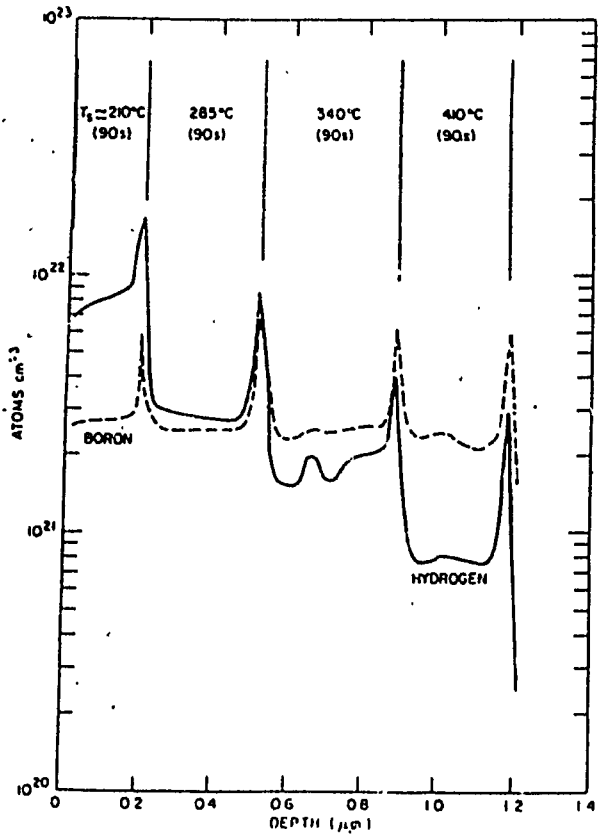

Fig. 4 A compositional profile of a boron-doped a-Si:H film deposited at four different substrate temperatures.

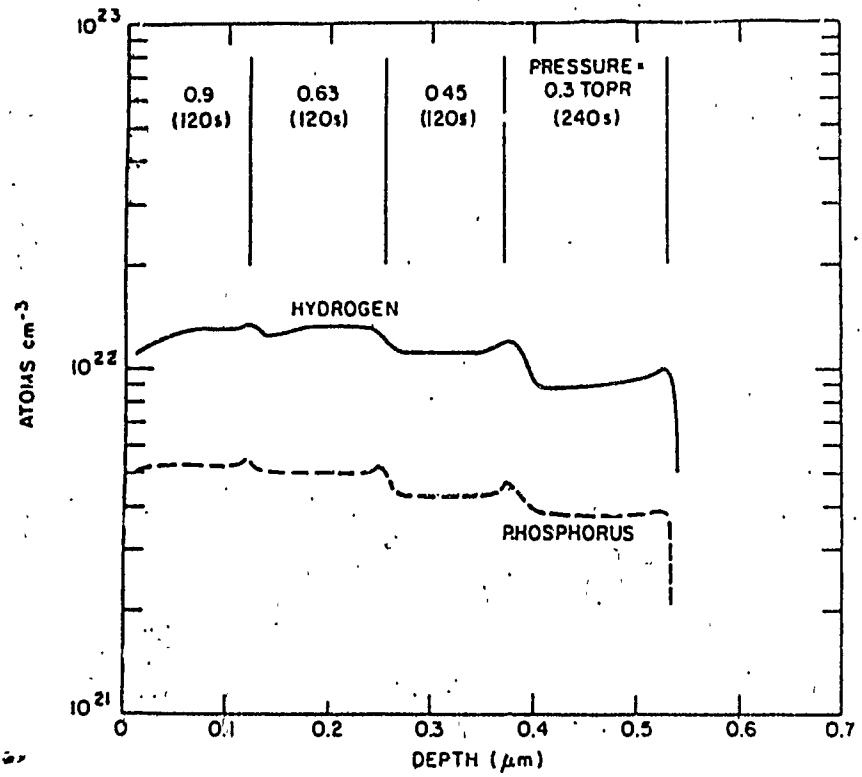

Fig. 5 A compositional profile of a phosphorus-doped a-Si:H film deposited at four different pressures (~4% PH_3 in SiH_4).

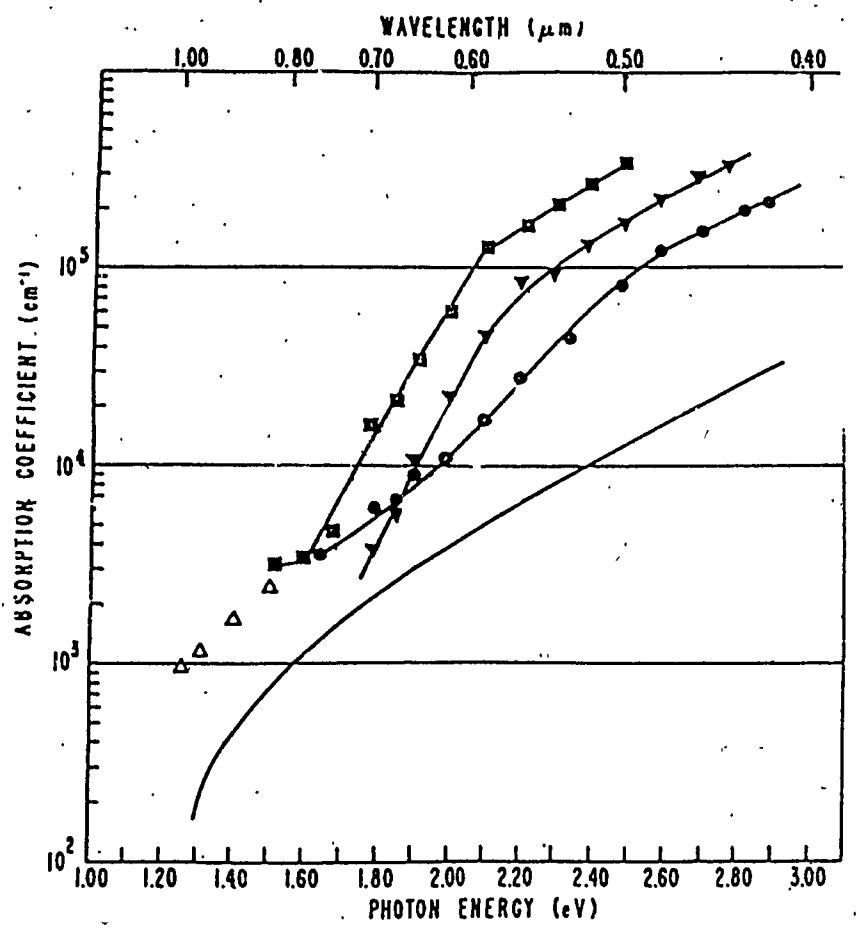

Fig. 6 The optical absorption coefficient vs. photon energy for undoped a-Si:H films grown at $T_s \cong 200°C$(·), $T_s \cong 300°C$(▼), $T_s \cong 400°C$(★).

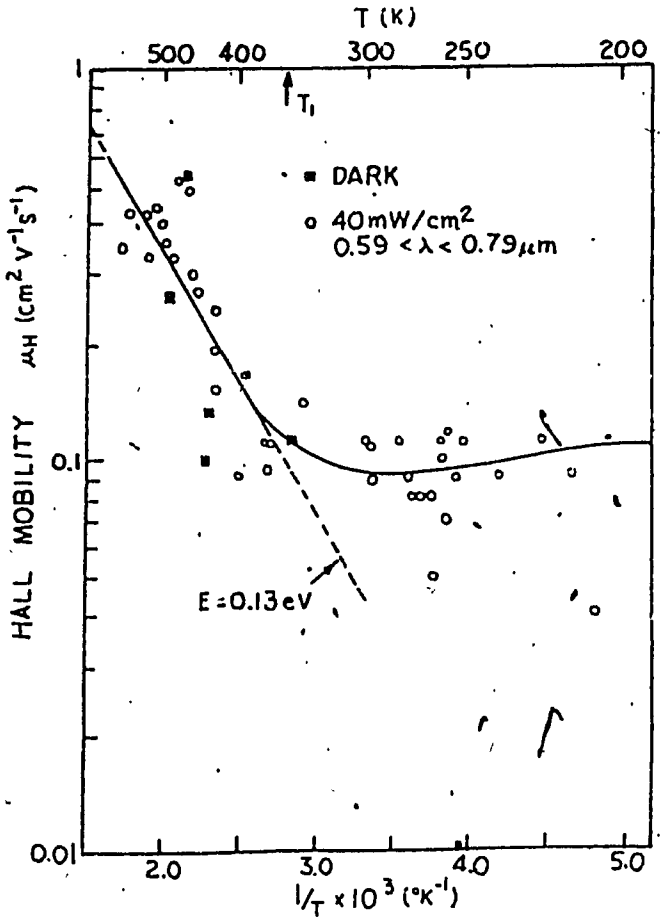

Fig. 7 The Hall mobility of electrons in undoped a-Si:H (slightly n-type) as a function of $10^3/T$.

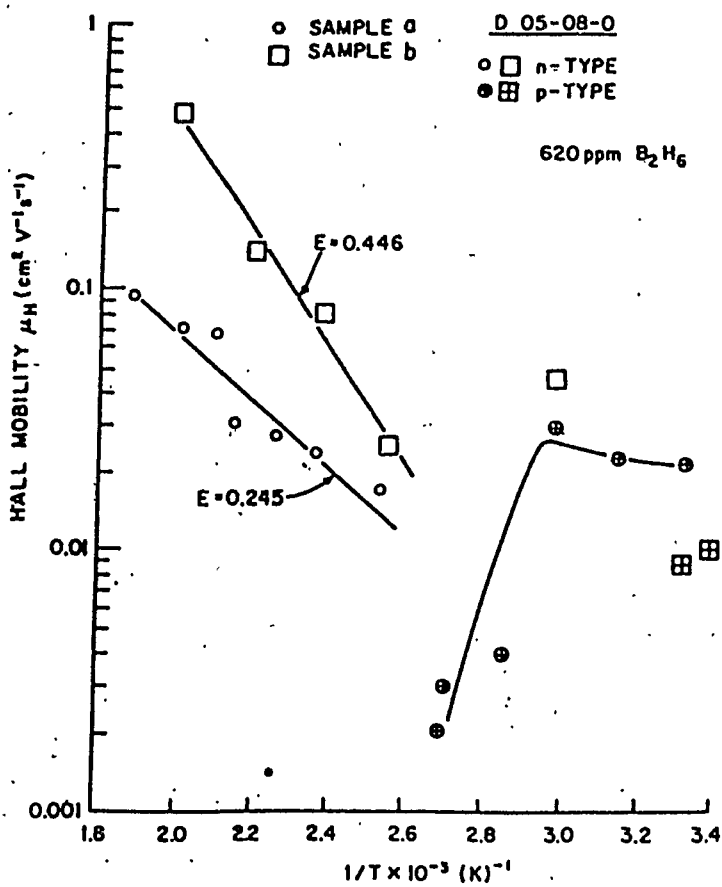

Fig. 8 The Hall mobility of holes in boron-doped a-Si:H as a function of $10^3/T$.

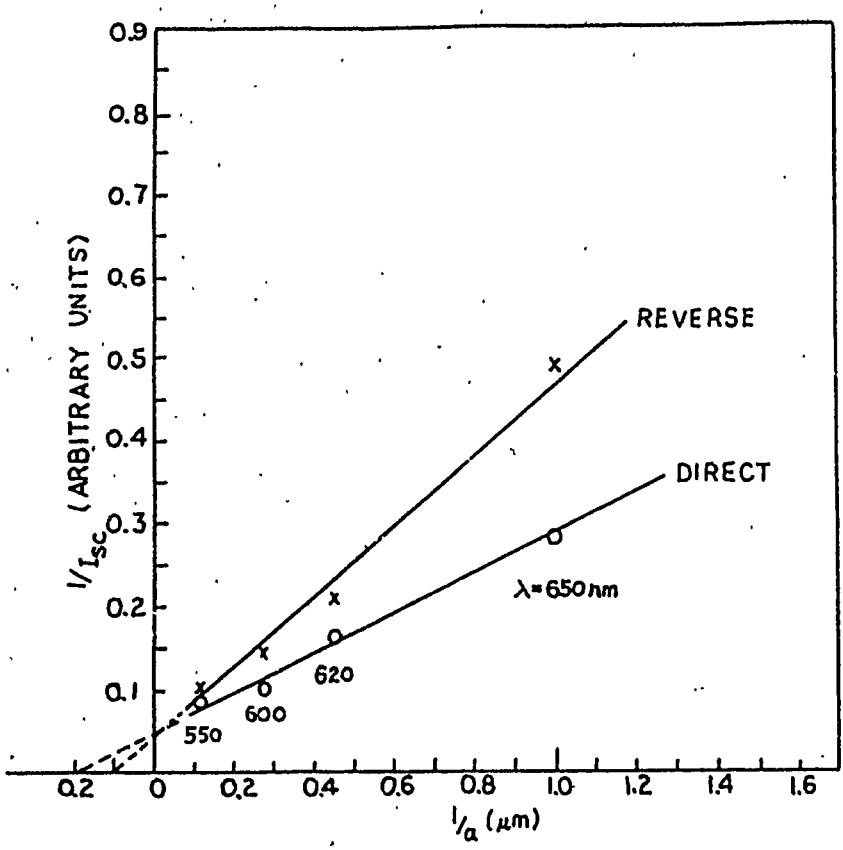

Fig. 9 A plot of Isc^{-1} as a function of α^{-1}.

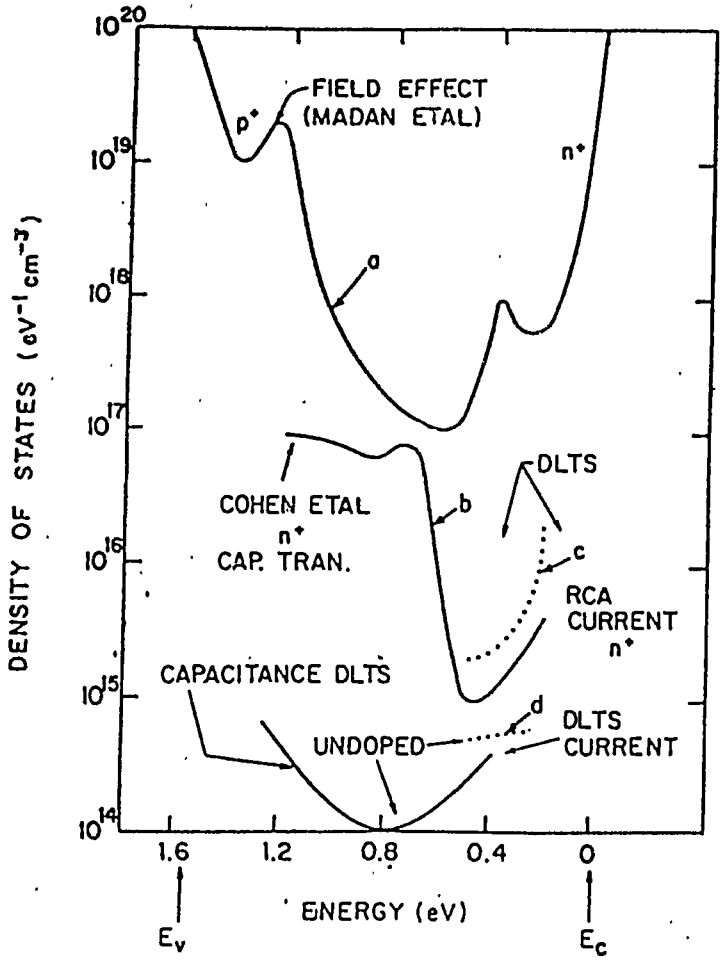

Fig. 10 The density of states as a function of energy for a-Si:H films.

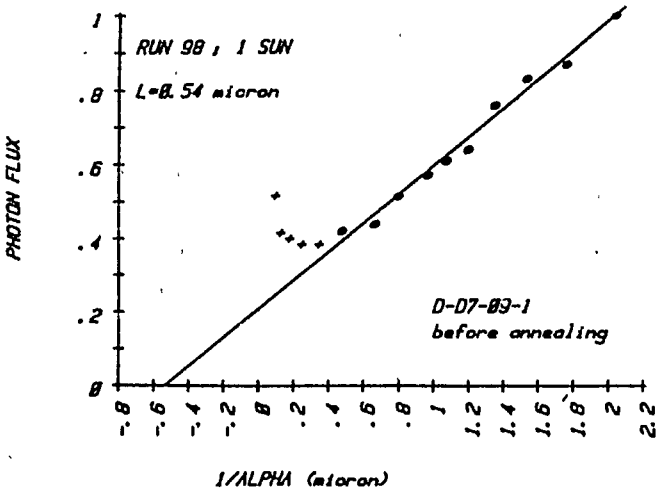

Fig. 11 Photon flux as a function of α^{-1}.

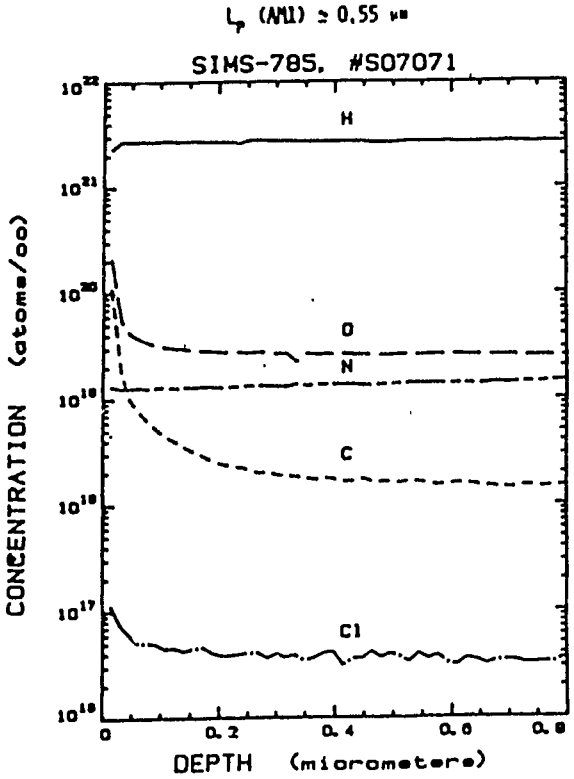

Fig. 12 A compositional profile of an undoped a-Si:H film (Lp≃0.55μm).

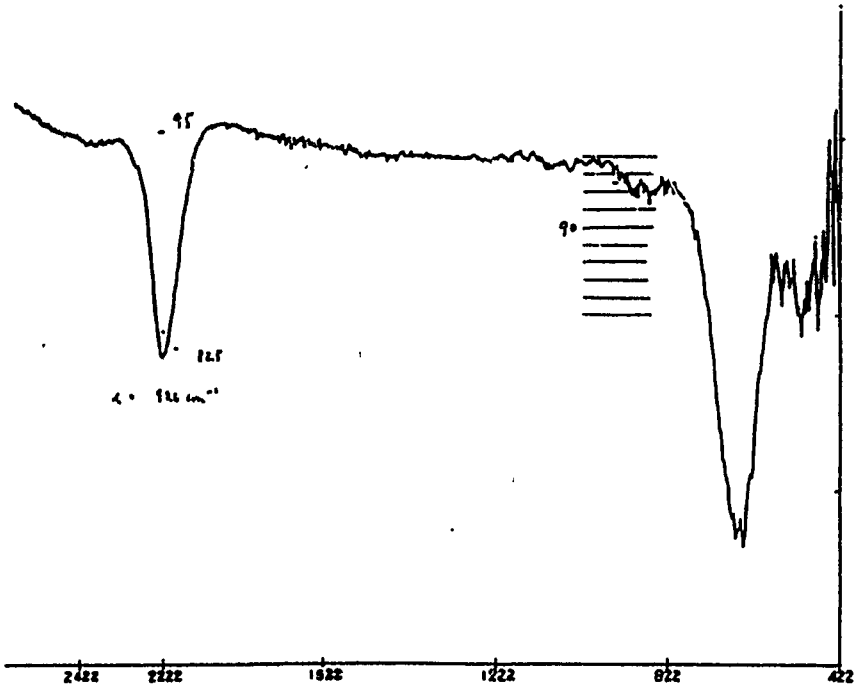

Fig. 13 The infrared absorption spectrum of an undoped a-Si:H film (Lp≅0.55μm).

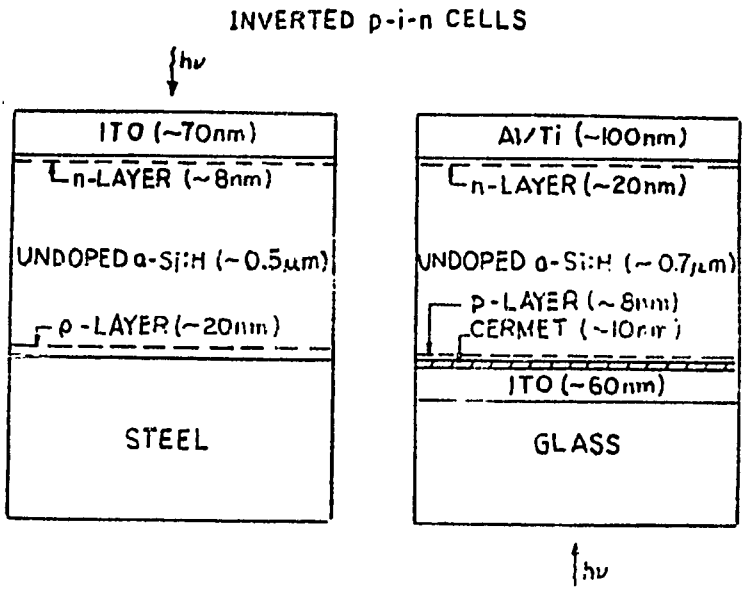

Fig. 14 The common p-i-n solar-cell structures.

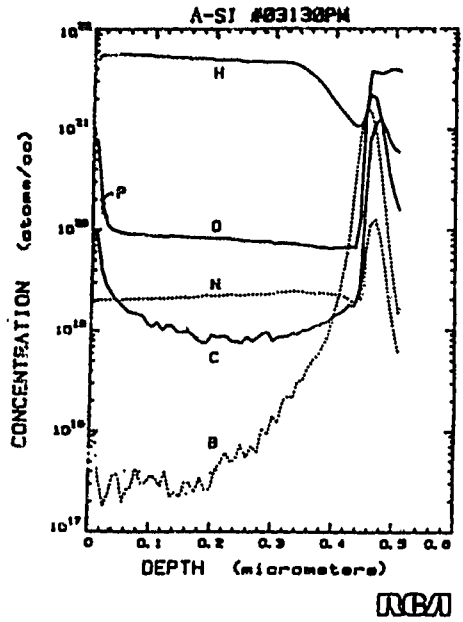

Fig. 15 A compositional profile of a p-i-n cell deposited on stainless steel.

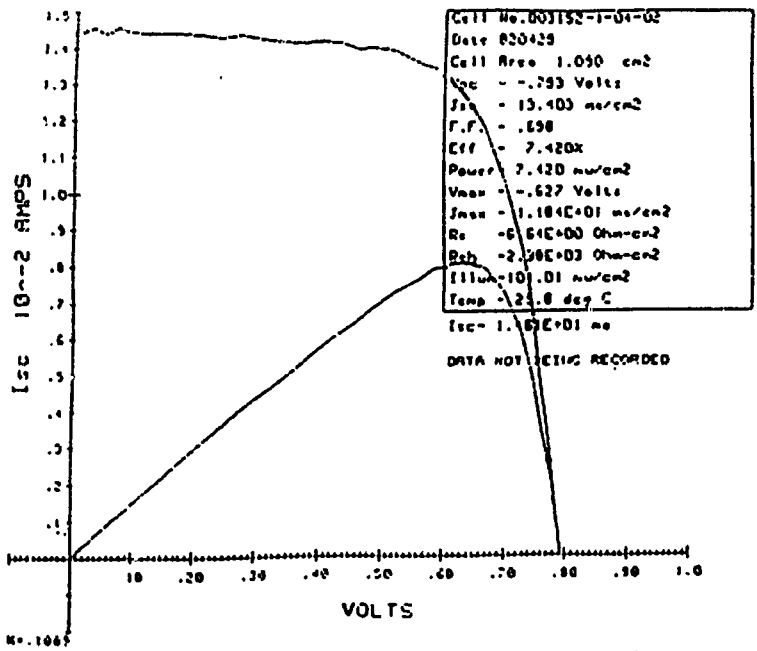

Fig. 16 An I-V plot of a p-i-n cell deposited on SnO_2/glass where the p layer is alloyed with carbon.

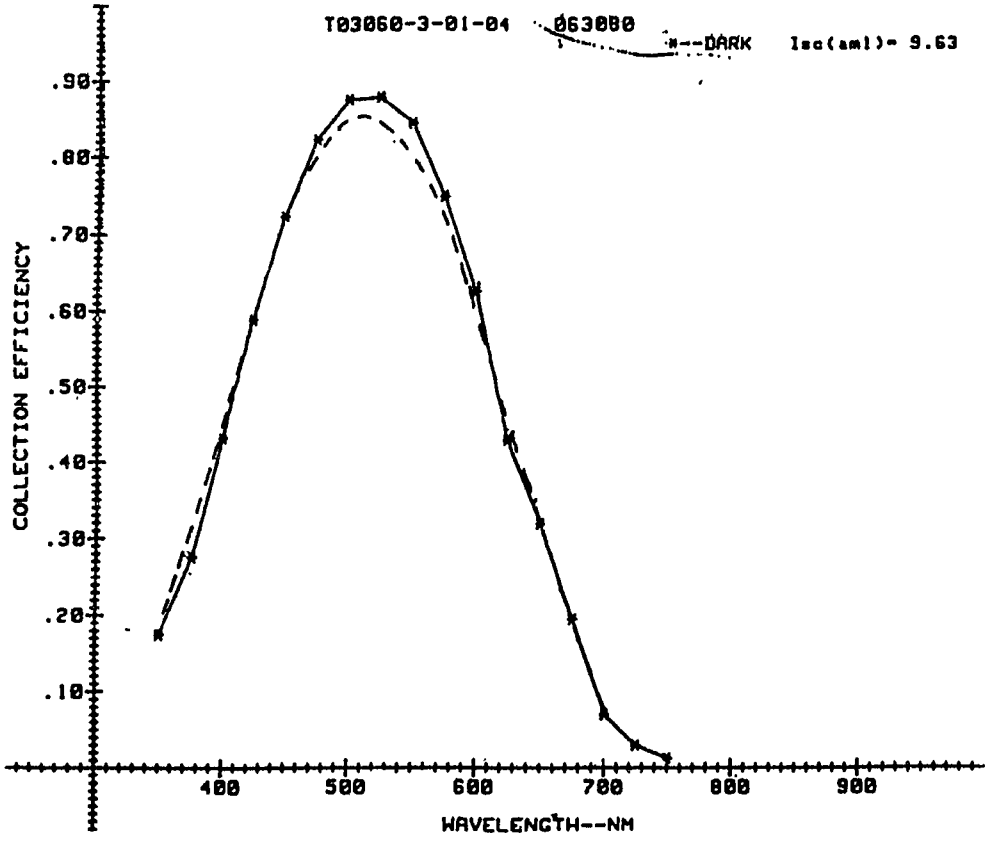

Fig. 17 The spectral response of a p-i-n cell deposited on stainless steel.

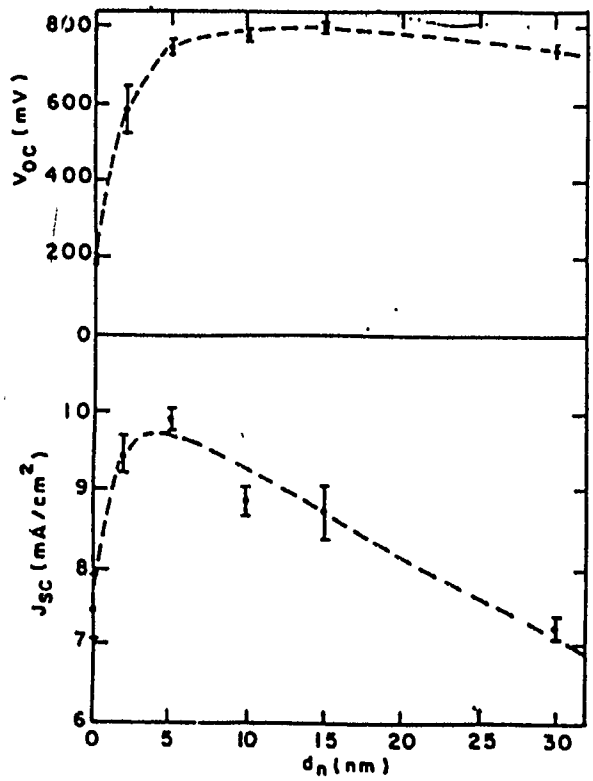

Fig. 18 The open-circuit voltage (Voc) and short-circuit current density as a function of the thickness of the top n layer in a p-i-n cell fabricated on stainless steel.

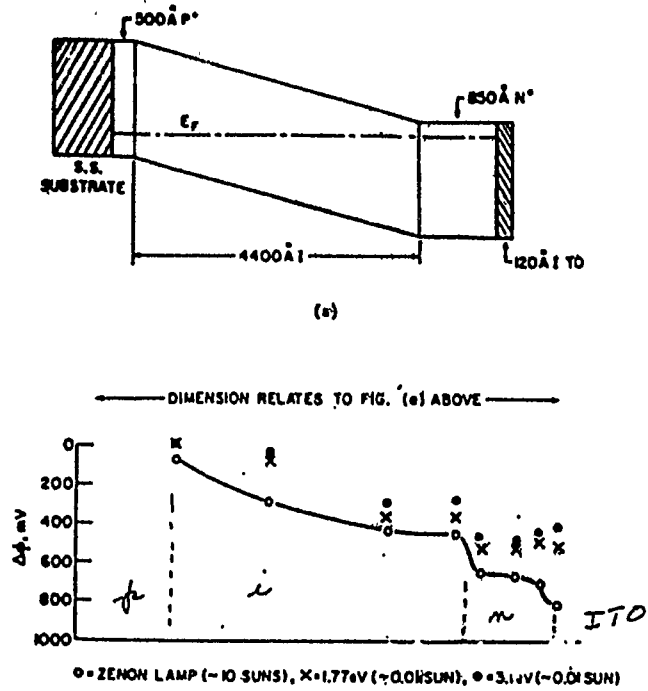

Fig. 19 A schematic of a p-i-n cell on steel that was fabricated with a thick n layer.

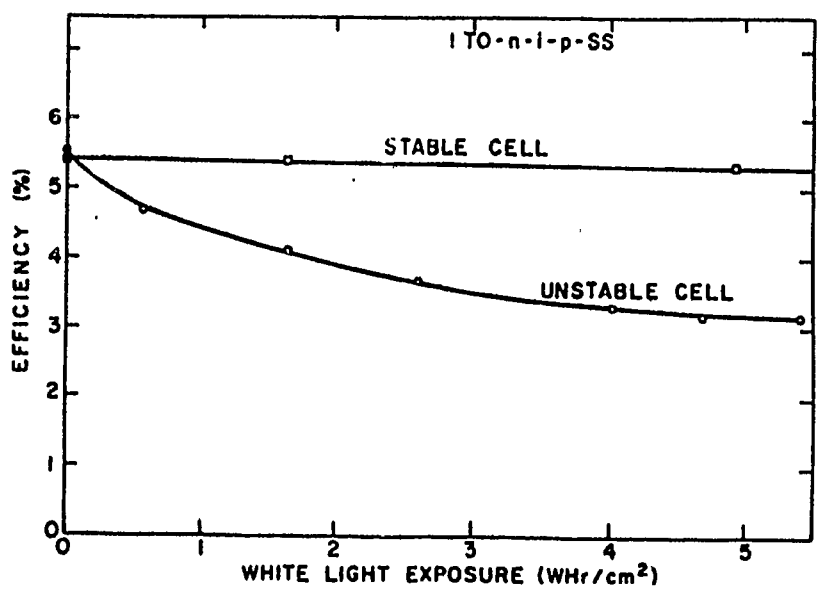

Fig. 20 Conversion efficiency as a function of white light exposure for a relatively stable p-i-n cell grown on steel and for an unstable cell.

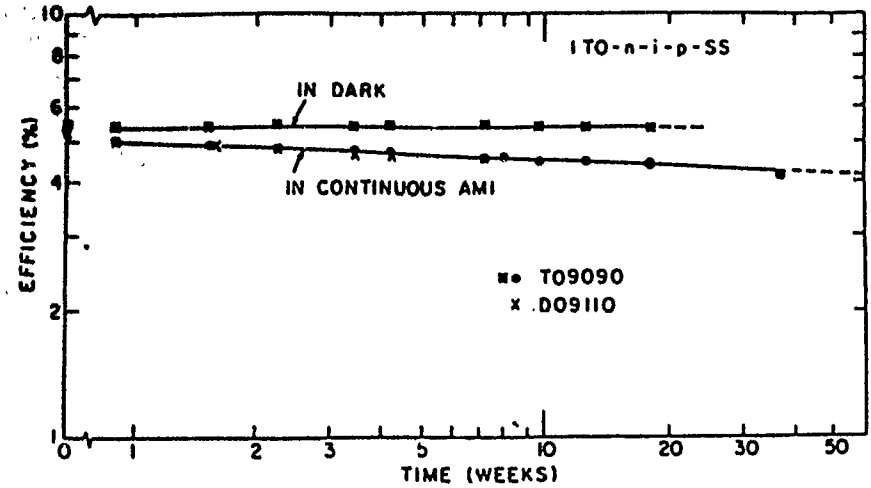

Fig. 21 Conversion efficiency as a function of time on a log-log plot for p-i-n cells grown on steel.

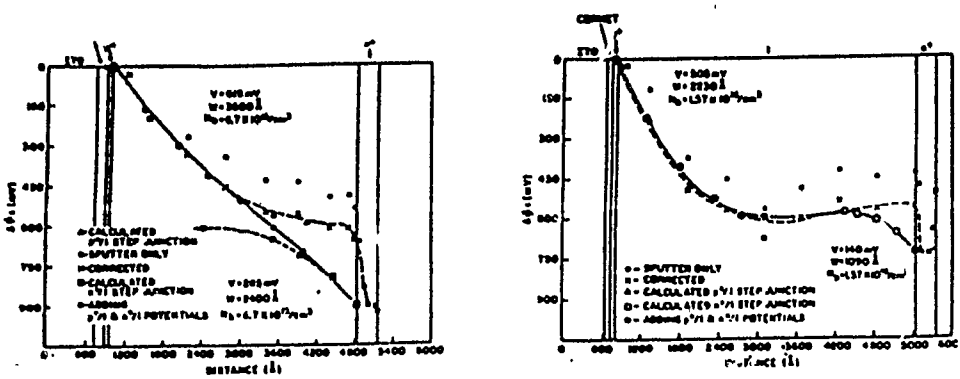

Fig. 22 Surface photovoltage profiles for a relatively efficient p-i-n cell (TOP) and for a poor p-i-n cell (BOTTOM).

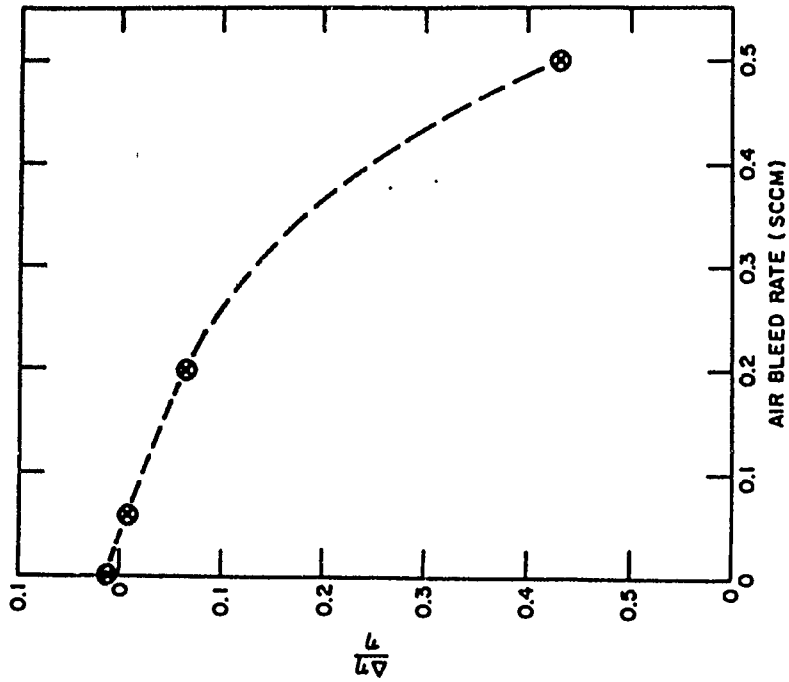

Fig. 23 The fractional change in efficiency as a function of an air bleed admitted during the deposition of the i-layer.

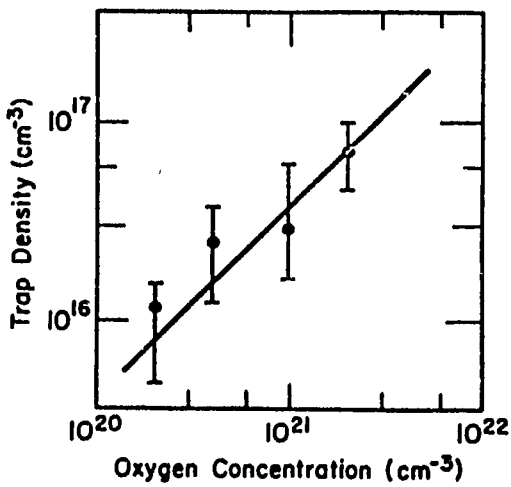

Fig. 24 The electron trap density as determined by DLTS as a function of oxygen concentration.

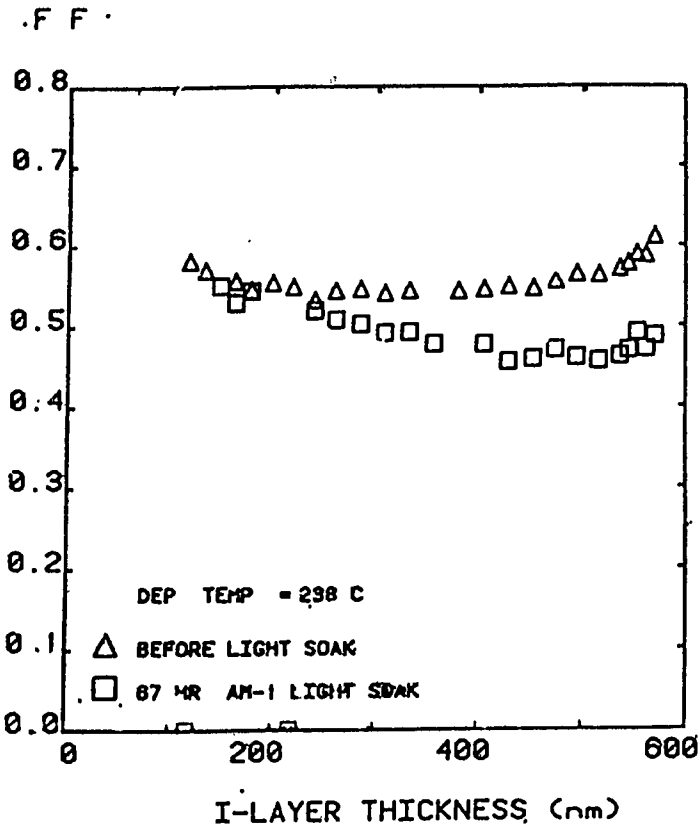

Fig. 25 The fill factor as a function of i-layer thickness for p-i-n cells before and after light soaking.

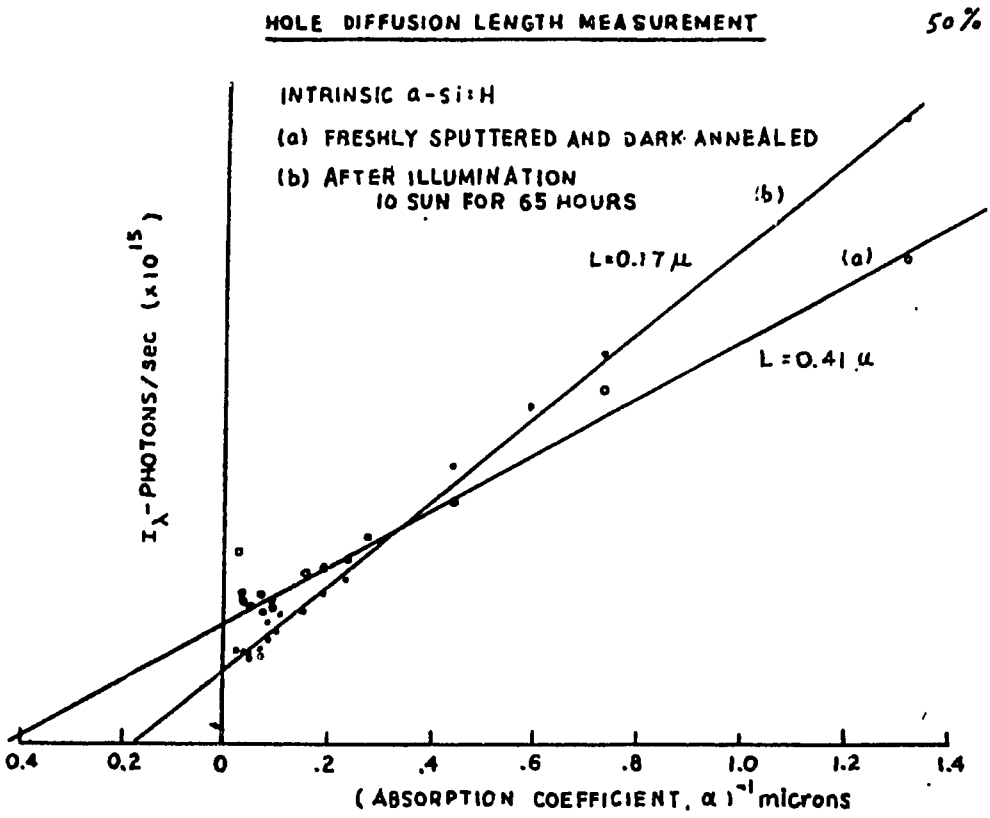

Fig. 26 Diffusion length data.

THEORETICAL EFFICIENCY LIMIT OF AMORPHOUS SILICON-SOLAR CELL

CONVERSION EFFICIENCY = SHORT CIRCUIT CURRENT (mA/cm^2) · OPEN CIRCUIT VOLTAGE (V) FILL FACTOR

$$\eta = J_{SC} \cdot V_{OC} \cdot FF$$

ILLUMINATION IS 100 mW/cm^2 OF SUNLIGHT

LIMITS

- J_{SC} = 22 mA/cm^2 (HIGHEST OBSERVED = 15 mA/cm^2)
  - CALCULATED WITH 2 μ OPTICAL PATH LENGTH
  - OPTICAL GAP = 1.7 eV
- V_{OC} = 1.05 (HIGHEST OBSERVED IN CELL 0.94V)
  - BAND TAIL STATE RECOMBINATION
  - 1.1 V OBSERVED AT LOW TEMPERATURE OR WITH ELECTROLYTE CONTACT
- FF = 0.87 (HIGHEST OBSERVED 0.74)
  - BAND TAIL STATE RECOMBINATION

$$\underline{\eta = 20\ \%}$$

Fig. 27 A brief outline of how the theoretical efficiency limit for a-Si:H cells is determined.

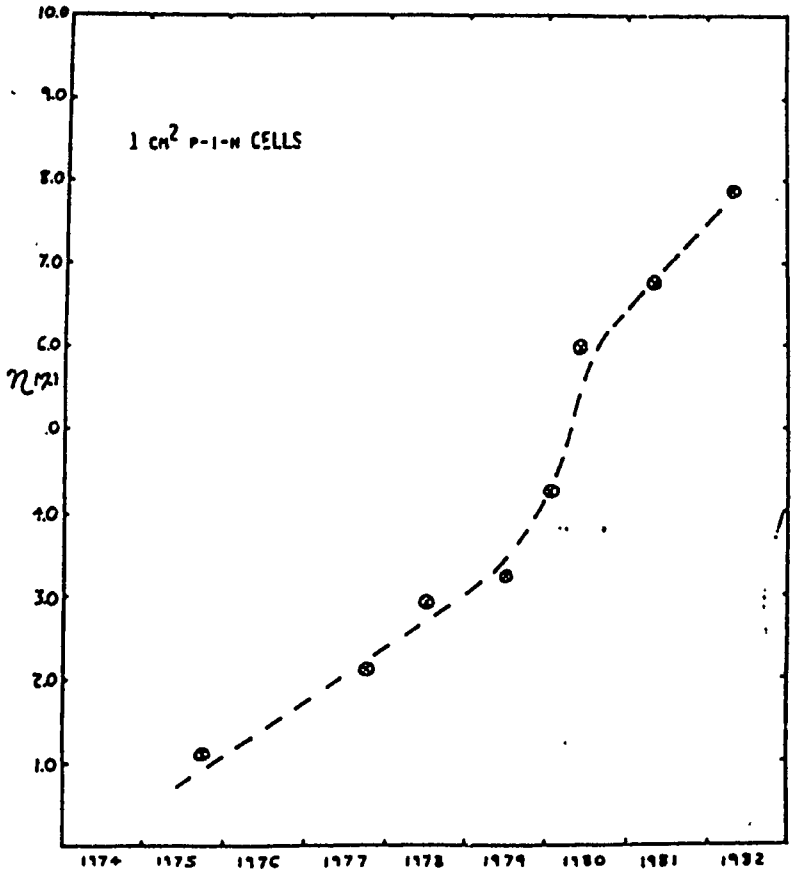

Fig. 28 Conversion efficiency as a function of time for 1cm² p-i-n cells.

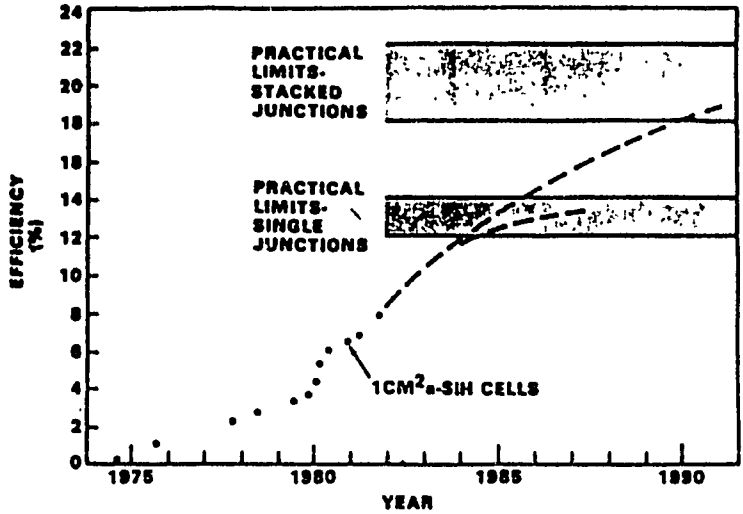

Fig. 29 Projected efficiencies for a-Si:H solar cells.

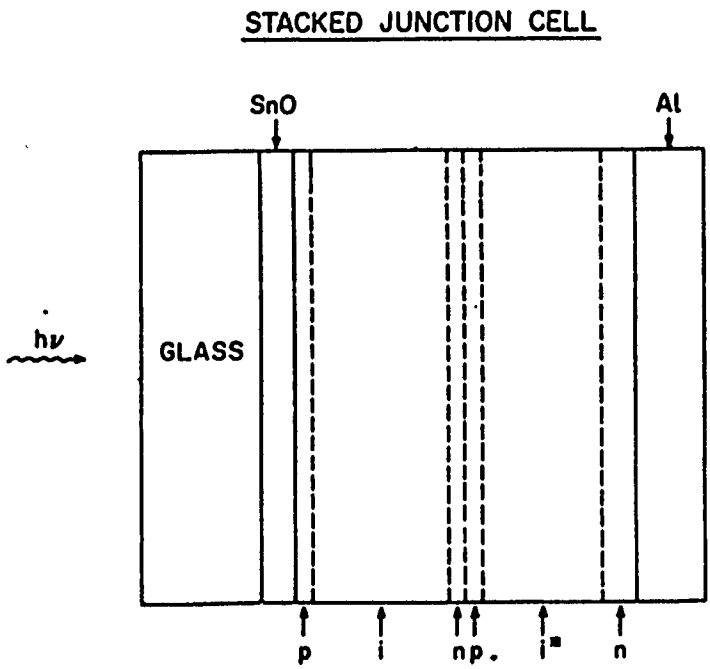

Fig. 30 A schematic of a two stack a-Si:H solar cell.

REPORT OF PHOTOVOLTAIC GROUP

by
Dr. David Carlson

Summary of Present Situation

1. ROC has a good foundation in single crystal Si technology for both solar cells and panels.

2. ROC has a well-balanced program in photovoltaic involving panel fabrication, systems research and performance testing.

3. Industry in the ROC has a small scale effort in present commercial solar cell applications and is very interested in new low cost technologies for future markets.

4. The National Science Council supports basic research both in photovoltaic material and technologies in the Universities.

5. The government has taken a leadership role by starting photovoltaic programs in INER and the Energy Research Laboratories.

Recommendations

1. The government should take a strong leadership role in two areas:

   (1) They should guide, coordinate and support a research and development effort involving Universities, industry and government institutions.

   (2) They should enact legislation to promote local usage of solar energy conversion systems and energy conservation measures.

2. Specific Recommendations

   (1) We recommend that the coordinating organization consist of a committee of experts from the institutions involved in photovoltaic R & D, this committee should report to some authority in the area of national science and technology policy.

   (2) The Ministry of Communication should consider photovoltaic in applications such as remote TV and microwave repeaters, lighthouses, railload signals, navigations aids, etc.

   (3) Photovoltaic water pumping should be given high priority for near-term market development for both domestic and export use.

   (4) The government should assist related industries in developing equipment for balance of system such as power conditioning units, d.c. motors and storage systems.

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(5) ROC should establish a cooperative effort with other countries or companies in developing new low-cost photovoltaic technologies.

(6) Taipower Co. (TPC) should consider demonstrations of photovoltaics to assist local industry in developing new technologies and markets.

(7) The government should educate the public about the advantages of using solar energy.

SALINITY GRADIENT SOLAR PONDS

by
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Introduction

Unlike other solar systems, salinity gradient solar ponds were not invented. They occur as a natural phenomenon. As long ago as 1902 Kalecsinsky studied the natural solar ponds in Transylvania and suggested that artificial solar ponds could be built to select and store solar energy for home and industrial use.

The natural solar ponds occurred where salt deposits made the lower levels of natural lakes nearly saturated with sodium chloride, while the surface was kept at low density from washing by the rain and overflow. The water with salt dissolved is denser than fresh water, so that normal convection is prevented. Solar energy that penetrates heats the bottom, and temperatures as high as 70°C have been reached in these natural lakes because the convection that normally would make the temperature uniform throughout cannot occur.

As shown in Figure 1, a solar pond has typically three zones, a lower convective zone where solar energy is collected and stored, a gradient zone that provides the insulation to retain the heat, and a surface convective zone. Good performance is achieved only with the gradient zone thick enough and the surface zone not too thick. As will be discussed later, control of the surface zone thickness is one of the aspects of pond operation that we are studying.

Figure 2 shows solar energy penetration into clean water. Even if the water is kept as clean as possible the penetration to a depth of one meter or more, as normally required, is at most only 35% of the incident radiation. However, the fact that a one meter nonconvective gradient zone has insulating value about equal to six centimeters of foam insulation makes it possible for a pond to collect energy all of the time, even when solar input is very low. Thus it turns out that the pond has about the same annual average efficiency as a glass or plastic convered flat plate collector, despite the higher peak efficiency of the flat plate unit.

Solar ponds can be used to provide low temperature heat for building heating, or industrial and agricultural applications. They appear economically desirable for such application because of the very low cost per unit area, as compared with other collectors, and because of their intrinsic heat storage capacity. In favorable sites where salt cost and construction cost are low they may also be useful for thermal and electric power generation. This application is being actively developed in Israel. It should be noted that the first work on solar ponds was done in Israel more than twenty years ago.

Solar Pond Construction and Use

The usual way to construct a solar pond is to make an excavation or earth embankment, line it with a plastic liner, fill it with water having the right density distribution, and provide a means for extracting the heat. The next group of Figures from 3 to 5 shows the construction of our 250 m^2 pond at the Farm Science Review grounds of The Ohio State University. After we completed the pond we put heat exchange pipes into the lower zone of the pond and used them to provide heat for drying corn in the corn tin.

Other solar ponds have been constructed at the Ohio Agricultural Research and Development Center for research on greenhouse heating (Figure 6) in the city of Miamisburg, Ohio, to heat the municipal swimming pool (Figure 7) and in India (Figure 8). There are three other experimental ponds in the United States not included in these slides, and one at Alice Springs, Australia built to study electric power generation.

The major work in application of solar ponds for power generation is being done in Israel. There was first a fairly small pond at the Ormat plant (Figure 9) connected to the 6 KW vapor turbine driven generator (Figure 10). The largest pond in operation is this 7000 m^2 pond at the Dead Sea that runs a 150 KW experimental electric power generator intermittently (Figure 11).

Research Questions

Some of the questions that we have been studying are the salt usage by solar ponds, means for controlling the thickness of the surface zone, and the amount of heat lost to the earth. We are using a 400 m^2 solar pond with nearly 200 thermocouples underneath to measure the heat loss to the earth. We have obtained good consistency in the data, and accounted for all of the input energy to within three or four percent. Although the efficiency of this 400 m^2 pond turns out to be very low, the consistency of the results allows us to use them to predict the behavior of other larger ponds. It is to be expected that in a pond of ten times the area of this one the fraction of the heat lost to the earth will be about one third as great and the efficiency for the same operating temperature will increase to 20-25 percent.

Effective salinity gradient solar pond operation depends upon maintaining an appropriate salinity profile. In order to determine the conditions for a gradient zone boundary to be stationary, we have measured the temperature gradient Gt and the specific gravity gradient Gc immediately adjacent to the boundary at times when the boundary position was stationary or moving very slowly. We have obtained data from the Farm Science Review pond and from small laboratory tanks. The results are shown in Figure 12.

From observation the best continuous record obtained is that for the 400 m^2 pond spanning the last half of 1981 and shown in Figure 13. The solid curve is molecular diffusion, calculated using the diffusion coefficient $D = 1.51 + 0.037\ (T\text{-}25) + 0.000225\ (T\text{-}25)^2\ Cm^2/sec$; T being temperature in °C. Normally diffusion transport decreases in winter on account of lower temperature, but in this case the increase in salinity gradient from decrease in gradient zone thickness had a greater effect than the temperature decrease. Average transport for this six month period is 2.2 $Kg\ m^{-2}\ mo^{-1}$, while for the entire year it is 1.8 $Kg\ m^{-2}\ mo^{-1}$. There is no indication in Figure

14 of departure from the diffusion transport rate in the 400 m^2 pond with insulated walls. The same is true of the other time periods during which continuity is maintained. This agreement of observed transport with the diffusion rate provides firm evidence that there is no appreciable convective motion or instability of any character within the gradient zone.

The surface zone will grow in thickness making the gradient increase at the top boundary of gradient zone to the observed larger value. Diffusion being a very slow process, a slow downward movement of the zone boundary serves to maintain the required large boundary gradient, which depends upon temperature, surface zone depth and maximum temperature gradient. In Figure 14 the increased gradient at both the top and bottom of the 14 Nov. 1980 data, which is the result of boundary movement. Salinity profiles depart from diffusional equilibrium whenever boundary movement occurs.

Freezing of the surface in winter causes salt to be transported downward so that the gradient zone is enlarged. In this case a 20 cm enlargement is observed in Figure 15.

Applications and Costs

It is expected that with 180 W/m^2 solar input ponds can produce about 45 W/m^2 of heat at 60° – 80°C. This can be used for building heating or process heat. In favorable sites, where salt cost and construction cost are low, this heat may cost as little as 0.4 cent US per KW hr thermal.

Ponds can be considered for power production only in favorable sites. Where such sites are available the experience in Israel leads to estimates of power cost in the range 7¢ to 15¢ per KWH electric. This figure is much higher than the cost for direct use of low temperature heat and partly because pond efficiency is lower at a higher operating temperature, but primarily because the conversion efficiency from pond heat to mechanical or electrical energy is only about 7 percent. This efficiency combined with 20 percent pond collection efficiency leads to an average output of 2-3 W electrical/m^2, or 2-3 Megawatt per square Kilometer of pond area.

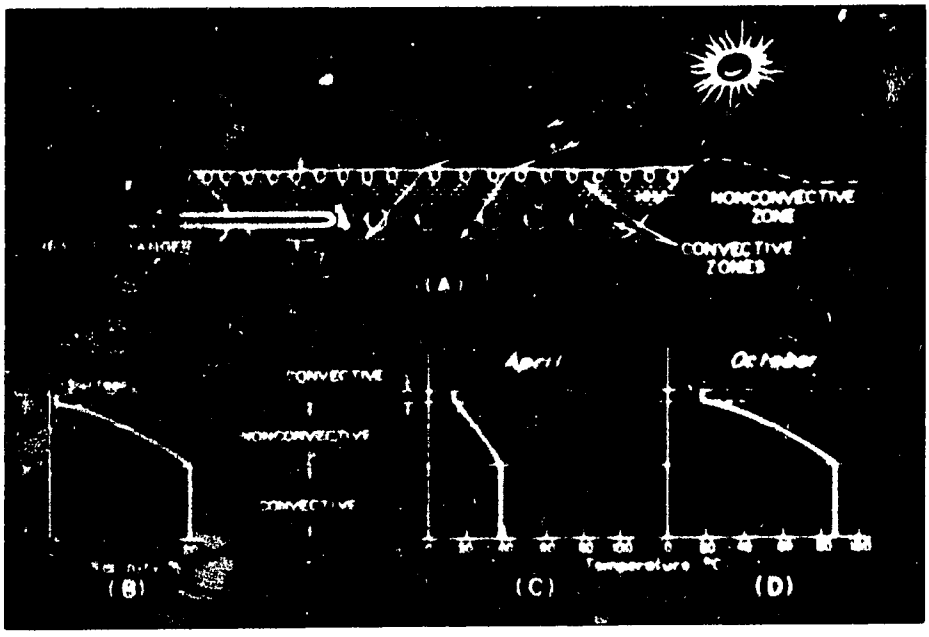

Fig. 1 Typical Salinity and Temperature Profiles of Solar Pond.

Fig. 2 Typical Solar Energy Penetration.

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Fig 3 Excavation of 250 M Solar Pond at Ohio State University

Fig 4 Placement of Liner in O S U Solar Pond

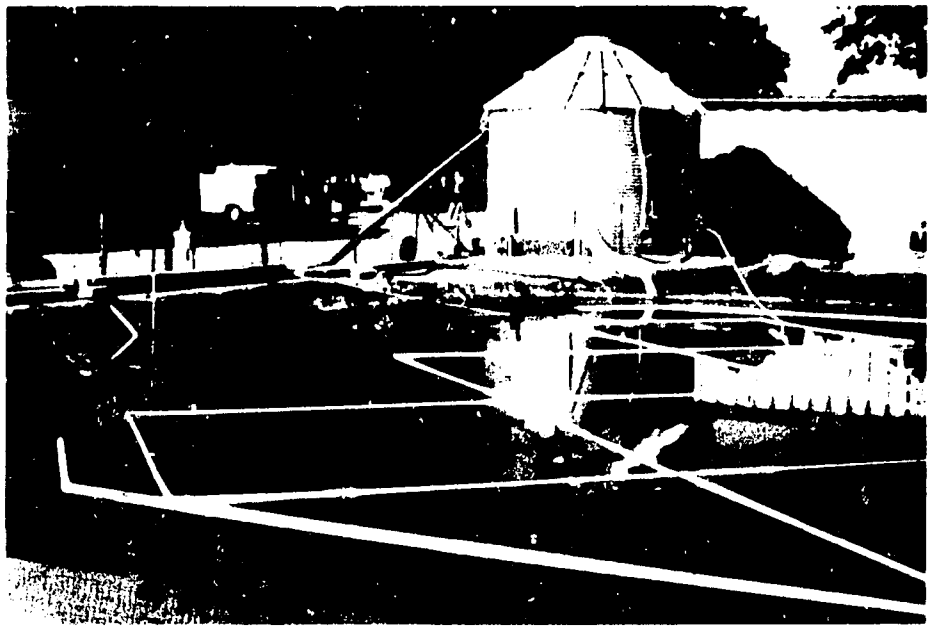

Fig. 5 The Completed O.S.U. Solar Pond and the Corn Drying Bin.

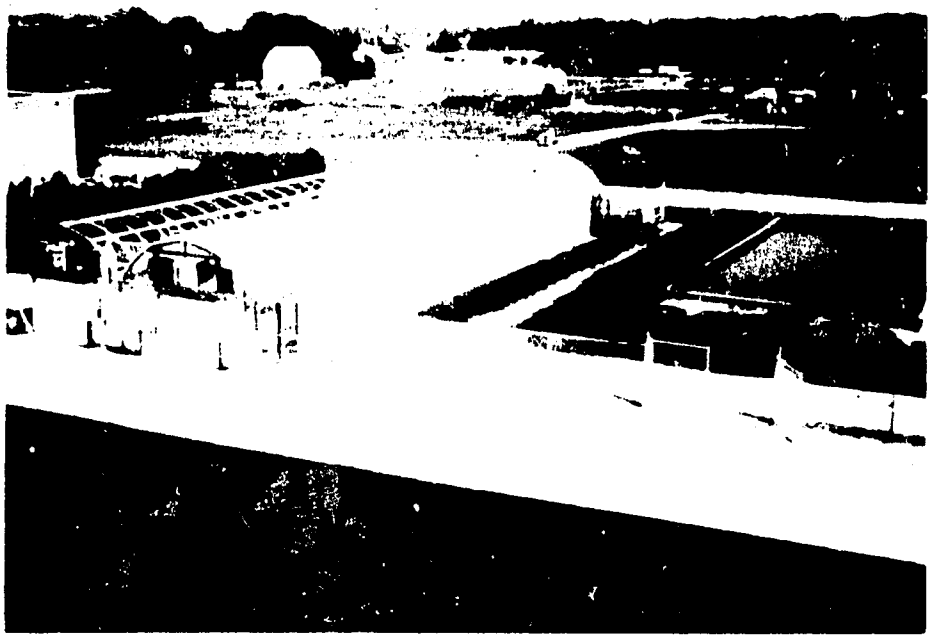

Fig. 6 Solar Pond and Greenhouse of the Ohio Agricultural Research and Development Center (A.R.D.C.).

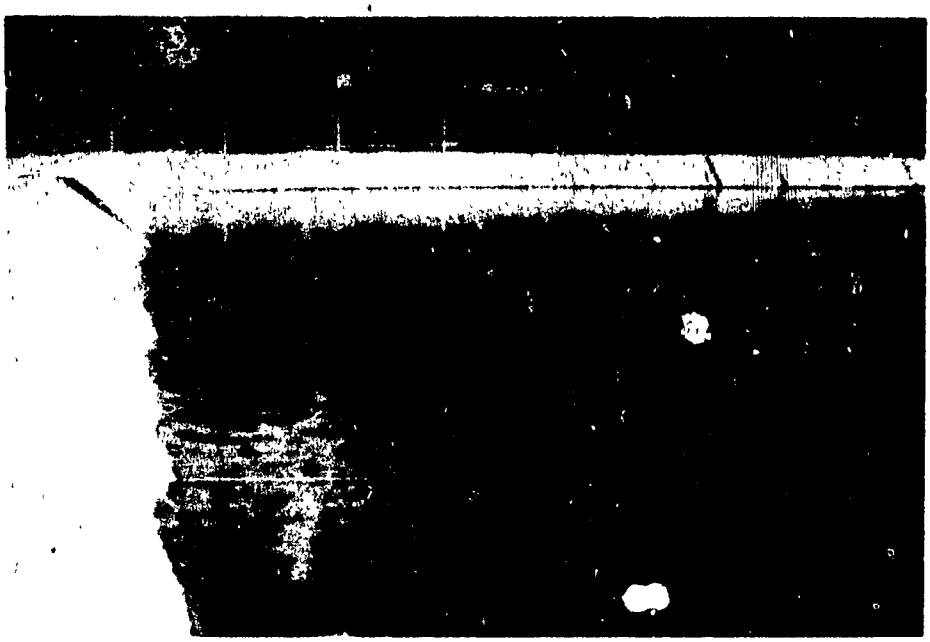

Fig. 7 Closed up of A.R.D.C. Solar Pond.

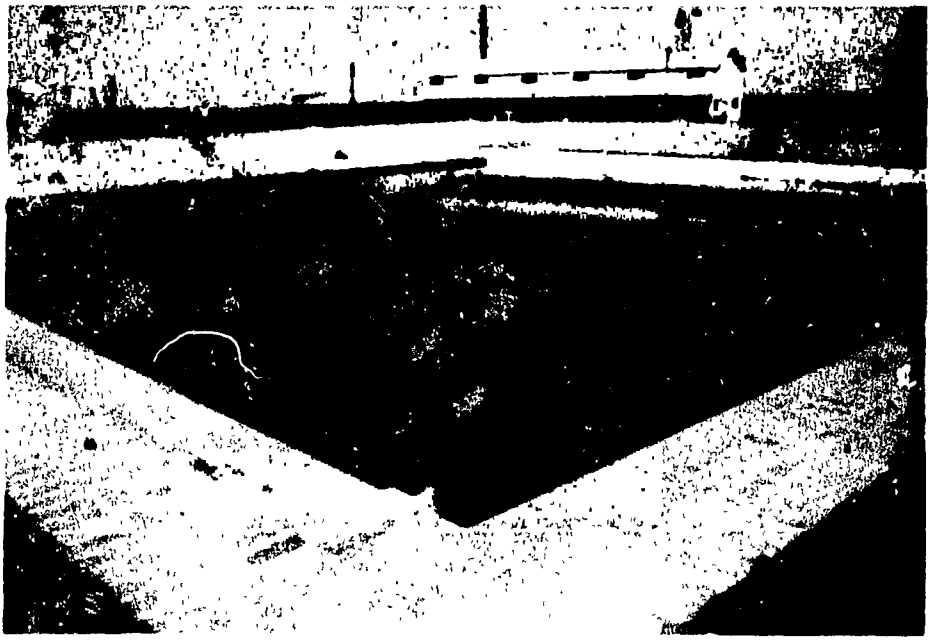

Fig. 8 A Solar Pond in India.

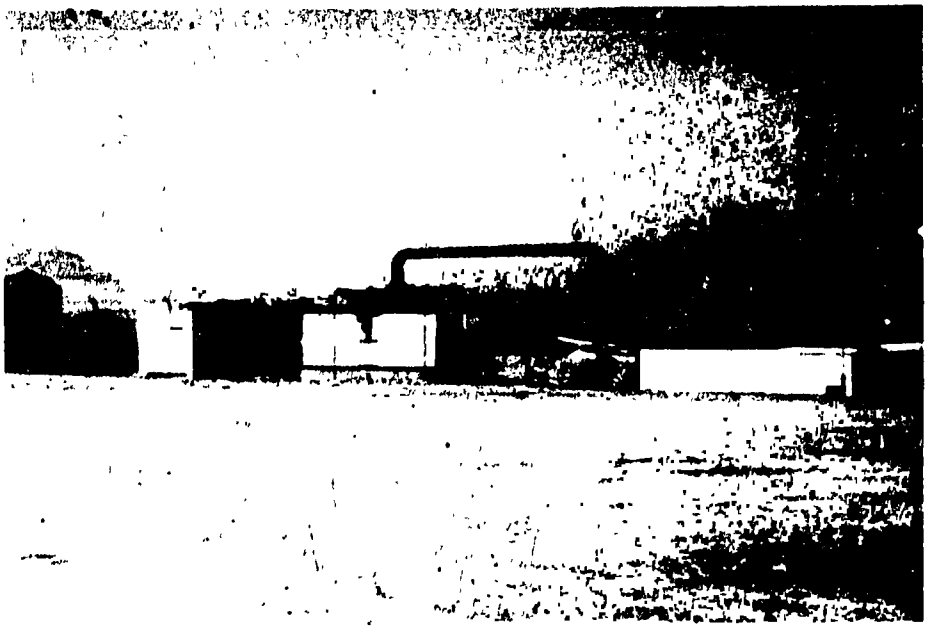

Fig. 9 Solar pond and Power Generator at Ormat Plant, Israel

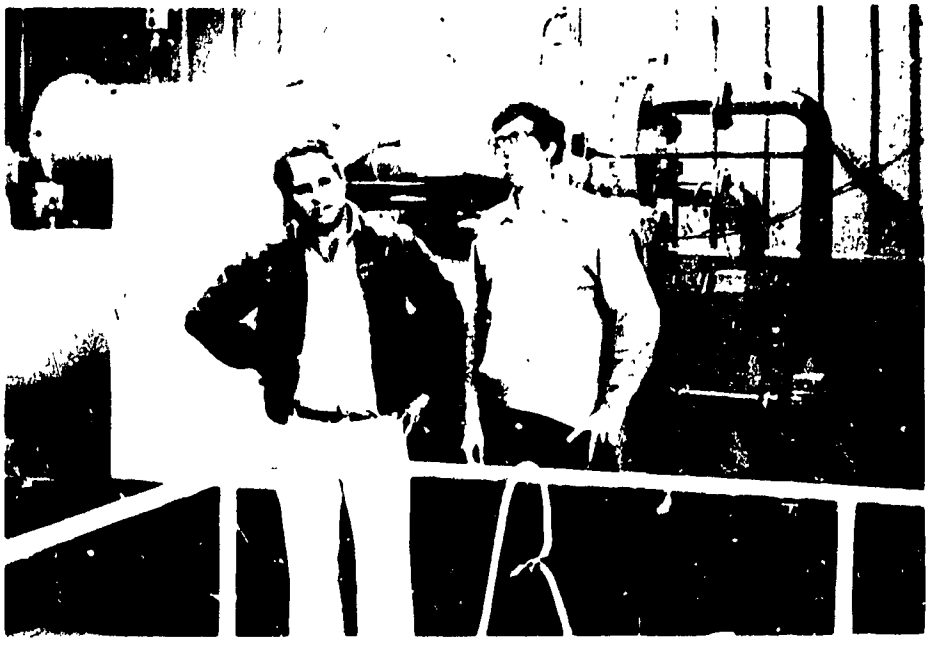

Fig 10 Six KW Vapor Turbine Driven Generator at Ormat Plant.

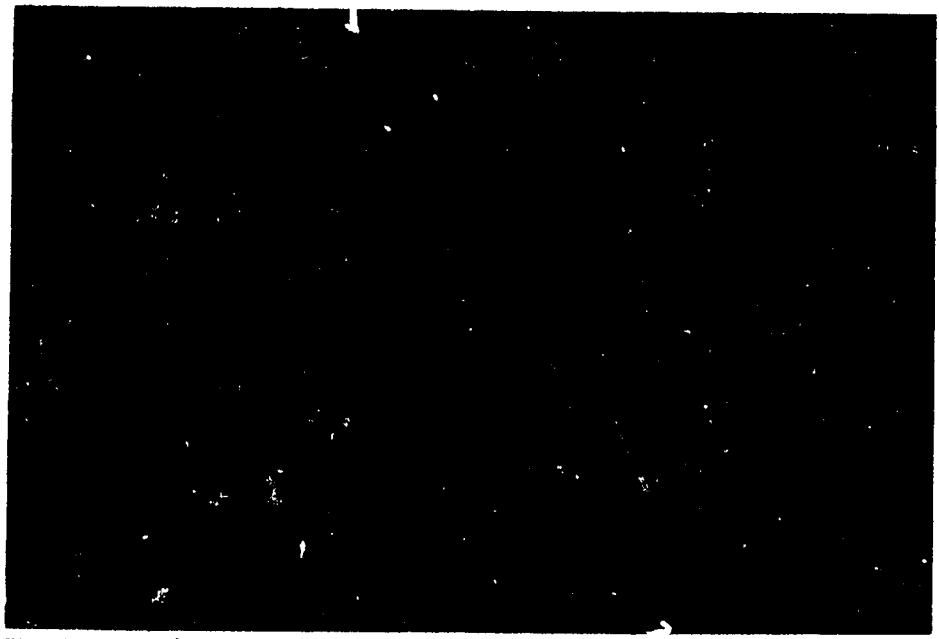

Fig. 11 7,000 M^2 Pond Runs a 150 KW Power Generator at the Dead Sea, Israel.

Fig. 12 Temperature Gradient, GT, VS. Specific Gravity Gradient, GC.

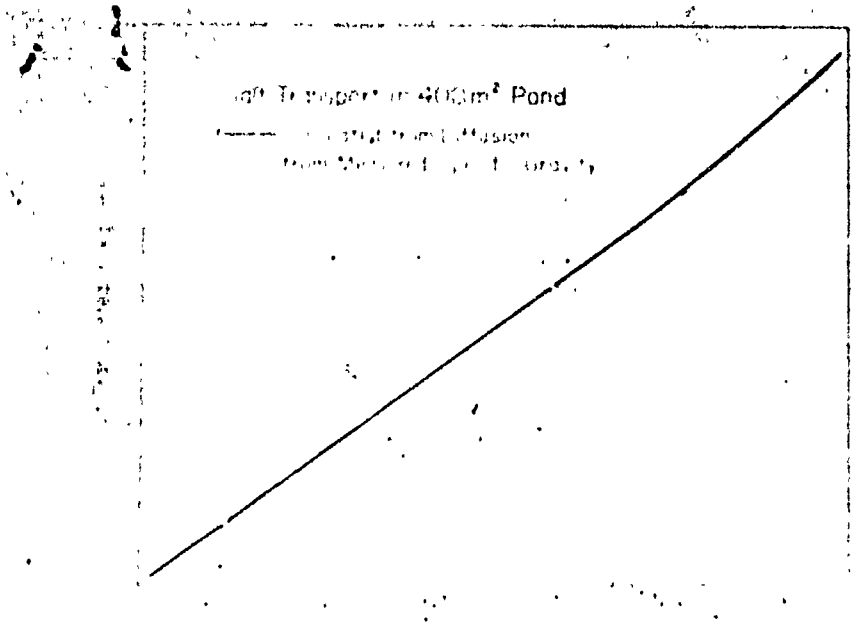

Fig. 13 Salt Transport in 400 M² O.S.U. Pond.

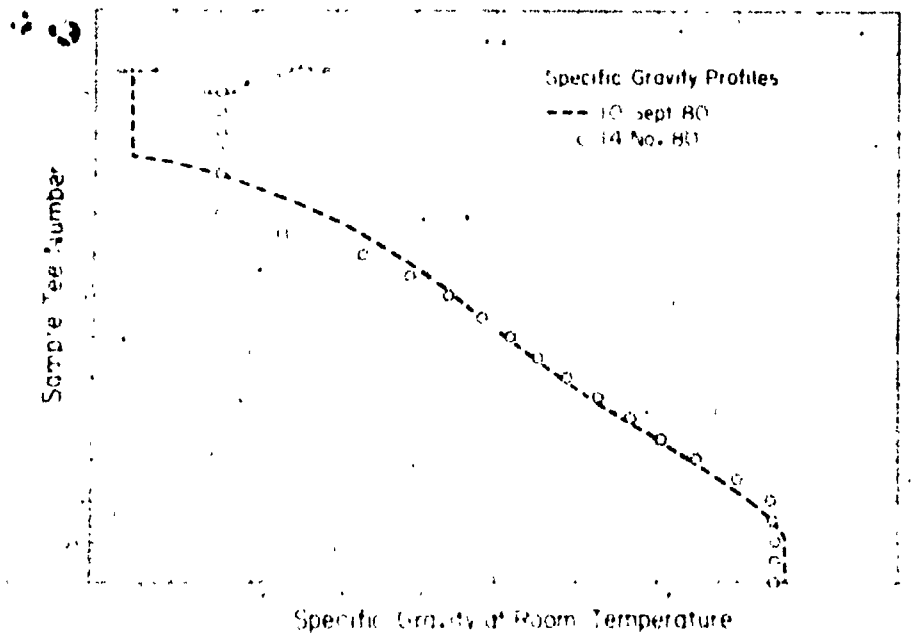

Fig. 14 The Downward Movement of The Specific Gravity Profile in 400 M² O.S.U. Pond.

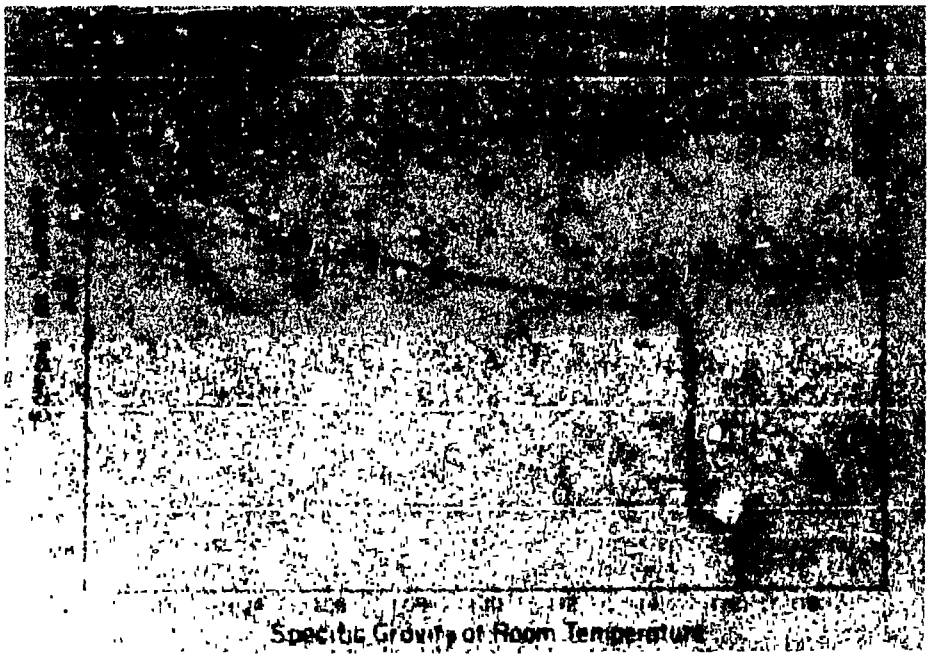

Fig. 15 The Upward Movement of The Specific Gravity Profile in 400 M^2 O.S.U. Pond.

REPORT ON SOLAR SALT PONDS

by
Dr. Carl E. Nielsen
Salinity Gradient Solar Pond Program

Backgound

Solar ponds can be constructed at the lowest cost per unit area of any solar collector, and they combine intrinsic storage capacity with a long term average collection efficiency comparable to that of conventional flat plate collectors. They are therefore very promising for utilizing solar energy to provide low temperature heat, and for solar thermal electric power generation in favorable sites. However, they are not yet in commercial use anywhere either for heat or for electric power, and there are some aspects of pond operation on which further research is needed.

Objectives

It seems likely that solar ponds can become a significant alternate energy source in Taiwan. In order to make their early application possible it is eppropriate to carry out a pond research program here. This program will (1) insure that workers here remain aware of worldwide developments in solar pond research and application, and (2) provide for the necessary study of questions specific to the construction and operation of ponds here.

In line with these objectives a research pond will be constructed and operated at a site provided by Taiwan Salt Works, and studies will be made of the feasibility of using solar ponds for providing process heat for the Salt Works and for electric power generation.

Research Program

Questions being studied elsewhere at present include methods for heat extraction, and procedures for the control of surface zone thickness. These questions will not be primary here.

There are two adjacent brine holding ponds available for solar pond research at the Salt Works. These are unlined. It has already been determind that water of 12% salinity is present at 2 m depth below the bottom of brine holding pond at this site, but it is not known whether this is to be considered ground water or seepage from the brine formerly in this holding ponds.

The Following pond research is recommended:

1. In order to study ground water movement and thermal properties of the earth, thermocouples will be installed at the under and on four sides of one existing brine holding pond. A gradient will be established and the performance as a solar pond will be studied. This will be done as soon as possible, without modification of the pond on addition of a liner. If possible the

thermocouple array will be installed without emptying the pond. Information about groun water movement will be obtained from comparison of temperatures at the four sides of the pond. Information on thermal properties of the earth and the depth of any heat sink that may exist will be obtained by analysis of the downward propagation of the temperature wave produced as pond temperature rises. Information about permeability of the earth will be obtained from accurate observations of salinity profile in the pond gradient zone. Leakage results in downward movement of the profile.

2. In order to compare pond operation using bittern with that using mixed concentrated brine, a second holding pond will be emptied, the walls reconstructed to uniform slope, a thermocouple array installed, and a plastic liner installed. Comparison of pond operation with sodium chloride and with magnesium chloride has not previously been carried out. One matter of especial importance is the question of surface zone behavior in the two cases.

3. Concurrent with the experimental pond program, feasibility studies relative to use of solar pond heat in various salt works processes will be carried forward as time permits.

4. Experiments will be undertaken to develop an understanding of wind control procedures required for large ponds.

5. The effect of heavy rainfall on pond surface zones will be observed to determine whether any special procedures are required for protection.

SOLAR COOLING

by
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Thank you very much Dr. Yeh, Ladies and Gentlemen. It is a great pleasure and honor to be here today and to speak to you on this program. My speciality is solar desiccant cooling. I was asked to first run through and review the overview of all solar cooling options. This is a bigger load than time allowed. I would try to do my best, I am sure I will be omitting certain things partly because of time being short.

Before we start talking about the solar air conditioning and solar cooling, we have to know what our competition is and what we are up against. Tradditionally, cooling is done either by vapor compression or absorption machine (absorption chiller), using typically NH_3-H_2O system driven by heat. Usually for larger installation, this system has good efficiency.

There are a few air conditioning systems operated by absorption chiller but they are not widely accepted. The other option, of course, is vapor compression system. Major components are condenser, expension valve, evaporator and compressor. The C.O.P. of this unit, we have to know from the onset in order for us to know what we are competing against, is between 2 and going up to 3 now. The C.O.P. means non-dimensional unit; i.e. unit cooling divided by unit energy input. For the most advanced systems, one must be careful with this number because we could see solar operated air conditioning systems that look very good, but if we look carefully, they said they have chiller C.O.P. 5 or 6. Now, if we have chiller C.O.P. 3, 4, 5 and 6 for the solar power system, we can have it without solar for few penies. We have to watch out for that. The compressor in the vapor compression system is driven in very different ways. It can be driven by ejector pump, engine or different source, Diesl engine or electrical motor; this is the most common mode to drive electrical motor.

Now, we come to solar air conditioning system. We have the following two options: either it provides electricity by photovoltaic cell, they said it is not cheap though we may have it in the future. I hope it will be but this is unsure in my opionion. If we have electricity, we can drive the electrical motor, which in turn we will drive vapor compression chiller which is very good efficiency unit. The other alternative is to use solar collectors. If we use the solar collectors, we can use them either to drive expander, the turbine, Stirling engine which we will be hearing later, or any other means or driving the standard compression cycle or we can alternatively use heat directly to drive absorption or desiccant cooling systems. All these require collector, and this is where the problem arises.

Today, collector is very expensive, I think I can say without reservation they are not competitive for cheap cooling, contrary to what one might think, solar energy is available in summer

when we need cooling, that is, source energy is in phase with the need. Nevertheless, when we look into this system, it is not in the state one can say it is competitive economically today. We will point out what the problems are and what to do about them.

In my talk, one of what I am planning to say is that collector today is too expensive. What we should do is to limit them altogether if we can. There are two options, either make them very efficient or make them very cheap. It is not clear that which way to go. Of course, the best way is to make them efficient and very cheap. And I would say something about them also. The other thing to worry about is that parasitic power should not be large. Parasitic power is the electrical power which we need to drive solar components.

We have to remember that we don't use large amount of electricity. We can easily get into this trap. If we use more electricity in solar cooling, then we might as well drive comparable vapor compression engine. And other things we have to watch out is auxiliary system. If we have to supply most power energy from solar, particularly all of it, that is possible but is difficult. Therefore we should supply some of the energy by other means to supplement the solar power system.

For example, to supply the electricity to supply heat, we are of course able to make it, because of C.O.P. of any solar driven systems will tell us today to be of 0.7. If we drive it by using electricity to supply heat in order to get chilling and cooling with the C.O.P. of 0.7, we should remember that we could use this electricity to obtain C.O.P. of 3 to get air conditioning. So, we have to watch out for these things.

Solar powered air conditioning is classified as passive and active. Passive air conditioning includes evaporative cooling, rock bed colling and nocturnal radiation.

In evaporative cooling, outside air is being humidified thus cooled before entering the house. Rock bed cooling is accomplished by passing cool air at night (or humidified air) through a rock bed, cooling it down, and during the day to pass air through the cooled rock bed and back into the living space (Fig. 1). Examining the processes on a psychrometric chart it can be seen that evaporative cooling ends up with higher air temperatures than when rock bed cooling is used (Fig. 2).

Nocturnal cooling is accomplished by cooling water, usually in plastic bags, located on the roof (Fig. 3). During the night the water bags are exposed to the environment and during the day an insulation cover is pulled over them and the living space underneath is cooled.

These schemes provide only sensible cooling and they work well where the night air is cool and/or the humidity is low and the skies are clear. Passive latent cooling can be accomplished by incorporating desiccant sections into the walls.

Active cooling schemes include vapor compression chillers driven by ejectors, turbines or electricity from photovoltaic cells. Another option is heat driven absorption systems or desiccant dehumidifiers.

Photovoltaic cells are at present too expensive for use with chillers and the efficiency of

ejector pumps is very low.

Rankine cooling systems include solar collectors, a turbine and a chiller (Fig. 4). The efficiency of the turbine increases with increasing inlet temperature while the efficiency of the solar collectors decreases with increasing temperature. Therefore, an optimal operating temperature for the combined cooling system exists (Fig. 5). This optimal temperature is about 90°C for flat plate collectors. An high performance integrated CPC collector, also known as the shaped tube collector (Fig. 6), (Fig. 7), has recently been developed at the University of Chicago.

We have performed a steady state analysis as well as an hourly simulation for Rankine air conditioning systems using both flat plate and integrated CPC collectors (Fig. 8). The optimum temperature for the integrated CPC collectors is 280°C and the cooling output is two & one-half times higher than when flat plate collectors are used. The integrated CPC collectors also lend themselves to mass production and the material cost is relatively low.

Presently, solar powered absorption systems using lithium bromide operate at somewhat lower regeneration temperatures than conventional absorption chillers. Arkin in the U.S. (Fig. 9) and Yazaki in Japan (Fig. 10) have produced a limited number of solar absorption chillers which operate at 80 to 90°C at a COP of about 0.7. These systems are at present prohibitively expensive primarily due to the cost of collectors and no significant chiller performance improvement is expected.

Liquid desicant systems typically use lithium chloride or glycol solutions (Fig. 11). Air from the space is passed through the dehumidifier which contains a strong solution. The dry air then passes through an evaporative cooler where it is humidified and cooled. Heat from the solar collectors is used to drive the water vapor out of the solution and the strong solution returns to the dehumidifier. Alternately, the desiccant solution can be regenerated as it flows slowly over an asphalt roof (Fig. 12). This approach appears promising since collectors are eliminated.

A solid desiccant closed system to provide refrigeration is presently being manufactured by the Zeopower Company where the desiccant is Zeolite and the entire system operates under a vacuum (Fig. 13). During the day, solar heat drives the water vapor out of the Zeolite and the water is condensed in a container. During the night, the water evaporates in the evaporator and the heat is being rejected by convection and radiation to the atmosphere through the collectors which absorbs the moisture (Fig. 14).

Open cycle desiccant cooling systems are being developed in the United States by Airsearch, IGT and IIT. The Airsearch system uses silica gel in rotating drums (Fig. 15). Air from the residence passes through the dehumidifier bed, it then goes through the heat exchanger where it is cooled and finally it passes through a humidifier, and into the conditioned space. Another stream of air, heated by the solar collectors first goes through the heat exchanger, and then through the desiccant bed which is regenerated (Fig. 16). The IGT system uses rotating wheels rather than drums (Fig. 17), (Fig. 18). They use molecular sieve which requires higher regeneration temperatures.

The IIT desiccant cooling system, (Fig. 19), uses fixed beds rather than rotating wheels or

drums (Fig. 20). The desiccant is 9 micron silica gel particles formed into sheets by a special manufacturing process (Fig. 21). The novel concept of the IIT system is that the desiccant bed is being cooled while undergoing dehumidification. This increases the sorption capacity and the coefficient of performance. A 0.8 x 0.8 x 0.8 meters dehumidifier which has a capacity of about one ton was designed and built (Fig. 22). The dehumidifier was first tested in the laboratory and subsequently an entire cooling system consisting of two dehumidifiers and heat exchangers was built and tested (Fig. 23). As expected, the system performance increases with increasing room temperature and with decreasing ambient temperature and ambient humidity ratio (Fig. 24).

We have also performed a theoretical analysis of the performance of the system and solved the equations of conservation of heat and mass for the sorption processes. Following the classical approach of Hougen and Marshall that consider gas film resistance only, we found that the theoretical predictions strongly deviate from the experimental results. We have devised a fairly simple scheme which assumes a linear distribution of moisture within the desiccant. With this modification, the agreement between experiment and analysis is good. Using this simulation procedure we obtained performance maps for the system (Fig. 25). The performance predictions were then cast as quadratic algebraic expressions which were incorporated into a transient simulation model for the system. Preliminary results show that 56 meters square of Solaron 3000 collectors provide 90% of the cooling required for a typical residence at a daily COP of about 0.61 (Fig. 26).

We had also determined that the cooled system is less sensitive than adiabatic dehumidifiers to the heat exchanger effectiveness and that the required regeneration temperature for the cooled bed is 65°C while the required regeneration temperature for the adiabatic bed to give the same quality of process air leaving the system is 82°C (Fig. 27).

All the desiccant cooling systems considered so far have a COP which is disappointingly low – 0.5~0.7. In an attempt to understand the constraints and potential of open cycle cooling systems, we have performed a reversible thermodynamic analysis of such systems. The performance of the system now depends not only on the temperatures but also on the humidity ratios. We have determined that it is possible to express the combination of temperature and humidity ratio as an apparent temperature for the evaporator and the condenser and that the reversible coefficient of performance at ARI conditions is about 4.0 for open cycle systems (Fig. 28). This compares to 1.8 for closed cycle systems. It therefore appears that the performance of open cycle desiccant cooling systems can be substantially improved. A component energy analysis is now being carried out at IIT.

Some recent development and research into improved desiccant system performance is the wound ribbon concept where silica gel particles are attached to a very thin nylon ribbon which is wound to form the dehumidifier and the use of a heat retaining substance jointly with the desiccant to increase the thermal capacity during the sorption processes.

Another concept is a hybrid arrangement where conventional and desiccant cooling systems are combined to improve the overall system performance – an example being the use of heat rejected to power a dehumidifier (Fig. 29), (Fig. 30).

Fig. 1 Rock Bed Cooling.

1. Outdoor Air Temperature
2. Supply Air Temperature
3. Room Exhaust Temperature

Cycle performance for RBR
compared to a simple evaporative cooler.

Fig. 2 Cycle Performance for Rock Bed Regeneration Compared to a Simple Evaporative Cooler.

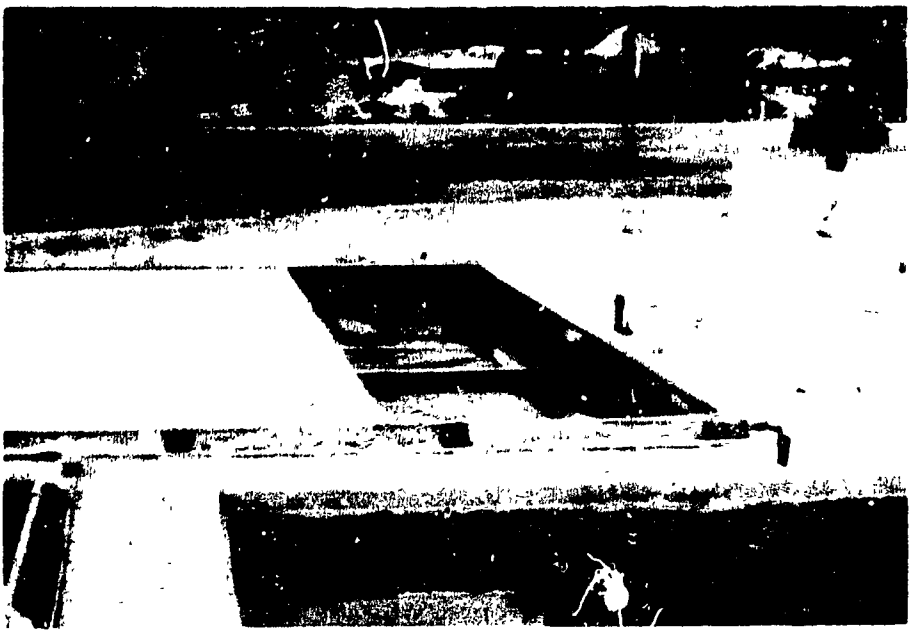

Fig. 3 Radiative Cooling.

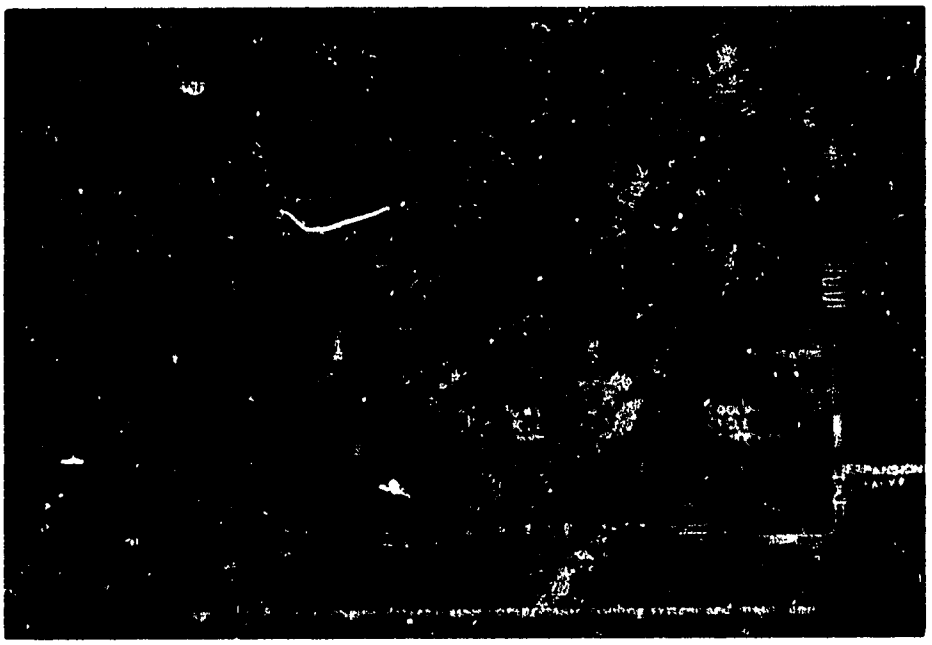

Fig. 4 Diagram of Rankine Engine Driven Vapor Compression Cooling System and Major Units.

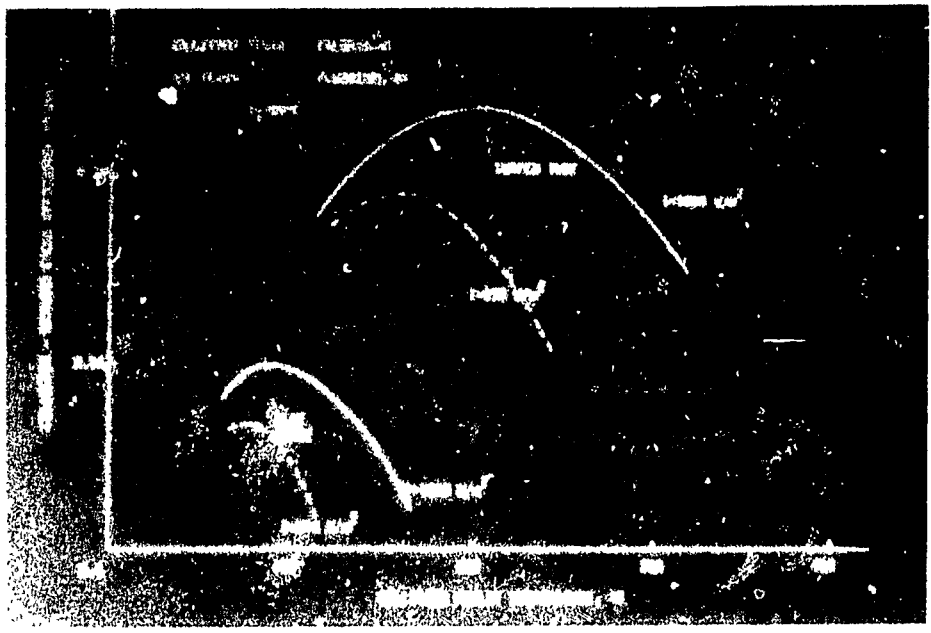

Fig. 5 Combined Collecter-Rankine Cycle Efficiency.

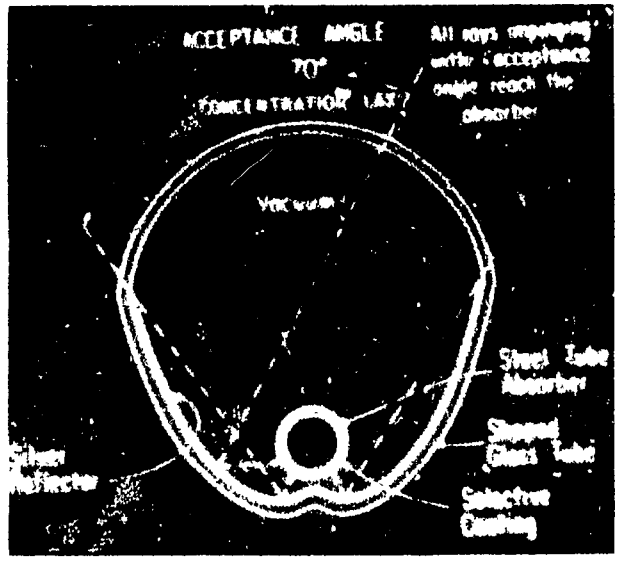

Fig. 6 Cross Section of Concentrating Tube (Compound Parabolic Concentrator).

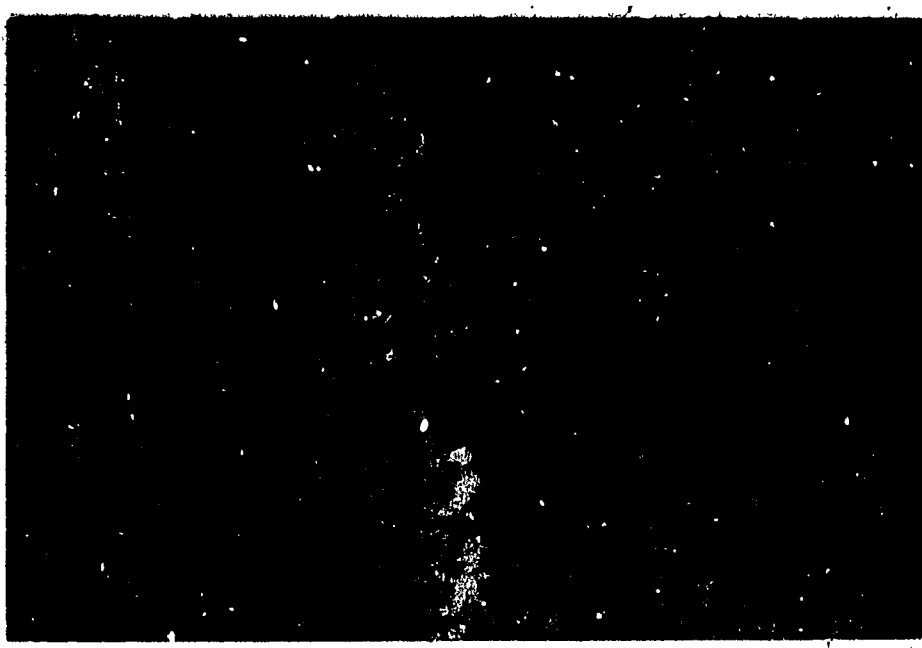

Fig. 7 Efficiency Curves for Shaped Tube and Double Glazed Flat Plate Collectors.

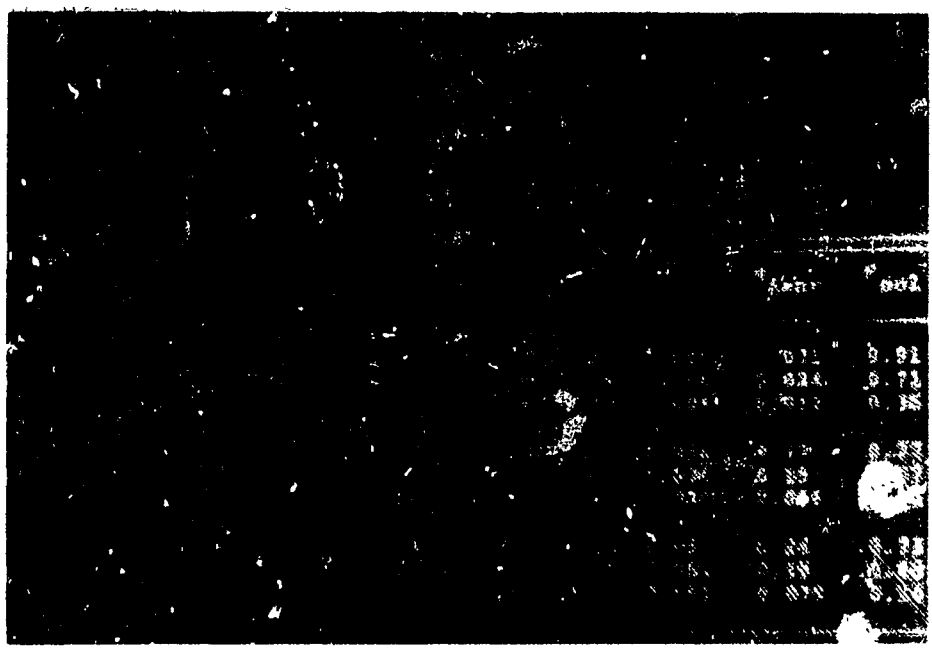

Fig. 8 Simulation Results for Rankine Air Conditioning.

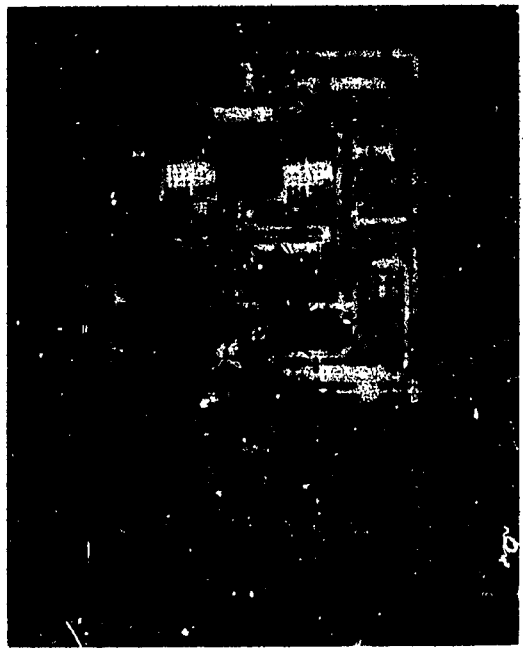

Fig. 9 Schematic Diagram of the Arkla 3-ton LiBr-Water Absorption Chiller with Built-in Evaporative Cooling.

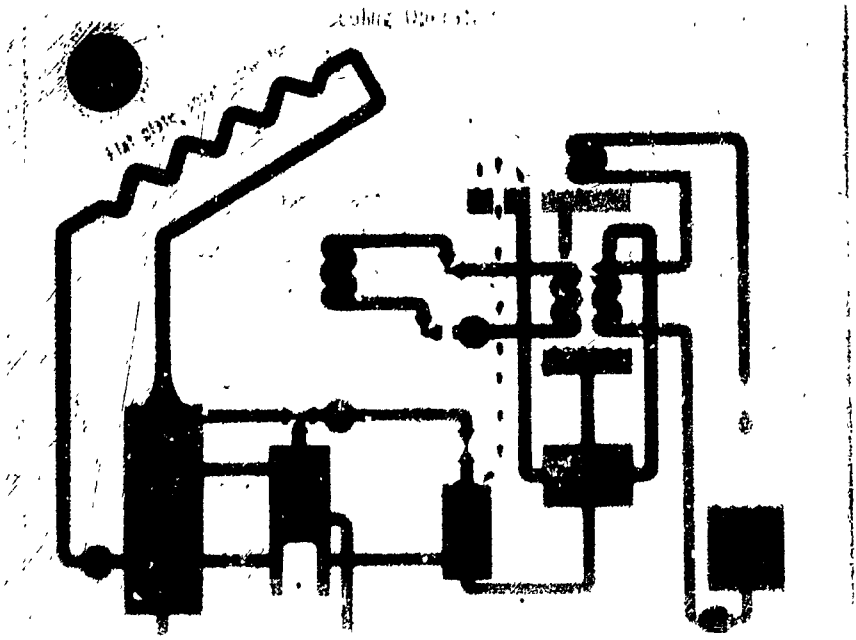

Fig. 10 Schematic Diagram of the Yazaki LiBr-Water Solar Absorption Cooling System.

Fig. 11 Diagram of a Liquid-Desiccant System with Air Heating Collector.

Fig. 12 Regeneration Roof for Liquid-Desiccant System.

Fig. 13 Eco-Power Company Solid Desiccant Closed System.

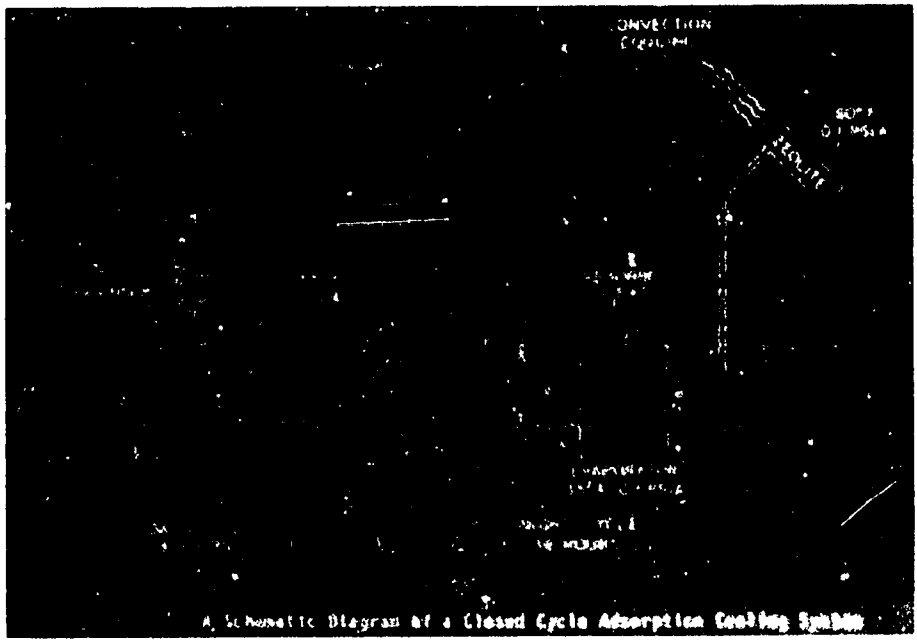

Fig. 14 A Schematic Diagram of a Closed Cycle Absorption Cooling System.

Fig. 15 Airesearch Desiccant Cooling System.

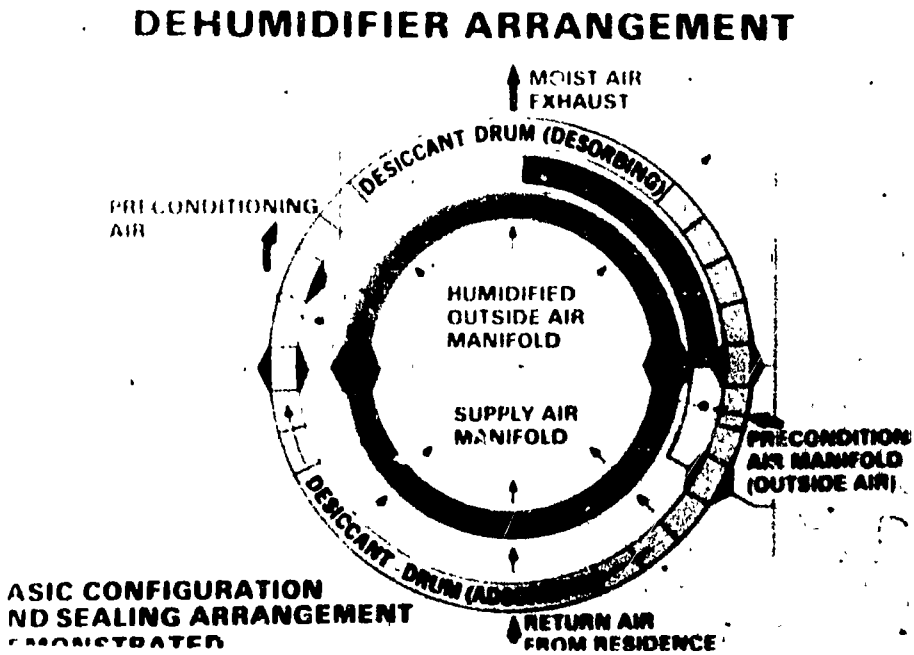

Fig. 16 Dehumidifier Arrangement of Airesearch System.

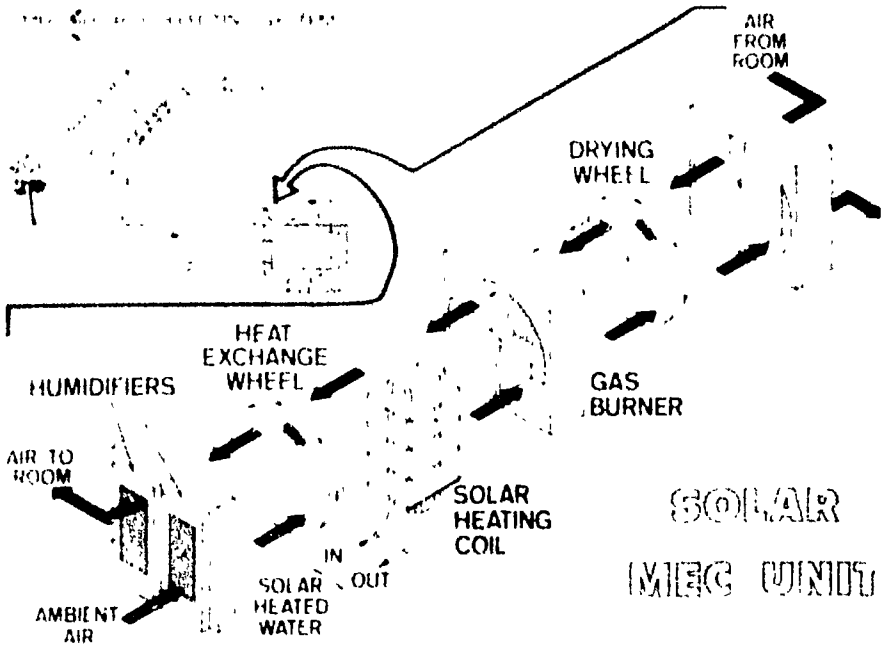

Fig. 17 IGT Desiccant Cooling System.

Fig. 18 Diagram of Rotary Axial-Flow Dehumidifier/Regenerator.

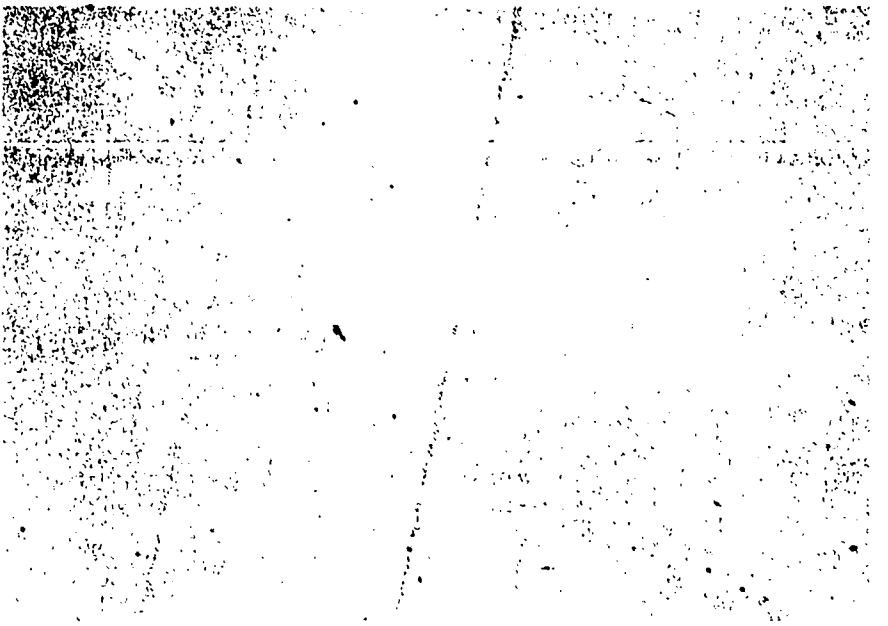

Fig. 19 IIT Desiccant Cooling System.

Fig. 20 IIT Cross-Cooled Dehumidifier.

Fig. 21 Structure of Silica Gel Sheet.

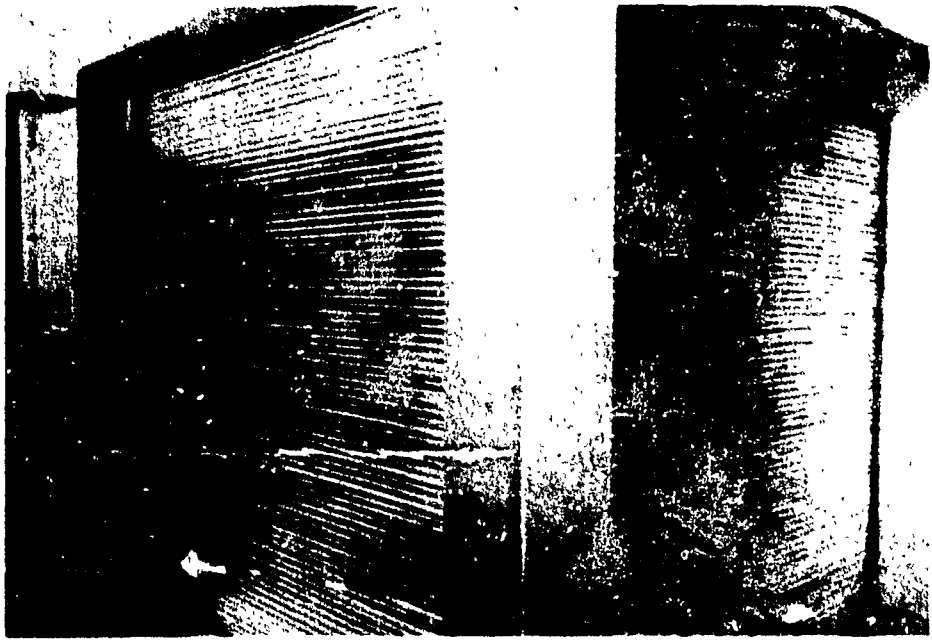

Fig. 22 Cross-Cooled Dehumidrfior Prototype.

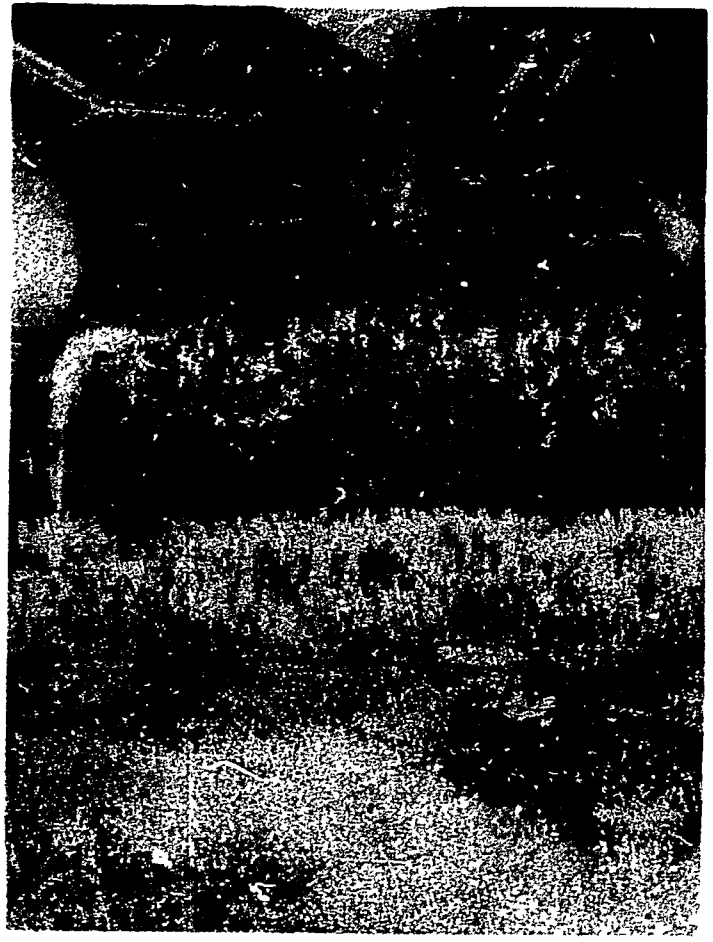

Fig. 23 Cross-Cooled Desiccant Cooling System.

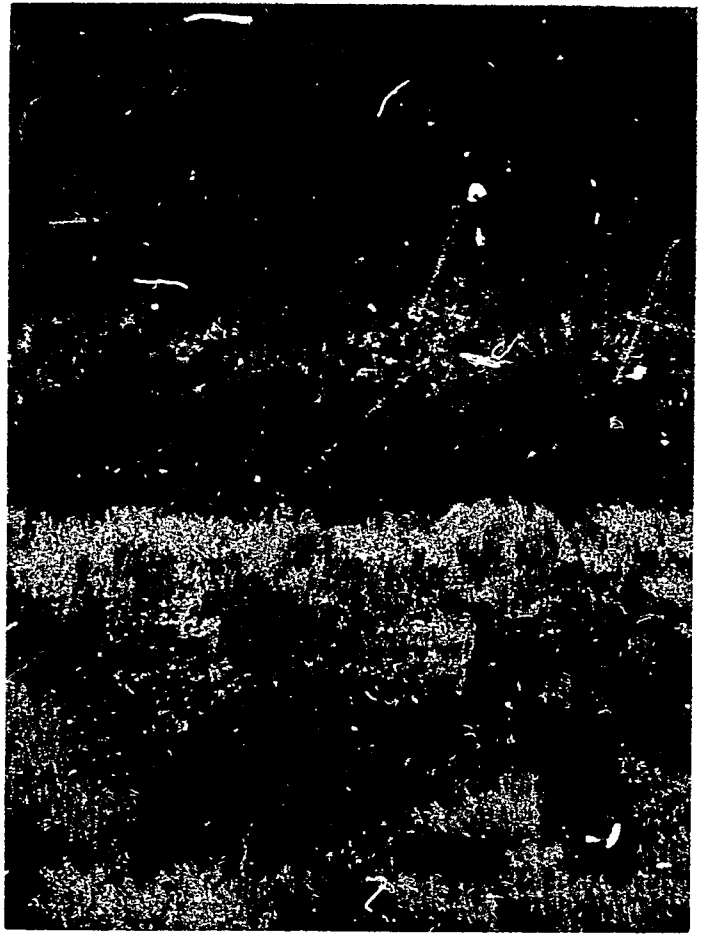

Fig. 24 Effect of Ambient Absolute Humidity on Cooling Capacity and C.O.P.

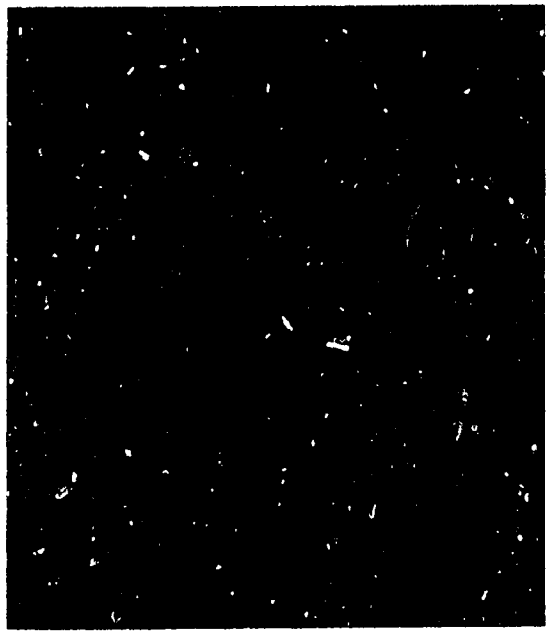

Fig. 25 Performance Map for Desiccant Cooling System.

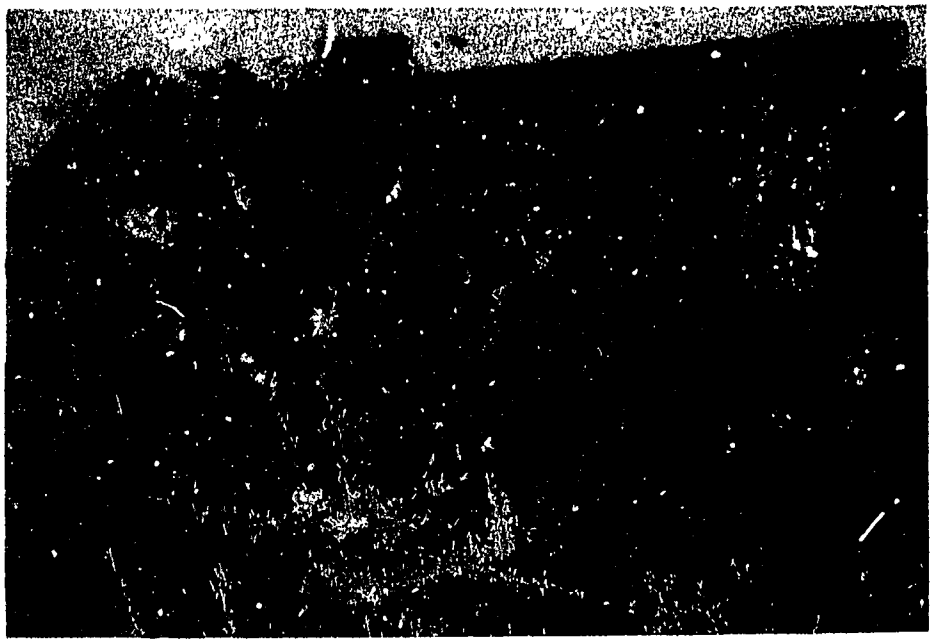

Fig. 26 Collectors for Desiccant Cooling System.

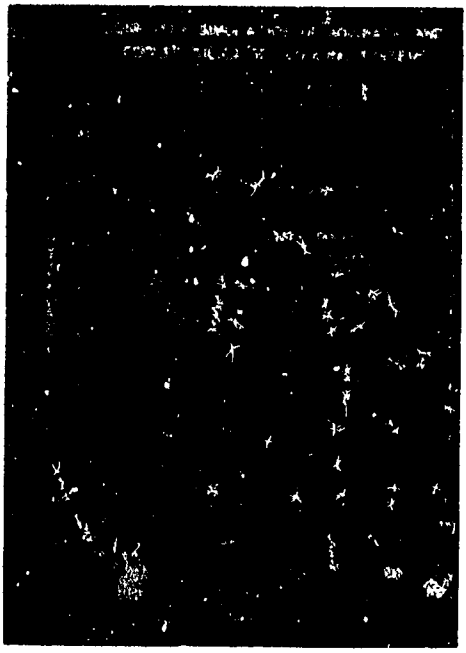

Fig. 27 Computer Simulation Adiabatic and Cooled Silica Gel Cooling Systems.

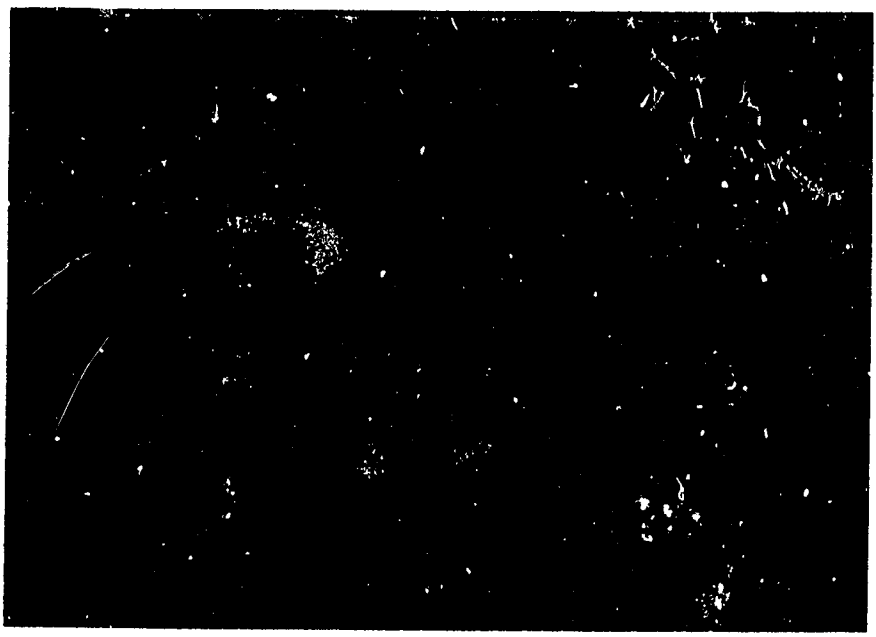

Fig. 28 Isontropic COP VS. Outdoor Humidity Ratio.

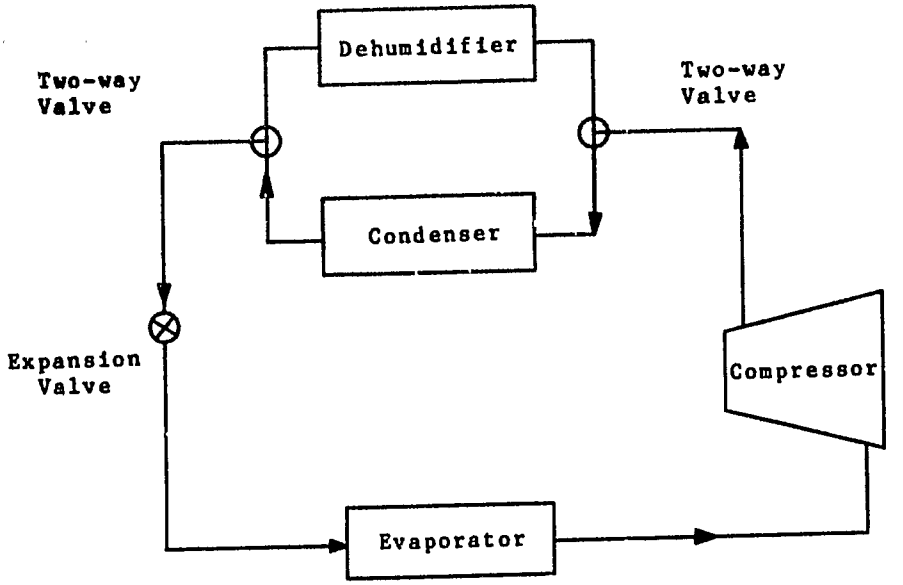

Fig. 29 Hybrid System Refrigerant Flow Schematic.

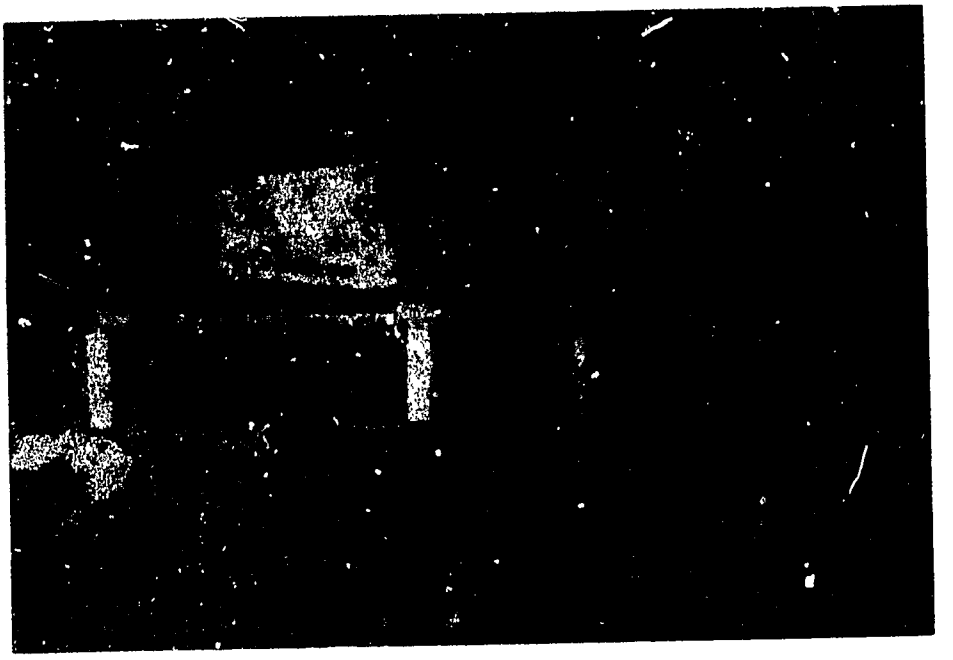

Fig. 30 Prototype of Hybrid System.

REPORT OF SOLAR COOLING

by
Dr. Zalman Laven

A. Needs and Objectives

1. There is a need for air-conditioning in Taiwan throughout most of the year.
2. The latent cooling load is particularly high.
3. The highest priority is air-conditioning for industries such as electronics and textiles.
4. Air Conditioning of buildings for occupant comfort is also important.
5. Develop a first hand capability in solar cooling technologies that are most likely to benefit Taiwan needs.
6. Help develop a solar industry for both local and export.

B. Evaluation of Solar Cooling State of The Art

1. Presently active solar cooling is prohibitively expensive due to the high cost of collectors and the low COP of the cooling systems.
2. Ejector cooling systems are very inefficient and operate poorly at off design conditions.
3. Photovoltaic cells are too expensive for driving vapor compression systems.
4. Rankine chillers can benefit from high performance (low heat loss) collectors.
5. Absorption and Desiccant systems can benefit from inexpensive collectors operating at 60-90°C.
6. Open Cycle cooling systems have a high potential for performance improvement.
7. Liquid desiccant systems can be operated without collectors, thus vastly reducing system cost.
8. Cooled or isothermal dehumidification is preferred since
   (a) Cooling capacity is increased
   (b) COP is higher
   (c) Lower regeneration temperatures are required
9. Laminar channel flow is preferred for sorption processes of solid desiccant cooling system.
10. Hybrid cooling systems appear attractive. For example use the heat rejected from the chiller condenser, from the exaust gases of a turbine or from the cooling water of a diesel engine to provide dehumidification.
11. Rock-bed cooling and nocturnal radiation are cost effective when night air temperature is low and the skies are clear.

C. Recommended Research and Development Activities For The Republic of China

1. Evaluate the possible combination of air-conditioning need and availability of waste heat or geothermal energy.
2. Carry out research and development on solid and liquid desiccant cooling systems preferable in cooperation with a foreign research unit.
3. Carry out research and development on hybrid (conventional-desiccant) cooling system.
4. Keep up with research and development activities in absorption cooling and in Rankine

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cooling.

5. Cooperate with local manufacturers toward production for both domestic use and export of
   (a) High temperature non-tracking collectors (~250°C)
   (b) Inexpensive medium temperature collectors (~80°C)

MINI-HYDRO

by
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75016 Paris
France

We are going to speak now about a technology that has been around for quite a long time and for a while they were abandoned because it became so cheap to generate electricity by other means. Then, the rapid increases in oil, for example, began to load a gun at hydropower. In the United States, in my career, we began to look at the big ones and I soon found that I had to go into another field. But, here I am back in this field again.

Figure 1 is just to show you how old hydro is. And this is from the western part of the world. In this part of the world it is even older. Waterwheels are still around and can be very efficient. There is nothing wrong with the water wheel except that to get the kind of power we need nowadays, the water wheels would have to be so large that it would be impossible to use them. The problems are not so much with technology as they are institutional, and immediately we run into the problem as we were discussing yesterday, of what do we mean by mini-hydro. When I first came here, to this meeting, I had one idea in mind and I found out I really wanted to talk about something else. This has been a problem all around the world since we have been talking about small hydro. What is small hydro, what is mini, what is micro, tiny or whatever you want to call it. There is no special definition but there really are people who are beginning to say may be we ought to try and standardize our definition.

Figure 2 is just one organization which is a United Nation's related group in Latin America for energy, suggested just this sort of thing.

In the United States we started out oringinally talking low head. We assumed immediately that anything with low head was small. Well, we soon began to realize, that the Columbia River for example, has a number of by definition low head hydro plants. But we certainly wouldn't consider them small by any definition. And so there obviously is a combination of H and Q.

Small hydro was a political definition in the United States at that time about 15 megawatts or smaller and about 20 meters at head or less. It was political because they were talking about loans grants, so everybody accepted that definition immediately and started talking about giving money on the basis of that definition.

To let you know how much hydro had actually died, in the United States at least. When I was at the University of Idaho, at that time we decided to give a short course in designing small hydro plants. We advertized this course, and one of the first groups that asked us to come and

present this week-long course was the U. S. Corps of Engineers. Now, I hope you understand what I have just said. When you start to teach the U. S. Corps of Engineers something about hydro electricity, well, you realize hydropower had begun to go out of favor, because the Corps of Engineers of the United States is one of the biggest organizations for hydropower and has been traditionally taking the most responsibility in developing it.

There are a number of problems with small hydro projects and most of them are not technical problems, most of the ones that I have seen are institutional problems. First of all, of course, is the heavy investment in cost per installed kilowatt. In terms of small hydro, we have the problem that we have been used to thinking in terms of large hydros. When we began to study this problem, we don't gear our thinking down and we immediately start full fledged feasibility design studies. And pretty soon we find that we've got so much invested in studies that we can't afford to finish the things. The cost of small hydro in proportional to the studies could be overwhelming. If you talk about R.O.C. this would make the whole system uneconomical based just on the cost of studies. Of course, we haven't had a whole lot of experience in the United States in these small studies, particularly financing organizations have not had a lot of experience and they're very leary of small projects. If we start talking about 5 or 10 megawatts or smaller as compared to 150, 200 or 1000 megawatts plants, it is a completely differnt scale and financing organizations just are not used to dealing with these small ones. For example, the World Bank would find it very difficult to fund a 5 megawatt plant.

Another problem in terms of small hydro is that too often that it has been an assumption that all you have to do is providing the electricity in the rural area and there would be a blooming transformation completely changed social economic system as a result simply puting in electricity. Up a few years back, there was a conference in Washington D. C. sponsored by the Corps of Engineers. In which, there were a number of speakers dead set against the small hydro. Because the experience they had with a country supported small hydro systems, rural systems, not connected to an electrical grid. In which the experts came in, built a system, had it operating marvellously, walked away, and within a short time something happened, the system broke down and nobody was prepared, in any sense, to repair and get the system going again. They depended so heavily upon the fund and experts.

Figure 3 shows an ad. appeared in a number of newspapers in Idaho about the time we had conference on low head hydro. You can see the top, it is "Bulb Turbines, They'll help, But They Can't Solve All Your Energy Problems". This was produced by the Idaho Power Company in the State of Idaho. It is not an uncommon reaction by utility companies. They can't see the small things that is doing much more then providing a lot of troubles for American and they can't if they're not properly developed.

In United States, you can go just a few miles on the rivers in the Northeastern, you will find another dam. They have been built originally to provide mechanical power for industries along the river. And then once the electric generator was developed, they can convert it to electricity for much more efficient application of the energy. Then, when the oil came in, the price of oil was so cheap that the hydro power developed from these dams could not compete and people just abandoned the dams, they would pull down the turbines, the generators, and sold them, or junk them and these dams became the scienic places rather than working hydro power sites. Then, once the oil price came back, people began to look at these sites again and the U.S. Department

of Energy started the program on low head hydro. The 20 meters turned out to be the political term.

The ad. by the Idaho Power Company saying "OK! There is some electricity but it is not going to solve the problem". And it is not, in any case nobody should think small hydro was going to solve the problem, but it was going to contribute to the solution.

Another problem was that no matter what the size of your unit was, you still had to go through the full licencing procedures as you had another Grand Cooley Dam. From now, for small units, the Federal Government said there is a simplified system which made a lot more senses proportional to the size and the output of those dams. In addition, the Federal Government now says that the utilities must buy the electricity produced by these units. Not only they buy it, but they must buy it at essentially the marginal cost production of the next unit that the utilities would have to build in order to supply more electricity.

Now, what is the small hydro, what is hydro. Hydro is a system which can include a dam intake works, conduct system, silt basin, forebay, penstock, power house, power system and tailrace. Every one of which is particular for sites. And it is not the way just coming in with a package by a helicopter and saying: "Alright now, just install it". It depends on where you are, what kind of system the hydrologic system is.

In the very small hydro system what you want to do is going from prefeasibility directly to design and try to eliminate any formal feasibility studies as you can. For the smaller ones, you want to use much more local material, your drawing is going to be the kind that the local person can understand. And it is not necessary to do all the same as you do for larger ones. In a very small system, if you have diversion structure, the dam might be replaced by a number of large boards. When the flood comes, it washes out the boards, you just find some more boards and put them in there, the system will function again. This can reduce the cost in building the dam in a traditional way considerably.

SMALL HYDRO TECHNOLOGY

Basic Hydraulics

Hydroelectric energy technology has been around for a long time. The basics are rather simple:

$$P_{kw} = \frac{QHe}{11.8}$$

Where P_{kw} is power in kilowatts, Q is water flow rate in c.f.s., H is the net head available to the turbine/generator in feet, and e is efficiency.

Thus, some of the first things an engineer must determine are (1) how much water is available in a river (and when), and (2) how much head (drop) is potentially available (and when). From

the basic information he will bogin to try various configurations of dams, penstocks, etc. – including the type of turbine – in order to minimize the cost while producing as much power as possible. He usually conceives a number of possible configurations, each of which must be evaluated in more or less detail.

Turbines basically fall into two categories: Impulse and reaction.

Impulse Turbines:

On this kind of turbine "buckets" on the periphery of a wheel are moved by the force of a jet (or sets of jets). The available (net) head is converted to kinetic energy, of which a portion creates the torque. Generally, impulse turbines are used for high heads, although one modern design is efficiently used in the low-head range.

Impulse turbines are enclosed in a case, but operate under atmospheric pressure in air. There is, therefore, some unused head because they must effectively be set above the tailwater level (they can be operated below tailwater levels, but then only under positive pressure), Fighure 4.

Reaction Turbines:

Reaction turbines are generally of two kinds – mixed flow and axial flow. Energy is imparted to the turbine from the flowing water by a reduction of pressure and velocity. On Francis type turbines, water enters radially, continually impacting the "buckets" and discharges (usually vertically) down (axially) the center into an expanding draft tube. Effective head range is quite large, from low-to high-head. Propellor type turbines can be serviced by the flow much as a Francis turbine (radially then axially), or in more modern applications (tubular) by designing the water passage purely axially. In any case, the flow to the propellers is axial. Effective heads are in the lower to middle ranges. Reaction turbines take advantage of the total head available to the tailwater level (see Figure 5). As a result, however, the setting of the turbines must be very carefully designed to avoid cavitation.

Examples of Turbines

The following is not intended to be an exhaustive discussion of all manufacturers, but rather to cover the range of types of turbines.

Impulse Turbines:

Perhaps the most commonly thought of impulse turbine is the Peltontype. Figure 4 illustrates such an installation. Each "bucket" is in fact divided into two identical parts, separated by a thin edge, or "splitter" when the jet strikes a bucket, the splitter divides it into two equal portions which are then deflected by the curved sections in opposite directions, nearly opposite to the direction of entry. Peltontype impulse turbines are normally considered for high-head

installations. They have found wide use in small hydro programs where high heads combine with low flows.

The Ossberger turbine is a radial, impulse-type low-speed turbine, often referred to as cross-flow. The intake water is forced through a rectangular cross-section and guide-vane system through the blades of the cylindrical runner, first from outside to inside and then, after passing through the interior of the runner, from inside to outside, as illustrated in Figure 6.

Flow can be restricted by two balanced guide vanes (1/3 or 2/3) so that the arrangement permits the use of any water quantity in the range of 16% to 100% with optimum efficiency in all ranges, as shown in Figure 7.

"Common knowledge" has it that impulse turbines are generally eliminated from consideration in the very low-head range. However, the Ossberger unit has been satisfactorily installed at heads as low as 18 feet, and operated ideally with heads up to 650 feet – a borad range of applicable head. Both the Pelton and Banki (a "crossflow" turbine very similar to the Ossberger) have found wide application in micro-hydro application.

Reaction Turbines:

Reaction type turbines under consideration for small hydro projects are varied, and are manufactured by a number of different companies. Following is a brief description of each of three turbine types: (1) Francis, (2) Kaplan and (3) tubular. Tubular turbines are subdivided into Tube-type, Bulb, and Rim. In practice the penstock and draft tubes must be considered an integral part of the design.

Francis:

The Francis turbine is a mixed flow turbine. Water enters this turbine flowing toward tha axis; it then flows through passages caused by vanes and by families of curved buckets and exits flowing axially. The actual flow path through the runners depends on the design, and there are wide variations in design for various flow and head conditions.

High head Francis runners are characterized by large entrance diameters and low heights – followed by a small discharge diameter. They have been designed and used for heads exceeding 1500 feat. For medium heads the inlet and discharge diameters are practically the same.

For low-head Francis runners the inlet diameter is characteristically considerably smaller than the discharge diameter, and in order to provide greater entrance area the entrance height is substantially increased.

Francis turbines can be installed vertically or horizontally, and are available for operation at heads of 16 feat and above.

Generally, the hydraulics of a Francis turbine are such that their operating speeds are lower

than comparable propeller runners, and as a result have higher generator costs. They may not be as competitive in the lower head range.

In the vertical installation the turbine shaft can be connected directly to the generator by a coupling that drives the generator at turbine speed. The use of a speed increaser permits use of higher speed, and thus lower cost, generators.

In horizontal settings the turbine shaft is parallel to the power-house floor, with similar generator couplings available as with the vertical installations (see Figure 8).

Even though the cost of the generators may be less for the horizontal installation (because of the smaller thrust bearings required), it will require greater floor space. And although the performance characteristics are the same as the vertical setting, the horizontal installation capacity of the spiral case causes inherent problems in powerhouse arrangements.

Efficiencies of the Francis turbine can be quite high, but in low-head range they will not be as "flat" as some of the other designs. Figure 7 compares the cross-flow and a typical Francis efficiency curve.

Kaplan:

The advantage of adjustable runner blade propeller turbines in combination with wicket control to provide optimum hydraulic performance were realized early. The Kaplan turbine maintains good efficiency under part load (Figure 9) — it was the original in the application of adjustable blade settings and wicket gate control.

For heads below 150 feet a propeller type turbine is usually chosen, and the Kaplan type (adjustable blade) is generally preferred because of its greater flexibility in operation. The adjustment capabilities of the Kaplan turbine permit it to be used efficiently at locations where the unit operates at various flows and heads. Their additional cost however, makes their use in very small developments somewhat doubtful. As will be discussed later, high overall efficiency can also be obtained by unequal sizing of turbines. Figure 10 illustrates a typical large vertical shaft Kaplan turbine installation.

Propellers runners with adjustable blades are also used in tubular turbines and are often referred to as "Kaplan" runners.

Tubular:

Turbines in which the water flow is conducted to the runners coaxially with the shaft are called tubular as well as axial-flow turbines. Tubular turbines include tube-type ("TUBE" is a registered name of the Allis-Chalmers Corporation) bulb and rim turbines.

All tubular turbines have propeller-type runners, each having individual characteristics concerning generator placement. They can be located in any of a number of shaft configurations, as

will be seen, and may be either fixed or adjustable runners.

Those with adjustable blade runners, as noted before, are able to maintain optimum efficiency over a broad operating range. Fixed-blade runners have good efficiency within a narrow range, dropping off rapidly for other flows. Because of its simpler design, however, the fixed-blade propeller runners will have lower capital costs. Figure 9 compares efficiencies of the adjustable (Kaplan) and fixed blade runner turbines.

Tubular turbines have several general advantages over Francis or vertical Kaplan installations: (1) flow pattern deviation in spiral casings and the necessity for substantial draft tube bends are eliminated or greatly reduced. This can result in efficiency gains of up to several percent, (2) axial flow conditions increase flow capacity and thus energy output, for the same runner diameter this increase may be in the 5-20% range: (3) the dimensions of the tubular units are usually considerably less than the Francis or vertical Kaplan, resulting in smaller housing requirements: (4) if draft tube bends can be eliminated there should be considerably reduced excavation requirements, and (5) straighter flow passages require less concrete form costs.

Tube-type turbines are manufactured by a number of companies world-wide. The distinguishing feature is that the generators are located outside the water passages, either directly coupled with turbine shaft or with speed increasers. Figure 11 illustrates several typical installations.

The Allis-Chalmers Corporation expresses the merits of its TUBE turbine as recommending it for use for two principal applications: (1) in standardized form for low-head hydro installations which would generally operate unattended and for which more efficient and more elaborate bulb or rim type units are either not available or not economical, and (2) for the rehabilitation of old low-head plants where in many instances the physical constraints favor the TUBE concept.

Advantages of tube-type turbines include a relatively simple seal arrangement and the fact that the generator is easily accessible for maintenance and repair. Disadvantages include the typical necessity for a long drive-shaft to connect the turbine with the generator, and because of the distance between turbine and generator a large powerhouse is sometimes required to accomodate and service both components.

Bulb turbines have become very popular for low-head hydro application. As has been noted before, to some "low-head" and "bulb turbine" have erroneously become almost synonymous. In this configuration the generator (driven directly by the turbine or with speed increasing gears) is encapsulated in a bulb-like housing directly in the flow passageway. For maximum efficiency it is attached upstream from the turbine runners.

Because the bulb turbine/generator is directly in the flow passage-way, it must be streamlined, the passageway must be as compact as possible. The compactness of the generator area means that the rotor diameter may be considerably smaller than the turbine runner diameter, which is compensated for by an increase in the generator length. Cooling is a problem that must be overcome.

The small rotor also has inherently low inertia; not a desirable consideration. The compactness can also lead to problems of access to the generator. Access to bulb turbines is usually

provided by shafts, which, depending upon the bulb size may permit full installation and removal of components. However, if such access is not available, long delays may be necessitated for removal of generators for repair.

In addition to all the advantages generally attributed to tubular-type turbines, bulb turbines have one advantage concerning the electromechanical equipment. Because of the compactness and location, although for an equivalent vertical Kaplan turbine these equipment costs do not vary appreciably, construction costs can be as much as 30% lower. It has been suggested that the use of bulb turbines should be most effective in the higher capacity installations where the improved turbine efficiency resulting from long conical draft tubes would be most valuable. Figure 12 illustrates a typical bulb turbine installation and cross-section.

Bulb turbine performance has been suggested to be the same as for a vertical Kaplan unit; overall efficiencies, however, may be one to two percent higher due to the straight flow passageways and the reduction in the head losses at the entrance.

Rim generating unit installations are unique in that the generator rotor is mechanically attached to the periphery of the propeller runner blades and carries the poles. The generator itself surrounds the entire passageway at the runner, see Figure 13.

The "torpedo" container of the rim generating unit is considerably smaller than the bulb turbine capsule; Figure 14 compares a "bulb" and "rim" installation.

Despite the compactness of this unit, the manufacturer (Escher Wyss of Switzerland currently manufactures the only rim units – called STRAFLO) suggests that all the disadvantages of the bulb turbine previously mentioned, have been eliminated.

* The generator diameter is about 50% larger than for the bulb turbine which removes all difficulties connected with rotational speed, output, compactness factor, reactive power factor, and cooling.
* As far as is possible from the manufacturer's point of view, there is no limitation to the size of turbine and generator.
* Three to four times as much inertia.
* Turbine and generator are in the same vertical plane which thus makes only one erection pit necessary.
* Good accessibility to the generator. By moving the stator axially, poles and stator windings are completely accessible.

The difficulty of providing a satisfactory runner seal to prevent water from reaching the gnerator has been stressed by speakers and writers. Such problems, according to the manufacturer, are apparently overly exaggerated. It is stated that with the development of hydrostatic seals preventing the entrance of water to the generator and bearings, the unit is particularly suitable for medium and large outputs.

Although no rim generator units have been installed to date (1980) in the United States, 73 were installed in Germany and Austria between 1937 and 1950. It is suspected that with increased marketing efforts, the rim generator units will see increase popularity.

Planning for Proper Nanagement

Whenever I am asked for my opinion on small hydro I try to respond very carefully. Not because I have doubts about my facts, but because there are so many cases around where hydro's capabilities have been oversold. I spent one 2-hour period listening to a very knowledgeable engineer tell me how stupid it was to develop these plants in remote areas and expect local "politicos" to run them properly. And, of course, he was absolutely correct – excpet for one point: It was not the hydro system that failed, it was the lack of planning for proper management. The proper management of the system must be considered no matter what installed capacity is being considered.

In a discussion of micro-hydro installations Armstrong-Evans (1979) suggested some excellent ideas for consideration by planners, particularly if it is expected that local expertise will be used in the plant operations. As he notes, "If you build one large plant and it is a failure you lose everything, but with smaller units you can afford many more so you disseminate the technology faster and it is extremely unlikely that all your plants will fail. Even those plants that have failed can be moved on to new sites or rebuilt by those people who have made a success of other schemes, so all may not be lost even with initial failures. Large schemes, however, train few people and any mistakes in engineering tend to be very permanent and expensive to rectify."

He suggests that developments be planned for expansion and that "training" be a very important part of the total package. Several specific points for consideration are listed:

(1) In the expansion of a system will the existing plants simply lose their present consumers to a new project or will they be worked into the new system?
(2) Who will control water diversion and water rights?
(3) What standards of voltage and frequency will be adopted?
(4) Is it possible to use alternative energy sources (such as diesel) temporarily before a major water power scheme is constructed?
(5) What kinds of tariff structures can be used to stop peak load problems from developing?

(6) What industries can be promoted to use surplus power during wet seasons?

Finally, it must be realized that in those areas where electricity is being introduced for the first time, the early years of operation are very likely to be unprofitable. It will take time for the people to adjust to the use of electricity and for small industries to develop to use the newly available power. It is important that this be carefully evaluated and proper considerations be made to ensure the development's solvency.

Environmental Impact

1. The effects and available information on water quality in the impoundment and tailwater areas.
2. Anticipated or potential effects within the reservoir or downstream of flow and/or water level fluctuations due to daily and seasonal operations of the hydro facility.
3. The anticipated effect on known resident and migrating fish in the vicinity, and height of potential fish passage facilities.

4. The effect and extent of any dredging that might be required during development.
5. Review and discussion of previous environmental studies completed in the vicinity of the site.
6. Any anticipated changes in environmental conditions resulting from retrofitting or rehabilitating existing hydro plants.
7. Known or potential environmental issues at the site, such as past, present or planned designation as Wild or Scenic river or existence of any threatened or endangered species.

Safety Assessment

When an existing structure is to be used it is important that its safety be established. The assessment should discuss the safety hazard, if any, either existing or introduced by the development, and processes by which such conditions would be overcome.

Socio-Institutional Assessment

Any legal, social or institutional situations or constraints associated (or potentially associated) with the project should be investigated.

In terms of the possibility of the hydropower around the world, I understand that you are looking first of all at the possible application in Taiwan. But you can see that the total potential is relatively untapped in most of the world except in Europe we leave 59% that is the technical exploitable, in United States we have approximate 36%. But others, you can see there is a great potential for investment, for development around the world.

There are a number of positive factors for small hydro and negative factors began to be considered and should be considered that the small hydro again is not the answer to produce a great deal of power. It would not solve the energy demands that we have been looking for throughout the world. But my feeling is that I think really we can not just simply depend upon one system, to solve the problem. You need to be looking at all possible alternatives when we are looking at the energy situation around the world.

Thank you very much.

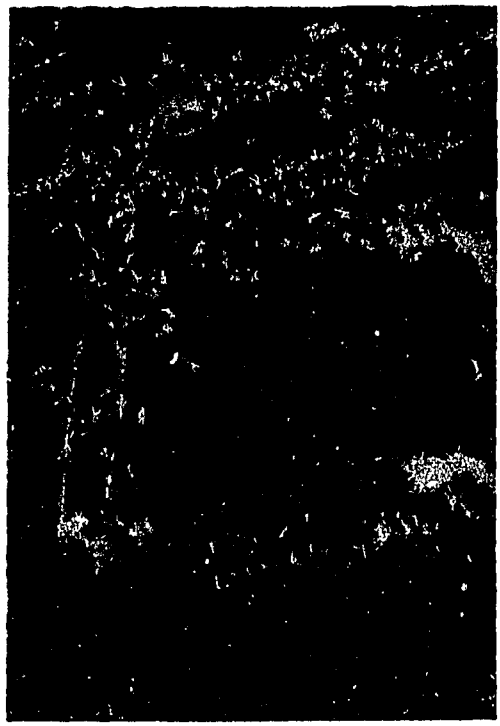

Fig. 1 Water wheeh and Irrigation Woodent by Vitrur 1567.

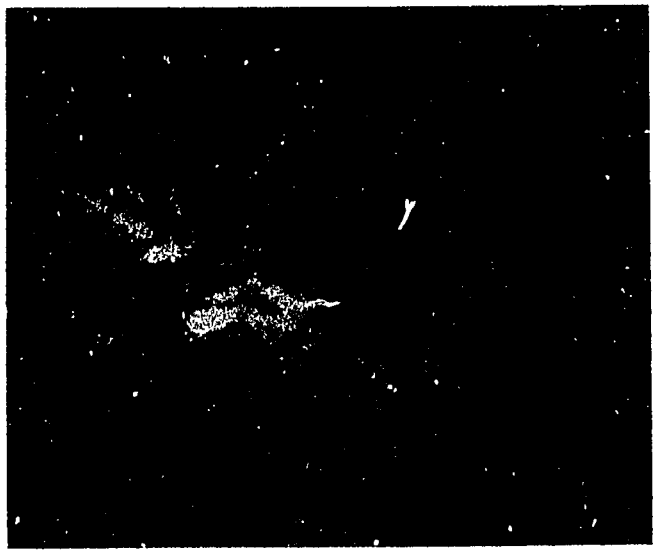

Fig. 2 System proposed by Olade For The Latin American Region and the caribbean.

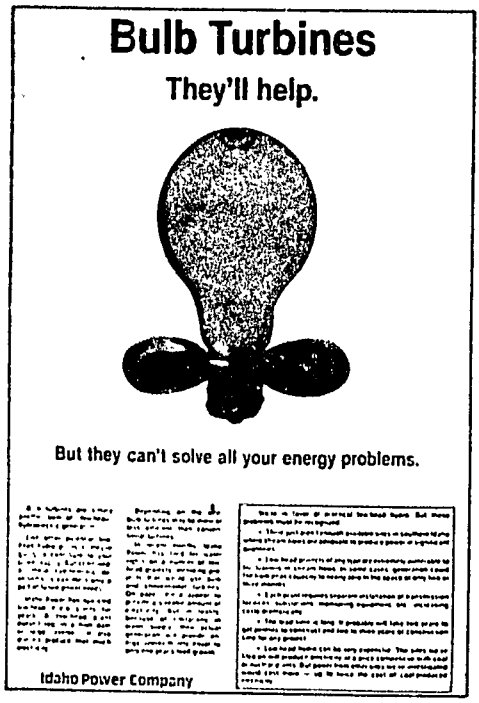

Fig. 3 One utilities opinion of low-head hydro.

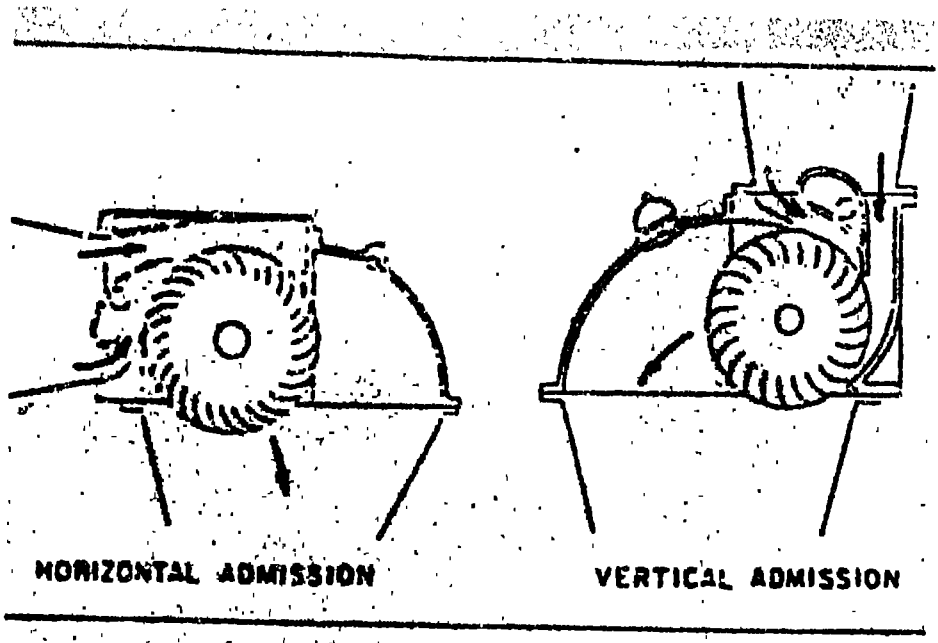

Fig. 6 Ossberger Cross-flow turbine.

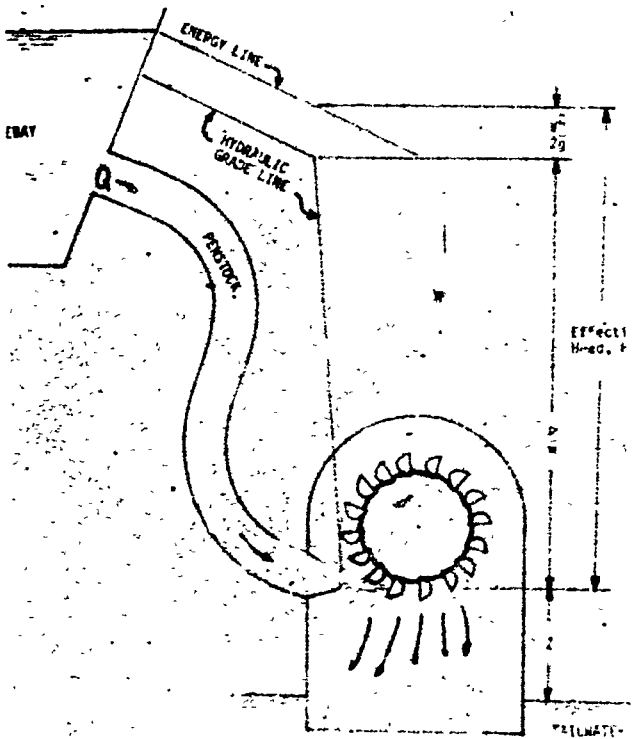

Fig. 4 Hydraulics of Impulse turbines — definition sketch.

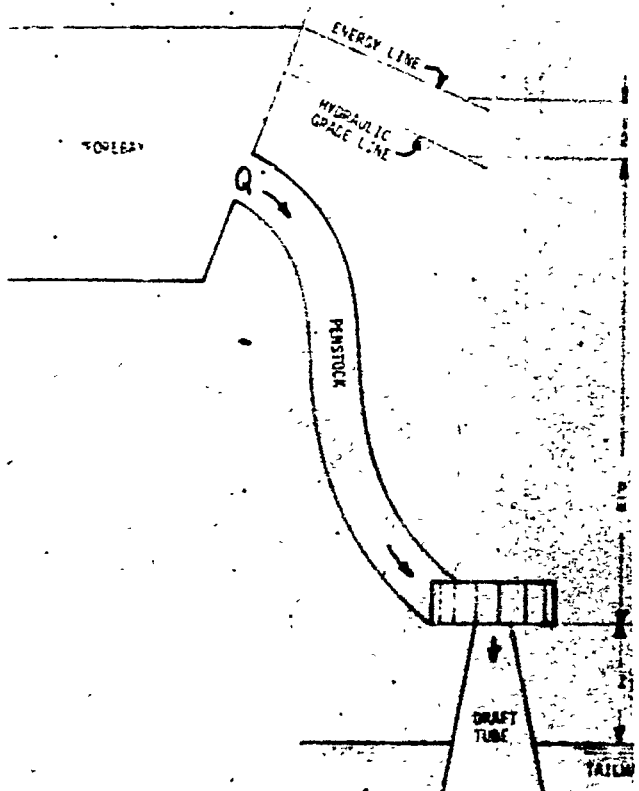

Fig. 5 Hydraulics of Reaction turbines — definition sketch.

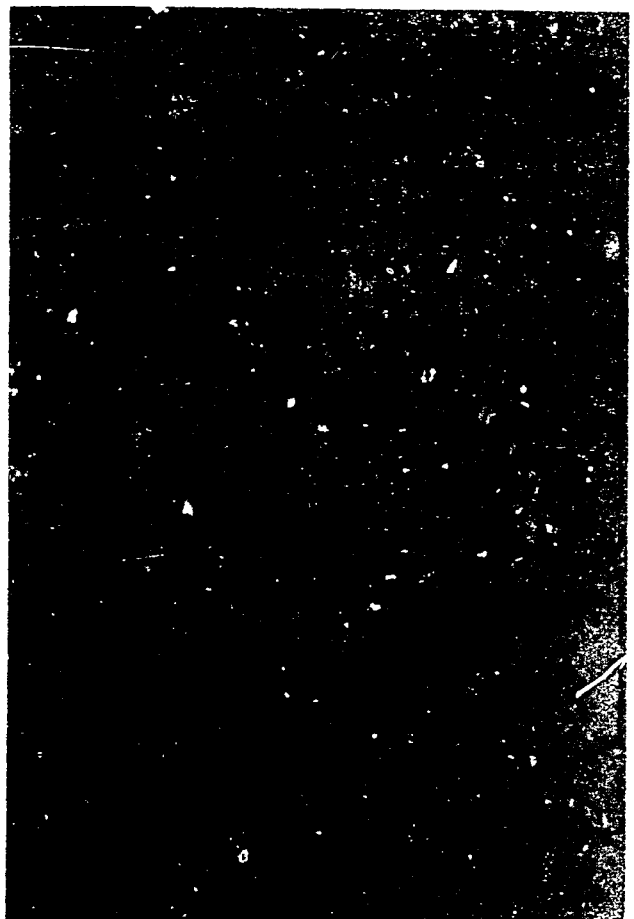

Fig. 7 Osberger VS. Francis Turbine Operating Efficiencies.

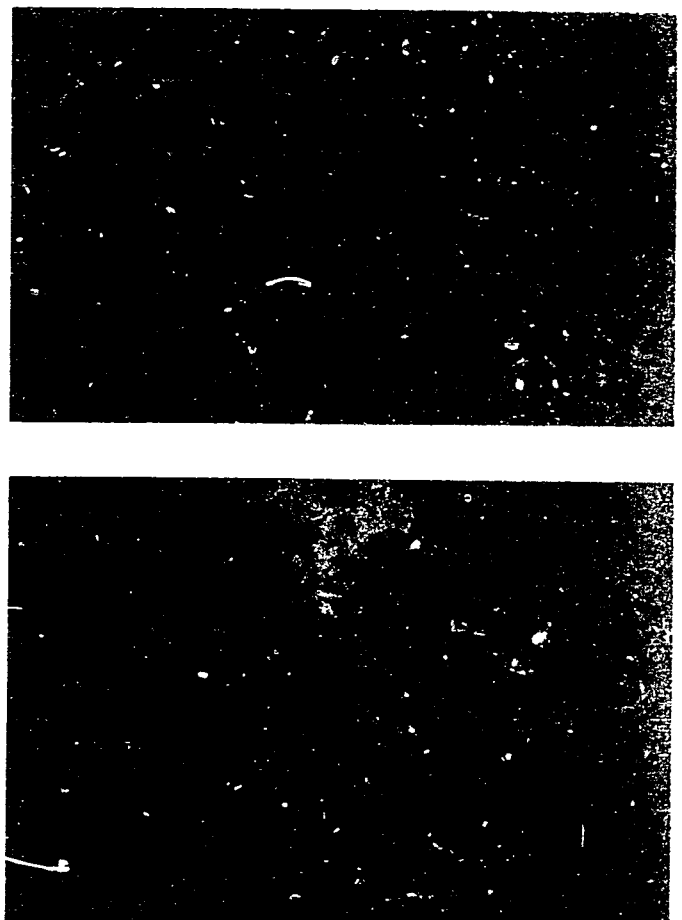

Fig. 8 Francis turbines: (a) horizontal, (b) vertical installations.

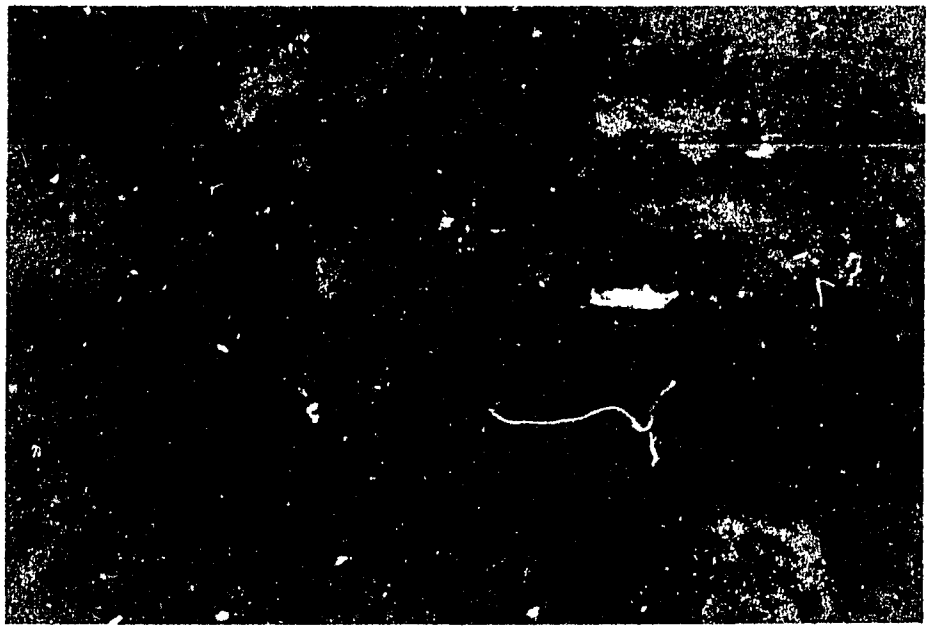

Fig. 9 Comparative efficiency curves: kaplan VS. fixed blade propeller turbines.

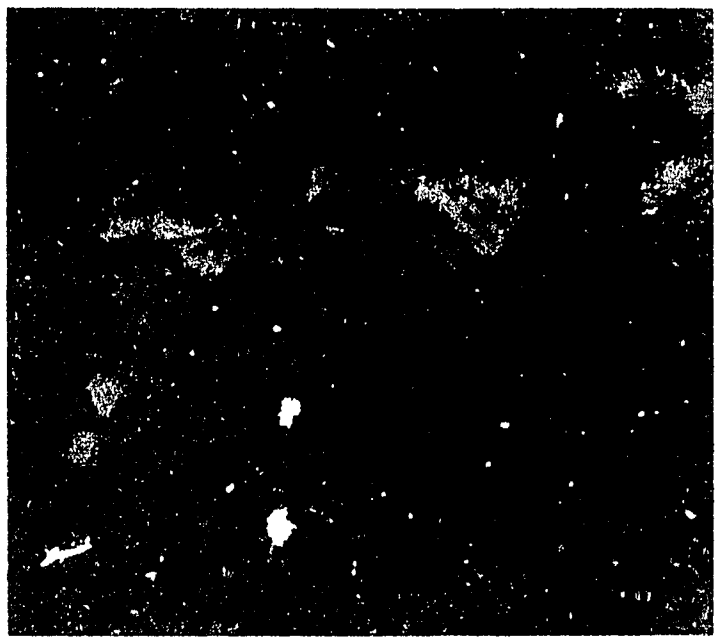

Fig. 10 Vertical kaplan turbine installation.

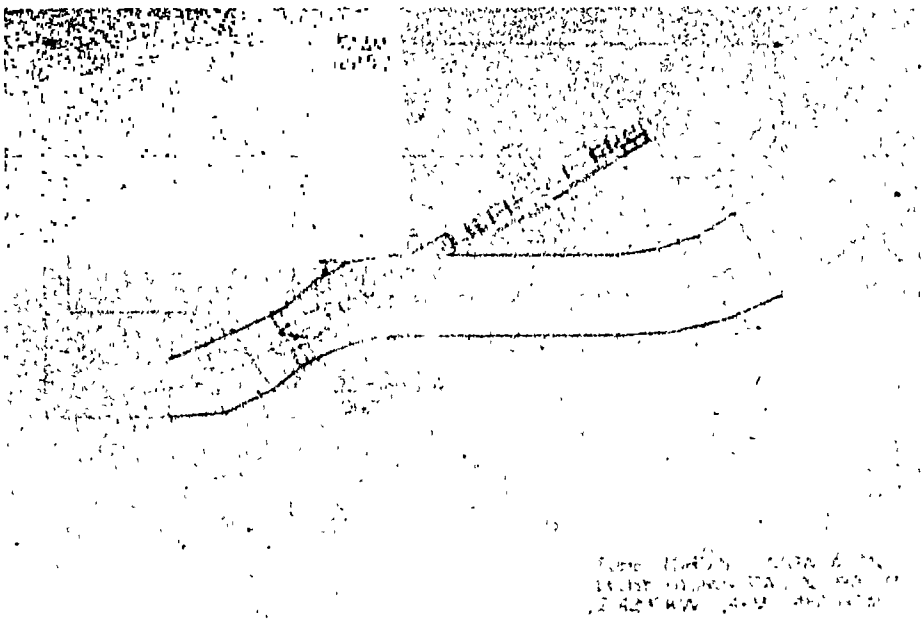

Fig. 11(a)

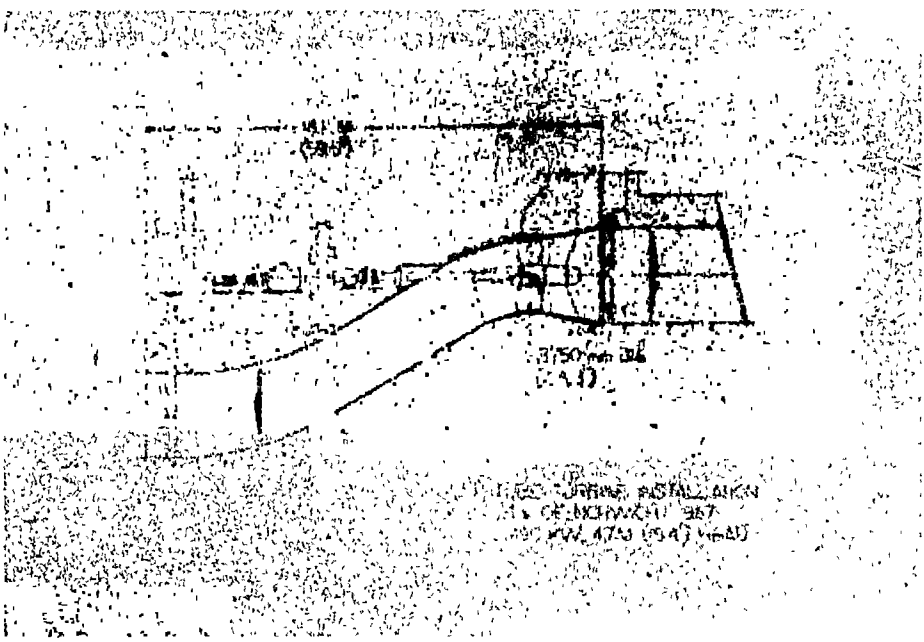

Fig. 11(b)

(a) (b) Two Tube Turbine Installation.

Fig. 12 Section through a bulb unit.

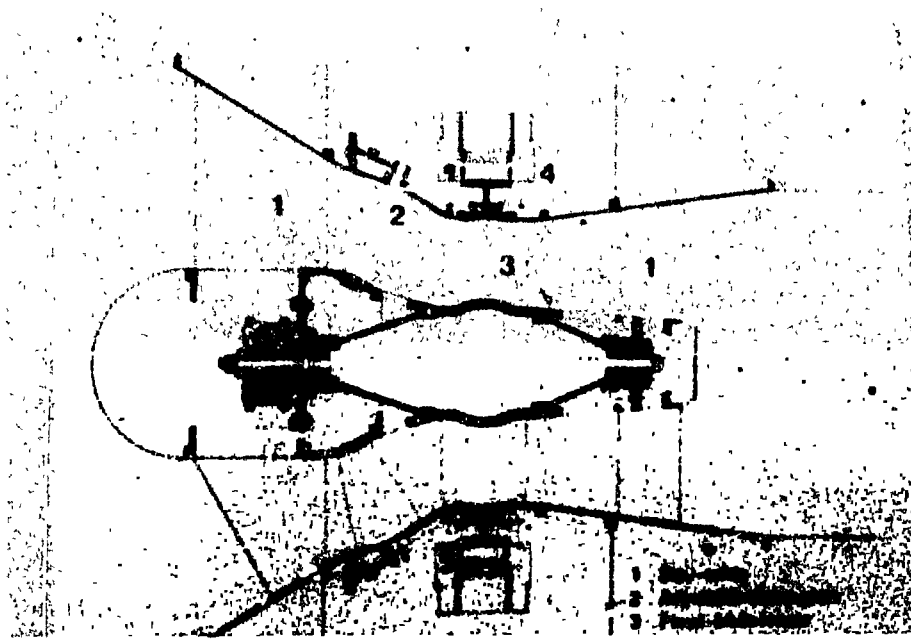

Fig. 13 Typical cross-section of straflo (rim) turbine.

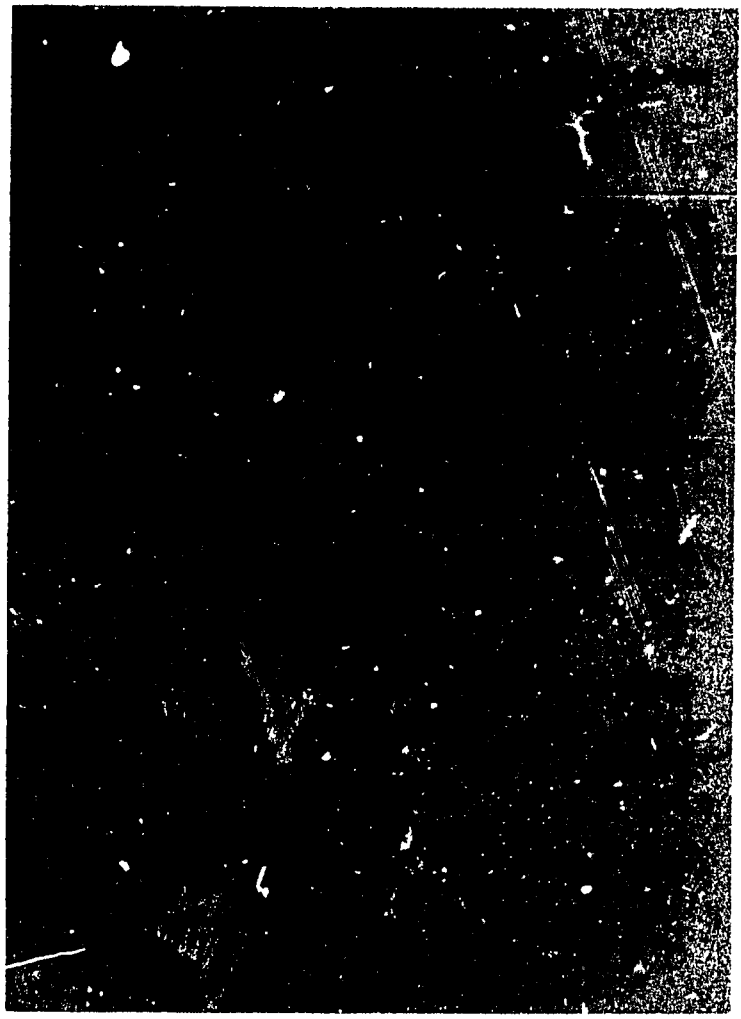

Fig. 14 Comparative sections of bulb and straflo (rim) units.

MINI-HYDRO

With the increasing cost of alternative energy sources, small hydro is becoming an energy resource worth serious consideration. Many sites are economical now. Although small hydro has many positive attributes, it has negative aspects as well. Some of these positive and negative aspects of small/low-head hydro are summarized below.

Positive Aspects

* Hydropower uses a renewable resource.
* Capital expenditure is a one-time expense and not subject to inflationary factors.
* "Fuel" and operating costs are small compared to other energy alternatives.
* Hydropower is relatively non-polluting by almost any standard.
* The state-of-the-art is fully developed. We know what hydropower can and cannot do.
* The use of its water resource means that a country is less dependent upon external sources for its fuels.
* Many dams already exist without installed hydroelectric production capabilities. Installation at these sites will cause almost no additional environmental stresses and produce electricity at considerably lower unit cost.
* The simple fact is that in most parts of the world the hydroelectric potential far exceeds that which has been developed.

Negative Aspects

* Construction sites may not be available where stream flows are adequate to produce power in significant quantities.
* Because small/low-head plants will often be run-of-river the energy produced is extremely vulnerable to fluctuation in stream flows. Generation could fall to zero, requiring some back-up system.
* Unless the energy is to be used nearby, each plant may require separate installations of transmission facilities, substations and monitoring equipment. This could increase costs dramatically.
* Because of its small energy output, the unit cost of production may be high.
* Although it is claimed that environmental degradation will be smaller because of the obvious small scale of operation, the reaction of environmentalists and recreationalists has not yet been well tested. If it should prove to be as difficult to develop small hydro plants as to develop larger alternative energy sources it will be difficult to convince investors of the value of considering them.
* A large number of small plants implies a possibility of coordination and operation problems.

It is my opinion that if properly addressed, the negative aspects should not represent serious obstacles.

As stressed repeatedly, small hydroelectric energy generation will be but a small part of a total energy package. But the use of renewable water resources for electricity generation in conjunction with other development projects makes sense. It could make a significant positive contribution to any country's energy difficulties.

Finally, although this presentation may have given the impression that the planning and design of small hydroelectric plants is straight-forward, it is not. Experience is extremely important, and knowing where efficiencies can be economically maximized for overall impact can be critical. As a result, I would like to finish by stressing the need for the careful selection of consulting engineering firms. Rediscovery of the wheel goes on all the time – but it is an extremely costly business, which fortunately has a simple solution.

MINI HYDRO-ELECTRIC POWER DEVELOPMENT CONCLUSIONS AND RECOMMENDATIONS

Jointly By Dr. John S. Gladwell
Mr. Tony T.L. Liao

1. The Republic of China on Taiwan is meager in energy resource of both fossil and nuclear fuels but is endowed with a considerable amount of hydro potential. The theoretical hydro potential of 151 rivers on Taiwan is estimated to be 12,000 Mw of which about 5,300 Mw is estimated to be economically feasible today. Up to date, a total of 1,387 Mw has been developed by stages and utilized by thirty hydroelectric plants. The total energy generated from hydro plants in 1981 was 4,770 Gwh, representing 11.9% of the total generation and corresponding to an equivalence of 7.5 million barrels of oil.

2. As the hydro potential is the only major indigenous energy resource in Taiwan, and the world energy situation remains tenuous, the hydro potential should be given a high priority for development. Small hydro developments appear to offer excellent opportunities for consideration.

3. Small hydro has been widely developed around the world; however, the per Kw cost is typically high, increasing with a decrease in unit size. In order to greatly reduce the cost and to make them more attractive, standardization of locally manufactured package units would be very desirable. For this purpose a market survey should be carried out following which the Government should encourage private manufacturers with aid for the manufacture of such standardized packages with an export trade highly probable.

4. The Government should consider extending long-term loans with low interest rates to those who wish to develop small hydro sites. Such development should be planned in coordination with the overall development scheme of a river basin.

5. Taiwan Power Company, which has ample experience in planning, design, construction, operation and maintenance of hydro-electric plants should be encouraged to increase its national and international technical assistance activities.

6. Hydroelectric plants have many distinct advantages over thermal plants. When evaluating the feasibility of a proposed hydroelectric project in comparison to alternative fossil-fuel thermal plants, it is clear that the differences in reliability of service, flexibility of operation, availability of required fuel and environmental impacts between hydro and thermal plants should be seriously considered in the calculation of the annual benefit stream of a proposed project. Procedures for this consideration should be studied and recommended. This would be an excellent opportunity for extended cooperation between the universities and the Taiwan Power Company, and should be encouraged.

7. The experience already developed by the TPC in small hydro-power development is marketable. Serious consideration should be given to the establishment of training programs in planning and design. Included in this would be the development of design manuals (including

basic semi-standard system layouts); courses might be given in developing countries as well as in Taiwan); and establishment of a demonstration power of operating small hydro units (emphasizing locally manufactured products).

8. The continued use of the term "low head" (even though correctly applied to the condition presently under study) should be dropped. The empahsis should be switched to small energy output (including high head), and the program should include high head developments as well.

9. The universities should cooperate with TPC in assigning to their engineering students projects of an applied nature with reference to small hydro projects. In so doing the students and professors will gain valuable practical experience and TPC will benefit from the study results.

10. The true value of energy produced from small hydro units is often difficult to evaluate, especially when it is to be connected to a transmission grid. Of great value would be the development or modification of a simulation system by which the effort of the governmental energy in a mixed system could be evaluated. This would be a good appointment for University/TPC cooperation.

11. The hydro potential studies (and procedures used) should be packaged and made readily available to interested parties. It has been found that this information can have considerable spin-off value in addition to locating hydro-electric development sites.

STIRLING ENGINES

by
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The Stirling engine was invented in Scotland in 1816 and was used successfully as a water pump and general purpose engine, usually operating on coal, in Europe and the USA until about 1910 when it was displaced by electric motors and internal combustion engines.

The Philips Company of Holland revived the Stirling engine in 1945 and developed it for automotive use. General Motors, Ford, United Stirling and MTI have all worked on the very difficult problem of practical design for automotive use. Despite their efforts, the automotive Stirling is still much too expensive, and only marginally superior to the Diesel in fuel economy. It also has very difficult seal problem.

United Stirling has recently modified its automotive Stirling for use as a solar power converter and is also considering for its use in submarines. There are at present no commercially available automotive type Stirling Engines.

Free piston Stirling engines can be made hermetically sealed and thus avoid the shaft seal problem which is so difficult in automotive Stirling. Free piston engines are nearing commercialization as heat pumps, air conditioners, water pumps and electric generators.

They are being developed by Sunpower Inc., Mechanical Technology Inc (MTI) and General Electric. Free piston Stirling development is being funded by NASA, Argonne National Labs, Oak Ridge National Labs, Gas Research Institute, and by a number of US European and Japanese companies.

It is expected that within two years there will be commercially useful free piston designs for heat pumps, Solar electric generators and water pump. These machines will have good efficiency and will be cost competitive with existing machine. They will have advantages of low noise and long life.

Another class of Stirling engine nearing commercialization is the hot air crank drive type. Sunpower will deliver to Dacca, Bangladesh a rice husk fired 4KW shaft power hot air engine in August, 1982. This work has been sponsored by US AID, and is intended to be a general purpose biomass fired engine. The design will be available from AID.

Stirling engines of the free piston or hot air type are quite simple to make, and offer no technical challenges to industry in Taiwan. When successful engines are demonstrated, which should be within two years, Taiwan should consider their manufacture for local use and for export. An important requirement for commercial success is a thorough understanding of the

nature and varieties of Stirling engines, and of their potential uses and application of greatest competitive advantage.

It would be good to let you know a little bit about how a Striling engine works (Figure 1). It is a very simple idea. And I prepared this slide to give you, I think, as simple as possible the concept of how the Stirling cycle performs. Imagine first that you have a simple cylinder, which has got gas in it and you put a very loosely fitting tin can or some equivalent cylindrical object which will slide easily back and forth inside that cylinder. And you apply heat to one side and you cool the other side, the other end of the cylinder. And you put a pressure gauge on the cylinder to give you an idea of what might be going on inside.

So now, imagine that for some reason you have been able to move this thing, this loosely fitted cylinder which we called a displacer, over to the hot side of the cylinder, which requires all the gas, of course, to go to the cool space. If you do that you will find that because most of the gas is cool in comparison to the initial condition where the gas was partially hot and partially cool, the pressure drops to what it was before, and then if you move the displacer over to the right hand side and change all the gas from the cool space to the hot space, you will find the pressure will rise. So, you have got a nice little toy. In fact we have made these things which fascinate the students and cause considerable puzzle on their part, which consists of the cylinder, hot on one side and cool on the other, one tilts back and forth in his hands which allows the displacers inside slides back and forth and the pressure goes up and down. And the question of course to the student is what's inside the box. That causes vast confusion on the part of the student. Until someone tells them what's in the box, then they know.

So, this is all very good, but this is not doing you any good. you see an infinite amount of work going in the pressure gauge and nothing coming out of this device. However, it is obvious that if you can expend the gas to do work when the pressure is high and then have the gas co-pressed back to its original volume when the pressure is low, you can go around a thermaldynamic cycle and get useful work. And that, of course, is the Stirling cycle.

So. we go through the process indicated here, 1234, (Figure 2). We put the gas in the hot space. We now do not have a completely sealed cylinder. We have one with a sliding piston on one end. And from state 1 to state 2, we expand the hot gas to do work to the pressure volume charge here to the heart of mechanical engineers. The area underneath the PV diagram is the work done by the piston. Going from 1 to 2, it is obvious that the work is done if the piston being pushed out. Then we go through the trick of moving the displacer back to a position while inside the gas are all cold and that drop the pressure. Then you can drop the pressure in the cylinder while not doing any work at all. You just displacing the gas from hot space to the cold space. Then we go through the compression process. From 3 to 4, you move the piston in and that requires work, of course. But you are doing less work in compressing the gas from point 3 to 4 while it is cold. Then you got out and getting the gas from 1 to 2, so you have gained a net amount of work, exactly like putting money in a bank and, a little while later, going to the bank getting money plus interest. You got a net gain on the process. Now to return to the original state, all you have to do is to move the displacer again from point 4 to point 1 and get the gas from the hot space.

You are now ready to go through the cycle again and get your interest again. So everytime

you go around the cycle, you get a certain amount of mechanical work. And as long as you retain a temperature difference between the hot and the cold, then you will continue to do that. So if you go around the process 12341, you will get a ntework output. Now it should be clear that if you go around the process 14321, in other words, reverse the process. Around this group, you are getting work out when the pressure is low and you are putting work in when the pressure is high. You will have to put the work into the system, but now you are pushing heat out. You are pushing heat out into the high temperature region, the opposite condition when you run through the process, and you now have a heat pump.

This is an old Stirling engine (Figure 3). This is the one that heating the boiler of our building for sometime until the fellow who lend to us decided that he wanted to have them back. It is an Ericsson engine, so called, because it is manufactured by a company founded by the famous Swedish Engineer Ericsson. But it is in fact, a Stirling cycle machine. The motion of the piston and the displacer, being inside the cylinder approximately here, the piston, being on the top, this being the fire box, the key to the hot end, and a water jacket to cool the cold end. That motion was accomplished by a mechanical linkage called the Ericson linkage. And the power output came from a rotating shaft which in this case pumped water. This is an 1900 Stirling engine, a very popular machine in the U.S.. The family home of former President Rooselvelt has a Stirling engine in it. It is still used to pump water. Of course, it is a national shrine now. People came to visit the place and they can see a good size Stirling engine three to four times as good as this in pumping water. I'd mention that was quite a successful commercial machine and many hundreds and thousands of them were sold all over the world.

This is a drawing of that machine which we showed you the photograph (Figure 4). And its output is approximately 50 watts, a very small power output which is less than one man can do on a stedy state basis. The energy efficiency of the thing was vanishingly small. It would be very hard to detect the difference between the heat energy going into this engine and the heat energy coming out, with much less than 1%.

Recently, we did a design using modern engineering analytical method and using modern materials such as stainless steel which is approximately no difference in size (Figure 5). It was a very similar machine at the same mechanical linkage and so on, and using the same work force, which is air. And we are able to get not some of 750 watts as this slides shows but one kilowatts of mechanical power from that machine at a very respectable thermodnamic efficiency around 20%. It is a very simple machine, nevertheless, one that could easily be made in any place that could build bicycles. And we have a program right now to design a 4 kilowatts shaft power machine to run on rice husks which are excess supply in Banglalesh generate mechanical power and to run the rice mills which is a funded program by the Agency for International Development in the U.S.. The design will be finish in a firly short time. And it would be free to anyone who wants to write to AID to get the plans for.

A typical modern hot air machine looks like this. And again, this is one of the machine, which I consider to be a viable commercial product today. Frankly, I am absolutely astounded that these machine are not available in the market because they do not challenge any technology we know about. The knowledge is very simple, it is just that people forgot about it. They are not paying enough attention.

The machine is simple crank mechanism, using dry bearings or sealed ball bearings. Piston and displacer connected appropriately to move the piston and displacer back and forth in correct phase relationship. A water jacket, the regenerator, a fundamental component of the machine, in order to get high thermodynamic efficiency, one cannot simply move hot gas to a cold space. The heating and cooling of gas absorbs the available energy in the system. To avoid that loss, one puts in the regenerator which is essentally a wire mash, a steel wool, such as the gas move back and forth between the cold and hot spaces, every thing is either stored or taken out from the regenerator. The regenerator is a vital component of the Stirling engine. Although a small Stirling engine, not interested in thermal efficiency, the regenerator is not absolutely necessary. The absence if regenerator will actually increase the power of the machine, reduces the thermal efficiency.

In this design which is a rice husk fired engine, have a mechanical drive of auger, which is moving a small amount of rice husk per unit of time, equivelant of a carbeurator into the burner, have a blower driven by the crank machine, which is blowing air pass the exhaust gas, in order to pick up heat from the exhaust gas, otherwise wasted heat from the exhaust gas, and combustion gas comes in mixes with the rice husks, directs a very hot flame to the extended heater surface of the hot air engine. We have at the point of burning rice husk in such a burner very effectively. The exhaust temperature was more than adequate to drive, a Stirling engine and there doesn't seem to be a technical problem at all.

This is a photograph of the one kilowatt engine (Figure 6). It has a propane burner on it. For purpose of demonstration it was much more practical to use propane, which is readily available in U.S. rather than rice husk, which obviously is not in the U.S.. The hot air crank drive, low speed, moderately high efficiency, very simple and easy to make. There's another class of Stirling machine which is unique and is properly a crank device. Others, stupidly persistance in trying to make the machine work. The idea is simple, and actually work.

Some typical installations of propane powered Stirling engine for water pumping are shown in Figures 7 and 8. Figure 9 shows a kerosene fired 100 watt portable Stirling enginegenerator.

Figure 10 is a photograph of 100 watt solar powered Stirling engine electric generator and Figure 11 shows how a low cost solar collector is constructed using pressurized transparent and aluminized sheets. Figure 12 shows a drawing of solar powered 10kw free piston-linear alternator and Figure 13 a free piston duplex Stirling concept. A free piston duplex Stirling heat driven heat pump is shown on Figure 14.

Figure 15 is a chart showing various applications of free piston Stirling engines, and finally Figure 16 summarizes the state of development of Stirling engines.

Recommended immediate actions are:

a) Gathering of information of state of the art.
b) University research projects on analysis, component development and prototype design and test.
c) Visiting committee to get first hand look at work going on in the US and Europe.
d) Initiation of business contacts with leaders of technology in US, Europe and Japan.

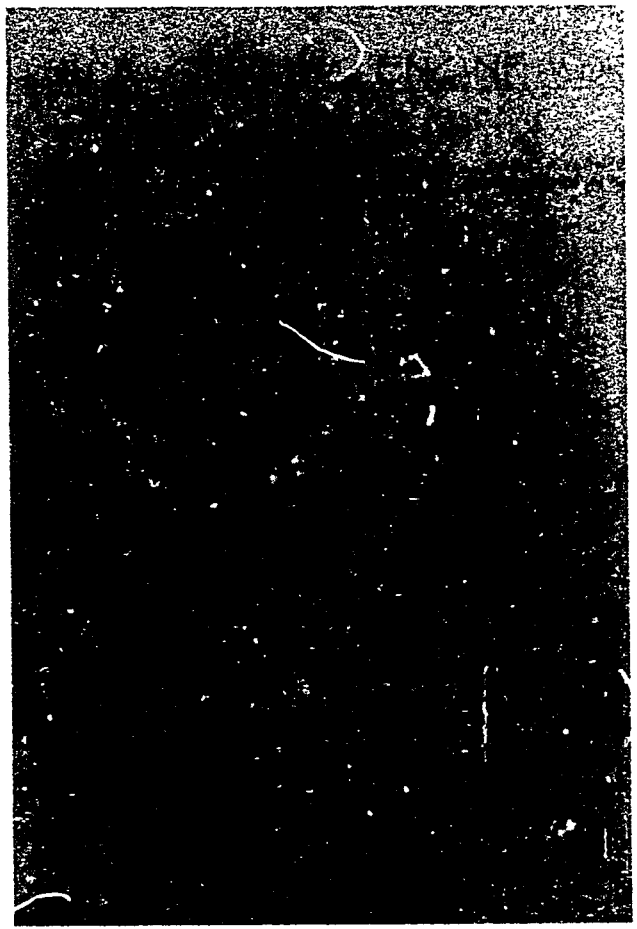

Fig. 1 How A Stirling Engine Work.

Fig. 2 Stirling Cycle Schematics and PV Diagram.

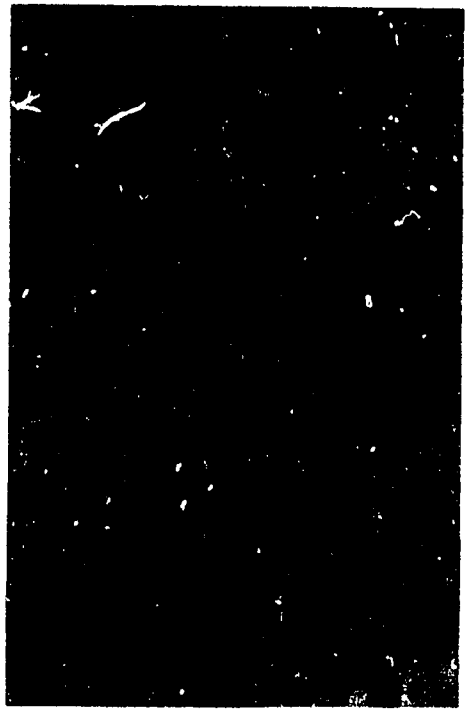

Fig. 3 An Old Stirling Engine Manufactured by Ericsson.

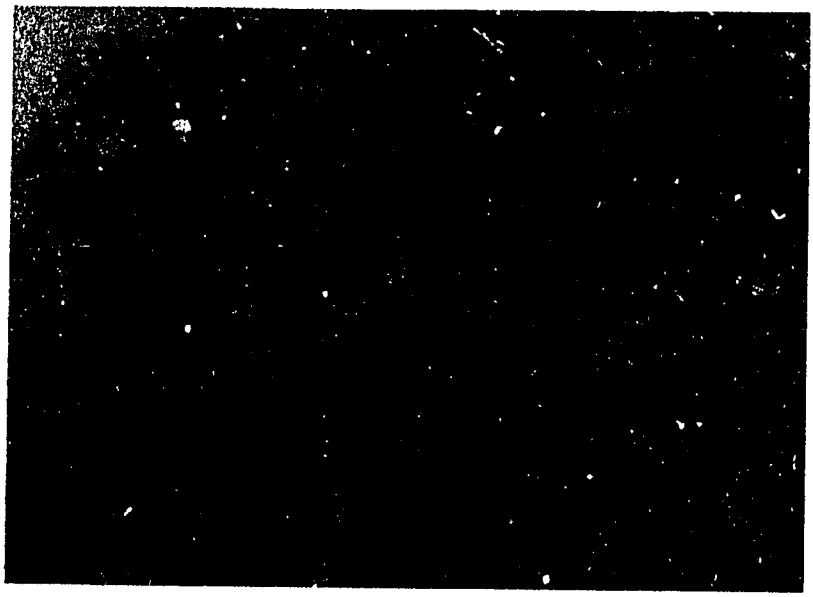

Fig. 4 Drawing of Stirling Engine Manufactured by Ericsson.

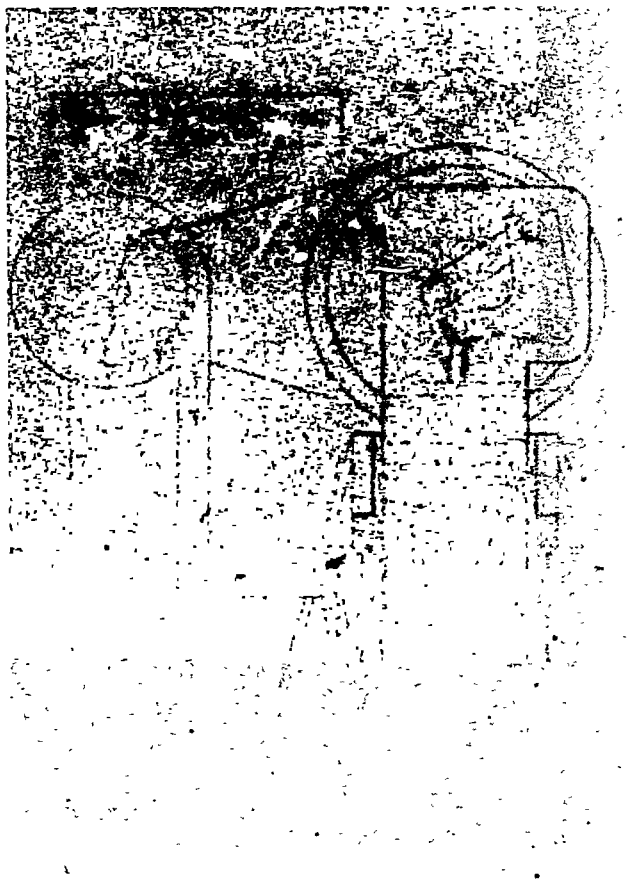

Fig. 5 One Kilowatt Stirling Engine Designed by Sunpower.

Fig. 6 Photograph of One Kilowatt Stirling Engine Manufactured by Sunpower.

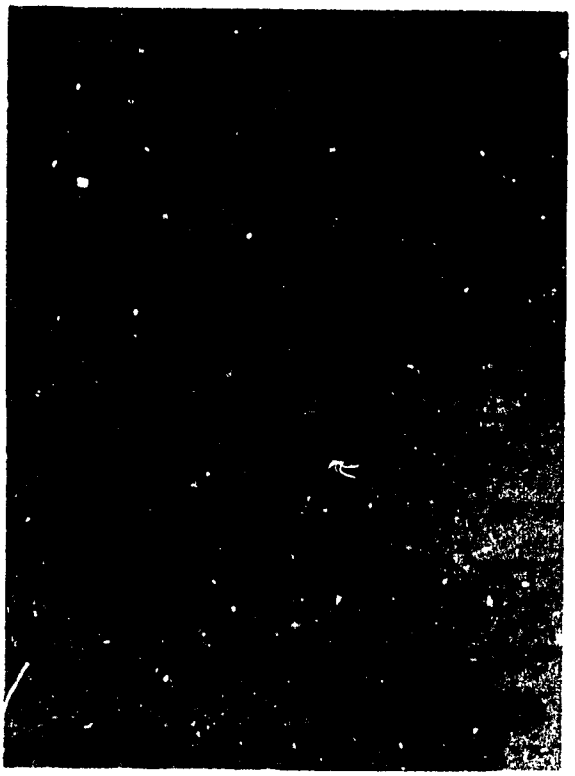

Fig. 7 Propane Powered Stirling Water Pump.

Fig. 8 Propane Powered Stirling Water Pump for Irrigation.

Fig. 9 Kerosene Fired 100 Watt Portable Generator.

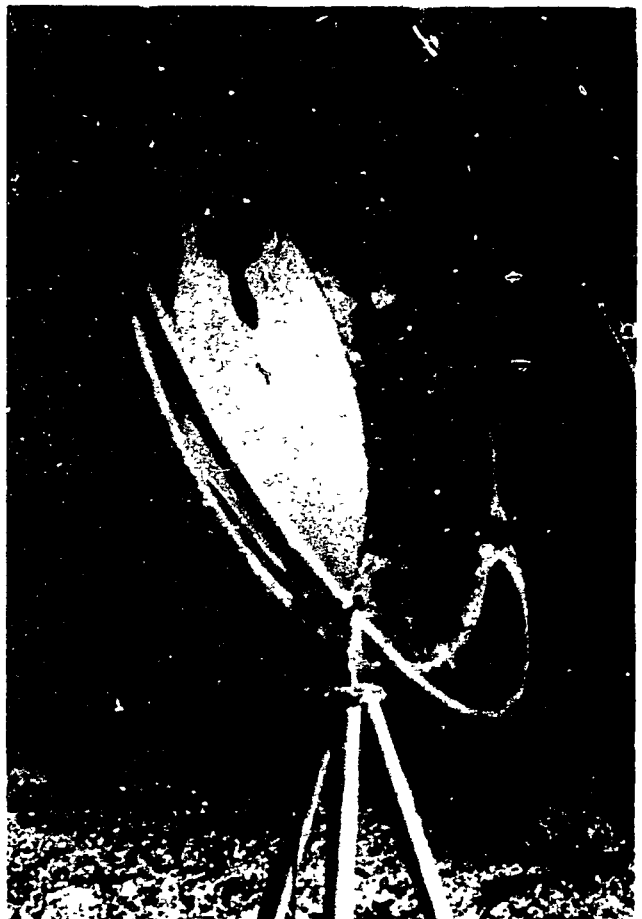

Fig. 10 100 Watt Solar Powered Stirling Engine Electric Generator.

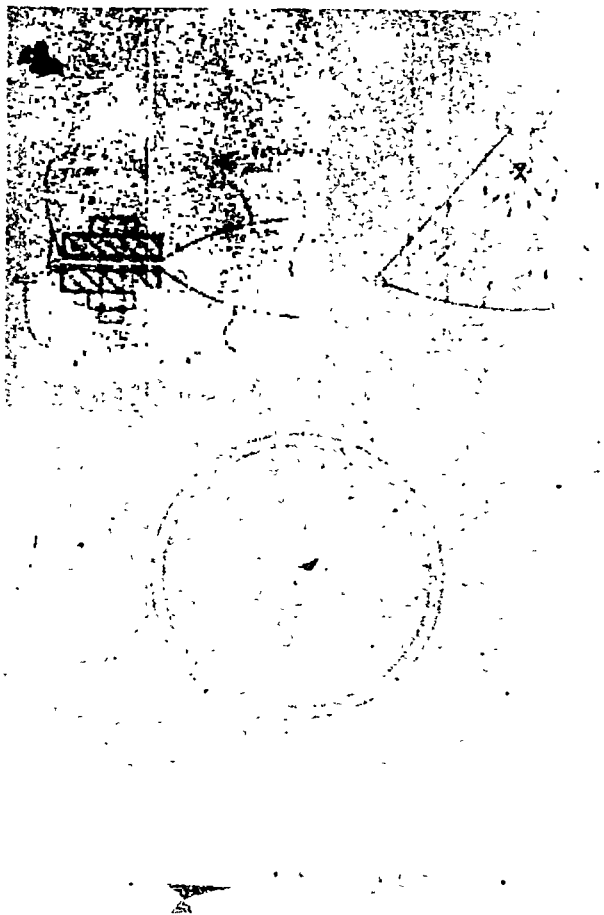

Fig. 11 Low Cost Construction of Pressurized Transparent and Aluminized Sheets.

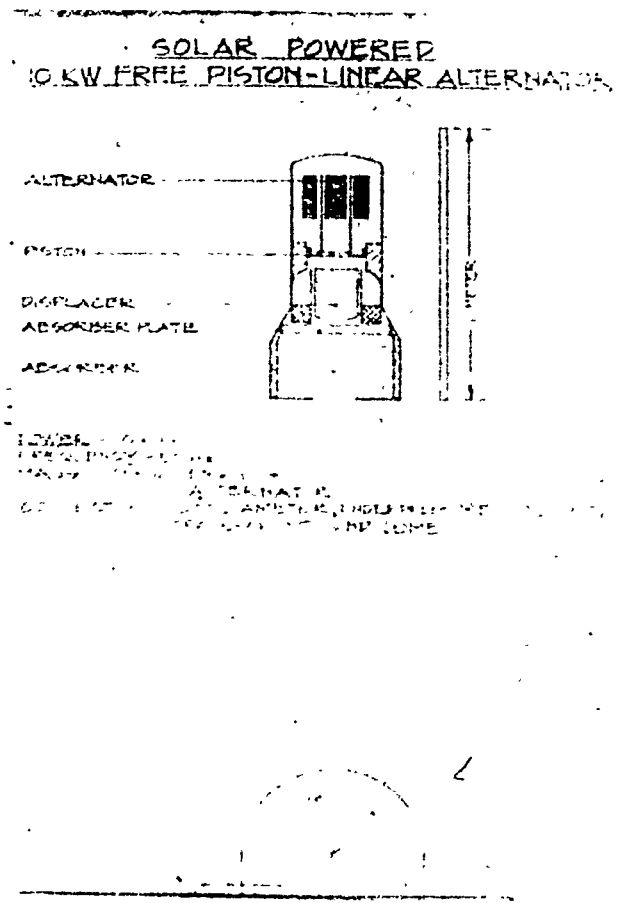

Fig 12 Solar Powered 10KW Free Piston-Linear Alternator.

Fig. 13 Free Piston Duplex Stirling Concept.

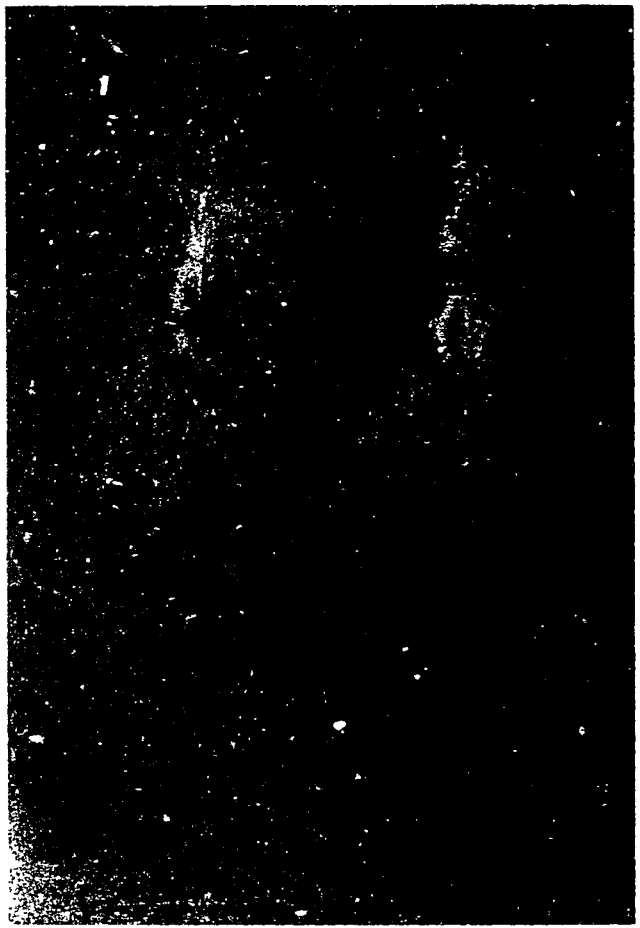

Fig. 14 Free Piston Duplex Stirling Heat Dirven Heat Pump.

APPLICATIONS
OF
FREE PISTON STIRLING ENGINES

APPLICATION	HEAT SOURCE	TYPE OF ENGINE
WATER PUMPS 50-5000 WATTS AND UP	BIOMASS SOLAR COAL	FREE CYLINDER ATMOSPHERIC AIR FREE PISTON CERAMIC HEAD LIQUID PISTON HOT AIR CRANK
FOOD COOLER FREEZER 20 WATTS-UP	ANY HEAT SOURCE	DUPLEX STIRLING
AIR-CONDITIONER 200 WATTS-UP	GAS LIQUID SOLAR BIOMASS	DUPLEX STIRLING
CROP DRYER (AIR BLOWER & HEATER)	BIOMASS CROP WASTE	HOT AIR CRANK FREE PISTON-ALTERNATOR
ELECTRIC GENERATOR (BATTERY CHARGER-GENERAL PURPOSE POWER)	ANY	FREE PISTON-ALTERNATOR

Fig. 15 Applications of Free Piston Stirling Engines.

STATE OF DEVELOPMENT
STIRLING ENGINES

ENGINE TYPE	COMPANY	STATE OF DEVELOPMENT
FREE PISTON & LINEAR ALTERNATOR	SUNPOWER MTI	100 WAT DEVELOPMENT 10 KW DEVELOPMENT (RUN JUNE 1982) 3 KW RUNNING
FREE CYLINDER WATER PUMP	SUNPOWER	30 WATT MODEL RUNNING 150 WATT DESIGNED
DUPLEX STIRLING HEAT PUMP (10 KW)	SUNPOWER	FIRST RUN MAY 1982
STIRLING-RANKINE	MTI GE	COMPONENT TESTS RUNNING-DEVELOPMENT PROBLEMS
ATMOSPHERIC AIR FREE PISTON	SUNPOWER	CONCEPT
LOW PRESSURE AIR CRANK	SUNPOWER	RUN JUNE 1982 (RICE HUSK FUEL)
LIQUID-PISTON	METAL BOX CALCUTTA	100 WATT MODELS TESTED

Fig. 16 State of Development of Stirling Engines.

REPORT OF STIRLING ENGINE

by
Mr. William beale

Stiring Engine is still under development in USA and Sweden. No commercial units are ready today.

Major development effort in the U.S. are:
a) Automotive Stirling
b) Heat driven heat pump or air conditioner
c) Stationary generator set. (free piston)
d) Hot air crank drive engines

The automotive Stirling is still a long way from commercial usccess because it is very expensive in comparison to present gasoline engine or diesels. And there are reports that the US government has decided not to fund the Auto Stirling after 1983. There is some interest in the automotive engine for other uses, such as for solar electricity generation. The Heat driven heat pump is being funded more in 1983 than in 1982. It looks very promising. Gas Research Institute is supporting Sunpower Inc., Colombia National Gas is supporting MTI. Also Oak Ridge National Lab is supporting MTI. Two foreign private companies are supporting Sunpower heat pump development.

Time table for Heat driven heat pump is:
1982-demonstration in Laboratory
1983-field trials
1984-start of production in Germany, US and Japan

U.S. and West German Economic Analysis for heating heat pump shows 50% saving of heating cost and payback in 3 years. This result depends strongly on local fuel and electricity costs.

In U.S. cooling heat pump has payback in 3-4 years. But field trials are necessary to show what the true value is.

There is a possibility that performance will be much better than this, as indicated by computer simulation, but considerable component development will be necessary to reach full potential of any of these machines.

The free piston-linear alternator is being developed for U.S. military as a quiet battlefield generator by MTI. Sunpower is developing this engine as a solar powered generator (10 KW) for a German comany to be used in combination with a air pressure formed thin film parabola for pumping water in the Sahara. Sunpower is also developing a small, cheap portable electric generator running on Kerosene for use in S.E. Asia, Africa and Latin America to run small appliances. This engine can also be made to run on wood, charcoal or coal.

In the U.S., Stirling Power Systems, a subsidiary of United Stirling of Sweden, has made a

10 KW electric generator with a crankshaft drive. This machine has only slightly better efficiency than a small gasoline engine but is much quieter. It suffers from the shaft seal problem of all high pressure light gas stirling engine using a crank drive, but it seems to have an adequate seal life for auxiliary power use. Since the machine is not in production, its commercial cost is not known.

Very large coal burning stationary power units have been studied by Argonne National Lab. Their economics seem to indicate costs per installed watt 2-3 times greater than Diesels, with a long payback time. There are no plans at present to build any of these machines.

The small simple hot air engine, delivering rotating shaft power, seems to have promise as a general purpose power source in any situation where its capability of using biomass or coal fires has an economic advantage over petroleum burning enging. An example of this is the 4 KW engine burning rice husks to power rice mills and irrigation pumps in Bangladesh. Rice husks are in plentiful supply there and Diesel fuel is very expensive.

The Sunpower rice husk fired hot air engine will be delivered to Dacca in August 1982. The design drawings will be available from USAID.

Very big hot air Stirling engine have been advocated by Prof. Graham Walker of the University of Calgary. He argues that these machines can compete with Diesel Automotive engine and stationary power plants. But there remains a great deal of development effort to prove this assertion.

Taiwan Capabilities for Stirling Engine Manufacture

The existing manufacturing capability of Taiwan industry is more than adequate to make most of the Stirling engines presently under development, except possibly for the advanced automotive Stirling which has many complex high tempeature components using exotic metals and ceramics.

Costs of Stirling Engines

The simplest Stirlings can be very cheap. The 150 Watt free cylinder water pump is estimated to have a manufacturers cost less than US$50 when made in larger numbers.

The 1 KW electric alternator is estimated to cost US$600 in lots of 100,000.

The 10 KW free piston linear alternator engine is expected to cost USS2,000 in lots of 100,000.

Automotive Stirling engines are variously estimated to have cost 2-3 times the Diesel of the same power.

Biomass field hot air engines are estimated to cost $200/KW when manufactured in low

labor cost areas (Gangladesh).

Suggestion for Taiwan Stirling Engine Activity

1. Monitor U.S. and European Development

The great activities in the U.S. and Euqopean development laboratories will bear fruit within the year in the form of working laboratory prototypes of heat pumps, small free piston alternator, small hot air engines, solar electric generators and automotive type machines.

If any of these machines appear promising. They should be considered for manufacture in Taiwan.

2. Make business agreement to transfer technology to Taiwan ot promising technology, when the time is appropriate. Consider, for example, the heat driven heat pump, using oil as fuel at cost of 14.5 NY/liter and electricity cost of 3 NT/KW hr. Assuming a C.O.P. of 3 for the electrcity air conditioner and 1 for the fuel driven heat pump, the operating cost turns out to be the same for both. On the other hand, if the heat driven heat pump is used on a fishing boat to freeze fish, its cost and complexity would be less than that of an engine driven Freon compressor used for the same purpose. It would also be used whenever cooling is needed and electric power grid not availble.

Other applications are appended to this report. These arose during discussion with the R.O.C. group during the Workshop and are merely a start to a much more lengthylist of possibilities.

3. Establish Stirling engine research in University

There has been very little university research work on Stirling engine analysis and component development. The followings are fruitful areas for work:

a) Regenerator-theory, materials performance.
b) Heater head materials for high strength at high temperature and low cost.
c) Cycle analysis and numerical modelling. System optimization
d) Experimental investigation of gas springs, nonlubricated sliding seals, heater and cooler, recuperator, burner, linear alternator.
   These are easy and cheap to make and appropriate for investigation by graduate students in Mech. Engineering.

4. Set up a stirling Engine Committee to travel to the US, Sweden, Germany and Japan and become acquainted with the state-of-the-art. This committee might also develop a list of potential application and rank them according to potential for commercial exploitation. As a first step, it should acquire the existing application studies from the U.S. and Japan, as well as other Stirling Engine publications, particularly the IECEC proceedings and the books by Prof. Graham Walker.

APPENDIX-Applications To BE Considered (in no order of priority, incomplete list)

Computer power supply-fail safe multiple engine-alternator battery charge. (y)
Eel Fish farm airator (z)
Battery charger for sailboat-diesel fired, automatic control (y)
Biomass fired general purpose shaft power = export to S.E. Asia and elsewhere (z)
Food freezer, fish freezer on boats-diesel fired (y)
Solar electric generator-export to Sunny Countries (y)
Air compressor (a)
Oxygen Air-Nitrogen liquifier for Laboratory use (x)
Irrigation pump-free cyclinder engine biomass fired, for export or local use (a)
Home local energy system cooling, electricity, hot water (x) (y) (a)
Mobile vacation home power supply (y)
Emergency power supply (y)
Village power supply-biomass fired (z)
Diary milk cooler-biogas fired (x)
University demonstration-experimental unit (x) (y) (z) (a)

x = duplex stirling heat driven heat pump
y = free piston linear alternator
z = hot air crank drive engine
a = special purpose free piston

GEOTHERMAL ENERGY

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Geothermal energy has already had a long history of development, compared to most of the other types of renewable energy resources we have heard discussed yesterday and earlier this morning. Geothermal resources which are natural occurring underground steam and hot water, were first used to generate electric power about 75 years ago in Italy. However it was only after the oil shock of about 10 years ago, when we saw OPEC oil prices increase four-fold almost overnight, that there began a significant expansion in the world wide installed capacity of geothermal electric power. During the past five years, the annual rate of installed capacity expansion has averaged about 20%, to where now the total world wide installed capacity is slightly over 2.5 million Kilowatts. That amount will supply the electricity needs of a city about the size of Taipei.

The reasons for this recent expansion are primarily two fold. One is pure and simple economics. As the price of oil and other alternative fuels goes up, geothermal energy development is increasingly cost competitive. The other primary reason for expansion has been, in some cases, for reasons of national security. The increased development and use of any domestic resource, of course, reduce the risks of maintaining the desired or required levels of national energy supply.

So, if reduced cost and increased security are the reasons for expansion, what are the factors that are now limiting the rate of expansion? First, it is not a simple task to locate the underground potentially commercial geothermal reserviors. Second, depending on the specific characteristics of those geothermal resources that are found, there may be specific technical problems to be solved, such as sealing or corrosion. And third, in countries like the United States, where the power generating facility are usually built and paid for by private or public owned utility companies, those utility companies have generally been reluctant to invest in this new types of power plants. Usually the utility companies can set the same rate of return by continued investment in the traditional-old-types of power plants.

That's a very brief and general summary of both why geothermal energy expansion is desirable, and why that expansion is being somewhat limited. However, before leaving that point, let me give you an example as to how the third limiting factor can be eliminated, that of utility company's reluctance to invest. Look at what has been recently happening in the Phillippines. There, using government utility, they have in only the past five years gone from 0 to almost half a million kilowatts of installed capacity, that is 20% of the total worldwide geothermal development. And they plan to double that by the end of next year, to almost 1 million kilowatts.

So the real limiting factors are only the ability to locate the underground resources, and to

technically accomplish their development.

Let's now turn to what is being done to improve the ability to locate geothermal resources, because this is where the exploitation and development always must start.

The experience of over 20 years of geothermal exploration by private industry in America can be summarized as follows:

(1) Geochemical exploration techniques, particularity those applied to the isotopic, elmental, and complex analysis of surface and near-surface fluids, are critically important to make initial regional assessments. In other words, geochemical exploration can be used to determine, region by region, the potential for locating commercial geothermal resources at sufficiently shallow depth. As many of you know, these geochemical techniques, developed, described and perfected by the United States Geological Survey over the past ten years, allow us to make an initial characterization as to the type of geothermal resource that is expectable whether it is probably dry steam or hot water, and if hot water, at what minimum temperature and at what approximate salinity pH, etc.

(2) To further define drilling targets within those initially selected areas of potential geothermal resources, as indicated by surface fluid geochemical analysis, the preferred technique is now magnetotellurics.

The electrical and electromagnetic methods used in geothermal exploration have historically included both "Active" (controlled-source) methods and the "Passive" methods that use naturally occurring fields. "Active" methods, such as dipole-dipole, bipole-dipole, and Schlumberger vertical electrical soundings were very popular 15, 10, and even 5 years ago. However, all active methods have serious disadvantages, particularily the lack of depth penetration below 500 to 1000 meters.

Two passive techniques exist, self potential and magnetotellurics, both use natural fields. Self potential surveys are simple and inexpensive, but the results can be obscured by cultural or natural noise voltages.

Much preferred now is the MT method, which generally stated, is a way of determining the electrical conductivity distribution of the subsurface (to depth of at least 10KM) from measurements of natural transient electrical and magnetic fields observable on the surface. This electrical conductivity is affected primarily by the rock type present, its porosity, the salinity of the pore fluid present, and the temperature. Hot, somewhat saline liquids found in porous or highly fractured altered rock, which are the typical conditions of geothermal reservoirs, can be identified as relatively high conductivity zones locatable in both areal extent and depth by MT survey techniques.

Significant advances have been very recently made in further developing MT field instrumentation, software, and mini computer hardware. Field facilities can now do real time processing of multiple station data, thereby both insuring the proper acquisition of sufficiently high quality data in sufficient quantity, as well as to allow rapid modification and optimization of the on-going survey plan with respect to actural station locations.

(3) The third significant geothermal exploration method, which like MT is currently now going through a rapid technological development and application in the United States, is curie point depth calculation. The basic principle, of course, is that when ferromagnetic minerals are heated above a certain temperature, they rather abruptly become paramagnetic and lose their ability to retain magnetism. That important temperature is called the curie point, and for the common ferromagnetic minerals in the earth's crust, the curie point temperature is about 575°C.

Because the earth's magnetic crust consequently has a finite thickness, the depth to the center of the magnetic crustal thickness, which is the centroid depth, can be calculated by spectral analysis of typical airborne survey magnetic field data. Then, after the depth to the top of the magnetic crust is determined, and by reasonably assuming that the magnetic crust is symmetrical about its centroid, a calculation can be simply made of the depth to the bottom of the magnetic crust, which is the curie point depth.

By making a number of such average curie point depth calculations within a series of areally overlapping blocks of cells, a contour map can be made of the curie point depth calculation results, which is in effect a contour map of the depth of 575°C isothermal surface.

It is now 5 years since Bhathacheryya and Leu published their results using this general method at yellowstone park. Significant advancement have been and are now still being made in further developing and improving many of the specific computational techniques being used. More appropriate corrections are now being made to the recorded field data. By having made significantly more 3-dimensional, magnetic model studies, an improved means of selecting more appropriate brock size has been developed. And there are new improved and more sophisticated multiple methods of centoid calculation, which can be used to evaluate the accuracy (or precision) of the results. Those results can also be used to made maps of the areas variation in average temperature gradient; and of the apparent temperature at the top of basement.

The real benefit of the curie point depth calculation techniques is that it provides the ability to locate regional areas of apparently high temperature in areas that do not have any surface evidence, such as hot springs fumaroles alteration or recent volcanism. What now can and should be done is to capitalize on the development of these proven geothermal exploration techniques. Perhaps an interesting example for you is to tell you what is now going on in Japan. Japan has for obvious reasons set a very high priority on expanding geothermal energy development. Japan has import over 98% of the oil they use, and about 83% of the electricity now produced in Japan is from oil and other imported fuels.

Two years ago the Ministry of International trade and industry (MITI) requested that a program be designed for a total nationwide geothermal resources survey. The first purpose for this survey is to provide sufficient information to preliminarily identify those areas in Japan having the highest probability of containing the required subsurface condition for commercial electricity generation using geothermal resources. The second purpose is to provide the best technical information available to estimate the total geothermal resource potential of Japan.

The Japanese government is now spending the equivalent of 30 million US dollars a year to promote the exploration for and the further development of geothermal resources. Their goal for 8 years from now is to have 3,000,000 kw of installed capacity, by 1990. This will require a

massive, organized, and optimize use of the most efficient exploration method. In the time remaining we should turn to some of the specific technological problems that have had to be solved, in the United States and elsewhere to actually accomplish the expanded development of the resources discovered. (Figures 1 through 11 were presented here).

The Imperical Valley of Southern California contains very significant quantities of hot water type geothermal resources. This resource area, first discovered over 50 years ago, is now known to reach temperatures of at least 350°C, at depths between 4.5 and 3 kilometers. The total dissolved solids content ranges from less than 2000 ppm to over 300,000 ppm—30% dissolved solids.

Development has been slow, while we learned to avoid precipitation of those dissolved solids in the form of sulphite, silicate and carbonate scales which, when uncontrolled, plugged production wells, surface facilities, and injection wells. The specific chemical characteristic of the Imperial Valley brine are highly variable, and in some aspects they may be unique. But, the presently successful development of chemical treating technique indicates that we can now see the light at the end of the tunnel, as we say.

For within the last two years two 10,000 kw pilot plants have been built, one being a binary installation, the other a single flash unit, and although their initial operating records were certainly not trouble free, in fact far from it, they have now performed satisfactory enough to encourage the presently ongoing final design and construction permitting of at least five 40,000 to 50,000 kw power plants. Let me now try to briefly summarize what may be of value to Taiwan, with regard to geothermal power development.

First, it may be of long range value to stand back and re-examine what has been done to select the areas when development is now being pursued. Use of the significantly improved MT and Curie Point exploration techniques, combined with existing knowledge, may indicate additional areas for exploration that could contain more desirable resources.

Second, for the shorter range, it is important to now determine what can be done to demonstrate the development capacity of the resources discovered on Taiwan to date.

There now exist very good, theoritically sound, technically feasible methods of geothermal reservoir evaluation. These methods can give you a good approximation to the answers that you want, how much will these reservoirs yield, and how long will they last.

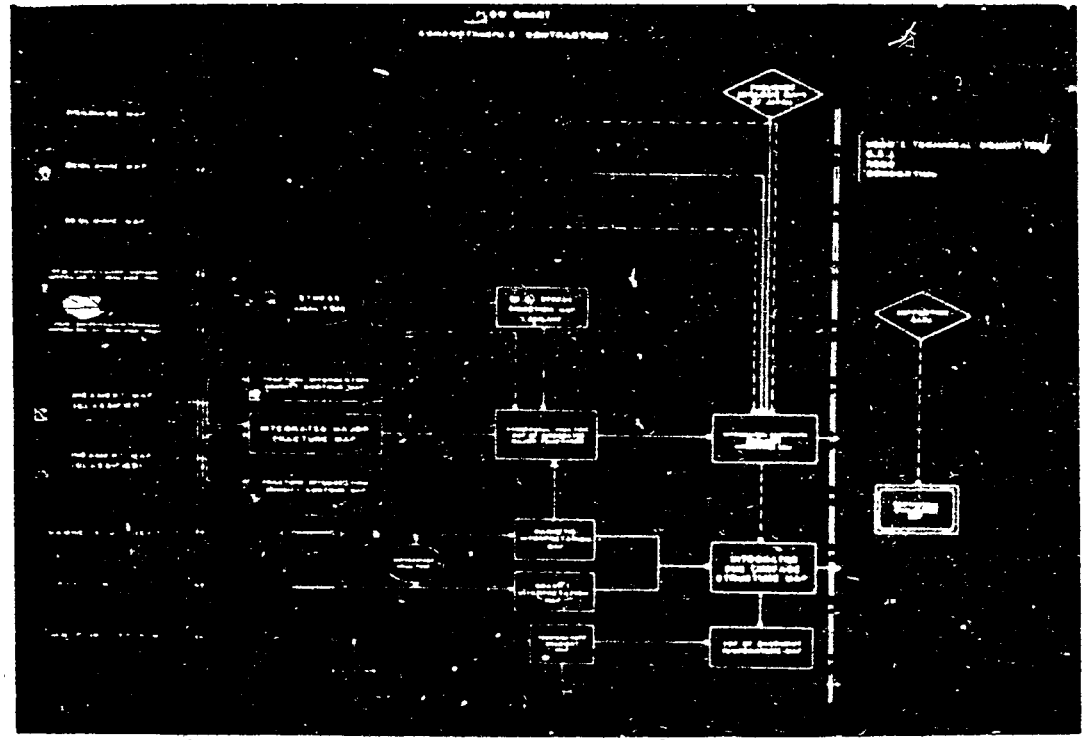

Fig. 1 Flow chart of Consortium and Contractors

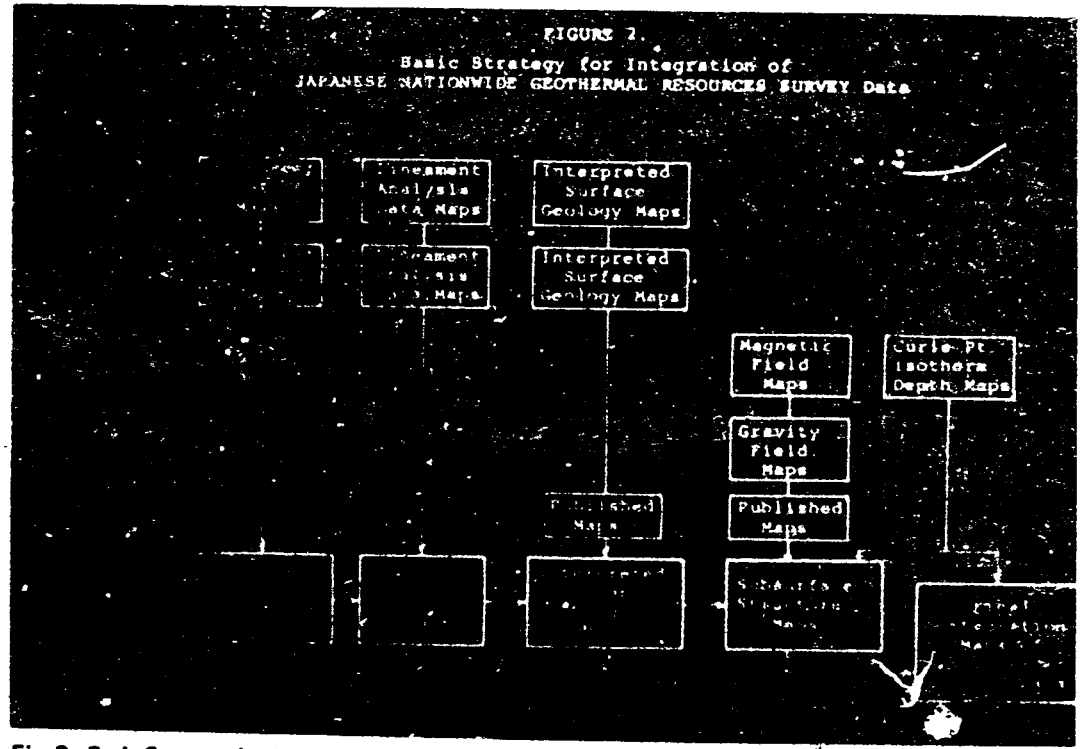

Fig. 2 Basic Strategy for Integration of Japanese Nationwide Geothermal Resources Survey Data.

Fig. 3 Present Schedule of Completion of Nationwide Geothermal Survey Tasks of Data Aquisition, Processing, Interpretation, and Interpretation Assessment.

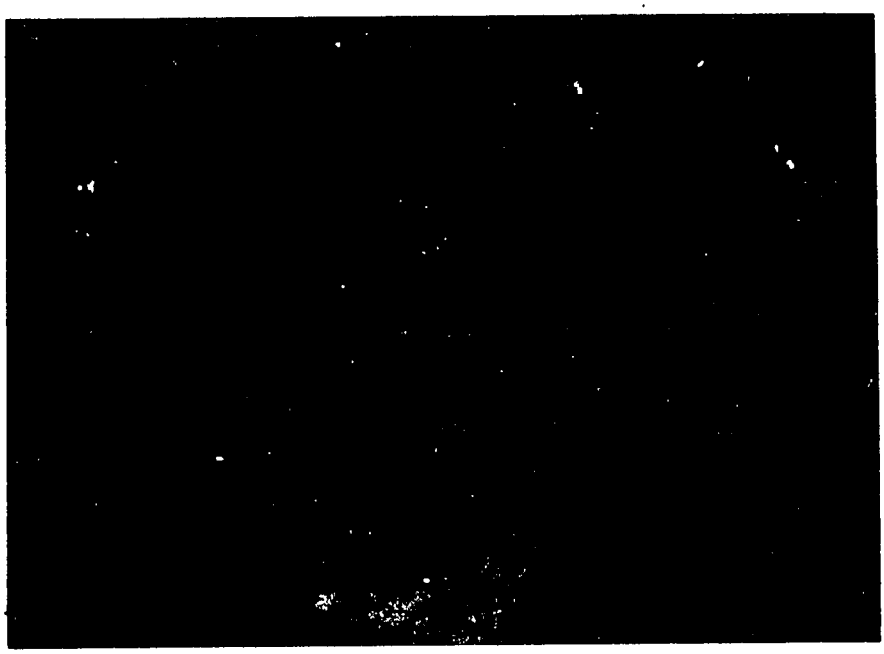

Fig. 4 Conceptional Design of Nationwide and Regional Surveys to Explore and Develop Geothermal Resources in Japan.

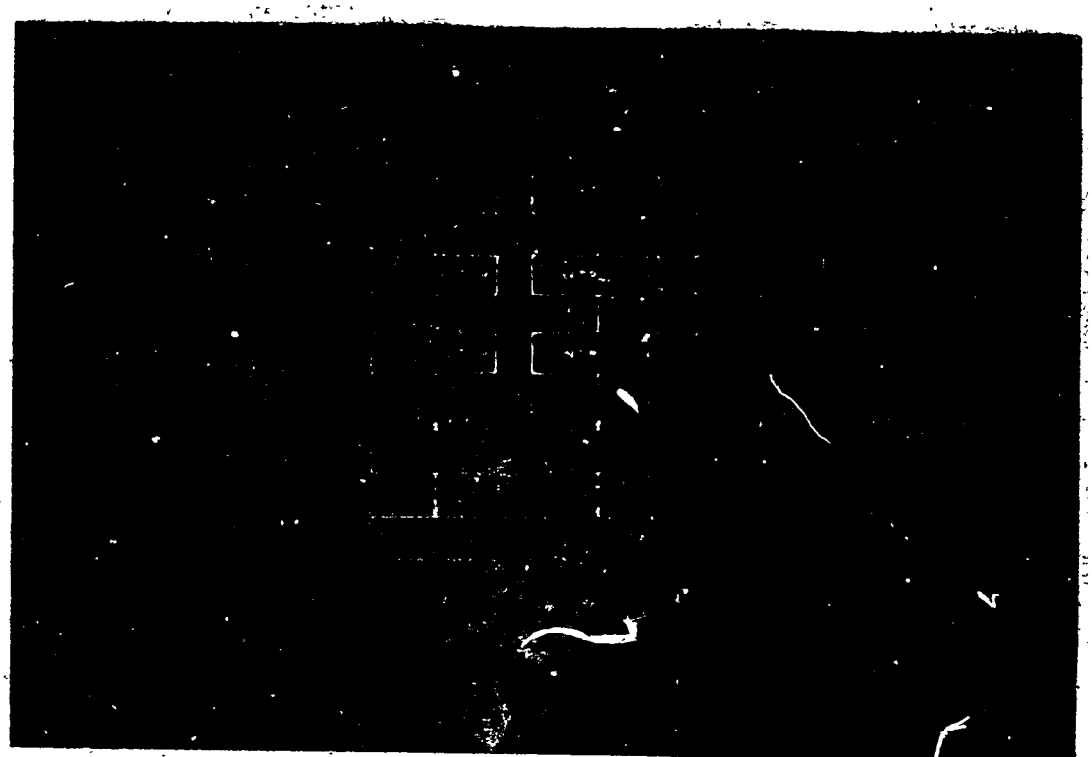

Fig. 5 Conceptional Design of Interpretation and Intergration of Nationwide Geothermal Survey Data.

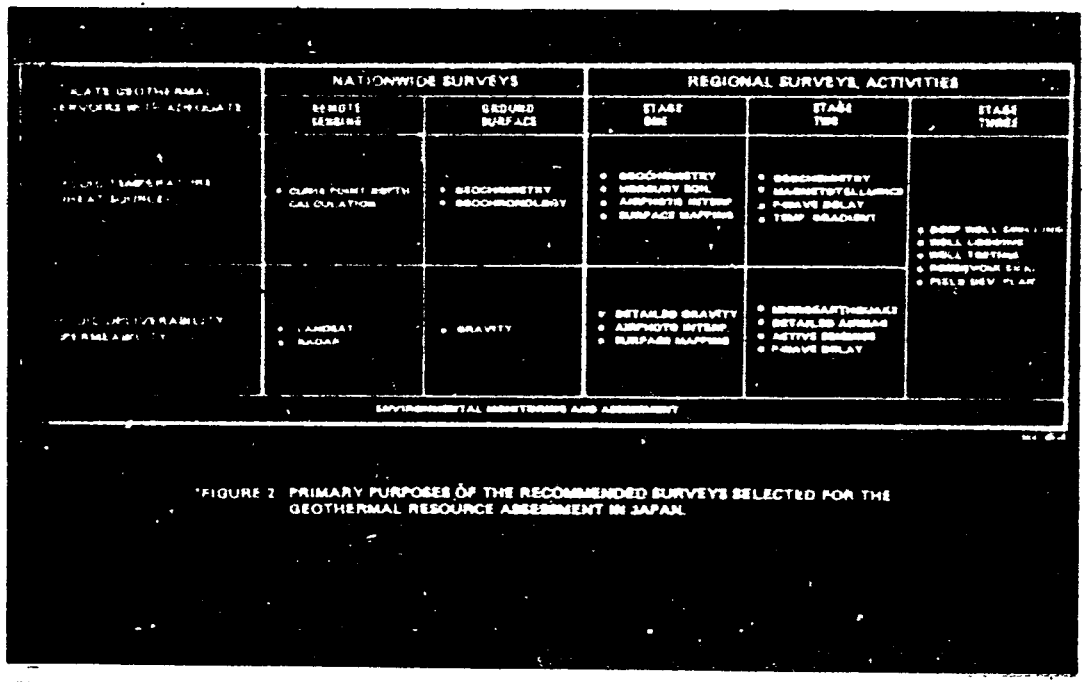

FIGURE 2 PRIMARY PURPOSES OF THE RECOMMENDED SURVEYS SELECTED FOR THE GEOTHERMAL RESOURCE ASSESSMENT IN JAPAN.

Fig. 6 Primary Purposes of the Recommended Surveys Selected for the Geothermal Resource Assessment in Japan.

Fig. 7 Photographic Survey Data, N-S Mosaic, Japan.

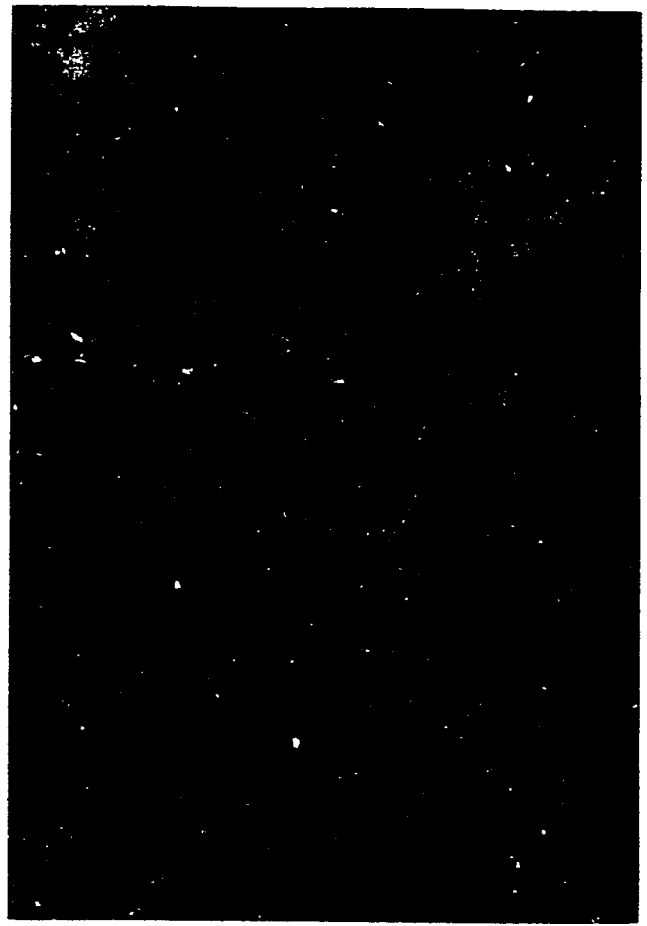

Fig. 8 Curie Point Survey Area to be Surveyed.

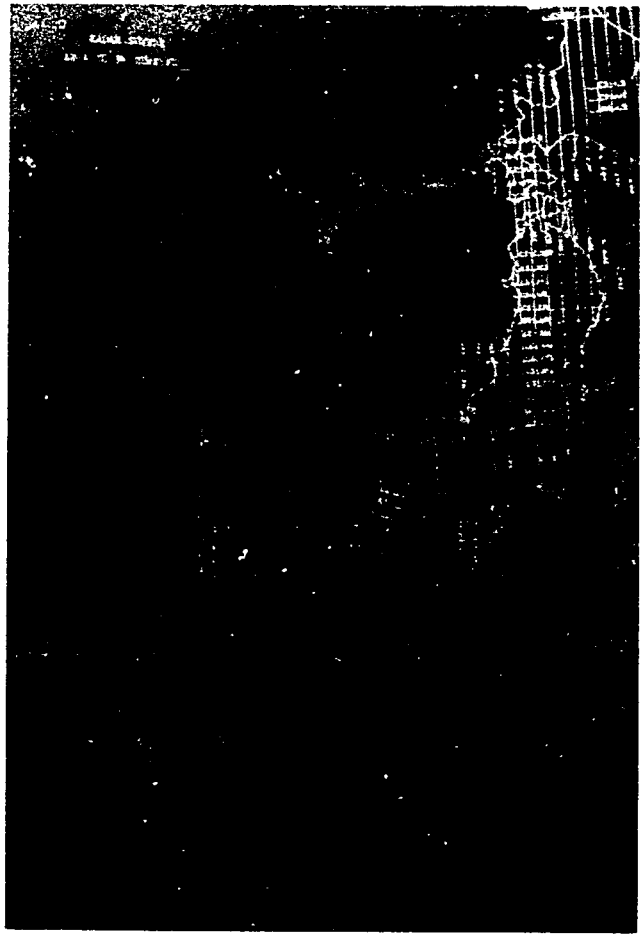

Fig. 9 Radar Survey Area to be Surveyed.

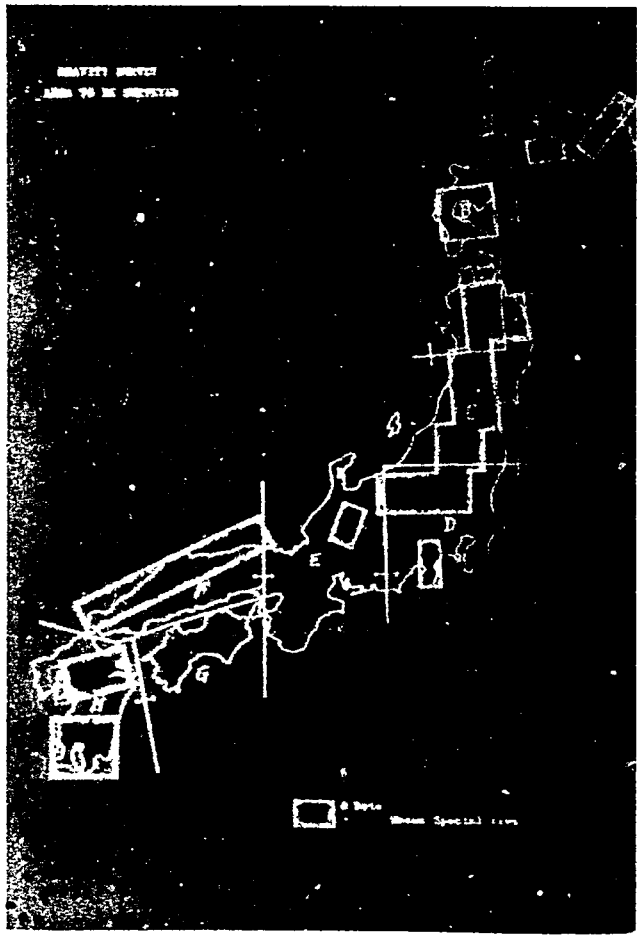

Fig. 10 Gravity Survey Area to be Surveyed, Japan.

Fig. 11 Landsat Frame Coverage of Japan.

SUMMARY REPORT ON GEOTHERMAL ENERGY

by
Dr. John L. Smith

Introduction

The geothermal energy group has reviewed in some detail the results obtained to date with regard to geothermal exploration and development in Taiwan.

Considering these facts, we have concluded that future operations be directed to successively achieve specified short range, middle range, and long range goals. Briefly stated, the short range goal is to demonstrate successful geothermal development in Taiwan, as soon as possible, even at an initially small scale. The middle range goal is to locate additional areas suitable for detailed exploration and deep drilling, during the next one to two years. The long range goal is to locate new areas, not now identified, that can be reasonably expected to have a high possibility of thermal success as well as adequate steam flow.

With these goals in mind, the following recommendations are submitted:

A. Short Term (Immediate to 1 year)

1. Chingshui Geothermal Field

The fundamental problem in this field is to locate reservoir rock with an adequate fracture system to sustain sufficient flow of geothermal fluids. The best target known at present, is the middle sandstone member in the slate series. An assessment should now be made of the depth and extent of all lost circulation zones in each well so far drilled, comparing these to electric loss run, and correlating these zones with the observed production horizons. If correlations can be identified, it will then be possible to predict where to drill, to intersect these zones to obtain higher production rates from future wells.

Temperature and permeability are the two fundamental factors in all geothermal energy development. It is not advisable to drill simply in the hottest areas, if those areas contain less fractured zones. It is very important to locate the future drilling sites according to fracture targets, which may not be in areas of maximum temperature.

The production history of each presently producing well in the Chingshui geothermal field should be now instrumented to continuously record the temperature, pressure, and flow rate of fluid. These records, as they are developed, will provide important information on the producability of specific fracture zones in the subsurface, and also help identify any down hole chemical scaling problems in the wells.

2. Tatun Geothermal

The important past problem in this field has been the production of low pH fluids from the

deep Miocene to Oligocene sandstone formations, which have caused serious corrosion troubles. The volcanic rocks overlying those sandstones generally contain hot geothermal fluids that have neutral pH values. Sufficient steam flow may be obtained from within the fractured volcanics. The Tatun volcanic area has immense surface manifestations of heat flow, which is very promising, on a world standard for geothermal exploration and development. It is therefore recommended not to abandon this volcanic area as unfavorable for continued geothermal exploration. However, future drilling targets in this area should be selected exclusively within the Pleistocene volcanic rocks overlying the sandstones. Drilling should stop before the sandstone is penetrated, to prevent low pH fluids from entering the well bore from the sandstone reservoir below. There remains a considerable extent of volcanics that should be evaluated by future exploration programs, and that should be exploite for the geothermal resources.

B. Middle Term (1 to 2 years)

1. It is recommended that the middle range goals of the Taiwan geothermal program include detailed exploration surveys in both the Litao-Wulu hot springs area, and in the Chipen area.

The Litao-Wulu area is selected for recommendation because of the high temperature surface manifestations (ovter 90°C), and because of its location in an area where open fractures, necessary to sustain commercial production rates, can reasonably be expected to exist at depth.

At Chipen, existing shallow wells have sufficiently high temperature to justify now recommending that deeper wells be drilled at sites selected so that the same reservoir will be encountered at a deeper location, where even higher temperatures can now be predicted to exist.

2. It is also recommended that after the existing Chingshui wells have been examined in the manner previously described, and additional well data are acquired, that a reservoir evaluation and resource assessment be made of the total Chingshui area, to determine the future electric power potential of this field.

C. Long Term (2 to 5 years)

1. It is recommended that an airborne magnetic survey be made of the island of Taiwan. These survey data will initially be of considerable direct benefit to the ongoing geothermal program, as well as for industries such as for mining exploration and development. Furthermore, as it is important that the area surveyed include the near-offshore regions up to 50-75 kilometers offshore, the aeromagnetic survey data may be of potential value to oil and gas exploration.

It is recommended that immediately after these aeromagnetic data are acquired, the data be processed for Curie Point depth determination. This result should be of real significance to assist in locating new areas that have a high probability of containing subsurface temperatures suitable for detailed geothermal exploration and probable development.

2. It is also recommended that an investigation now be made of the existing electric log data, obtained from previously drilled geothermal wells, to determine if there is a positive correlation of high conductivity zones with zones of relatively high fluid productivity. If such a correlation exists, and it is anticipated that it will exist, it is then recommended that magnetotel-

luric surveys be done in areas of possible geothermal potential, to determine if deep drilling is justified, and if so, at what locations and to what depth.

Finally, it is important that the geothermal exploration program in the Republic of China be undertaken step by step, and that steady progress to accomplish its goals be encouraged by long range planning and long term budget support. Only in this manner will it be reasonable to anticipate steady progress in accomplishing the final goal of significant commercial development of Taiwan's geothermal resources.

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