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DESERT TECHNOLOGY III

第3回国際砂漠技術会議

1995年10月15—20日、富士本栖湖ホテル

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特別協賛：日本万国博覧会記念協会、イオングループ環境財団、日本学術振興会

特別後援：環境庁、山梨県

日本沙漠学会

Guest Editorial

This Special Issue of the Journal of Arid Land Studies contains a proceedings of the International Conference on Desert Technology III held October 15-20 at Lake Motosu, near Mt. Fuji, Japan.

The invited special paper presentations were of 20 min. duration, denoted by *, while other oral papers were of 15 min. duration.

The draft manuscripts of most of the oral 76 papers, including the invited special papers, were submitted by June 30, 1995. The full manuscripts of the papers were reviewed by two (or three; third referee was added when the two judges were conflict each other) anonymous reviewers prior to the conference. The manuscripts revised based on the reviewers' comments were submitted again and fortunately all submitted were finally accepted for publication after peering into them during the conference, excepting papers withdrawn upon authors' requests.

The full manuscripts of the poster 28 presentations were voluntary, but, same review processes as above were also conducted for the submitted manuscripts.

A smaller number of papers denoted by + as "This paper did not receive a full review." were specially edited for publication without review process. This was not caused by their contents, but by their late submission or mailing trouble.

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Nov. 2, 1995, The Guest Editorial Board
Y. Abe, V. Raghavan, I. Endo
K.K. Tanji, and T. Kojima
for the special issue of Desert Technology III

D E S E R T   T E C H N O L O G Y   III

Oct. 15-20, 1995, Fuji Motosuko Hotel, Japan

*The Japanese Association for Arid Land Studies in cooperation with Engineering Foundation.
With the grant of The Commemorative Association for the Japan World Exposition (1970),
AEON Group Environment Foundation, and Japan Society for the Promotion of Science.
Under the auspices of The Environment Agency, Japan and Yamanashi Prefecture.*

an ENGINEERING FOUNDATION CONFERENCE

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Final Program

Sunday, Oct. 15, 1995
18:00- Registration, Dinner & Welcome Reception
21:00- Social Hour & Free Discussion

Monday, Oct. 16, 1995
07:30 Breakfast
08:30-08:50 Opening & Overview(O)
08:50-12:45 Morning(E1) & Before noon(E2) Sessions
(Break, 10:30-45)
Lunch (Local organizing committee's meeting) & Free
(14:00- Mini Tour to Mountain Sites)
17:00-18:00 Social Hour, 18:00-19:30 Dinner
19:30-21:30 Night Session(B1)
21:30- Social Hour & Free Discussion

Tuesday, Oct. 17, 1995
07:30 Breakfast
08:30-12:45 Morning(B2) & Before noon(R1) Sessions
(Break, 10:30-45)
Lunch (International committee's meeting) & Free
(14:00- Mini Tour to Lake Sites)
17:00-18:00 Social Hour, 18:00-19:30 Dinner
19:30-21:30 Night Session(R2)
21:30- Social Hour & Free Discussion

Wednesday, Oct. 18, 1995
07:30 Breakfast
08:30-12:45 Morning(A1) & Before noon(A2) Sessions
(Break, 10:30-45)
(10:00- Spouses' Fullday Tour to Minobu Temple)
Lunch (Local organizing committee's meeting)
14:00-16:00 Afternoon Session(V:Posters & Videos)
16:00-18:00 Evening Session(L1)
18:00-19:30 Dinner
19:30-21:30 Night Session(L2)
21:30- Social Hour & Free Discussion

Thursday, Oct. 19, 1995
07:30 Breakfast
08:30-12:45 Morning(C1) & Before noon(C2) Sessions
(Break, 10:30-45)
Lunch (International organizing committee's meeting)
14:00- Conference Tour (Winery Visit & Dinner)
21:00- Social Hour & Free Discussion

Friday, Oct. 20, 1995
07:30 Breakfast
08:30-12:20 Morning(W1) & Before noon(W2) Sessions
(Break, 10:30-45)
12:20- Future Plan & Closing(O), Lunch

P r e f a c e

Desert Technology III

Desertification (land degradation) is of world wide concern. The process of desertification occurs on 70% of drylands, 3.6 billion hectares or a quarter of the total land surface of the world. The aim of Desert Technology conferences, held biennially since 1991, is to provide a forum to address the science and technology to sustain a habitable environment in arid regions. This forum provides an opportunity for diverse disciplines involved in the utilization and effective development of resources in arid regions, and protection against desertification and land degradation.

Desert Technology III was held October 15-20, 1995 at Lake Motosu, one of five lakes at the base of Mt. Fuji, Japan. This international conference was organized by the Japanese Association of Arid Land Studies in cooperation with the U.S. Engineering Foundation, with grants from The Commemorative Association for the Japan World Exposition (1970), AEON Group Environment Foundation, and The Japan Society for the Promotion of Science under the auspices of The Environment Agency, Japan and Yamanashi Prefecture.

The conference was chaired by Professor T. Kojima, Seikei University, Japan and co-chaired by Professor K.K. Tanji, University of California, Davis, USA and Professor I. Endo, RIKEN, Japan. They were ably assisted by the members of the international advisory board; Professor Y. Abe, University of Tsukuba, Japan, chair of the program committee; Mr. K. Yuki, Ebara Corp., Japan, chair of the local organizing committee; Prof. I. Kobori and Mr. T. Nagahama, President and Head Officer of the Japanese Association of Arid Land Studies; the other members of the local organizing committee; Ms. P. Yamada, Mitsui Const. Co.; Prof. M. Ozaki, Maebashi City Col. Tech.; Y. Hirosawa, Shimizu Co.; Staffs and students of Seikei Univ. and Labs. of Prof. Kojima and Prof. Abe; students from Kyoto and Tokyo Univs.; Suntory Winery staffs; and Hotel staffs, for registration and conference proceedings.

The format of Desert Technology III consisted of morning and evening sessions with the afternoons devoted to field and sighting trips as well as informal discussions (see attached program). The sessions covered topics on Energy and Desalination, Biodiversity and Afforestation, Urban, Sand and Wind Resources, Land Use and Soil Management, Crop and Bioremediation, Water Resources and Management and World Wide Ongoing Activities in Desert Technology. A total of 76 papers were orally presented along with 7 videotapes and 30 posters including four papers presented both in oral and poster sessions. These presentations were received enthusiastically and elicited much discussion by the 122 participants coming from 18 countries: North America (US,6; Mexico,1), Europe (France,1; Russia,1; Uzbekistan,4), Africa (Burkina FASO,1; Senegal,1; Togo,1), Middle East (Kuwait,1; Saudi Arabia,2; Israel,11), South Asia (India,1; Nepal,1; Pakistan,1; Thailand,3), Australia(5), China(20), and Japan(61). Desert Technology III was a huge success.

Desert Technology IV is scheduled to be held in Kalgoorlie, Western Australia, in September 1997, and Desert Technology V in San Diego, California, USA, in 1999. Further information will be distributed by the Engineering Foundation (fax:+1-212-705-7441).

October 20, 1995, at Fuji Motosuko Hotel
The Conference Chairmen, T. Kojima,
K.K. Tanji, and I. Endo, and
The Organizing Committee of
Desert Technology III

沙漠研究 5S, iii-vi(1995)
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Deserts, Development and Peace

– The opening address –

Iwao KOBORI*

Abstract – The historical progress of desert engineering gives us various meaningful lessons of success or failure stories about technology. Deserts might be sustainably developed for the peaceful use for the future generation of our planet.

Key Words : Desert, Development, Environment, Peace, Cooperation

It is my great honor and pleasure to welcome you at the foot of Mt.Fuji.

I do remember the first International symposium on Deserts, which was held on the other side of Mt. Fuji (at Fujinomiya) in 1980 on the occasion of the International Geographical Congress in Japan.

At that time, we discussed several topics on Desertifitation in and around Arid Lands. There we learned the first real information on Deserts in China by Prof. Zhao Sung Qiao. At that time, the local and national newspapers did not pay so much attention to our academic event. Living in a desertless country such as Japan, we, most of Japanese scientists, found it hard to recognize the raison d'être of that symposium. However the assembly of eminent desert scientists gave a strong impetus to subsequent development of Arid Land Studies in Japan.

If we compare this academic event of 15 years ago with the present meeting on Desert Engineering, I have to say that time passes like an arrow and we have a great responsibility in the future of Deserts, Development, and Peace through sincere cooperation in the field of Desert Studies.

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President, The Japanese Association for Arid Land Studies,

I started my career as a desert scientist in the Middle East. In Mesopotamia (northern Iraq and Syria). Palestine (Lake Galilee) and other parts of the Fertile Crescent, I have done field work and seen many archaeological and historical sites which show the decline of civilizations.

Needless to say, our colleague, Dr. R. Adams, has already point out that the decline of Mesopotamian Agriculture might have been caused by an inadequate drainage system or salinization of the soils. The process of urbanization has accelerated deforesteration of the area. When we see the remaining tiny forest of Cedar of Lebanon in Mt.Lebanon, we can not help but obliged to recognize the important role of human activity in land degradation.

In the 1960s and 70s, I had the chance to visit the New Valley Project in accordance with bi-lateral technical cooperation between the U.A.R (at that time) and Japan. We recognized Egyptian efforts to develop oases areas using fossil water, but unbalanced exploitation of the groundwater caused several negative effects, such as lowering of the water level or salinization of the soil. At that time, we brought a solar energy system for lighting (light houses on the desert road) and automatic groundwater monitoring system. This was so early in the development of the solar energy that the system costed a great deal.

In the 1980's, I had the chance to visit Libya. With respect to Desert Engineering, Libya is a place where various new technologies from developed countries are being experimented with installation of a central pivot irrigation system, automatic monitoring and control system of various water systems and finally a great man-made pipe-line from the Kufra Oasis to the Mediterranian Area. This project does not mention cost of development, but seems to favor self-sufficiency in agricultural products. They say that the grounwater exploitation from Calcaire Intercontinentale may not last over 50 years but this does not matter, because we may dig a new well. We are here to discuss science and technology, and not politics. However, unfeasible exploitation of limited resources (sometime in inter-states) may cause problems for next generations.

In comparison with Libya, which is so rich in oil revenues, Algerian case may give us some hints as to what needs to be seriously discussed. I have been interested in more than 30 years field work in oases of Tidikelt in the Algerian Sahara, and have been able to observe a radical technology transfer to the oases, with the introduction of new irrigation technology in the cultivation of crops (wheat, barley), replacing the traditional agriculture based on date palmes. The speed of transformation of the irrigation System is slow and may not be compared with the Libyan case. But here is also the difficult task for Oases inhabitants to follow this new decision-making. The Algerian government has recently started to introduce Solar Energy into remote isolates oases. In my personal view, there are still gaps between the feelings of policy makers and the inhabitants of oases (a very simple example is the maintenance of distilled water). To overcome these dilemmas, we may need to give more serious attention to the socio-cultual background.

From 1981 onwards, I have participated in joint research projects on Karez irrigation with Chinese friends. One of the results was already published in the proceedings and I am very glad to note that the Xinjiang Autonomous government has paid more attention to rehabitation and research on Karez irrigation. As Iranian says, Karez or Kanat may be one of largest Desert Engineering compared with great walls in China. However, hard works to dig tunnels does not attract young generations. We definitely need an innovation of technology for digging the tunnel.

Recently, I saw one of the worst examples of environmental destruction by man. I do not wish to point an accusing finger at those responsible for the Aral Sea Basin. Rather, I want to see discussion of these questions: To what extent can we rehabilitate the Aral Sea Basin through our technology and international cooperation (of course including self-support efforts of riparian countries). One acute problem is the provision of water to inhabitants who have suffered. An appropriate long-term project may be to improve irrigation and drainge systems. How can we move from theory and study into effective action? In this respect, the Aral Sea problem may no longer be an intra-state problem, but rather an Inter-states and global problem without commenting on other states.

Ladies and Gentlemen, I have touched on a number of topics, and may have confused you. If we cite Senator Al Gore's book " Earth in the Balance " (1992. Chap.12, Dysfunctional Civilization, p.218) " The Cartesian approach to the human story allows us to believe that we are separate from the earth, entitled to view it as nothing more than an inanimate collection of resources that we can exploit however we like; and this fundamental misperception has led us to our current crisis. " The strict separation of Nature, God and Man is not part of the typical Asian mindset. Frankly speaking, I, as a Japanese, have many difficulties to fully understand the mind and the way of life of desert people, even deeply involved in their daily lives. It is said that monotheism was born in deserts and Animism was born in tropical regions. A British journalist, Ritchie Calder used a very appropriate phrase " Men against Desert " as the title of his book. He did not say " Men with the Desert " . I find this title appropriate, because he was educated in Europe.

In Chinese poems of the Tang dynasity, we find lines to do with soldiers in deserts. They are often melancholy, but seldom show men in confrontation with the desert. Classical literature including such as the Bible or the Qoran which often refers to deserts depend on the circumstances in which those books were written. We must be careful about the application of new Technology to different socio-cultural contexts.

We have examples of success stories of desert technology in developed countries but tragic examples in developing countries. Sustainable development is easier said than done. The history of development has always been parallel with the history of the destruction of environment. The task for us who are approaching the 21th century is how to reduce the risk of environmental destruction in the process of desert development. For this purpose, we have to bear in mind two essencial factors:

NO.1 Sophisticated Technology ～ Technology which is soft and consumes less energy. We would like exchange and discuss our views on this topic during this meeting.

NO.2 Peace ～ All our efforts and good will to develop deserts areas will be suddenly destroyed by war. I will not quote examples, but contemporary historical events tell us this without exception. And the effects of nuclear tests in deserts are still obscure.

Deserts are our common global treasures. It is our responsibility to maintain unique and beautiful natural landscapes and also to examine the possibilities of better peaceful use of the areas concerned. How to reconcile these apparently conflicting goals is a task which will require our unending cooperation.

Ladies and gentleman, let us work together for the peaceful development of desert areas hand in hand.

Final Scientific Program & Papers

*: 20 min. oral lecture & 4 min. discussion,
-: 15 min. oral lecture & 4 min. discussion,
#: videos & posters, +: not received full reviews.

Opening & overview

0: Chaired by T. Kojima & Y. Abe

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Energy & desalination

E1: Chaired by D. Faiman & Y. Taki
E2: Chaired by K. Tanji & M. Kinoshita

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Invited Special Articles

沙漠研究 5S, 1-4(1995)
Journal of Arid Land Studies

Energy and Environmental Issues in Desert

Toshinori KOJIMA*

Abstract - Several global environmental issues have been focused and discussed independently, however they are deeply concerned with each other. In the present paper, desertification issue, including utilization of desert area is discussed from the view points of global warming and energy issues. Firstly, the relation between the surface ecosystem and carbon dioxide problem is discussed. Next, the possibilities of alternative energy source to wood which is one of causes of desertification, and energy production in the desert are discussed. These points of view will be key factors when human beings should utilize the desert as the last land resource on the planet.

Key Words: Desert, Energy, Environment, Global warming

1. Introduction

There should be strong relation between global environmental and energy issues, *e.g.* carbon dioxide problem and acid rain. Global environmental issue itself could conclusively be caused by human beings. Therefore any counter-measures should be meaningless without considering the human activity. The desertification should also be caused artificially, though it is assisted or directly caused by some natural fluctuation in climate and even if human could not identify the cause. Too frequent and vastly abnormal climate, which is normally thought to be the cause, may possible be caused by human activities.

The cause of desertification is much related to energy issues. Firewood collection often leads to the damage of ecosystem. On the other hand, the desert is filled with renewable energy sources, *e.g.* solar, wind. Desert energy should be utilized to prevent desertification and desert development. Without the utilization of the renewable energy, large scale greening or prevention of desertification should be difficult.

From the view point of environmental issue, we could hardly say, what is good for earth. If we use plenty amount of fossil fuel to prevent desertification, it will not benefit the earth, though most of human activities consume plenty amount of fossil fuel.

In the present paper, the relation between carbon dioxide problems and ecology especially desert and desertification is examined, because carbon dioxide problem is thought to be energy issue itself. Next, the possibility of the energy production and alternative energy development is discussed, including the view point of environment.

2. Carbon Dioxide problems and Afforestation (Kojima *et al.*, 1995)

The surface plant is thought to be one of the most feasible final sinks because it converts carbon dioxide into carbon using the solar energy which is presently difficult for us to use effectively and economically. Plants can fix CO_2 in atmosphere dispersed from various sources. Greening of arid and semi-arid lands may be promising because they have a large potential to fix carbon.

The amount of carbon dioxide released by the destruction of forest was estimated from the deforestation rate, more than 10 Mha/y, and the difference between the carbon in tropical forest and that in grass land or desert, around 150-200 t/ha. Accumulation of CO_2 in the atmosphere is thought to be around 3.5 Gt-C/y. If we could stop the destruction of the tropical rain forest, and afforestation progressed at the same rate as above (10 Mha/y), the accumulation

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would be stopped, assuming that the missing sink works as it is. Furthermore, the cumulative contribution of surface biosphere is almost double of that from fossil fuel.

For the performance of afforestation, the arid and semi-arid lands are thought to be most promising. The global arid land area including desert, grass semi-arid land, salt affected land, and unused land is more than 6 billion ha, which is equivalent to 600 years' measures based on the area of desired afforestation per year. Furthermore, the conversion of carbon dioxide in atmosphere is performed by using the sufficient solar energy which has not been used artificially and the produced carbon is automatically stocked in the plant.

To build up a forest ecosystem, more than 600 kg-water/m^2/y, or 600 mm/y of rainfall is thought to be essential. To produce the amount of fresh water from sea water, more than 30 MJ is necessary even when an energy saving membrane process is employed for it (Matsumura and Kojima, 1991). On the other hand, the biomass produced from the ecosystem is expected to be less than 20 MJ/m^2/y. This means that the afforestation of arid land is negative measure and is not independent if all needed water is produced by conventional methods.

Thus the net amount of fixation is to be evaluated as the amount of the fixed carbon from which the energy input is subtracted. Furthermore, the average value should be considered. As to how long period should be considered, its value itself is one of the most important parameters. The period may not be longer than several hundred years, because the fossil fuel will be consumed, while it may not be shorter than several tens of years, because alternative soft energy passes will not become main energy sources in this time period.

More detailedevaluation is needed by considering the energy input and output of the system.

3. Fossil and Renewable Energy Sources for Cooking and Living

Another important view point is the alternative energy to fire wood, which is one of the most important causes of desertification. It is commonly accepted that coal is worse for earth than biomass, because coal combustion produces carbon dioxide, and sulfur and nitrogen oxides, while biomass is renewable energy and its combustion produces less amounts of sulfur and nitrogen oxides than coal. However, when the wood is not replanted after deforestation by firewood collection, carbon dioxide is also released. If the tree is young and still growing, the potential of its carbon stock is abandoned. The desertification is often accelerated in this way.

In such a case as above, the use of coal is to be surely a countermeasure against the desertification and carbon dioxide problems. The energy utilization for cooking in developing and developed countries are shown in Table 1 (Kammen, 1993). It is clearly suggested that the energy efficiency for cooking is quite low in the developing countries and it is mainly caused by the use of firewood or charcoal. It can be easily suspected that the conversion efficiency of solid fuel into heat is too low. Therefore, even if coal is utilized instead of wood, the conversion of solid fuel into gaseous fuel is most attractive way to use sold fuel effectively. Among coal gasification processes, *i.e.* entrain beds, fluidized beds, and fixed beds, small scale gasifiers such as fluidized beds operated at relatively high temperature will be preferable. The produced gas may also be used to generate electricity by using gas engines. Gasification technology of wood and other biomass will also play a great important roll in such area to improve the energy efficiency.

4. Energy Production in Arid Land and its Transportation

It is well known that the average sun light intensity in arid lands is much higher than temperate zone with much clouded and rainy days. They often have stronger wind in arid land than in the temperate zone. Furthermore, destruction of ecosystem need not to be taken into consideration. Therefore, it is often proposed that renewable energy should be produced in such area as arid land. Such an electricity produced renewable energy could be utilized to the production, pumping up and transportation of water, for afforestation. Direct uses of the renewable energy have also proposed such as solar pump system using solar heat, and wind pump (Ushiyama, 1993). However, if we would like to use such renewable energy in arid lands as above for a world wide large scale energy, the conversion into electricity is essential. The use of wind turbine is one of the most feasible technique in arid lands. We can find a series of wind turbine in California, USA (Ushiyama, 1993).

Table 1 Energy for cooking (Kammen, 1993)

	Energy consumption W/cap.			% of energy for cooking in total energy use	
	individual	average		individual	average
Firewood and charcoal					
Tanzania	570			85	
Cameroon	430			76	
Nicaragua	260			55	
Kenya	420	420		74	73
Firewood and charcoal					
Guatemala	420				
Brazil	430				
India	290	380	400		
Kerosene, Propane, LPG					
Guatemala	50			65	
Brazil	70			27	
India	60	60		60	51
City-gas					
USA	70			1.2	
France	50			0.7	
Sweden	40			0.7	
Japan	30	50		0.6	0.8

In most of desert, its latitude is low or middle and it has little rain. Therefore, the energy of $1kW/m^2$ or so is available in most of the day time. The energy efficiency in desert is several times higher than that in Japan with much rain.

The efficiency of solar cell has been improved year by year. And the efficiency is now approaching the theoretical estimates. To improve the production cost, especially energy cost is of course the next target (Inaba *et al.*, 1993). Additionally, prevention from sand disaster and erosion is essential. Such kinds of problems are now under the investigation.

The future but most important and essential problem will be the transportation cost. Why are the power stations located in coastal areas in Japan? Because energy source of fossil fuel is easy to obtain and the consumers locate in the vicinity of it. Cooling water is also easy to obtain. Oil and coal is transported to Japan mostly "freely". However the amount of energy sources is limited. Global warming issue caused by carbon dioxide release is now seriously arising though the amount of coal resources is abundant. The atomic power have the problems of safety and nuclear resources though it hardly has the problems of carbon dioxide.

An estimation on the transportation cost of energy sources has been presented as shown in Table 2 (Fujii, 1993). It can be concluded that the long distant transportation cost of the electricity is the extremely high while it can be utilized most conveniently and effectively among the energy sources. On the other hand, conventional fossil fuels especially coal and oil are cheapest to transport. Other alternative energy transportation carriers are cheaper than the electricity, however, they are still more expensive than natural gas to transport. If the desert area where the electricity is produced from solar or wind, is close to the consumers, the hydrogen, which is produced by electrolysis of water, may be transported by pipeline with reasonable cost. But, Japan is so far from desert. Methanol/carbon dioxide cycle has been proposed so far (Park, 1993). However the cost may still remain high and energy efficiency low.

Table 2 Transportation cost of various energy (Fujii, 1993)

	Transformation cost $/Ton Oil Equiv.	Transportation cost per distance $/Ton Oil Equiv./10,000km
Electricity	100	1700
Oil, coal, methanol	<<50	<<50
Natural gas		
liquefied	100	50
pipeline	<<50	200
Hydrogen		
liquefied	400	200
pipeline	<<50	250
Cyclohexane cycle	100	100
Carbon dioxide ($/Ton-C)		
Liquefied	100	150
pipeline	0	600

In near future, there may exist more effective transportation way of renewable energy though it may not be classified into intrinsic energy transportation. For example, the replacements of energy consuming industry, such as iron and aluminum making industries, to the desert area is to be enhanced. The transportation of such products from the desert area to the overseas consumers is thought to be a kind of energy transportation, in some meaning. The other is hydrogenation of heavy oil. Hydrogen produced from solar energy could effectively utilized. Liquefaction of coal does not have meaning from the view point of global energy issue if it conducted in Japan, however, transportation of coal liquefied with hydrogen produced in desert has. We should start such on site hydrogen utilization technology as above, as soon as possible.

5. Conclusion

In the present paper, the relation between desert and energy was focused. We may not find best solution but we should start. One of the most important factor we should introduce may by some political or economical means such as regulation or carbon, energy and environmental taxes.

What is the most energy consuming materials? Its answer is human beings. Thus, the relocation of human may be the ultimate solution of this problem when the desert is to be the energy production base. Desert Technology should play an important roll under such condition in near future.

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Management of Inland Lakes for Peace in the Central Asia and Middle East

Masahiro MURAKAMI*, Juha UITTO** and Iwao KOBORI**

Abstract - Intensive water development of the rivers has had significant influence and/or adverse effects on the water balance and eco-systems of the inland lakes in the semi-arid region. The water levels have been significantly lowered in some inland seas in the central Eurasia, corresponding to intensive withdrawal of river waters to feed them. Very little attention has been paid to solving the increasing potential conflicts and the creeping environmental problems concerning the international waters, and time is fast running out. Managing water with decision making in the transboundary inland lakes and the rivers would lead to peaceful resolution by sharing resources and benefits among the riparian states. This paper describes the outcome of a joint research workshop held in March 1995, by the United Nations University (UNU), Japan International Cooperation Agency (JICA), and International Water Resources Association (IWRA) on the international waters of the Caspian, Aral and Dead Sea to develop ideas for international cooperation opportunities.

KEYWORDS : Inland lakes, Semi-arid region, Hydropolitics, Eco-politics, and International waters

1. Introduction

In 1978, Centre for Natural Resources, Energy and Transport (CNRET) identified 214 international rivers and lake basins which cover nearly 47% of the land area in the world (excluding Antarctica). After the termination of the cold war in 1989, increasing fears of conflicts among the riparian states have surfaced around international rivers. Area of the arid to semi-arid region covers one-third of the world continent including many of the inland lakes and/or seas without outlet to the ocean.

Intensive water development of the large international rivers, which feed the large inland lakes in the Central Eurasia, resulted in decreasing inflow and water in the inland lakes including Aral Sea (Khazakstan and Uzbekistan), Hamun e Saveri Lake (Iran and Afghanistan), and Dead Sea (Israel, Palestine and Jordan). By early next century some inland seas will disappear if water continues to be extracted at the present rate. Conservation and management of water resources are the first priority issue to solve the problems. While there are still increasing demands for water, not only to sustain a better quality of life of the people but also to support the economical development of the arid countries. The problem is that the major inland lakes in the semi-arid region are located in the developing countries where neither international nor domestic politics are rather stable with a fear of increasing conflict over the international waters. Development and management of water in the semi-arid region is also largely dependent on the eco-political decision making of the cooperative international development projects.

The joint UNU-JICA-IWRA research program aims at providing a comprehensive and objective environmental management setting not only for sustainable development but also for peace in the perspective of the 21st century. This paper presents selected examples on hydropolitics and eco-political decision making concerning the inter-state regional development of the Aral, Caspian and Dead Seas, with the aim of elaborating schemes to mitigate the future potential sources of political conflict by sharing the resources and benefits.

2. Aral Sea and Caspian Sea : Creeping Environment and Hydropolitics in the Central Asia

In the Pleistocene age, Aral Sea and Caspian Sea were connected to form a vast inland lake in the central Eurasia. The Aral Sea is going to disappear, owing to past political decision making in the 1950s-1960s on the intensive water development of the SyrDaryia- AmuDarya river system for irrigation. The water level in the neighboring Caspian Sea, located only 500 km to the west from the Aral Sea, has been continuously rising since 1977 exceeding the historical average water level. The scientific explanation of the mechanism is still unclear, but the process is causing significant damage through inundation along the coast of the five riparian states, including Russia and Iran and the newly independent states of Khazakhstan,

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Azerbaidzhan and Turkmenia.

Some ideas of large water transfer schemes including the Obi river diversion to the Aral Sea were discussed in the 1980s, but these have been put aside pending questions related to the funding of global scale mega-projects, with budgets above US$1 billion, as well as the somewhat confused state of international politics in Central Asia. Another idea of transferring Caspian water to the Aral Sea is being discussed not only to compensate the water balance but also to restore the water environment (Fukushima & Murakami 1995).

3. The Dead Sea and Peace Drainage Canal : Eco-political Decision Making in the Middle East

The lower Jordan system, including the Tiberias Lake and the Dead Sea, which is shared by the three riparians of the Israel, Palestine (West Bank), and Jordan (East Bank), will be a focus area to demonstrate the international cooperation opportunities for peace in the region. The "Peace Drainage Canal (hereinafter refereed as PDC)" scheme, which would salvage brackish water, including saline springs and irrigation return in the Jordan Valley from the Tiberias Lake to the Dead Sea, is proposed not only to protect water quality environment of the Tiberias Lake and the lower Jordan main stream but also to supply fresh potable water from the RO desalination plant at the terminal end of canal system (Murakami, 1991b, 1995, Murakami&Musiake 1994) . The PDC scheme would envisage an 85 km long drainage canal from the Tiberias Lake to the Dead Sea along with the lower Jordan River in either West Bank or East Bank, installing brackish water reverse osmosis (RO) desalination plant with an installed capacity of 200,000 m3 per day at the terminal end of the canal system. The RO desalination plant would convert useless or harmful saline waters to safe potable water at a reasonable cost of US$ 0.48/m3, taking into account the induced incentives on the eco-political decision making to share the resources and benefit among the three riparians (Murakami 1995).

3.1 Conceptual Planning

The PDC scheme is being proposed to take into account the following six planning elements with eco-political decision making initiatives;

(1) *Water environment* : Sustaining fresh water quality environment of not only the Tiberias Lake but also the lower Jordan system by diverting the harmful saline springs and the wastes which are the main contaminants of the river system, taking into account the potential down stream water users of the Palestine (West Bank) and the Jordan (East Bank).

(2) *Feedwater source* : Brackish waters including saline springs, base flow and brackish groundwater in the Jordan Valley would be collected from the three riparian states. Israel salvages saline springs in the Tiberias Lake and others in and around the Beit She'an. Palestine and Jordan collect saline springs, irrigation return, deep percolation, saline groundwater in the shallow sandy aquifer and brackish groundwater in the deep sandstone aquifer in the Jordan Lift Valley.

(3) *Conjunctive water management* : Diversion intake, infiltration pond and dual purpose well system would be incorporated in a plan to salvage 50-100 million m3 of residual winter flows in the lower Jordan system for conjunctive use. The dual purpose wells are mainly sunk in the sandy shallow aquifer system. The tubewells to pump 25-50 million m3 per year of brackish groundwater in the deep sandstone aquifer system will be added to supply feedwater during dry season.

(4) *Drainage canal system and RO plant* : The drainage canal would collect saline water and wastes from Israel, as well as the West Bank and East Bank. The canal route is planned to be along the main stream of the lower Jordan, either through the West Bank or the East Bank. The RO desalination plant, including pre-treatment and post-treatment unit, will be installed at the end terminal of the canal system.

(5) *Water pipeline system* : The main water pipeline, which is planned to be along with the coast of the Dead Sea, will link the major towns of Suwayma, Qumran, Ein Gedi, Ein Bokek, and Al-Mazra'a, sharing the fresh potable water from the RO plant.

(6) *Waste water treatment system and reuse* : Waste water treatment facilities in the major towns would be incorporated not only to reuse the treated waste water for tree crop or garden irrigation but also to protect the clean water environment of the Dead Sea.

3.2 Reverse Osmosis Desalination

The heart of the "Peace Drainage Canal" project is the reverse osmosis desalination plant including the following three units;

(a) *Pre-treatment* : Before being desalted, the water passes through three pre-treatment steps to remove all solids that would quickly clog the expensive desalting membranes if they are not removed. Pre-treating the water will ensure a membrane life of three to five years.
(b) *Processing* : Reverse osmosis is the separation of one component of a solution from another (in this case, salt from the water) by means of pressure exerted on a semi-impermeable plastic membrane. A total of about 6,750 membrane elements, inserted into fibreglass pressure vessels desalt the water. While the pressure tubes are all 6 m (20 feet) long, some membranes have a diameter of 30 cm (12 inches) while the diameter of others is 20 cm (8 inches). The element is made up of a number of sheets rolled into a spiral wound membrane. Separation of salt is a chemical process and a physical diffusion process. The water is forced through the walls of the cellulose acetate or synthesized membranes by applying pressure at about 15-25 kg/cm2, allowing only the freshly desalted water to pass through. This process permeates 75% of the feedwater and removes about 97% of the salts from it.
(c) *Post treatment and energy recovery* : The product water with a salinity level of 300-500 mg of TDS per litre will be treated to make safe drinking water with WHO standards. The water pressure in the brine reject (25% of the feedwater with 10,000 mg/l salinity) would be recovered to generate electricity with 1MW of mini-hydro power plant at the end of the RO module circuit. After retrieving the energy or electricity of 6.4 million kWh per year, the brine is directly drained to the Dead Sea, where it mixes with extremely high saline water body with 300,000 mg of TDS.

3.3 Project Cost and Unit Water Cost

The unit cost of the brackish water reverse osmosis desalination with the construction of 85 km of drainage canal is preliminary estimated to be US$0.48/m^3, which includes four cost elements assuming a construction period of three years for the RO plant and an interest rate of 85 as shown in Tab.1.

Tab. 1 Major cost element of the RO desalination

Cost element	US$
Capital cost	211,518,000
Design and construction management	2,911,000
Financial expenditure	68,672,000
Annual operation and maintenance cost	20,551,000

The operation and maintenance costs of reverse osmosis desalination would likely to be reduced by using the cheap electricity during the off-peak hours (i.e., from night to morning) and developing low-pressure type of high efficiency membrane modules. The product water of 75 million m3 per year from the RO plant could be shared equally among the riparian states of Israel, Palestine and Jordan. This water would be mainly used for M&I water supply with the aim of supplying fresh potable water exclusively in the major towns and cities along the coast of Dead Sea. The Peace Drainage Canal scheme with RO desalination plant and link water pipeline system will have the highest priority in a basin water master plan for environmentally sound sustainable water development project to induce peace cooperation and regional economic development incentives.

3.4 Integration of the Peace Drainage canal with the Med/Red-Sea Canal Scheme

The Mediterranean/Red-Sea canal scheme is being discussed in the Peace Process among Israel, PLO and Jordan. The scheme aims not only to restore the Dead Sea level but also to generate hydro-electricity with some of the hydro-powered seawater desalination options. Without the Med/Red-Dead Sea canal project, the Dead Sea will continue to drop and shrink. The water budget of the Dead Sea indicates that a decrease in inflow from the Jordan River catchment would also suggest the additional introduction of Mediterranean seawater to the Dead Sea, thereby increasing the system's hydro-potential energy (Murakami&Musiake 1991, Murakami 1991).

Although not much wildlife is being affected (except for bacteria, the Dead Sea is appropriately named), potash works and health resorts on both shores will continue to contend with the additional costs for an increasingly distant shoreline. One clear environmental benefit of the project would be the restoration of the Dead Sea to its historic level. The RO desalination in the "Peace Drainage Canal" scheme will also reduce substantial amounts of discharge into the Dead Sea. This could add 10MW of hydro-potential (or 60 million kWh per year of electricity), if the Med-Dead canal or the Red-Dead canal is incorporated in the integrated development plan (Murakami, 1995).

4. International Cooperation and the Role of the United Nations University (UNU)

The UNU's activities focus mainly on research and advanced education on issues relating to pressing global problems, including peace and governance, development, environment, and science and technology. All of these topics are pertinent to the issues discussed above.

The research on hydropolitics and eco-political decision making aims to identify the issues in disputes concerning water resources, selected alternative scenarios that could lead to the solution of complex problems related to water and environment issues, and recommended processes through which the countries concerned are likely to agree on mutually satisfactory solutions to the problems by sharing resources and benefits. The research will also provide a comprehensive and objective environmental management setting for the sustainable development in the perspective of the 21st century.

This approach was first developed in connection with the Middle East Water Forum organized in 1993 (Biswas 1994; Murakami 1995; Wolf 1995a). Later, it was applied to the international rivers in Asia, including Salween, Mekong and Ganges-Brahmaputra river systems (Wolf 1995b)

UNU is continuing to organize a series of research projects on the international waters that work to harness the inextricable link between hydropolitics and eco-political decision making in arid and volatile regions. It is felt that UNU, as an autonomous international academic organization, will be in a good position to provide a politically independent venue for such studies (Biswas 1994, Murakami 1995, Wolf 1995a, Wolf 1995b). International cooperation, either multi-lateral or bi-lateral or combined the two, would be highly valuable in bringing together scholars and researchers from public, private and non-governmental sectors to share the data and information. UNU also encourage the participation of developing country scholars in the research efforts.

5. Concluding Remark

International rivers and inland lakes in the arid to semi-arid zones are likely to be located in the regions with unstable international politics including ethnic problems. Current geopolitical setting of the riparians of the central Asia in the CIS and the Israel and Palestine in the Middle East may lead either to conflicts or compromise. Also, eco-political decision making, based on solid scientific data and open information, can provide an effective tool for finding lasting solutions to sustainable development of scarce water resources in a peaceful setting.

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Freeze desalination for supplying water and chilled air in an arid area.

Atsuko Kobayashi* and Yoshihito Shirai*

Abstract - Freeze desalination is a method to produce fresh water by forming ice crystals from sea water. Therefore, this method is able to provide not only fresh water but also coolant. In freeze desalination, however, it is difficult to remove salts from the surface of ice crystals produced because the size of ice crystals produced was very small. We found a novel method to make large ice crystals in sea water and enabled to separate ice crystals easily from sea water. Moreover, we assessed energy consumption in the production of fresh water when freeze desalination could be coupled with an air conditioning system using ice crystals produced.

Key Words : Desalination, Freezing, Air conditioning

1. Introduction

Water issues are serious problems in deserts and arid areas, and desalination systems are required in these regions. Currently, some desalination systems, i.e. reverse osmosis, electro-dialysis and multi-effective evaporation, are widely used for that purpose. These systems can supply more than 1,000 ton per day of fresh water, but involve some problems of much energy consumption for making fresh water, deterioration of filters in reverse osmosis and so on.

Freeze desalination is a method to obtain fresh water by forming ice crystals from sea water. This method enables to produce not only fresh water but also coolant. Therefore, reducing costs for making fresh water can be expected by coupling freeze desalination with a heat pump system using ice crystals produced. However, freeze desalination is difficult to remove pure ice crystals from sea water because salts adhere on the surface of the ice crystals resulting in lower quality of fresh water produced. To overcome this drawback, large ice crystals which have a small specific surface area are required to reduce the amount of salts adhering. We have succeeded in making large ice crystals from sugar solutions, of which sizes are more than 2mm in diameter (Kobayashi et al., in press). In this work, we applied this method to freeze desalination and obtained easily fresh water with higher quality. Moreover, we estimated energy consumption in the production of fresh water by this desalination system when coupled with an air conditioning system.

2.Experiments

2.1 Freezing process A batch crystallizer in which coolant were circulating in the wall was used in the freezing process shown in Figure 1. 400ml of sea water was added into the crystallizer and cooled there. When temperature of sea water reached near freezing point, 10 weight % of seed ice crystals introduced into the crystallizer to initiate crystallization. After 2 hours, produced large ice crystals

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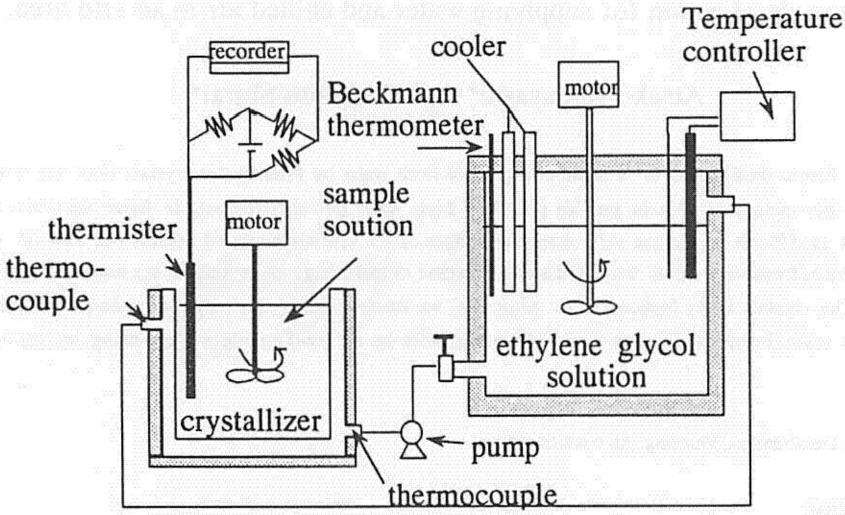

Figure 1 The crystallizer used in freezing process.

were sampled to observe their shape and sizes (Kobayashi et al., in press). The most significant points in this method are to introduce a certain amount of seed ice crystals and to keep the initial subcooling, the temperature difference between the minimum temperature and the freezing point just after seeding, as small as possible. We call this one Method A.

Another experiment in which a piece of ice crystal was introduced into the crystallizer to initiate freezing process was performed for the comparison (Shirai et al.,1987). We call it Method B.

2.2 Separating process Figure 2 shows the illustration of a washing column used in separating process. Ice crystals produced in freezing process were added into a column covered with a heat insulating material. A dryer was working at the top of the column to melt a part of ice crystals. Ice crystals in the lower column were washed by the water that originated from the ice crystals melted at the top. The ice crystals in the whole column were sampled and separated into several parts. Then, the salts concentrations of ice crystals melted at each fraction were determined by measuring its electric conductivity.

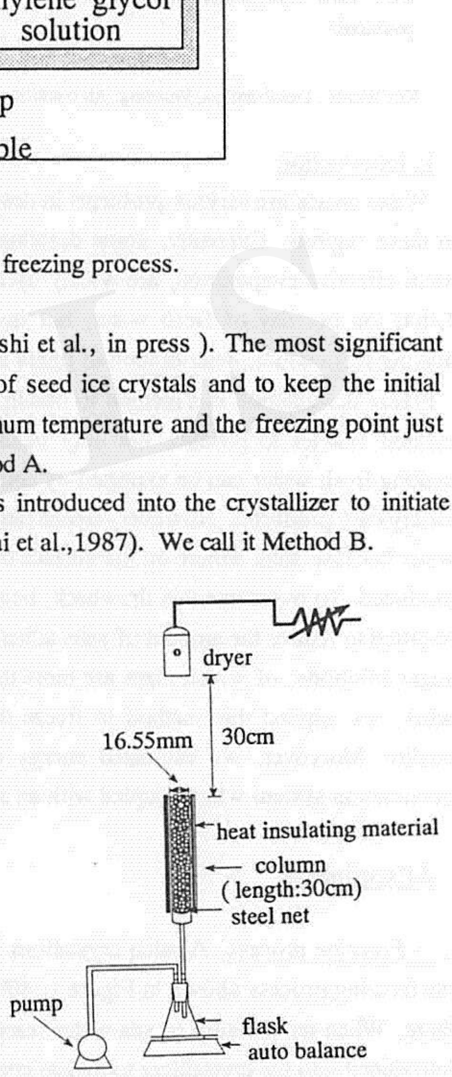

Figure 2 The washing column on separation process

3. Results and discussions

Figure3-a and 3-b show the microscopical photographs of ice crystals produced by Method A and Method B, respectively. Large and uniform sized ice crystals are found in Fig.3-a. The average diameter of ice crystals was more than 2mm in diameter. On the other hand, no large ice crystals are found in Fig.3-b.

Table 1 shows the ratios of good desalination after separating process. The ratio of good desalination indicates how much fresh water less than 500ppm of impurtites occupies the washing column. As shown in this table, fresh water less than 500ppm of impurities could be easily obtained from the ice crystals produced in Method A. However, fresh water such high quality could not be obtained by Method B. We could obtain fresh water from sea water easily using a method which we originally developed.

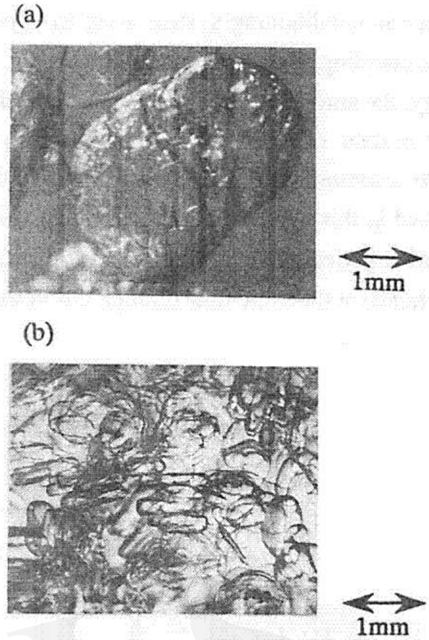

Figure 3 The microscopical photograghs of ice crystals produced by (a) Method A and (b) Method B.

Table 1 The ratios of good desalination[1)] in separation process in Japanese case

recovery rate of ice crystals[2)]	80%	90%	95%
Method A	35.5%	21.4%	18.3%
Method B	0%	0%	0%

1) ratio of good desalination = $\dfrac{\text{The amount of ice crystals whit fresh water in a washing column}}{\text{The amount of ice crystals in a column}}$

2) recovery ratio of ice crystals = $\dfrac{\text{The amount of ice crystals in a column after experiment}}{\text{The amount of ice crystals added to a washing column}}$

Moreover, we estimated an energy and cost performance in coupling system of freeze desalination with an air conditioning system using ice crystals produced. Figure 4 illustrates a schematic diagram of the coupling system of freeze desalination with air conditioning system. From an estimation on energy, the amount of energy for making fresh water was estimated at about 20kW/h per $1m^3$ of fresh water in case of an office building in which total floor area was $10,000m^2$ and 1,500 people were able to accommodated. Finally, we estimated that about 70L /day per person of fresh water would be supplied in this system. These results suggest that this coupling system would be advantageous for hot and dry areas such as deserts and arid areas because not only fresh water but also chilled air could be obtained at the same time through this system.

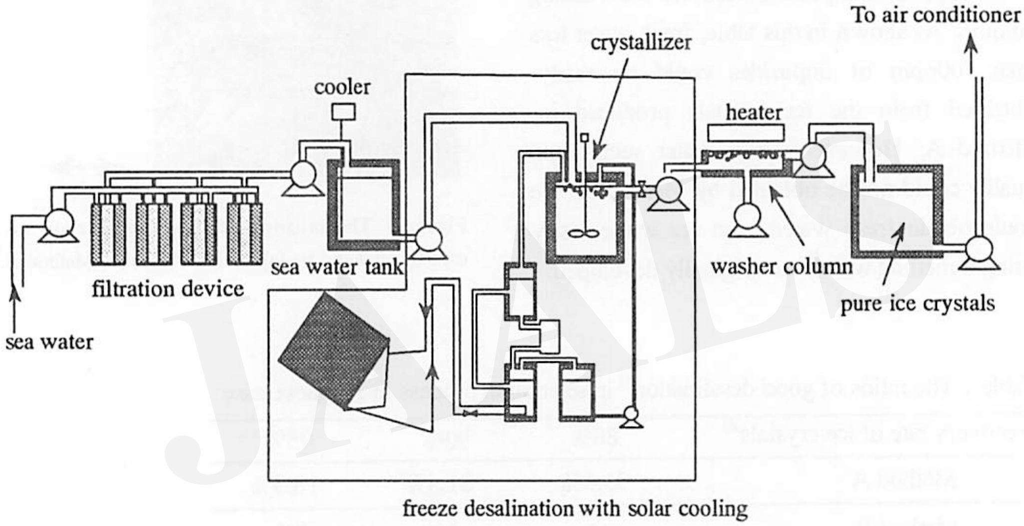

Figure 4 The schematic diagram of freeze desalination system with an air conditioning system

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STUDY ON SOLAR STILL USING CONCRETE SLAB AS SOLAR COLLECTOR

Yoshiaki KURUMI*, Kazuo MURASE**, Masaaki NAKAMURA* and Shigeki TOYAMA*

Abstract - A solar still using a concrete slab as a solar collector and the enhanced evaporating plate was developed. Brine was filmwisely fed into grooves of parallel polyethylene ropes under the slab onto which porous sheet was attached. The productivity of distillate remarkably depended on feed rate divided into three regions; dry-out, effective and independent part. The result of simulation with respect to meniscus film flow shows the mechanism of heat transfer due to the surface area ratio of the sheet to the meniscus film.

Keywords : Solar Still, Desalination Plant, Concrete Slab

1. Introduction

A roof-style solar still has been developed for the purpose of water supply in desert plantation[1,2]. This type has adaptability which enables the hybridization with a panel of photovoltaic cell and the combined use of a greenhouse[3,4].

In this study, the new type of solar still using a concrete slab as a solar collector and the enhanced evaporative plate was developed. The concrete slab has a number of merits; the low cost, high strength and corrosion free for the desert climate and sea water and thermal storage. Due to difficulty of the flat film flow, adopted was a stable flow way formed grooves of parallel polyethylene ropes and a porous sheet, which enhances evaporative heat transfer. The performance of this type depends on feed rate, solar intensity and the design of grooves. Simulation of film flow in grooves results in the mechanism of heat transfer and optimal conditions with respect to the design and operation.

2. Experiment

2.1 Experimental Apparatus and Procedure for Distillate Production The experimental apparatus for liquid evaporation is shown in Fig.1. A concrete slab was used as a solar collector and the enhanced evaporating plate. A porous sheet was attached onto the lower surface of the concrete slab and pressed by parallel polyethylene ropes, which form parallel grooves. The upper surface of the concrete slab was heated by a silicon rubber heater instead of the solar radiation. The temperature distributions of the upper surface of the concrete slab, brine flowing in the sheet attached onto the lower surface and distillate on the condensing plate were measured at nine points in the flow direction with copper-constantan thermocouples. The solar intensity converted from the heater power, the feed rate, the inclination of the solar collector and the pitch of polyethylene ropes were taken as parameters, and the temperature distributions and distillate productivity were measured at steady state. The concentration of NaCl in the inlet brine was 3.5

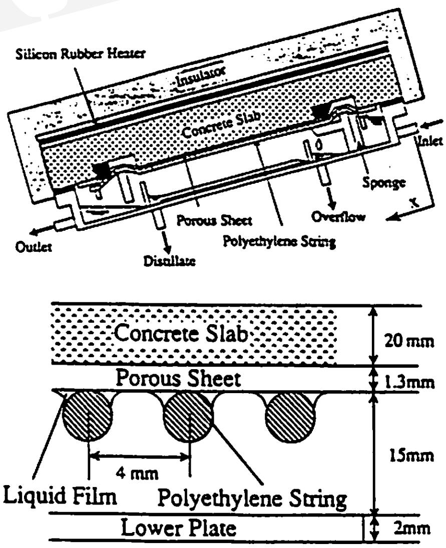

Fig.1 Experimental apparatus

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wt%. The time variations of the concentration of NaCl in the outlet brine and the distillate were measured by using a conductivity meter.

2.2 Measurement of the Saturated Feed Rate

The porous sheet was sandwiched by two acrylic plates and three platinum electrodes were installed in the width direction at a downstream point. The electric resistance was changed by liquid saturation of the porous sheet and was included in the bridge circuit. The voltage change was recorded.

3. Simulation of Meniscus Film Flow

It is considered that the liquid forms meniscus film flow in grooves of parallel polyethylene ropes. The contact angle of the meniscus was assumed to be 0 deg. because the surface of the polyethylene ropes was wet. The meniscus film flow was calculated by the finite element method supposing that the liquid flows parallel to the ropes and that the curved surface of the meniscus is an arc[5,6].

4. Results and Discussion

4.1 Saturated Feed Rate in the Porous Sheet

The effect of the feed rate on the voltage is shown in **Fig.2**. The voltage sharply increases near a critical value of the feed rate. Beyond the value it becomes unchanged, which corresponds to the saturated condition in the porous sheet. Such the critical value is defined as the saturated feed rate(Fs). It is seen from Fig.2 that Fs is 4.6 $kg \cdot h^{-1} \cdot m^{-1}$ at 40 deg. of inclination of the solar still. Also Fs is 3.2 $kg \cdot h^{-1} \cdot m^{-1}$ at 20 deg. It is considered that the meniscus film flow is formed when the feed rate is beyond Fs.

4.2 Concentration of NaCl in the Distillate

When brine is fed, the time variations of the concentration of NaCl in the outlet brine and the distillate are shown in **Fig.3**. The concentration of NaCl in the distillate is low all the time. It is confirmed that the fresh water is produced steady.

4.3 Temperature Distributions in the Solar Still

The temperature distributions of the upper and lower surfaces of the concrete slab and the lower condensing plate at solar intensities of 576 and 1488 $W \cdot m^{-2}$ are shown in **Fig.4**. The distance of 0.5 m is needed to heat brine at the low solar intensity. At the high solar intensity, however, the distance to heat brine becomes short.

4.4 Distillate Productivity The effects of the

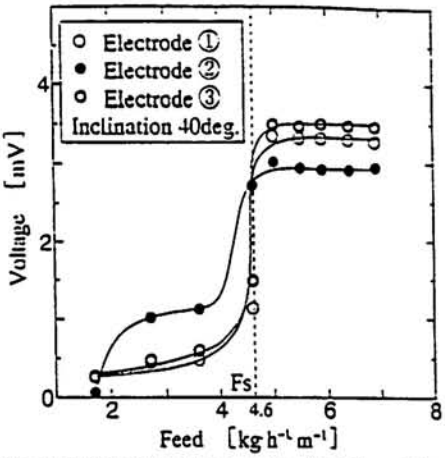

Fig.2 Effect of feed rate on the electric resistance

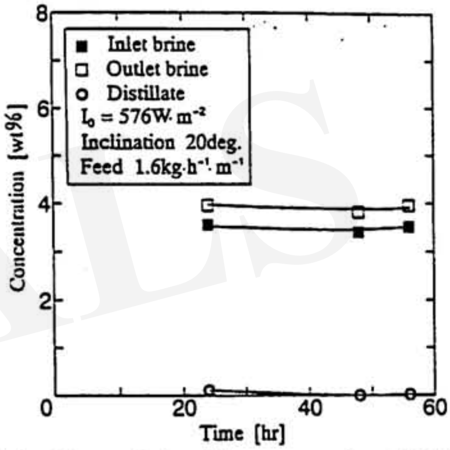

Fig.3 Time variation of the concentration of NaCl

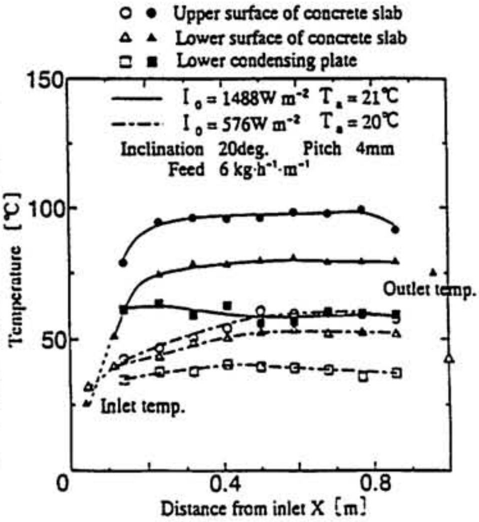

Fig.4 Temperature distribution in the flow direction

feed rate per the width of the concrete slab, the solar intensity and the inclination of the solar still on the distillate productivity are shown in **Fig.5**. The broken lines show the saturated feed rates(*Fs*) in the porous sheet for the respective inclination of 20 and 40 deg. The maximum value of the distillate productivity appears at the lower feed rate than *Fs*. However, such a lower feed rate is considered to be unpractical, because the dry out in the sheet occurs and the scale forms. Also beyond 15 $kg \cdot h^{-1} \cdot m^{-1}$ the effect of the feed rate becomes small and the distillate productivity becomes almost constant and independent of the feed rate. The patterns of curves for both the inclination of 20 and 40 deg. are the same and it is considered that the inclination of the solar still effects little on the distillate productivity in the range of inclination from 10 to 40 deg.

4.5 Evaporative Efficiency The effect of the solar intensity on the evaporative efficiency is shown in **Fig.6**. The evaporative efficiency is defined as the ratio of the latent heat of evaporation to the solar intensity. When the feed rate is low below *Fs*, the evaporative efficiency increases with increasing the solar intensity. Beyond *Fs*, however, the effect of the solar intensity becomes small.

4.6 Simulation of Meniscus Film Flow As seen from above figures, the change of the distillate productivity with the feed rate is not monotonous. Therefore, the change of the meniscus shape was calculated using the feed rate as a parameter. It is considered that the difference between the feed rate and *Fs* ($Q=F-Fs$) forms meniscus films in grooves of parallel polyethylene ropes. The results are shown in **Fig.7**. The surface of the porous sheet between ropes is not perfectly covered by the meniscus film and water evaporates from both the surfaces of the porous sheet and the meniscus film.

4.7 Surface Area Ratio of the Porous Sheet to the Meniscus Film Since the change of the meniscus shape has a significant effect on the distillate productivity, the ratio of the evaporating surface area of the porous sheet to the meniscus film (*Ap*/*Am*) is shown in **Fig.8**. The characteristic of the area ratio curve is similar to that of the distillate productivity curve. Evaporation from the surface of the porous sheet is dominant. Therefore, effective increase of the distillate productivity is expected below the feed rate at which the ratio of surface areas is about unity (*Fu*), because the thickness of the liquid film, the average velocity

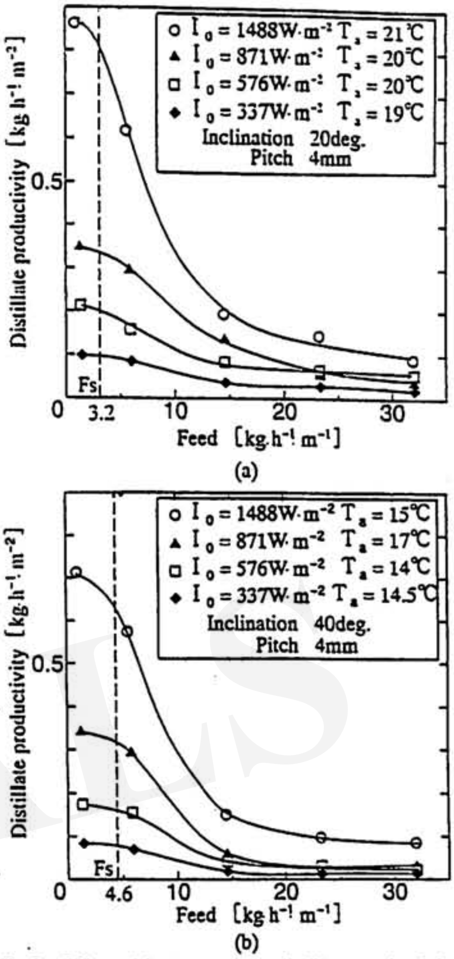

Fig.5 Effect of feed rate on the distillate productivity

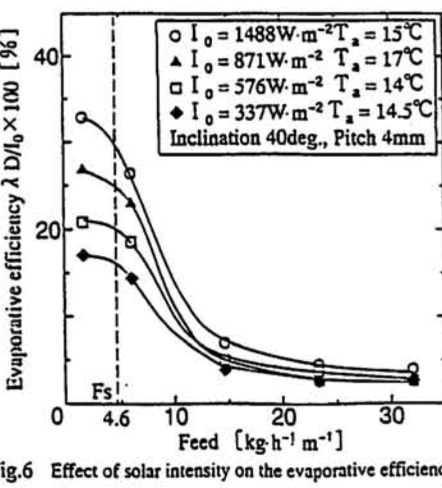

Fig.6 Effect of solar intensity on the evaporative efficiency

and the evaporation rate in the sheet are differed from those in the meniscus film.

When the feed rate is relatively low, the distillate productivity is high because *Ap/Am* becomes high. However, when the feed rate is lower than *Fs*, the dry out occurs and the scale forms.

On the other hand, when the feed rate is relatively high, it is considered that the liquid film formed in grooves supplies water to prevent the dry out and scale formation in the porous sheet. However, the distillate productivity is low and unchanged with the feed rate.

Accordingly, the optimal condition of the operation is the range of feed rate from *Fs* to *Fu*.

5. Conclusion

The roof-style solar still using the concrete slab as a solar collector and the enhanced evaporating plate was developed and the characteristics were examined theoretically and experimentally. The following results were obtained.

1. The feed rate remarkably effected on the distillate productivity within the range of feed rate from *Fs* to 15 $kg \cdot h^{-1} \cdot m^{-1}$ but had no influence on productivity beyond the value of 15 $kg \cdot h^{-1} \cdot m^{-1}$.
2. As the evaporating surface area of the sheet became larger than that of the meniscus, the distillate productivity increased suddenly.
3. The optimal operating condition of feed rate range is from *Fs* to *Fu* to prevent the dry out in the porous sheet.

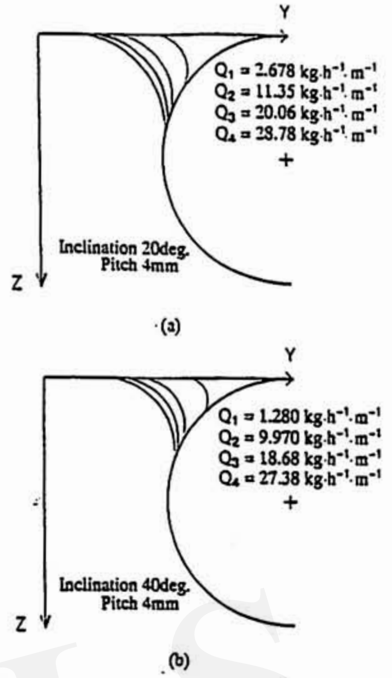

Fig.7 Effect of feed rate on the meniscus shape

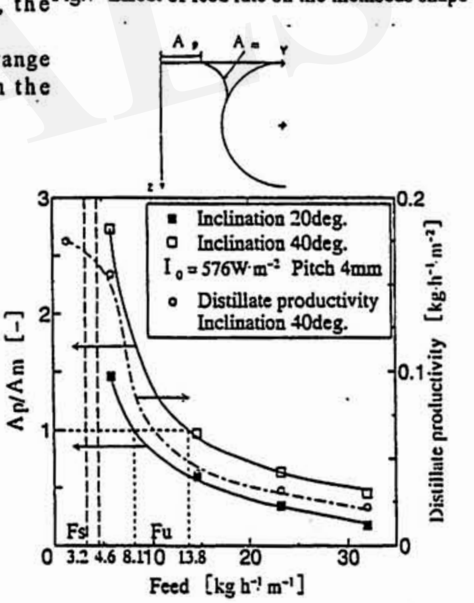

Fig.8 Effect of feed rate on the surface area ratio

Nomenclature

Am = evaporating area of brine film formed between ropes[m^2]

Ap = evaporating area of porous sheet [m^2]

D = distillate productivity [$kg \cdot s^{-1} \cdot m^{-2}$]

F = feed rate [$kg \cdot h^{-1} \cdot m^{-1}$]

Fs = saturated feed rate in porous sheet [$kg \cdot h^{-1} \cdot m^{-1}$]

Fu = feed rate at which ratio of evaporating surface area of porous sheet to meniscus film is about unity [$kg \cdot h^{-1} \cdot m^{-1}$]

I_0 = solar intensity [$W \cdot m^{-2}$]

Q = meniscus film flow (*F*-*Fs*) [$kg \cdot h^{-1} \cdot m^{-1}$]

Ta = ambient temperature [°C]

λ = latent heat of evaporation [$J \cdot kg^{-1}$]

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SOLAR-CHIMNEY WIND POWER GENERATION SYSTEM USING A MACRO-STRUCTURE

Mikio KINOSHITA

Abstract - Theoretical studies on solar-chimney wind power generation system using a macro-structure with height of several kilometers in arid region are reviewed and discussed.
In order to achieve a several 100 GW class electric power plant in a subtropical arid region, we must construct a chimney-like macro-structure for updraft with height of several kilometers. Multi-cellular air-supported membrane structure is proposed. Theoretical approach is developed to describe performance of the solar-chimney power plant with the huge height. Energy density and thermal efficiency are calculated.

Key Words: solar-chimney, wind power generation, air-supported membrane structure

1. Introduction

It is known that hot air with lower density has potential energy to rise, and solar thermal energy is converted to kinetic energy of convection in the troposphere. Kinetic energy of intensive meteorological convection such as a cumulonimbus(scale:several km) in tropical or subtropical region is estimated at several 100GW.

In the field of artificial generation of updraft, solar-chimney is knouwn for ventilation system or solar-wind power system. For example, experimental study of a 50kW solar-chimney electric power plant with height of 200m has been done in Spain[1]. Because wind power of updraft increases drastically with the increment of the scale of the solar-chimney, construction of large scale solar-chimneys is a major isuue for the future solar-chimney plant. In recent years, multi-cellular air-supported membrane structure with height of several km is proposed for several 100GW class solar-chimney power plant[2]. And theoretical approach is developed to describe performance of the solar-chimney power plant with the huge height[3)4)5)6)].

In this paper, recent study on solar-chimney wind power generation system using a macro-structure is reviewed, and performance in arid region is discussed.

2. Theoretical approach[3)4)5)]

Fig.1 is a schematic view showing the solar-chimney system, where, z, h, P(z,u), $P_a(z)$, T(z,u), Γ, $T_a(z)$, and Γ_a denote altitude, height of solar-chimney, pressure of adiabatic updraft as a function of altitude z and velocity u, pressure of atmosphere as a function of altitude z, temperature of adiabatic updraft as a function of altitude z and velocity u, adiabatic lapse rate of updraft, temperature of atmosphere as a function of altitude z, and lapse rate of atmosphere, respectively. Temperature of updraft at altitude 0 is raised by ΔT.

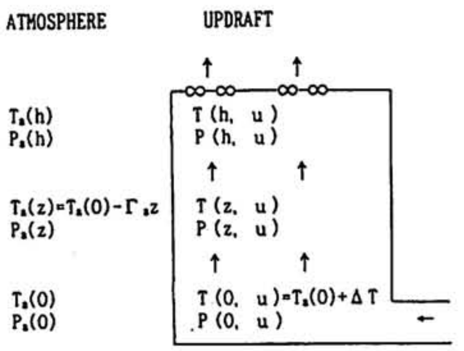

Fig.1. A schematic view showing solar-chimney.

We first calculate pressure of updraft with a slow velocity u→0 as a function of

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altitude z, where, boundary condition is that $T(0,u\rightarrow0)=T_a(0)+\Delta T$ and $P(0,u\rightarrow0)=P_a(0)$.

For adiabatic updraft with a slow velocity $u\rightarrow0$, the following equation stands.

$$dP(z,u\rightarrow0)/dz = -\rho(z,u\rightarrow0)\ g \tag{1}$$

where, $\rho(z,u\rightarrow0)$ is density of updraft with a low velocity $u\rightarrow0$, g is gravitational acceleration.

For dry(unsaturaued) adiabatic updraft, the following two relations

$$\rho(z,u\rightarrow0)=P(z,u\rightarrow0)/(R_d\ T(z,u\rightarrow0)) \quad \text{and}$$
$$T(z,u\rightarrow0)=T(0,u\rightarrow0)-\Gamma_d\ z$$

stand, where, R_d is gas constant for dry air(R_d=287JK^{-1}kg^{-1}), and Γ_d is dry adiabatic lapse rate($\Gamma_d=g/C_p$=0.00976Km^{-1}; C_p=1004JK^{-1}kg^{-1}:specific heat at constant pressure).

By solving equation (1) for $P(z,u\rightarrow0)$, on the basis of these two relations, we obtain the following equation.

$$P(z,u\rightarrow0)=P(0,u\rightarrow0)((T(0,u\rightarrow0)-\Gamma_d\ z)/T(0,u\rightarrow0))^{(cp/Rd)} \tag{2}$$

For wet(saturated) adiabatic updraft, $T(z,u\rightarrow0)$ is determined on the basis of moist adiabatic lapse rate Γ_w. And density $\rho(z,u\rightarrow0)$ is obtained numerically, on the basis of $T(z,u\rightarrow0)$ and estimated density of condensed water(cloud or water droplet). Therefore, altutude dependence of pressure $P(z,u\rightarrow0)$ for the wet updraft is calculated numerically.

We define differential pressure $\Delta P(z,u)\equiv P(z,u)-P_a(z)$.

Differential pressure for updraft with a velocity u is expressed by

$$\Delta P(z,u)=P(z,u)-P_a(z)=\Delta P(z,u\rightarrow0)-(1/2)\rho(z,u)\ u^2-\Delta P_{loss} \tag{3}$$

where, ΔP_{loss} is caused by friction between updraft and solar chimney. Because ΔP_{loss} for chimney with a huge height and a wide cross section is estimated that $\Delta P_{loss} < (1/2)\rho(z,u)u^2$, we neglect ΔP_{loss} in the present study.

Out put power of windmill P_{out} is expressed by

$$P_{out} = c\ S\ u_\infty(\Delta P(h,u\rightarrow0)-(1/2)\rho(h,u_\infty)\ u_\infty^2) \tag{4}$$

where, $c(c\leqq1)$ is a power coefficient for windmill, S is the cross section of rear flow of the wind mill, and u_∞ is a velocity of the rear flow. Energy density of the wind system W is expressed by the following equation.

$$W = u_\infty(\Delta P(h,u\rightarrow0)-(1/2)\rho(h,u_\infty)\ u_\infty^2) \tag{5}$$

The energy density W varies with u_∞. We can calculate maximum energy density W_{max} on the basis of equation (5).

Because $\Delta P(h,u\rightarrow0)$ has a dependence of atmosphere pressure $P_a(h)$, out put power P_{out} and maximum energy density W_{max} are influenced by aerological condition.

Altitude dependence of atmosphere for atmosphere in hydrostatic equilibrium is expressed by

$$P_a(z)=P_a(0)((T_a(0)-\Gamma_a\ z)/T_a(0))^{g/(R_d\ \Gamma_a)} \tag{6}$$

Theoretical efficiency η of solar chimney using dry(unsaturated) updraft in the atmosphere in hydrostatic equilibrium is expressed by the following equation.

$$\eta \leqq (C_pT(0,u\rightarrow 0)(1-P_a(h)/P_a(0))^{R/C_P})-gh)/(C_p\Delta T) \tag{7}$$

3. Multi-cellular air-supported membrane structure[2)]

Fig.2 is a schematic view of a macro-structure proposed for solar-chimney using a multi-cellular air-supported membrane structure. Each cell has a gas-tight structure, and pressured air or light gas such as nitrogen, water vapour, helium hydrogen or their mixtures is retained in each membrane cell. Air inlet for updraft is set at the bottom, and windmill is set at the top.

Fig.3 is a schematic view showing stress. Reduction of total density ρ_m of the membrane structure is important, in order to reduce stress σ_{zz} caused by gravity. Temperature of membrane may be raised, in order to reduce density of gas retained in the membrane structure. We can design the membrane structure to have extremely low density ρ_m like the baloon, where, the structure has sufficient strength against external forces such as wind force. For example, we can design 150 GW solar-chimney wind power generation system using dry updraft with height of 3 km, where, the designed tensile stress of the membrane is 100MPa, total amount of membrane is 3.5×10^9 kg(density of membrane material = 1800 kg/m^3). Fabric made of synthetic fibers such as carbon fiber, vinylon, or steel fiber etc. is usable for membrane material.

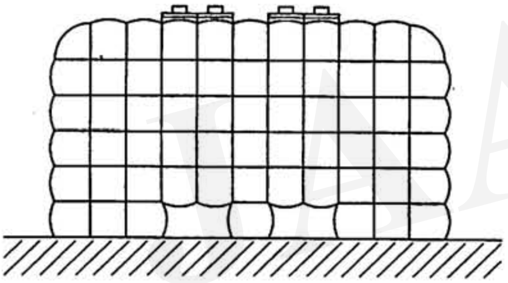

Fig.2 A schematic view of a multi-cellular membrane structure[2)].

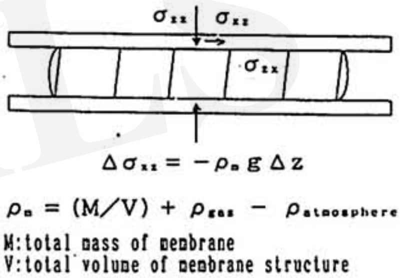

Fig.3 A schematic view showing stress.

4. Results and Discussion

Fig.4 shows differential pressure $\Delta P(z,u\rightarrow 0)$ for dry(unsaturated) updraft with initial temperature rise ΔT of 15K, 30K, or 45K, in the atmosphere in hydrostatic equiribrium, where, pressure at altutude 0 is 101300 Pa, temperature at altitude 0 is 300 K, lapse rate of atmosphere Γ_a is 0.0065 K/m. With the increase of altitude, $\Delta P(z,u\rightarrow 0)$ increases at low altitude, and reachs maximum, and begins to decrease at high altitude. The differential pressure at the windmill for solar-chimney with height of 3 km is, for example, 2 kPa with ΔT=30K, where, density of updraft at the top is 0.85 kg/m^3. In this case, we obtain maximum energy density Wmax of 54 kW/m^2(54 GW/km^2) using equation (5). The intial temperature rise ΔT is an important factor for solar-chimney system. In other words, ΔT of several 10K is required for solar-chimney system using dry updraft, in order to obtain differential pressure of several kPa at high altitude.

Fig. 5 shows altitude dependence of efficiency η with the same condition. With the increase of altitude, η increases linearly at low altitude, and reachs maximum and decreases at high altitude. Collector area for solar thermal energy is designed on the basis of efficiency η. For example, for 150 GW solar-chimney with height of 3 km, collector area will be ~1000km² on a subtropical plain.

Fig. 6 shows altitude dependence of differential pressure $\Delta P(z, u \to 0)$ for wet (saturated) updraft with initial temperature rise ΔT of 0K, 3K, 8K or 13K, in the same atmosphere condition as in Fig.2. Because release of latent heat at high altitude is expected, larger differential pressure $\Delta P(z, u \to 0)$ is obtained with lower intial temperature rise ΔT of several K. Low cost solar collector is usable. A subtropical sea or subtropical arid region where moist air is abundant, is suitable. The system has a possibility as a new water source for arid region, because water(or ice) droplet is available at higer part of the solar-chimney.

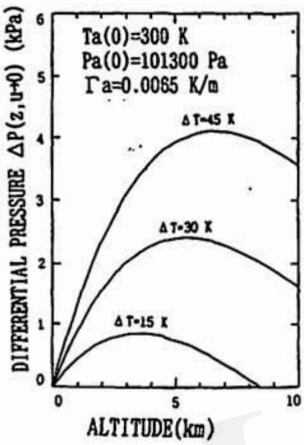

Fig.4. altitude dependence of differential pressure $\Delta P(z, u \to 0)$ for dry updraft[5].

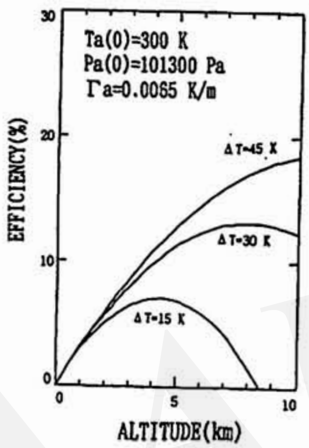

Fig.5. altitude dependence of efficiency η[5].

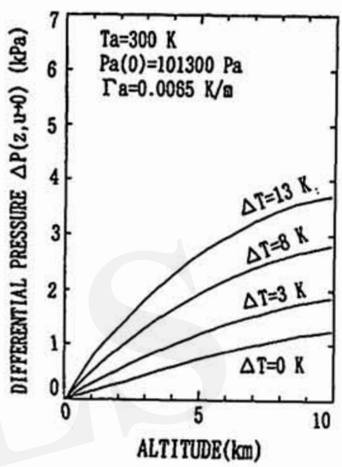

Fig.6. altitude dependence of differential pressure $\Delta P(z, u \to 0)$ for wet updraft.[4]

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Evaluation of Solar Energy in Deserts in the World

Yasuko NISHIGAMI*, Yukio YANAGISAWA** and Haruyuki HIGASHINO***

Abstract - The amount of solar energy reaching the deserts in the world is 3.27×10^{16}kWh/yr (350 times the 1990's primary energy consumption in the world). From a viewpoint of utilizing the solar energy in the deserts, it was classified according to the distance from shoreline and kinds of deserts. The amount of solar energy reaching deserts without dunes within 400 km from shoreline is 7.42×10^{15}kWh/yr (80 times the 1990's primary energy consumption in the world). When considering the present energy conversion efficiency of solar cells, the solar energy reaching there satisfies the energy demand in the world.

Key Words : Solar energy, Radiation, Desert, Dunes, Shoreline

1. Introduction

The atmospheric concentration of carbon dioxide (CO_2), which is an influential greenhouse gas, has been increasing from 280 ppm in pre-industrial time to 359 ppm in 1995 because of increased consumption of fossil fuels. Since fossil fuel consumption leads to emission of CO_2 and acidic substances, more use of solar energy is proposed as one of CO_2 reduction options. Solar energy also attracts much attention as an alternative energy source when fossil fuels are depleted in and after the 21st century.

A total of 3.9×10^{24}J of solar energy reaches global surface annually. It is ten thousand times as large as the amount of primary energy consumption in the world. Since the energy conversion efficiencies are not so high (1%-10%) by vegetative photosynthesis and solar cells, and the density of solar energy is low (1.0kW/m^2) at the surface of the earth, a large area is needed to capture solar energy as a substitute for fossil fuels. Not so much land for this use remains in the temperate regions because growing population demands land for agriculture, industrialization and urbanization. Desert regions receive plenty of solar radiation but have been previously excluded.

Developed countries require a large quantity of energy, more than 70% of the total primary energy consumption in the world, and most of them are located apart from deserts. The transportation of solar energy from deserts to consumption sites is a subject of technological developments. Three types of energy transportation method can be considered; ① Direct transportation of electric power; ②Pipeline transportation of hydrogen

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gas or its carbide; and ③Tanker transportation of liquid hydrogen or its carbide. The first method can be realized if a breakthrough technology of long range transportation such as the superconductivity cable is developed. The second one is already put into practice as natural gas pipeline in Europe, but pipeline transportation is not suited for island countries such as Japan. The last one is also actually practiced such as LNG and LPG tanker. The hydrogen transportation requires new technologies because it causes brittle fracture in metals.

In this paper we assessed the solar energy as a source of electricity generation. There are two kinds of indices evaluating solar radiation, whole sky radiation and radiation to sloped array. The whole sky radiation was used in our assessment and classified according to the distance from a shoreline considering transportation of the solar base energy to the consumption sites.

2. Solar Radiation in Deserts

Deserts are very dry with little precipitation. As the result, there is no vegetation. To select desert area, we used latitude/longitude grid data for vegetation map developed by Matthews, which were obtained from Global Ecosystems Database (GED) (Kineman& Ohrenschall, 1992) of U. S. National Geophysical Data Center (NGDC). This vegetation map was aggregated from many published maps and compensated by satellite information. We integrated radiation data of 1601 world observational sites (JWA/ NEDO,1992) with the GED grid data using IDRISI Geographical Information System.

There are 1.51 x 10^9ha of deserts in the world. The amount of solar energy reaching there is 3.27 x 10^{16} kWh /yr (1.18 x 10^{23}J) (Table 1), which is 350 times more than the amount of primary energy consumption in the world in 1990.

Table 1. Total Amount of Radiation in the World Desert

Desert	Area $10^{10}m^2$	Radiation Density kWh/m^2/day	Radiation 10^{13}kWh/yr
Sahara	800.4	6.25	1825.9
Namib&Kalahari	21.6	6.26	49.4
Arab&West Asia	297.6	6.18	671.3
Central Asia	269.6	4.51	443.8
Australia	122.5	6.22	278.1
North America	1.8	5.64	3.7
World	1513.5		3272.2

Table 2. Total Amount of Radiation in the World Desert without Dunes

Desert	Area $10^{10}m^2$	Radiation Density kWh/m^2/day	Radiation 10^{13}kWh/yr
Sahara	569.5	6.25	1299.2
Namib&Kalahari	18.0	6.26	41.1
Arab&West Asia	219.9	6.18	496.0
Central Asia	222.6	4.51	366.4
Australia	122.5	6.22	278.1
North America	1.8	5.64	3.7
World	1154.3		2484.5

3. Solar Radiation in Deserts without Dunes

Sandstorms frequently occur in deserts because of downward flow and a lot of sand. Moving dunes swallow structures and roads, making steady operation of solar cell facilities difficult. We can not effectively manage sandstorm or blown sand by present technologies, so we excluded dunes from potential areas for the facility installation. Desert areas without dunes occupy 1.15×10^{9}ha in the world and the amount of solar energy reaching them is 2.48×10^{16}kWh/yr (8.94×10^{22}J) (Table 2). This is about 270 times the amount of 1990's primary energy consumption in the world.

4. Deserts and Distance from Shoreline

We calculated the distance of deserts from a shoreline, because harbors will be necessary for energy transportation. We classified the desert area without dunes in every 100km distance from shoreline (Table 3).

Table 3. Desert Area without Dunes from Seashore (10^{6}ha)

Distance from Seashore(km)	<100	<200	<300	<400	<2600
Sahara	23.8	59.8	103.6	153.5	569.5
Namib&Kalahari	8.0	10.9	11.5	14.3	18.0
Arab&West Asia	26.2	59.5	97.3	134.3	219.9
Central Asia	0.0	0.0	0.0	0.0	222.6
Australia	0.6	4.7	11.6	24.8	122.5
North America	0.0	0.0	0.0	0.0	1.8
World	58.6	134.9	224.0	326.9	1154.3

5. Discussion

5. 1 Reliability of Radiation Data Climatic observation of solar radiation does not cover the whole earth surface sufficiently. We estimated solar radiation in each desert from the JWA/NEDO data base containing 1601 world observation points. There are, however, 251 missing data in the data base. If there are several observed data in the desert, their average was used to represent solar radiation in the desert (Table 4(A)). If no data are available in a specific desert, the solar radiation obtained from the nearest location outside of the desert was considered as the representative value. We also estimated solar radiation in each grid by interpolating the observed radiation (Table 4(B)). In this interpolation, a weighted average of solar radiation was calculated to each grid based upon the inverse square of distance from the observational points (Goodin et al., 1979). Then, the representative radiation was obtained by averaging the solar radiations in the grids included in the deserts. The interpolated

Table 4. Radiation Density (kWh/m^2/day)

Desert	(A)	(B)	(C)
Sahara	6.25	5.25	6.38
Arab&West Asia	6.18	4.92	5.75
Australia	6.22	5.19	5.75

data gave lower radiation densities than those obtained from the observational sites.

Budyko (1974) reported a world map of solar radiation, developed from observational data when available and estimated value using latitude and amount of clouds and moisture as parameters. We picked out a representative value for each desert from the map (Table 4(C)). Radiation densities shown in column (A) and (C) agree fairly well. Since there is a limitation to read out precise radiation density value from the map, the representative value obtained from JWA/NEDO data was used for further analysis.

5. 2 Whole Sky Radiation and Radiation to Sloped Array Solar cell is becoming common as means of capturing solar energy because its energy conversion efficiency is relatively higher and its maintenance is relatively easier than other methods. Solar cell converts not only whole sky radiation but also reflected sunshine from ground surface into electric power. Sloped array can capture both of them. We used the whole sky radiation to assess the solar energy potential because a large number of solar cells set up on the ground interrupt reflected sunshine. If a small-scale solar cell system is considered, it is usual to use the amount of the sloped array radiation.

6. Conclusion

The desert area without dunes located within 400 km from shoreline is 326.9Mha, being equivalent to 21.6% of the whole desert. The amount of solar energy reaching there is 7.42×10^{15}kWh/yr (2.67×10^{22}J), which is equal to 80 times the amount of 1990's primary energy consumption in the world. When considering the present energy conversion efficiency of solar cells, the solar energy reaching there satisfies the energy demand in the world.

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MOVABLE TYPE PHOTOVOLTAIC POWER GENERATION SYSTEM

Junichi HONDA *

Abstract - The New Energy and Industrial Technology Development Organization (NEDO) and the Ministry of Fuel and Energy of Mongolia (MFE) have agreed to undertake the "Demonstrative Research and Development on the Photovoltaic Power Generation Systems". Kyocera corp. has been entrusted with the execution of the Project. The purpose of development is to conduct a demonstration research project in Mongolia for improving a movable photovoltaic power generation system including peripheral equipment such as storage batteries and inverter, in terms of compactness, portability and reliability. The achievements of this project will also suggest an idea to improve the living conditions at desert area.

1. Introduction

Nomads in Mongolia are living in traditional movable tents, called Ger. Their moving range covers from the northern mountain regions to the central Steppes and the Gobi Desert in the south. In such area traditional sources of energy, principally firewood, agricultural residues and cattle dung will be continued as major energy resources because of lack of the physical infrastructure. If the stand-alone power generation system is the only means to bring electricity to the life of the people who living in the area, photovoltaic systems (PV system) are widely recognized as an attractive means to address some of the rural energy problems. The data collected and experience gained from the project shall be useful for the development of the desert, especially for people living in such area. Already 200 PV systems and 2 weather observation equipments are operating in Mongolia for improvement of living standard of nomads under this project.

2.. Principle of photovoltaic cell

PV cell is a semiconductor device that converts light energy directly into electrical energy. The PV cell contains a built-in-potential barrier (electric field). The barrier exists near the line dividing n-type from p-type semiconductor silicon. When the light that has enough energy to free an electron from a bond of atom is absorbed by a solid, the electron is torn from its place in the crystal. A bond missing an electron is called a hole. This light-generated electron-hole pair can move about in the crystal. Once the pair is within the electric field, the electrons are accelerated across the barrier into the n-type silicon, the holes into the p-type selectively. Connecting the n-type side to p-type side of the cell by means of an external electric circuit, current flows through the circuit because this reduces the light-generated charge imbalance in the cell. Fig.1.2. show schematic explanation of the generation and the isolation of electron-hole pairs, and the flow of electrons to produce an electric current.

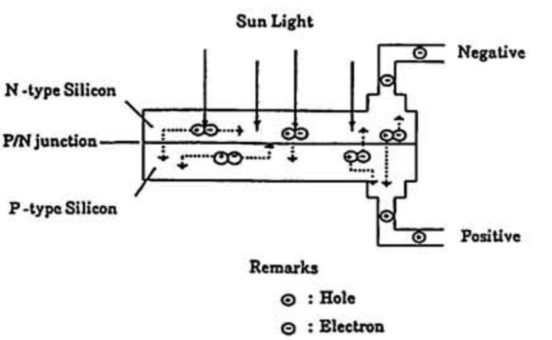

Fig.1. Generation and Isolation of Electron-hole pair in a Solar Cell

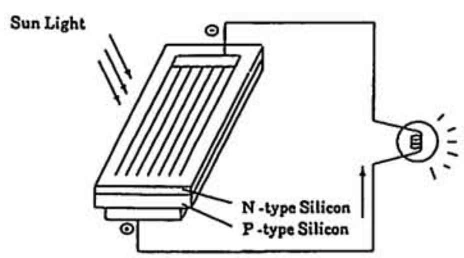

Fig.2. Current flow through external circuit

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3. Outline of the project

Mongolia is a land-locked country situated between China and Russia. The geographical condition is roughly classified northern mountain regions, central Steppes and the Gobi Desert in the south. The moving range of nomads covers every region. Electrification of the gers is not easy because of peculiarity of non-domiciliation. Fig.3. shows the system installation areas.

Basic system design concept are as follows.

1) Configuration of the system

- **The system is composed of component units to improve portability, each unit is made smaller, lighter and simpler to operate.**
- **The units are designed for outdoor use and resistant to vibrations and shocks during transportation.**

2) Assembly and electrical connection of the system

- **The system structure is simplified so that local people can assemble and install them.**

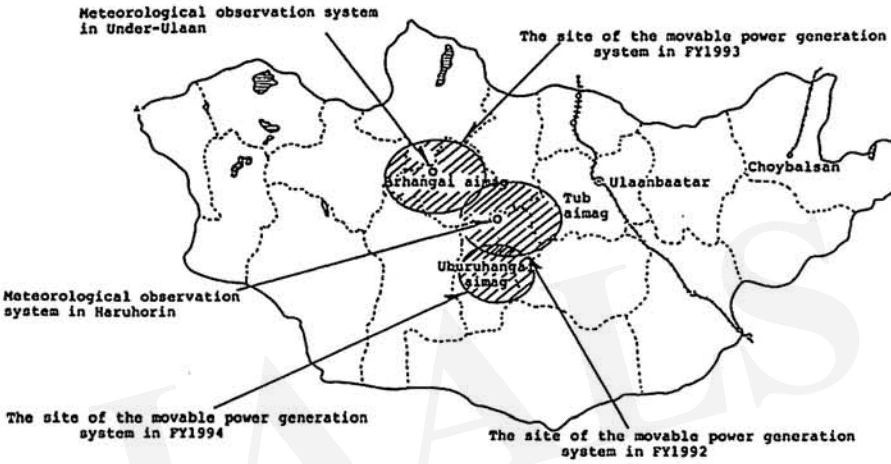

Fig.3. System Installation Site

Fig.4. shows a system block diagram, and Fig.5. shows an overall appearance of the system. An output electricity of the PV array is stored in the storage batteries of the battery unit via the charge controller and output as 220V AC power by the inverter.

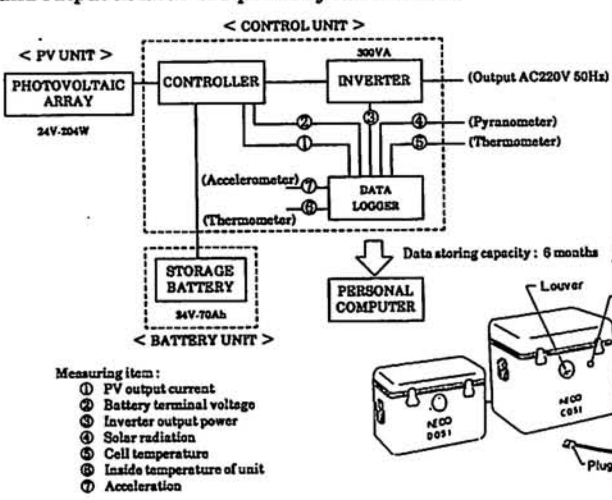

Fig.4. System Block Diagram

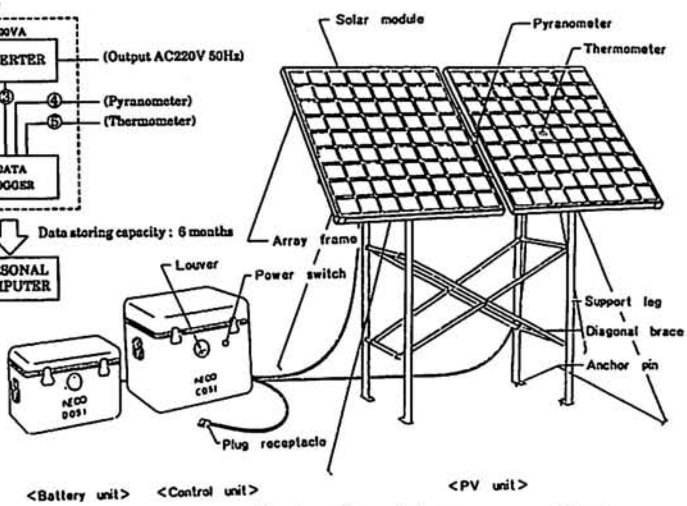

Fig.5. Overall Appearance of System

4. Result

1) Weather Observation Data

The weather observation data is measured every 10 minutes and memorized in the respective loggers. The logger can memorize up to about 7 months worth of data. Power supply for the observation system is performed by small PV system instead of dry batteries. Tables1. and 2. list the monitored data at Under-Ulaan and Haruholin. Irradiation on incline surface shows considerably high values.

Table 1. Weather Observation Data (Under-Ulaan)

Month		4	5	6
Irradiation on inclined surface (45° degrees)	(Total) (kWh/m²)	250.76	226.78	179.02
	(Mean) (kWh/m²·D)	8.36	7.32	6.63
Temperature	(℃)	-3.7	3.1	9.1
Relative humidity	(%)	51.9	53.4	66.9

Table 2. Weather Observation Data (Haruhorin)

Month		4	5	6	7	8	9
Irradiation on inclined surface (45° degrees)	(Total) (kWh/m²)	231.16	208.42	181.87	152.13	187.00	44.87
	(Mean) (kWh/m²·D)	7.71	6.72	6.06	4.91	6.03	5.61
Temperature	(℃)	1.5	9.2	14.4	15.8	14.7	12.6
Relative humidity	(%)	42.8	49.3	65.8	82.6	79.3	71.7
Precipitation	(mm)	13.5	12.5	40.5	139.5	82.0	44.5

2) Main System Operation Data

Fig.6. shows an example of the operating condition of the system and Table3 lists the annual average values and annual integrated values of the system operation data. The other systems' operation data also often show similar data over a long period. According to the operation data very many fine days and extremely few rainy or cloudy days existed in Mongolia, and that their irradiance conditions were incomparably better than those in Japan. The load was concentratedly used in the morning and at night. Particularly at night, it was used longer and the electric energy demand was high. When the systems were initially installed, some of them used only a little electric energy. As days go by, however, each system has increased its electric energy used.

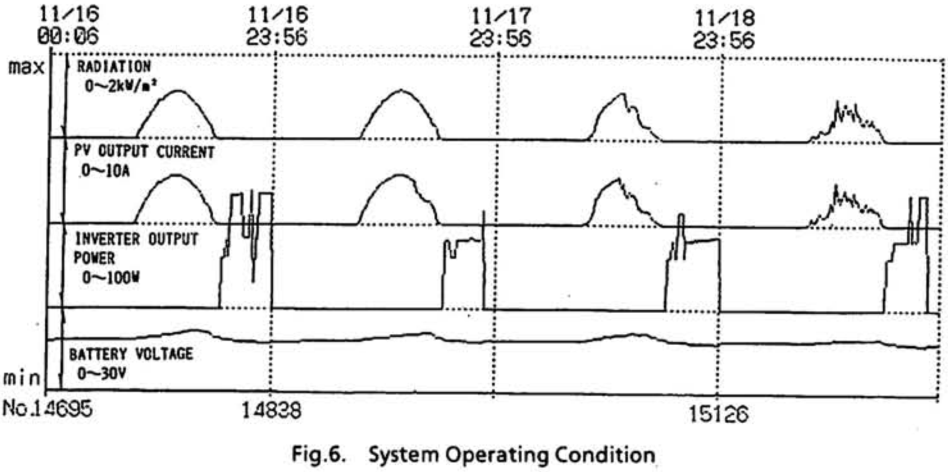

Fig.6. System Operating Condition

Table 3. Annual Average Values and Annual Integrated

SYSTEM No.	A003	A010	A027	A038	A041	A042	A047	Mean	Total
Irradiation (Mean) kWh/m²·D	4.75	4.18	4.97	4.11	4.37	4.60	4.48	4.48 kWh/m²·D	
(Total) kWh/m²·M	1141.38	931.90	1110.27	731.67	992.73	917.91	1156.64		6982.50 kWh/m²
Effective (Mean) kWh/m²·D	3.75	3.03	2.36	3.68	2.78	3.37	2.75	3.08 kWh/m²·D	
irradiation (Total) kWh/m²·M	897.54	670.64	538.52	657.83	635.91	665.56	733.62		4799.62 kWh/m²
PV output (Mean) kWh/D	0.60	0.51	0.41	0.61	0.50	0.54	0.45	0.513 kWh/D	
electric energy (Total) kWh/M	144.30	112.30	93.77	109.58	113.23	107.38	119.12		799.68 kWh
INV. output (Mean) kWh/D	0.32	0.30	0.19	0.34	0.26	0.33	0.25	0.280 kWh/D	
electric energy (Total) kWh/M	76.59	65.58	42.76	61.23	59.52	64.50	67.36		437.54 kWh
Battery voltage (Mean) V	25.33	25.49	26.05	25.22	25.79	25.55	25.71	25.60 V	
Cell temperature (Mean) °C	0.74	-1.23	8.09	-3.14	-	-	2.42	1.59 °C	
In-Unit temperature (Mean) °C	17.54	13.37	18.02	13.62	13.37	13.48	9.17	14.02 °C	
Irradiation energy availability %	78.64	71.96	48.50	89.91	64.06	72.51	63.43	68.74 %	
PV array effective conversion efficiency %	9.17	9.55	9.93	9.50	10.16	9.20	9.26	9.50 %	
Selfservice ratio %	53.08	58.40	45.60	55.88	52.57	60.07	56.55	54.71 %	
System efficiency %	4.87	5.58	4.53	5.31	5.34	5.53	5.24	5.20 %	
Overall efficiency %	3.83	4.01	2.20	4.77	3.42	4.01	3.32	3.57 %	
Number of effective days	240	224	226	179	228	200	263		1566 D

5. Conclusion

PV system proven that it can be operated by local people with almost no maintenance. This project is being carried out in a remote area of Mongolia. The climatic and living conditions are very similar to vicinity of the desert. It is also evident that a bigger PV system will contribute to develop the desert area as a power source for pumping for irrigation, desalination for drinking water or infrastructure for human life. Photographs 1. and 2. show examples of PV system.

Photo. 1. Weather Observation System

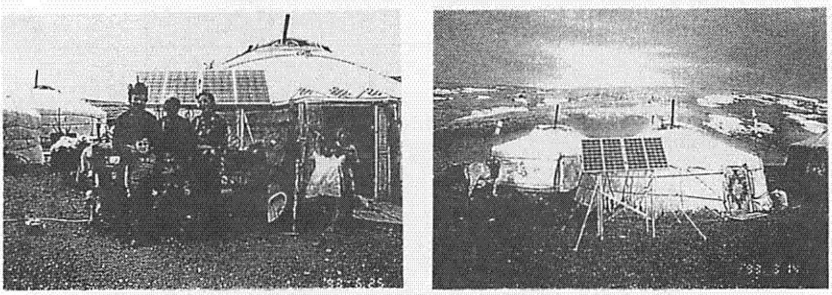

Photo. 2. Main PV System

References and acknowledgements

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Problems associated with using photovoltaic modules under desert conditions

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Abstract - This paper addresses four problems associated with the design of photovoltaic (PV) systems suitable for operation in remote desert regions, and outlines solutions that have been developed for Israel's desert conditions. These problems are: (1) The absence of reliable meteorological data - particularly direct-beam radiation; (2) The substantial differences that exist between PV module manufacturer's specifications (usually obtained using a solar simulator) and output power delivered under actual desert conditions; (3) The browning of ethylene vinyl acetate (EVA) laminates under desert conditions; (4) Unexpected problems arising from the design of PV systems by people unfamiliar with the terrain in which the system will operate.

Key Words: Multipyranometer, PV module ratings, EVA browning, Balance-of-system reliability.

1. Radiation survey

In order to design a PV system one needs accurate solar radiation data, usually in the form of hourly direct beam and global horizontal irradiance. A sun-tracking pyrheliometer is the instrument usually employed for accurate measurement of direct beam insolation. It suffers, however, from two drawbacks which require the daily presence of a technician. First, human intervention is required in order to check that the instrument is tracking the sun accurately. Second, the aperture window must be kept scrupulously clean from dust otherwise a substantial fraction of the incident beam radiation is diffused and absorbed by the interior walls of the instrument. These problems render this instrument unsuitable for radiation surveys in remote desert areas for to neglect them would result in data of a completely worthless nature.

As part of the Negev Radiation Survey, initiated some years ago by the Israel Ministry of Energy and Infrastructure, the author and his colleagues developed the multipyranometer (MP) [Faiman et al, 1987]. This instrument consists of 4 global pyranometers each set at a fixed but different orientation. Each pyranometer of the set views the sun from a different angle and sees a different part of the sky diffuse radiation. Artificial horizon masks ensure that no ground-reflected radiation is detected. Since the geometry of the earth-sun relative motion is known the output from the 4 instruments can be unfolded to yield the beam and diffuse components [Faiman et al, 1992, 1993].

Table 1: Comparison of MP predictions with measurements from carefully maintained standard "NIP" and "PSP" instruments at Sede Boqer [Faiman et al, 1993]

Year = 1989	Direct Beam [W/sq.m]		Horizontal Global [W/sq.m]	
	Measured Average	Mean Bias Error	Measured Average	Mean Bias Error
Jan	434	-9	346	-6
Feb	586	+8	501	-3
Mar	569	-18	558	-1
Apr	640	-4	651	+3
May	620	-8	679	+4
Jun	732	-19	700	+4
Jul	777	-28	712	+5
Aug	729	-10	676	+1
Sep	733	+11	633	-2
Oct	598	+12	517	-4
Nov	598	+1	431	-3
Dec	538	+2	368	-4
Annual	630	-5	564	-1

Table 1 displays, on a month-by-month basis, the mean bias errors observed during a year of side-by-side comparisons between a MP and well-maintained standard instrumentation at Sede Boqer.

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One sees that, for global radiation, the monthly mean bias error is always below 1%, and for direct beam radiation it is below 4% in the worst case. In addition to being completely free of moving parts the multipyranometer is as insensitive to dust as a standard global pyranometer, losing about 1 part per mille of sensitivity for each day the instrument remains uncleaned [Feuermann and Zemel, 1993]. In such circumstances, cleaning each month or two would suffice to produce data that are readily correctable for the 3-6% effect of dust that would accumulate between cleanings. It was concluded, therefore, that the multipyranometer is the ideal instrument for monitoring insolation in remote desert sites. Its output can be used for predicting (with similar accuracy to the global horizontal predictions [Faiman et al, 1993]) the irradiance on any stationary or tracking PV array.

2. Module ratings

When we test PV modules under natural desert sun conditions we find that manufacturer's specifications always over-rate the power output that may be obtained. This is not deliberate deception. Rather, it results from the fact that mass-produced photovoltaic modules are tested in the factory (for quality control purposes) using a set of lamps designed to simulate, *as well as possible*, natural sunlight. But photovoltaic material is acutely sensitive to the spectral content of the illumination. Indeed, the spectrum of natural sunlight changes from noon to sunset, even on a clear day, and module output (suitably corrected for changing illumination levels and cell temperatures) is observed to vary by some 5% over this period of time. Clearly, a set of electric lamps can not be expected to correctly simulate sunlight at all times (if, indeed, at all). At Sede Boqer we test modules at noontime on clear days [Berman et al, 1995] when their power output is a maximum. At this time too, the measured solar spectrum corresponds very closely to the international definition of the standard AM 1.5 spectrum [CEI, 1989]. We find that our measured power ratings are typically 10%-20% lower than manufacturer's specifications after the latter have been adjusted to the operating conditions under which we perform our tests. This is a most significant result for the design of systems that will operate under desert conditions: It warns us that they will either need to cost 10%-20% more than expected, or that they will produce this amount less of annual energy.

Table 2 shows some results for a selection of typical modules. Single-crystal (SC) and polycrystalline (PC) silicon cells are extremely stable over many years. The test measurements performed on 26.12.94 are probably close to the original "correct" ratings. Amorphous (AM) silicon modules, however, lose efficiency with time. Module AM1 in the table is still degrading after 8 years of use (currently 51% below its manufacturer's rating) but module AM2 appears to have stabilized at 32% below its manufacturer's rating.

Table 2: Comparison of manufacturer's maximum power point rating with measurements under desert conditions for a variety of PV modules.

Module code	Manufacturer's Rating [W, STC]	Start up date	Test [W, STC] (26.12.94)	Loss [%]
PC1	38	Feb 87	35.3	7.1
SC1a	43	Feb 87	38.0	11.6
SC1b	43	Feb 87	35.5	17.4
SC2	53	Feb 87	42.8	19.2
AM1	30	Feb 87	14.6	51.3
SC3	55	Jun 90	47.4	13.8
AM2	30	Jun 90	20.4	32.0
PC2	48	Feb 87	44.0	8.3
SC4	85	Dec 94	74.3	12.6
SC5	54	Dec 94	44.3	18.0

3. EVA browning

There has been much concern about the serious power loss experienced by the 5.5 MW PV power plant that was erected in the Californian desert at Carrisa Plains [Rosenthal and Lane, 1991]. The system power output was observed to decrease at about 10% per year until the station was finally closed down and dismantled. The loss of output was accompanied by a progressive browning of the EVA laminate employed in the mirror-enhanced PV modules. Although there has been some speculation that perhaps the browning phenomenon was not the real cause of power loss [Wohlgemuth and Petersen, 1993] there is widespread belief that the two were intimately related. At Sede Boqer, we have also observed EVA browning associated with the use of mirror enhancement.

We have been fortunate, however, in being able to quantify the loss of module efficiency associated with this phenomenon and found it to be at the level of about only 1% per year [Berman et al, 1995]. Moreover, when the mirrors are removed, further module degradation seems to fall to an unmeasurably low level.

Table 3 shows the mean measured I-V curve parameters for 188 browned modules at Sede Boqer and measurements on a single new module of similar type. Also shown are the manufacturer's sun-simulator measurements on this same reference module. The browned modules, although still of comparable power output to the new module were, however, found to be about 5% below their original estimated power rating of five years previously. We therefore believe that EVA browning need not be a serious source of concern for desert PV systems.

Table 3: Average field-measured I-V curve parameters for 188 browned PC2 modules compared with field-measured new PC2 module parameters [Berman et al, 1995]

Parameter	New PC2 Module Factory tests ($1000 W/m^2$, $25°C$)	New PC2 Module Field tests ($1000 W/m^2$, $25°C$)	Mean "browned" PC2 Mod. Field tests ($1000 W/m^2$, $25°C$)
V_{oc}	22.5 V	21.9 ± 0.3 V	22.8 ± 0.3 V
I_{sc}	2.84 A	2.76 ± 0.01 A	2.62 ± 0.07 A
V_{pp}	17.9 V	17.1 ± 0.3 V	18.3 ± 0.4 V
I_{pp}	2.64 A	2.54 ± 0.01 A	2.39 ± 0.06 A
Fill factor	74 %	71.8 ± 0.3 %	73.4 ± 0.9 %
P_{max}	47 W	43.4 ± 0.5 W	43.7 ± 1.3 W

4. Design considerations

The technology of computer-controlled stepping motors is sufficiently highly developed that serious consideration would normally be given to the employment of sun-tracking PV modules in order to increase the energy output of the system. Table 4 illustrates typical seasonal amounts of radiation that would be available to various kinds of stationary and tracking modules corresponding to PV systems we have tested at Sede Boqer [Faiman et al, 1995].

Table 4: Seasonal daily average global solar radiation on a variety of fixed and sun-tracking plane surfaces at Sede Boqer for a typical meteorological year [Faiman et al, 1995]

Month	Fixed horizontal [$kWh\ m^{-2}\ day^{-1}$]	Fixed 30^o tilt [$kWh\ m^{-2}\ day^{-1}$]	NS horiz. axis [$kWh\ m^{-2}\ day^{-1}$]	2-axis tracking [$kWh\ m^{-2}\ day^{-1}$]
Mar	5.11	5.58	6.04	6.45
Jun	8.03	7.08	10.43	10.53
Sep	6.15	6.77	7.89	8.43
Dec	2.91	4.06	3.69	4.88
Annual [$kWh\ m^{-2}$]	2038	2179	2564	2783

However, the amount of solar energy *available* to a given geometry is not necessarily what a PV system will actually process. System reliability is equally important as the following example will illustrate. For a 200 kWp PV system that we are in the process of designing for a certain Negev kibbutz, about 4,000 PV modules will be required. An important design questions is the kind of array geometry that should be employed. The simplest, a stationary array, has no moving parts to service and could employ a single power-conditioning system. If the latter were to fail, however, no power would be generated until it was repaired.

A two-axis sun-tracking system, on the other hand, could be expected to provide nearly 30% more annual energy, from Table 4. But since a single tracker can support only about 40 PV modules such a system would require about 50 trackers, each of which employs two motors. The system would also require 50 power-conditioning systems. Failure of a single motor or inverter would remove an entire tracker from service, resulting in a 2% loss of energy until it was repaired.

Finally, a single-axis system could provide nearly 20% more annual energy than a stationary array, according to Table 4. Here only about 20 motors would be needed (since one motor could drive an array of about 200 PV modules) together with a similar number of inverters. The number of potential component failures is clearly lower than for a two-axis system, but each failure would involve a 5% loss of energy until repaired.

The actual PV modules are, in our experience, the most reliable part of the system, but care must be taken to ensure that none of the modules is allowed to become partially shaded for this can result in serious system power loss and, in extreme cases, to module damage [Berman et al, 1995]. A detailed computer simulation permits the quantitative effect of mutual shading by modules and trackers to be taken into account at the design stage. However, if a building or other structure is erected near a PV system *after* the construction engineers have left the region, unforeseen shading might, thereby, be introduced. It is consequently necessary for the system to be periodically visited and inspected by a technical specialist in order to ascertain that local changes have not, inadvertently, been introduced.

Our experience with tracking systems at Sede Boqer is that inverters and tracking motors cause problems which often take a long time to repair - particularly if parts have to be obtained from overseas. In remote desert regions the down-time between repairs might be large, and careful thought has to go into deciding which kind of system would be expected to be the most reliable. In such situations maximum energy is intimately linked to maximum reliability.

5. Conclusions

Solar radiation data, accurate for PV system design purposes, may be obtained using a multipyranometer. This is the only instrument available for long-term, reliable, radiation surveys in remote desert locations.

As with system design in other types of location, PV modules should be field tested *in situ* in order to determine their true power ratings. Manufacturer's simulator-based ratings are typically about 10% too high. The true ratings, together with long-term, hourly climatological data, allow accurate computer simulations to be performed at the system design stage. Such simulations not only enable one to assess the cost/benefit of adopting various tracking strategies etc., but simulation of the final design is a valuable aid to diagnostic studies after data become available from the system.

The modules turn out to be the most reliable component of a PV system, EVA browning leading to a degradation of, at worst, about 1% per year.

Less reliable are tracking motors - particularly when dust gets into their moving parts, and far less reliable are power-conditioning systems. The principal design consideration for PV systems that will operate in remote desert regions is system reliability, owing to the expense and difficulty of servicing.

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