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Preface

The background of the Workshop on Material Demand is the followings: Task X participants are always facing to the difficulty to find out the comprehensive solutions restricted by the intra relationships among application fields, system consideration, component requirement and material itself for the development of cooperative research works even in the survey research. Throughout the past Expert Meetings, the participants recognized that identification of the material performance levels depending on the operating conditions for the various systems under various climatic conditions should be more emphasized in particularly Subtask A activities, unless otherwise the establishment of the material criteria would not be achieved which was the final goal of Subtask A. We also realized that the most of the Task X participants were specialist in chemistry and physics and were less familiar with the aspects required from system and component sides. Under this circumstance, we agreed to have relevant workshop on material demands from the system experts who have good experiences in various solar systems both in active and passive applications in order to make the bridge over the gap existing in the concept for material demand (properties) understood by the material scientist.

The workshop was structured for the participants to familiarize with the aspects from system, components and applications and to increase the understanding of the special topics in chemistry and physics as well as systems. The workshop was spent for two days and was divided into four parts, such as (1) lectures on application of the system (operating conditions) and material demand from system and component engineerings, (2) lectures on present state-of-the-art on material aspects related with performance, degradation mechanism, aging test, and service life prediction method, (3) discussion related with the future development of research works in Subtask A, and (4) discussion on research work plans of joint activities of Subtasks B and C.

Throughout the workshop, the importance of the interface between material and component was identified. Subtask A leader asked to the participants to keep close contacts with system engineers in own country further and stressed the importance of the special selectivity parameter in computor simulation models for the prediction of thermal performance to identification of the most used material. Subtask C leader asked for operating conditions, thermal performance and temperature to determine the condition required for the accelerated aging test in his case study.

The questions related with the further Subtask A activities were becoming more clearly: i. e., Do we define operating conditions which will never, ever or always occur or, do we define the boundary conditions which will be capable of the materials predictions by their test results and of the good selection for manufacturer as well as designer.

The workshop resulted in the following recommendation and conclusions :

(1) System engineers and material experts became more knowledgeable on the activities by each other. Hence, more specific and clear workplan for future work particularly in Subtasks A, B and C was resulted in.

(2) Future work as well as expert meetings will be strongly emphasized in the way of material groups in which specific experts from all subtasks join together. The following material groups will be formulated: absorbers with selective coatings, window glazing, heat storage media and possibly heat transfer media.

(3) Subtask A activities on operating conditions and thermal performance will more specificly and clearly be narrowed down with the respect to the joint case studies particularly raised from Subtasks B and C.

This proceedings covers the submitted presentations of the lectures given in the first two parts. Among nineteen lectures, the topics with heat transfer fluids were not given except the topics related with usage of freon as the transfer fluids for new type of collector coupled with heat pump. The digest of questions and/or answers forwarded to respective presentation were attached after respective presentation, although some of them were missed due to the lack of tape recorded material caused by some failures of the recording environment and the equipment.

We wish this proceedings will be a beneficial and relevant document to refer the present level of knowledge among the Task X participants.

The Use of Plastic Absorbers

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1. Introduction

We have been using plastic (high density polyeth.) as an absorber in, our solar systems for many years now.

To provide low cost energy-saving apparatus is an indispensable condition in the expansion of solar energy utilizing equipment. For this purpose, we have made efforts to put to practical use absorber for which a molding method suitable for mass production and handy material was used.

The high density polyeth. material used must have suitable basic properties such as heat resistance. It is also very important that it must have the most suitable properties to satisfy the molding methods for which it is to be used.

The properties of the materials used at present and a part of the methods used to evaluate durability for putting it to practical use is introduced below.

2. The use of plastic absorbers

Fig 1. Shows an exsample of the heat absorber.

Which I shall talk about is the first of its kind as a hollow molding compound made with high density polyethylene.

Hitherto, absorber made with high density polyethylene and joined by a pipe were sold on the market.

Examples of this are water tanks, transparent boards and packing boxes, the main portions of which are made of plastics.

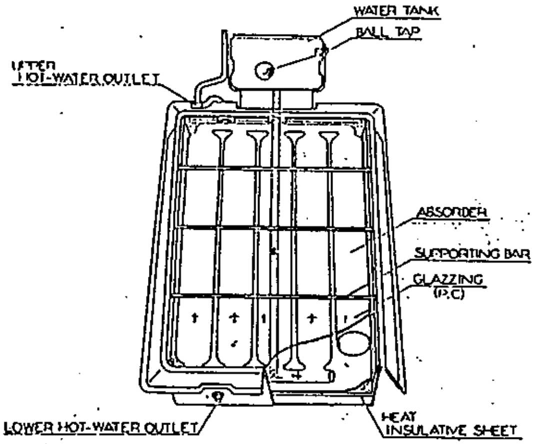

fig 1 WATER STRAGE TYPE

Similarly, examples of spontaneous circulation solar systems are shown here. (Fig 2)

Here we have plastic collectors of the flat plate type.

Plastic absorbers manufactured by this method are strong against corrosion and, because maintenance is hardly needed, it can be said that it is very suitable for Hot Water systems.

This flat plate type polyethyene absorber is used also by changing the shapes for domestic solar systems of the compulsive circulation type. (Fig 3)

Now I shall introduct a part of the hollow molding machine which manufacturers these molding compounds. (fig 4)

The raw material is gradually heated from lower hopper temperature of 210℃ and is completely melted at the top of the screw.

Then the oil cylinder operates and enters the Ram which measures the volume of the melted resin.

The resin pushed out form the Ram flows from the Parison which is adjusted at the Die head and Mandral.

The melted resin flows through the open cast and then cooled when the cast is closed at a specified position as air is blown in simultaneously.

As this is the molding method it must be borne in mind that "flowability" is important as one of the properties ofthe resin used. The shape and size must also be taken into account.

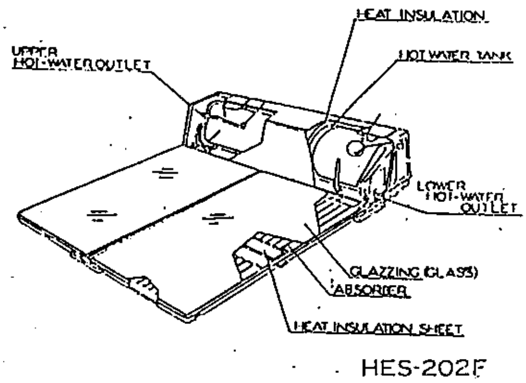

fig 2 THERMOSYHON LOOP SOLAR HEATER

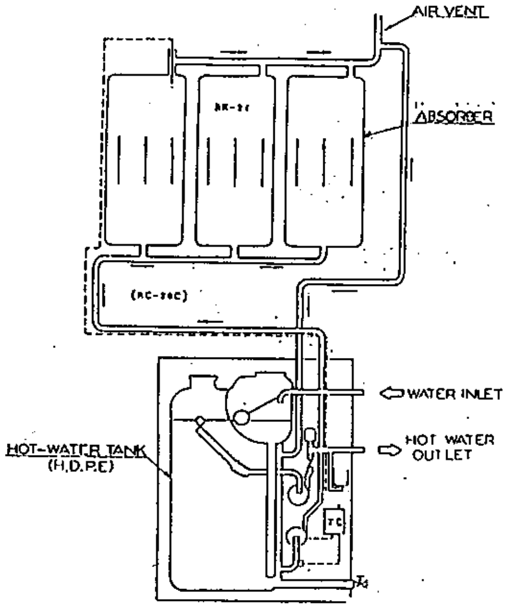

fig 3 A PUMPED-LOOP SYSTEM

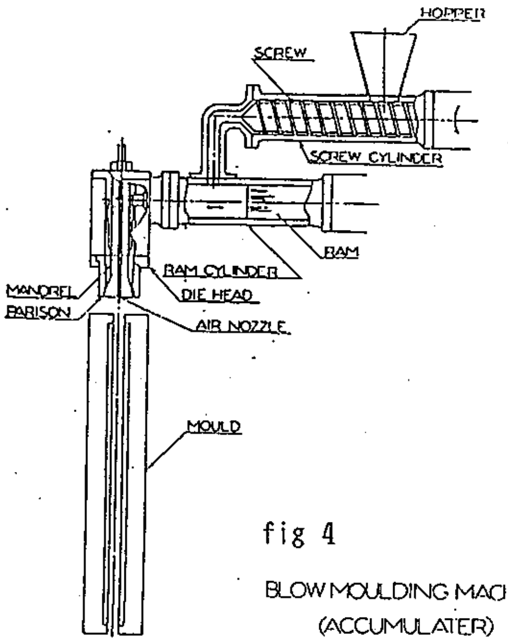

fig 4

BLOW MOULDING MACHINE (ACCUMULATER)

The properties the materials used at present and a part of the methods used to evaluate durability for putting it to practical use is introduced below.

The following individual methods are introduced for evaluating durability.

1) Heat pressure creap test

2) Creap test (tensile strength testing)

3) Freezing test

Now, it is necessary to estimate the life of the circular compound which was flow-molded with materials such as this.

So durability is evaluated by heat pressure creap test in actually environmental conditions.

The time it takes to destory the absober when air pressure is applied after dipping it in 80℃ hot water is measured.

The limit of usage (pressure) is calculated from the curve obtained by the heat fluctuation of the absorber from actual usage and the curve obtained from tests.

The foregoing are the actual tests but the main data comes from the creap properties from tensile strength tests which are the basics of the tests.

From the creap properties of polyethylene it is seen that if the pressure is slight the lower the temperature the longer it takes for the absorber to be destroyed.

From these test results it is clearthat it is necessary to have a desighwhich limits the force for eachportion of the molded structure to less than 20 Kg/cm^2.

It is designed in a unique from the point freezeresistance properties of the polyethylene absorber.
The section is of an elliptical shape and is prepared for capacity expansion.

Also to secure safety, freezing comes from bottom to top and finally, the expansion runs into a tank.
That is, the shape is fixed by calculating the heat capacity of each portionand we succeeded in obtaining a reoccurring pattern on repeating tests.
(fig 5)

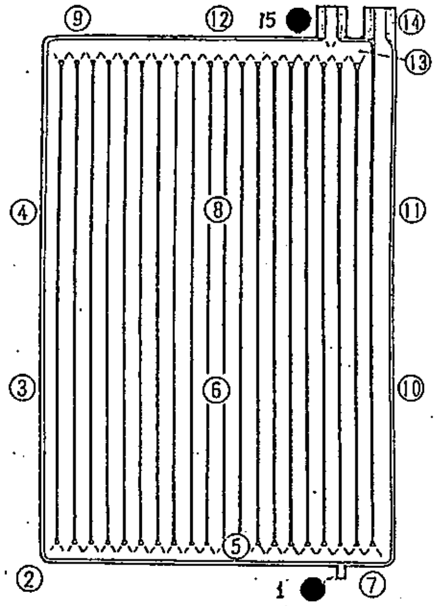

fig 5 ●~●; RANKING MARK IN FREEZING TEST

Q : How is the stability against UV radiation ?

A : According to the data by sun-shine weathermeter, HDPE lost 80 % of elongation by 500 hours, but by adding carbon black almost no degradation was observed.

Q : What kind of plastics is the glazing material ?

A : As plastics, PC was once used for the solar water storage heater.

Q : Will your absorber withstand to the stagnation temperature ?

A : No damage at all. Now it is under testing at Hamamatsu Solar Laboratory, and about 5 years have elapsed.

Q : What are the stagnation temperature and the stagnation pressure ?

A : The temperature depends on conditions but it reaches to 100-115°C, and the stagnation pressure is the atmospheric pressure.

Q : What are the condition of freezing test and the expected life time ?

A : -5 - 20°C, 10 hr/cycle; it is expected to be endurable to 500 cycles.

Q : What about heat collecting efficiency ?

A : (Explained by figures) This system has a favorable domain at lower temperature region.

IMPROVED FLAT PLATE SOLAR COLLECTOR and DESIGN CONCEPT of its ABSORBER

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[1] Introduction

There are several types of solar collectors currently in use. The three most common types are flat-plate collectors, evacuated-tube collectors, and concentrating or tracking collectors. The selection of collector type depends on what you want to use the gained solar energy for : space heating and cooling, hot water supply, pool heating, power or electric generation, etc.. We have been developing flat-plate collectors in order to use them for both active solar cooling systems with absorption chillers and solar heating systems. The reason why we chose to develope this type, aside from the ordinary advantages of the flat-plate collector (low cost, easy to install on roofs or in yards, does not require mechanisms, can use diffused solar radiation), is that it can operate efficiently at the operating temperature range of 80～90℃ which is required for an absorption chiller generator. In this paper, the high performance flat-plate solar collector that we have developed is introduced and some concepts for designing the absorber of this collector from the standpoints of durability and real application are described.

[2] Features of YAZAKI Super Blue-Panel, and performance

(2-1) Features

Yazaki has developed a solar collector (Super Blue Panel) with exceptionally high performance for solar cooling and heating applications. It is a typical flat-plate liquid solar collector and is composed of a "tube in sheet" type absorber, a transparent cover sheet of low iron tempered glass, 50mm fiberglass insulation behind absorber and a transparent heat trap of Teflon(Ⓡ) FEP between the cover sheet and the absorber. Table 1 shows the specifications of "Super Blue Panel", and Fig.1 gives the schematic diagram. The advantages gained by this collector design are

1) V-corrugated transparent heat trap reduces convection losses.
2) Low iron tempered glass with high solar transmittance of over 90% and with high strength.
3) Black stainless steel selective surface with high absorptance (α =0.91 ~ 0.94) and low emittance (ε =0.09 ~ 0.12)
4) Special corrosion resistant stainless steel absorber plate.

Table 1 Super Blue Panel Specifications

Model No.		SC-V1020-□□□	SC-V0818-□□□	SC-V0815-□□□	SC-V0812-□□□
Construction of absorber plate		Tube-in-sheet			
Transparent materials		Tempered water-white glass & V-corrugated transparent insulator			
Characteristics of selective surface on absorber plate		Black stainless selective surface (Solar radiation absorptance α = 0.91 ~ 0.94, emittance ε = 0.09 ~ 0.12)			
External dimensions (mm)		1002 × 2002 × 77	822 × 1817 × 77	822 × 1517 × 77	822 × 1207 × 77
Effective heat collection area (m^2)		1.91	1.41	1.17	0.93
Maximum flow rate for collector (L/hr)		1000			
Maximum operating pressure (kg/cm^2)		3 or 6			
Materials	Absorber Plate	Ultra-low carbon ferritic stainless steel (18Cr + 2Mo & Nb)			
	Cover plate	Tempered water-white glass (3mm thickness, transmittance = 0.90			
	V-corrugated transparent insulator	Transparent teflon (FEP)			
	Housing	Electrodeposition and acryl electrostatic paint on galvanized steel sheet			
	Insulation	Back: 10kg/m^3 fiberglass 50mm thickness Side: 24kg/cm^3 fiberglass 15mm thickness			

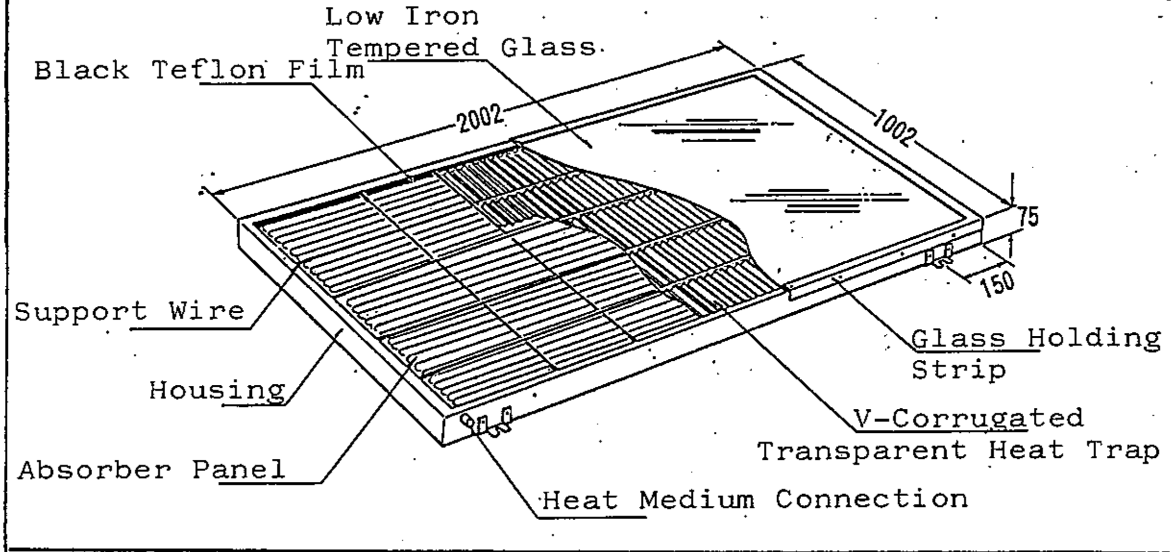

Fig.1 Schematic diagram of Super Blue-Panel

(2-2) Performance

In Japan, the "Japan Machinery and Metal Inspection Institute (JMI) is the only one that is nominated as the Designated Testing Organization for solar collectors. Table 2 shows the JMI test sequence[1] and Fig.2 gives the performance test results of YAZAKI Super Blue Panel. These results were gained by using an indoor solar simulator. Nearly the same results were obtained from tests performed outdoors by YAZAKI according to ASHRAE 93-73.[2]

Table 2. JMI Test Sequence for Solar Collectors

1. Receiving Inspection
2. Three-Day Exposure Test
3. Thermal Shock / Cold Fill Test
4. Mechanical Strength Test
5. Thermal Performance Test
6. Compound Heat Cycle Test
7. Static Pressure Test
8. Disassembly and Final Inspection

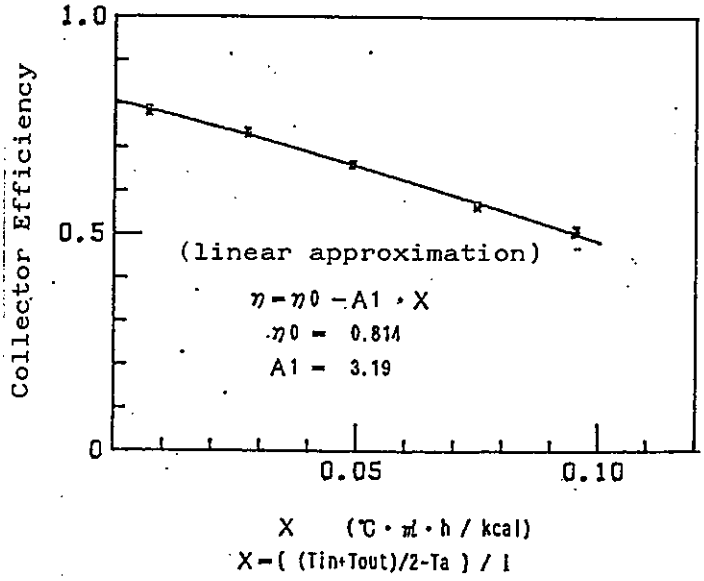

Fig.2 Collector Efficiency of Super Blue Panel (tested at JMI)

[3] Some concepts considered in designing the absorber

(3-1) Pressure design

There are two types of Blue-Panel, with operating pressure of 3 and $6kg/cm^2 \cdot G$. In deciding maximum allowable pressure, the following must be considered in addition to the total pressure drop across the loop and "Zero-flow head" of the selected pump.

a) For open systems,

Flashed vapor pressure is induced by putting relatively hot water into the hot collector, especially when the collector is under stagnation condition. Fig.3 shows flashed vapor pressure measured in Blue-Panels.

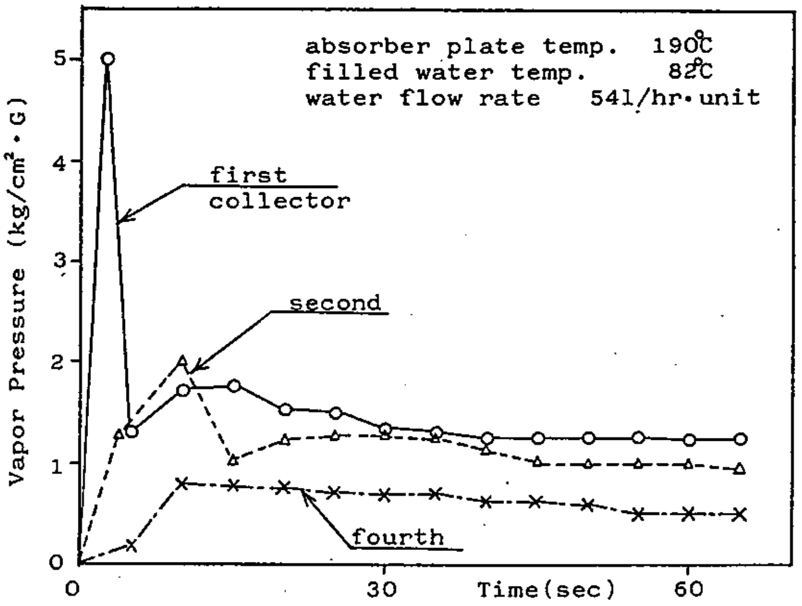

Fig.3 Test Results of Flashed Vapor Pressure (15 Collectors are connected in series and hot water is added)

b) For closed systems,

One solution to the problem of freezing is the use of an antifreeze solution. In this case, the fluid loop must be closed in order to avoid contact between the fluid and air, because of the fear that aqueous glycal solutions, both EG and PG, undergo acidification during long term exposure to air at high temperature. For closed loop systems the maximum allowable pressure must be higher than the highest pressure which occurs under stagnant exposure, which is the saturated vapor pressure of glycal solution at the stagnant temperature. For example, the saturated vapor pressure of 70vol% PG solution is 5.8kg/cm^2·G at temperature of 165℃. This value is lower than that of water (8.18kg/cm^2·G) at the same temperature.

(3-2) Absorber plate configuration

In general, the efficiency(η) of a flat-plate solar collector can be simply expressed by the following equation:

$$\eta = F'(Ae/Ag)\{(\tau\alpha)e - Ut(tw-ta)/J\} \qquad ①$$

where

Ae and Ag : aperture and gross collector area
($\tau\alpha$)e : effective transmittance-absorptance product
Ut : total heat loss coefficient
J : solar radiation

tw : average temperature of heat medium
ta : ambient temperature
F' : collector efficient factor

In deciding plate configuration, factors that must be considered are the kind of absorber material, the fabrication technique, and designing to make the F' and ($\tau \alpha$)e factors of performance, higher. The "tube in sheet" type showed in Fig.4 was selected from among a number of configurations because this configuration can make up for the drawbacks of the collector. That is to say:

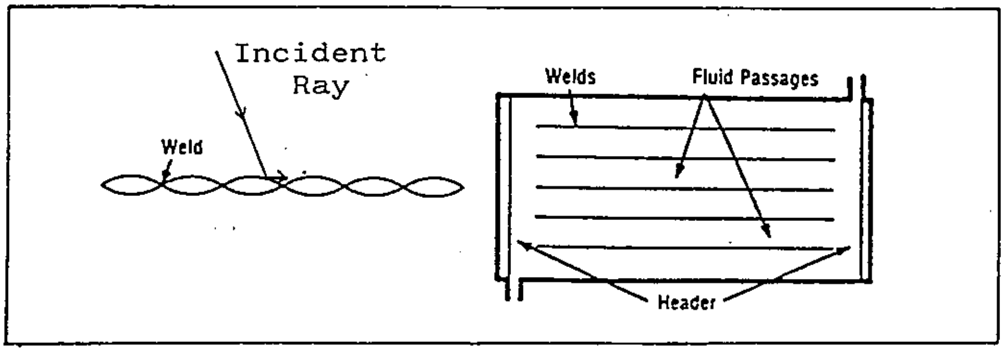

Fig.4 "Tube in Sheet" type absorber configuration

1) Although stainless steel is a poor candidate for absorber material compared with copper and aluminum because of its low heat conductance, the "tube in sheet" configuration results in a very good heat exchanger with a high wetted area, i.e. most of the internal surface is wetted by the heat transfer fluid. The most important variable in determining F' is "Fin efficiency" F. A larger wetted area brings a higher F value and hence a higher F' value.
2) The black stainless steel selective surface has an absorptance value of α =0.91 ~ 0.94, and an emittance value of ε =0.09 ~ 0.12, which are obtained from optical measurement by using a spectral photometer under laboratory conditions. These values are a bit worse than the ideal values, α =1.0 ε =0.0.

In practice, however the absorptance value of 0.95, which is caluculated from the collector performance test data by using the equation ① , is larger than the laboratory value. This increase can be regarded as the result of the multi-reflection effect on a waved surface as shown in Fig.4.

(3-3) Corrosion resistance of stainless steel absorbers

The critical component of the solar system is the absorber panel within the collector. Over the full life time of the system, on the order of 10 to 20 years, the absorber panel must be resistant to internal corrosion and its selective surface must be stable. Although plastics, steel, copper and aluminum have been considered for absorber panels, experience is rapidly accumulating in support of the conclusion that Type 444(18Cr-2Mo) ferritic stainless steel is the optimal absorber material in terms of performance, safety, reliability, durability and cost.

(1) Ultra-low carbon ferritic stainless steel
(18Cr+2Mo stabilized with Nb)

The ferritic stainless steels are known to have much better resistance to stress-corrosion cracking(SCC) in chloride environments than austenitic stainless steels. This is important because the chloride content of potable water at temperatures encountered in solar collectors could induce stress-corrosion cracking in susceptible materials. As shown in Fig.4, "tube-in-sheet" type panel produces a tight metal-to-metal crevice in it. The grade of stainless steel selected must be able to resist crevice corrosion. For solar cooling and heating systems, the transfer fluid reaches 80 to 90℃. The absorber panel can easily exceed 150℃ if drained during full sunlight, a condition which can lead to corrosion problems through concentration of the transfer fluid. As shown in Table 3 and 4, 18Cr-2Mo ferritic stainless steel(Type 444) has excellent resistance to crevice corrosion and SCC.(3) If a glycol solution is used, Type 444 is also unaffected by glycol or its degradation products.

(2) Improved seam welding technique

Two sheets of stainless steel, as thin as 0.35mm, are embossed with the flow pattern, faced together and welded by electrical resistance seam welding. In order to avoid losing its own corrosion resistance, the welding must be done carefully. The best method of controlling thermal distortion on the stainless steel is to prevent excessive heat buildup and absorption during seam welding. A newly developed system for cooling the work metal uses sprays of water directed on the work at the point of contact with the electrode wheels, resulting in reduced oxide layer production around the heat affected zone. At the same time, this cooling system solves the problem of 475 brittleness.

Table 3 Crevice Corrosion Resistance[a)]

Solution	Type 304	Type 439	Type 444
200 ppm Cl− deionized water[b]	P (0.020)[e]	P (0.100)	NP[f], NP, NP, P (0.040)
500 ppm Cl− deionized water[b]	P (0.250)	P (0.100)	NP, NP, NP, P (0.030)
1000 ppm Cl− Ann Arbor tap water[c]	P (0.090), NP	—	NP, NP, NP
2000 ppm Cl− Ann Arbor tap water[c]	—	—	NP
1000 ppm Cl− Simulated well water[d]	P (0.100)	—	NP, NP
2000 ppm Cl− Simulated well water[d]	—	—	NP, NP

[a] Metal-to-metal crevice, 90 C O_2-saturated solutions, 45 days.
[b] pH 5-6.
[c] pH 9-10.
[d] 24 ppm NO_3^-, 14 ppm $SO_4^=$, 180 ppm HC_3^-, pH 8.3.
[e] P = pitting observed; ( ) = penetration in mm.
[f] NP = no penetration.

Table 4 Stress Corrosion Cracking Resistance

	Time to Failure for Indicated Stainless Steels, h			
Test	Type 304	Type 316	Type 439	Type 444
Boiling 42% $MgCl_2$	<8	<24	>1700*	>1700*
Boiling 25% NaCl (pH 1.5)	<16	<144	>2000*	>2000*
NaCl Wick Test	<120	<360	>1440*	>1440*

* No failure observed.

[4] Conclusions,

In the pressure design of collector absorbers, flashed vapor pressure under stagnation condition in the open loop system, and saturated vapor pressure in the closed loop system, must be considered. The absorber configuration of "tube in sheet" type can improve the collector performance. Corrosion resistance depends on the grade of stainless steel used and on the welding technique.

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Q : What about the investigation on temperature resistance ?

Q : How does the absorber fail when it fails ?

Q : How much are cavity reflections ?

Q : Have you looked at methods of roughening steel ?

MATERIAL PROPERTIES
FOR THE EVACUATED GLASS TUBE SOLAR COLLECTOR

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Introduction

The heat loss from a solar collector is due to convection, conduction and radiation. Loss due to radiation can be reduced by using a selective coating, and vaccum insulation eliminates loss due to convection and conduction. Evacuated glass tube collector which put this principle to use is produced using the same technology as that used in the production of TV cathode ray tubes. The glass, metal and other materials selected have high quality. This report describes the property of these materiales, for an example, Sanyo evacuated glass tube collector.

1. Structure

Fig,1 shows the structure of Sanyo's single evacuated glass tube collector. The single tube consists of a glass tube containing a selective coating absorber plate. In the center of the absorber plate, there is an absorber tube passing through entire place. In the pipe the heat transfer medium flows. Both ends of the glass tube are sealed with metal end caps. The sealing material used here have roughly the same coefficient with thermal expansion of the glass tube. To keep the vaccum in the tube for a long period of time is the most important for evacuated glass tube collector.

2. Sealing Structure

Fig,2 shows the sealing structure of the end of the glass. In chosing sealing metal, a metal with nearly the equal coefficient of thermal expantion as that of the glass is selected. For example in the prodction of cathode-ray tube for TV sets, 42Cr-6Ni alloy or 18Cr ferritic stainless steel is used for soda lime glass, and Kover(Fe-Ni-Co alloy) is used for bolosilicate glass. Sanyo's collector is made of soda lime glass. So we chose 42-6 alloy for sealing metal. A ceramice glass is used for sealing material. The table 1 shows the coefficient of thermal expantion. In oeder to maintain a high degree of vaccum over a long piriod, the seals between the glass and metal must be of high reliability. This was achieved by compositing a stable chrom oxide film onto the surface of the metal. This chrom oxide film was formed by making oxidation in a wet-H2 atmoshere in a temperature over 900°C. To see the the oxide film property a flow button test was done.

3. Flow Button Test

The sealing materiales(ceramic glass) are put on the treated metal, and then they are heated in the real manufacturing condition. The treated test piece was observed with the angle of contact, the extent of sealing material and the rest of sealing materials. (Fig.3) The results dicide the best conditions for surface treatment of sealing matal. Samples tested are 42-6 alloy, 18Cr-ferritic stainless steel and 27Cr ferritic stainless steel. Two methods pre-treatments are used. One is only removing grease. And another is shot-blast after removing glease. Treatment temperature is at 950°C and 1000°C. The pictures in the left are test piece treated in the manufacuring process. The pictures in the center show how mach the sealing materials were remained after peeling the ceramice glass off the metal. The pictures in the right indicates the button surface that have been peeled off. No oxide films are observed on all buttons. From these results, these oxide films show that a combination between the glass and metals is good.

In addition, the sealing metal needs to fix to another metals, copper tube or bellows. (Fig.1) Shape of sealing metal is formed in order to resist the external pressure. (Fig.4)

Sealing material is ceramic glass. In order to make the best coefficient of the thermal expantion for both the glass and sealing metal, a severe

4. Absorber Plate

The absorber plate must have good selective coating. Generally, most of absorber plate in the market are made of either copper plate with black chromium or anodized aluminium or stainless steel with chemically theated. In the initial period of our absorber production we used one in there materials, however, recetly we employed oxidized mild steel in our evacuated glass tube collector. Fig.5 shows the selectivity.

Why we used the mild steel ? Because insude of the glass tube is vaccum so there is almost no problems, and this has much strength and costs less, no corrosion even the absorber plate is made of a mild steel.

The absorber plate is pressed by machine to simply(no brazing at all) tightly catch the copper tube so that there will be no problen of any warps and coming-off of the plate and tube. But if the rate of thermal expantion of the absorber plate is different from the absorber tube, a problem is happened.

Table 2. shows the coefficient of thermal expantion, copper, mild steel and aluminium. This defference in table 2 moves the absorber plate. The stopper hole is made in the center of the absorber plate.(Fig.1) The usage of same materials may be left out of considerations. But, the usage of same materials have difficult problems, first of all the cost and a slight deformation by heat, for example, the copper plate which is very thin.

The difference of the coefficient of thermal conduction is this in table 2. The combination of copper and aluminium is much better than the combination of copper and mild steel. The thermal conduction between the aluminium and mild steel is (196-45) which is almost 150 is not itself desirable. However, the width of the steel in the tube is limitted, so that the problem by heat conduction is negligible.

5.Glazing

Three kinds of glasses have such a transemittance in Fig.6. Soda lime glass has plenty of transmittance on general collector. But the white glass which contain a low percentage of Fe or the glass whice etched the surface, for example AR-glass of Nippon Sheet Glass Co.,LTD, get the high efficiency. It is important that the glass has not defect, and do not remain stress.

Defect or stress fall down the straight of glass. It is very important that the glass must be made straight all the way from end to end. If the glass tubes are made in a carb, it is impossible to insert the absorber plate.

6. Bellows

Sanyo evacuated glass tube collector has a bellows on one side.(Fig.1) Because the absorber tube expands with the change of temperature, but the bellows can absorb it. Heat-pipe type or U-bend type don't need. In a collector that uses water as the heat transfer medium, it may be better to use bellows. Because a collector having bellows don't have a probelem of air stagnation in the vaccum tube during operation. The bellows works at least once a day, and in addition so that it works in a fine movement by stretching and shrinking during a day by the cloud. The bellows of Sanyo's collector have durability of 100,000times on 14mm or more.

7. Manufacturing

When the evacuated glass tube collector is assembled, in order to keep a vaccum for a long piriod of time, collector tube is evacuated and heated to remove gases in the glass tube. For example, Fig 7 shows the amount of disharged gas from the soda lime glass due to the temperature. There is a peak about 150°C. The gas discharged from the glass surface. However, When the temperature rises upto 500°C or more, the disolved gas in the glass itself is discharged.

Sanyo's collector is assembled above 400°C while evacuation in glass tube. Water adhering to the surface is almost removed. In normal operation, the temperature doesn't rise to 400°C. Because of the gas is not discharged any more, the glass tube keeps high vaccum for a long period of time. The end of glass is fixed with sealing materials at a temperature higher then 400°C. Evacuated glass tube collertor is exposed to the most severest condition during its manufacturing which has overcome the problem. Durability of each parts most be evaluated through these manufacturing processes.

8.Units

10 single tubes make a one unit.(Fig 8) It has two box on both sides. This box is not related to heat collection, This is to fix the unit to the installation fixture. The box must be made in consideration of the durability. The material is galvanized steel, and painted. The units which are installation near the sea coast are finished with powder coating that has a long life. Even tap screws are made of stenless steel against corrosion.

9.Conclusions

Sanyo's evacuated glass tube collector, that have resolved all of the problems being manufactured. And In the future, it is desired to develop a well-balanced collectors, at cost, efficiency, and long life, as a system as a whole.

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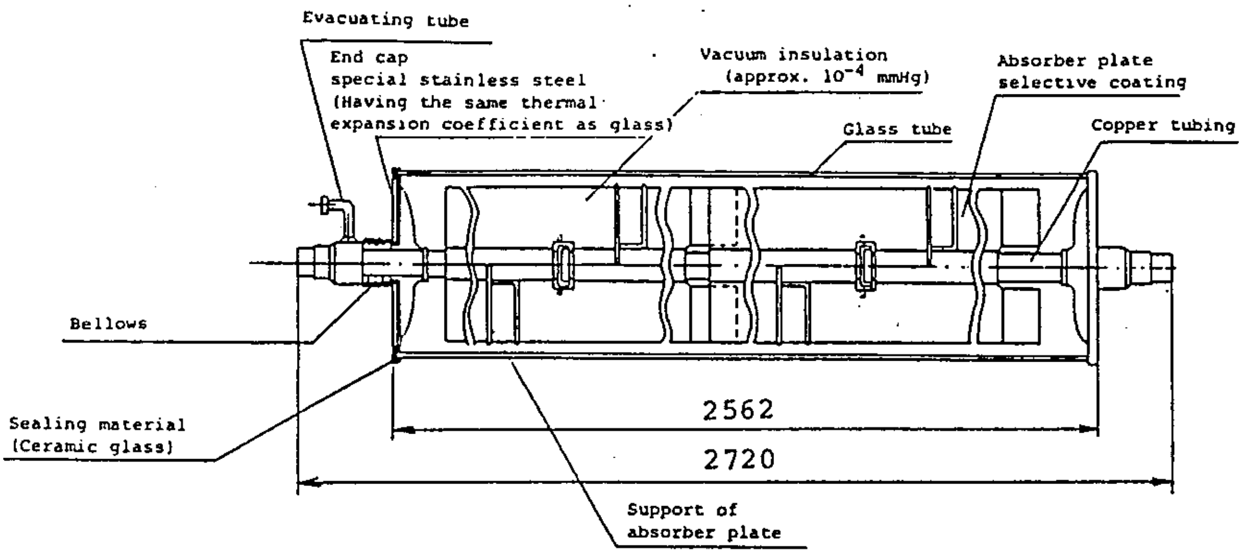
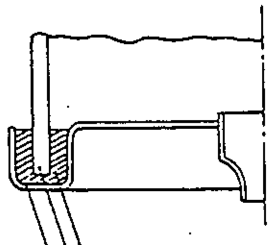


Fig.1 Structure of Single Tube

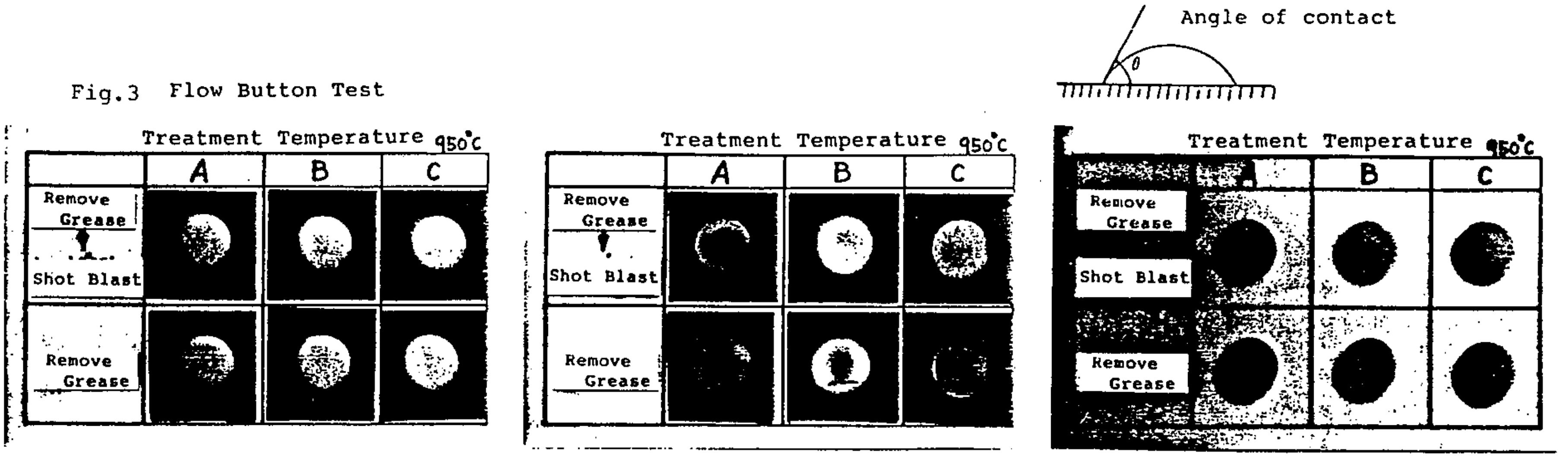
Fig.2 Sealing Structure



	Coefficient of linear expansion (30-450°C)
Sealant (Ceramic glass)	10.1×10^{-6}/°C
Glass tube	10.1×10^{-6}/°C
Special alloy	10.8×10^{-6}/°C

Table 1 Coefficient of Thermal expansion

Fig.3 Flow Button Test



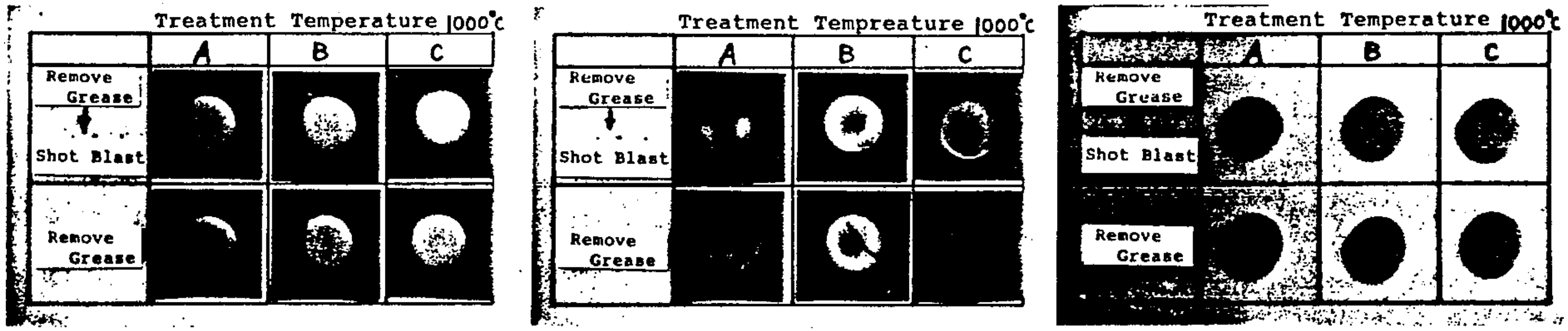
A; 27Cr Stenless Steel

B; 18Cr Stenless Steel

C; 42-6 Alloy

Better B>A>C

There is not the rest of sealing material



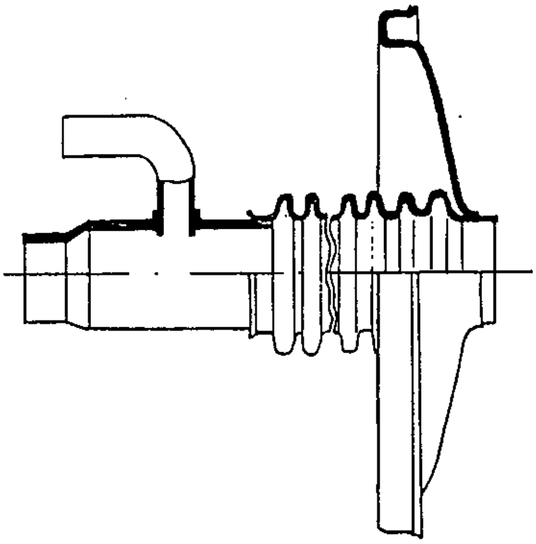


Fig.4 Bellows and Sealing Metal

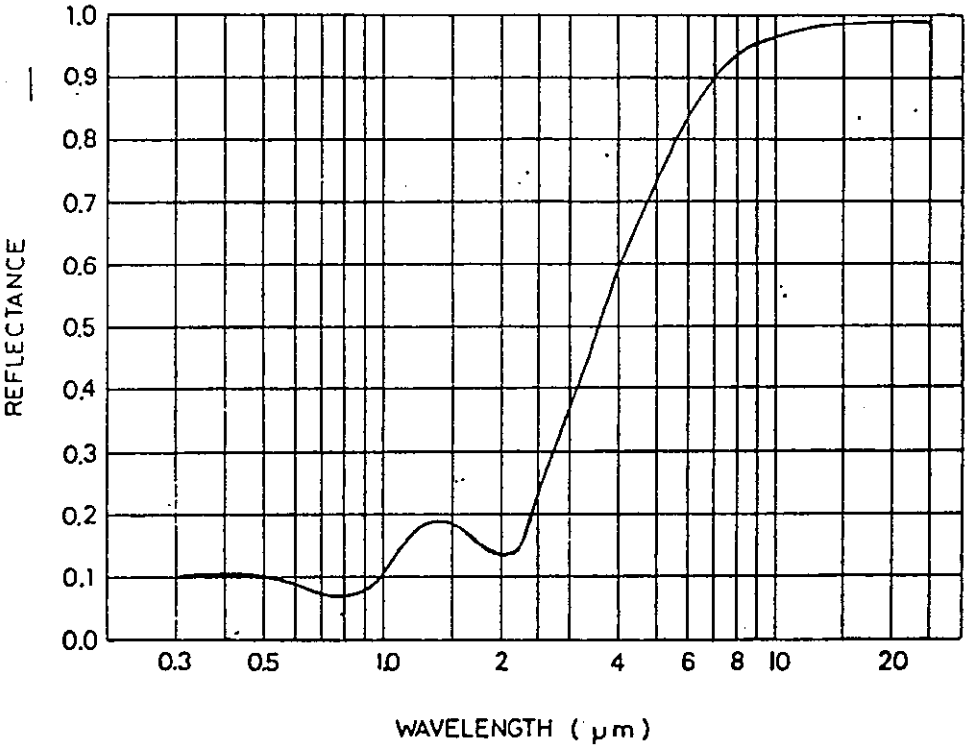


Fig.5 Reflectance of Fe Absorber

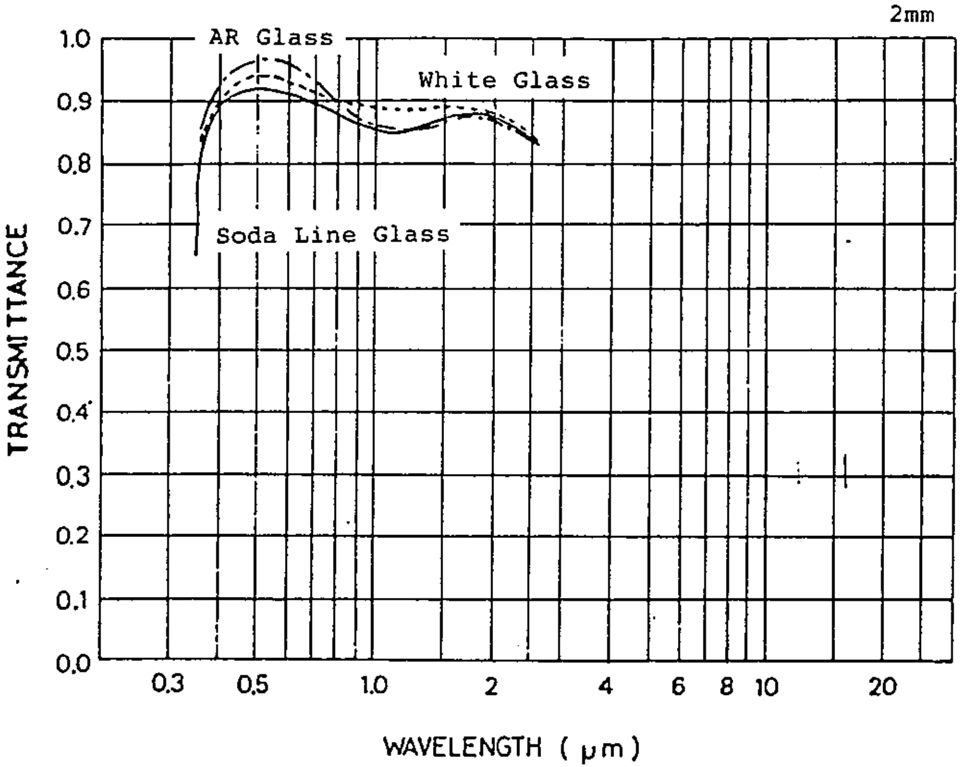


Fig.6 Transmittance of Glass

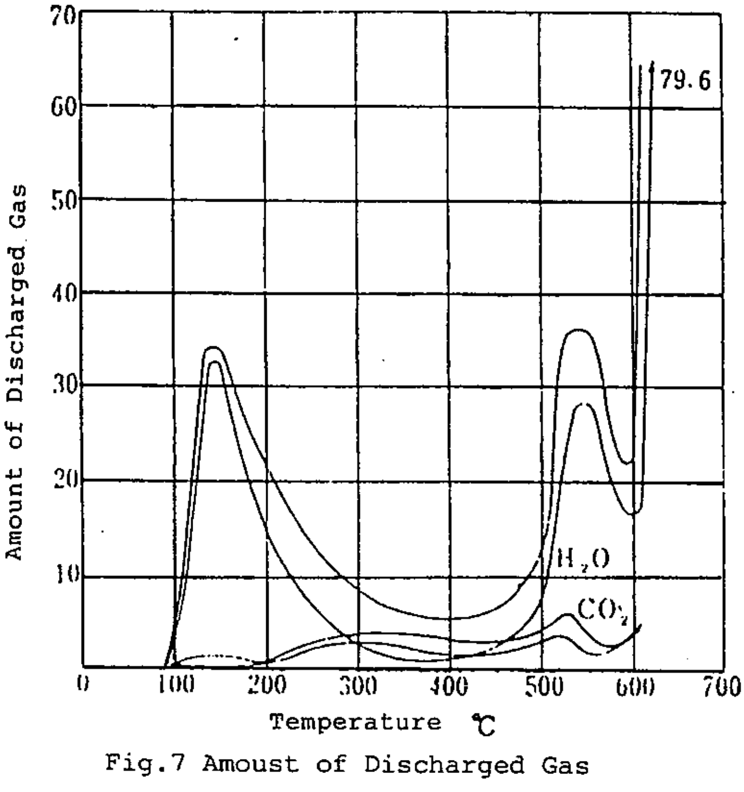


Fig.7 Amoust of Discharged Gas

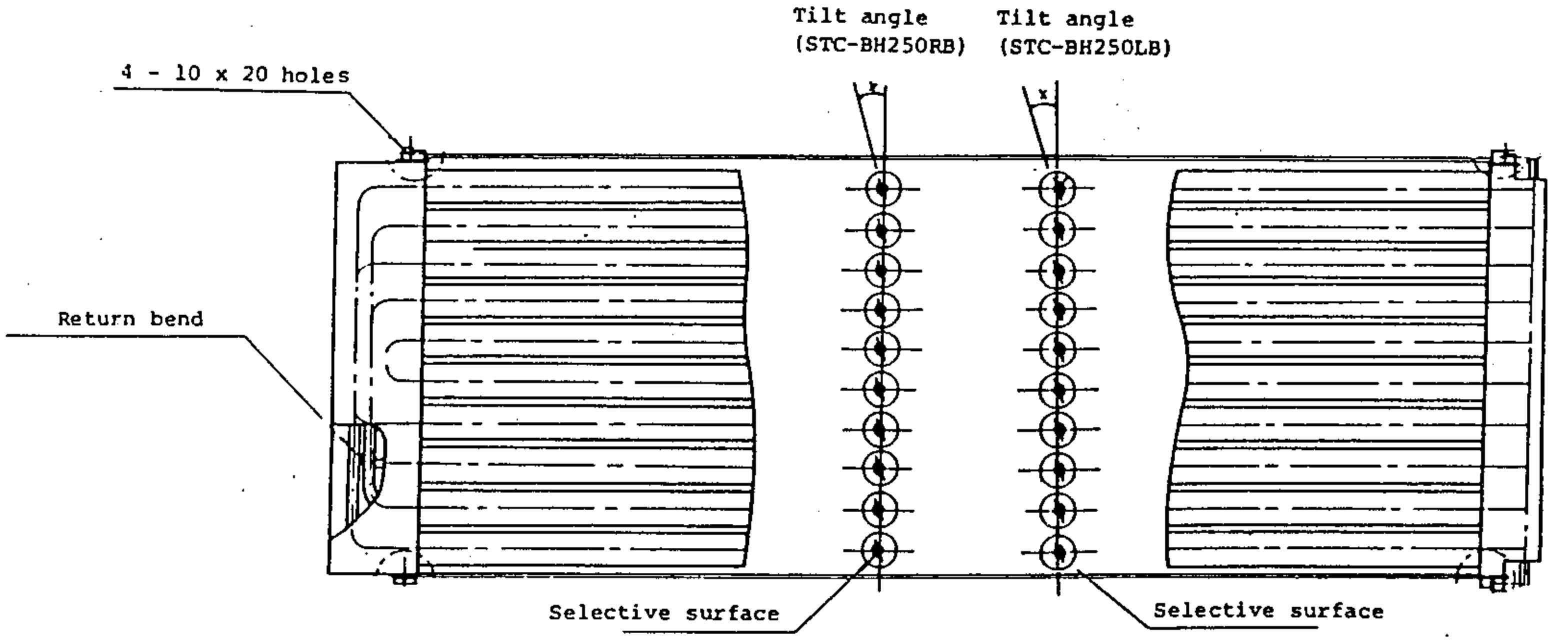


Fig.8 Struture of Unit

Table.2 Coefficient of Thermal Expansion & Thermal Conductivity

Absorber Plate		Absorber Tube		Δl(mm/℃·m)	Thermal Conductivity (kcal/m·h·°c)
	Coefficient of Thermal expansion		Coefficient of Thermal expansion		
Mild steel	13.5×10^{-6}	Copper	16.6×10^{-6}	0.031	45
Aluminium	22×10^{-6}			0.054	196
Copper	16.6×10^{-6}			------	332

Coefficient of Thermal expansion => 0 -- 300°c

Q : In which way was the absorber manufactured ?

Q : Are there no problems when outgas from coating comes out during service ?

Q : What is the stagnation temperature ?

Q : Why are the collectors so long, and what is the weight ? Why have you not two collectors ?

Q : Which is the first priority ?

Q : Ceiling is very expensive, why ?

Material Requirements for PCM Storage

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1. Introduction

When utilizing solar thermal energy, it is indispensable to average the random insolation and to make use of the energy whenever necessary by some sort of thermal energy storage apparatus, because solar insolation has such problems as the diluteness of its energy, the intermittentness due to day and night and the fluctuation and randomness due to the weather and the seasons.

There are several methods of storing thermal energy such as sensible heat storage, latent heat storage, chemical heat storage, and so on. In these methods, only sensible heat storage using water or rocks has been turned to practice. As to latent heat storage, developments of materials and application techniques are still carried out in parallel.

Advantages of latent heat storage are summerized as follows:

- Large amount of thermal energy can be stored in a narrow temperature range including the transition point.
- Much smaller storage apparatus can be designed compared with sensible heat storage.
- Heat loss is small because the temperature rises a little in spite of large storage capacity.

Supplying heat at a constant temperature near the transition point is one of the most significant characteristics of the latent heat thermal storage systems and is impossible for a sensible heat storage system. On the other hand, it contains a problem to limit the usable temperature range.

2. Characteristics requested to phase change thermal storage materials

In the category of phase change, there exist such phenomena as fusion, evaporation, sublimation, crystalline transition, and so on. However usable phase changes for thermal storage are fusion and crystalline transition

3. Temperature range for use of thermal storage

One of the merits of phase change thermal storage materials is charging and discharging thermal energy at a constant temperature. The temperature levels required to the systems are considered as follows:

(a) Recovery of waste heat in industry	300 - 100 °C
(b) Hybrid solar system supplying heat and electricity	250 - 100 °C
(c) Heat source for refrigerators	120 - 80 °C
(d) Heat source for hot water	80 - 50 °C
(e) Heat source for space heating	60 - 40 °C
(f) Passive solar systems	50 - 15 °C
(g) Heat source for heat pumps	30 - 15 °C
(h) Heat source for cooling	15 - 5 °C

It is necessary to select a material having a suitable transition point depending on the object system.

4. Materials appropriate for phase change thermal storage.

There are a lot of materials whose transition points are in the range of temperature listed above. The materials which have been considered applicable as thermal storage materials are classified into the following material groups:

(a) Inorganic salt hydrates (for example, $Na_2SO_4 \cdot 10H_2O$)
(b) Organic materials (for example, paraffins)
(c) Eutectic mixtures of the above-mentioned materials
(d) Natural elements (for example, sulfur)
(e) Simple compounds (for example, water, NH_4NO_3)

A salt hydrate is a compound crystal of a salt connected with water molecules. As salt hydrates are superior to paraffins in the point of heat of fusion per unit volume and heat conductivity, they are much expected to turn to practical use. But they all show more or less supercooling. Materials whose melting points are peritectic do not melt uniformly at the melting points when charging thermal energy. That is to say, they separate into two phase, namely, crystals whose components are different from the original ones (low hydrates) and solution equilibrating with the crystals. If the rate of reverse reaction at the discharging process is low, the phase separation is promoted. Supercooling and phase seperation prevent which do not contain a gaseous state.

Characteristics requested to phase change thermal storage materials in case of using heat of fusion are as follows:

(1) Physical and thermal conditions

- (a) Melting point of the material must exist in the desired temperature range of the application system.
- (b) Having large heat of fusion per unit volume.
- (c) Behaving surely and stably for the melting-freezing cycle, that is, not accompanied by supercooling or phase separation.
- (d) High thermal response, that is, having high thermal conductivity and a high crystallization rate.
- (e) Having small volume change at the phase change and having a small coefficient of thermal expansion.

(2) Chemical conditions

- (f) Being chemically stable
- (g) Not being toxic and dangerous for the human body.
- (h) Having little interaction like corrosion or dissolution against constructive materials such as vessels, capsules, heat exchangers, and so on.

(3) Economical conditions

- (i) Being easily obtainable as industrial products or as resources.
- (j) Low cost (including vessels, heat exchangers, etc.)

Similar characteristics are also requested to the storage materials using heat of crystalline transition.

As a matter of fact, there are no materials that satisfy all of these conditions, so considerably large compromises are necessary.

In these conditions, cost is one of the most important problems. A thermal storage apparatus does not produce energy, but it intends economical and convenient utilization of thermal energy. Therefore, if expensive materials are used, it does not make sense. For that reason, main purpose of the research and development is focused to how the materials which are industrially and cheaply produced in large quantity can be utilized as thermal storage materials. Newly synthesized materials are out of the question all along.

smooth discharge of latent heat and lower the heat storage capacity gradually. Solving these problems is one of the most significant points of the material development.

Among the material groups shown above, the following five materials are considered promising especially from economical conditions, and developments on these materials into practical use are being performed. The characteristics of these five materials are explained as follows:

(1) $Na_2SO_4 \cdot 10H_2O$ (Glauber's salt)

Sodium sulfate decahydrate (Glauber's salt, $Na_2SO_4 \cdot 10H_2O$) is one of the most famous inorganic phase change thermal storage materials which have been researched on application for a long time. This material is produced abundantly as industrial by-product, and is one of the most inexpensive latent heat storage materials. Its melting point is 32 °C and its heat of fusion is 251 J/g or 389 J/cm^3.

Pure hydrate exibits supercooling and phase separation. Supercooling is suppressed sufficiently by the addition of Borax ($Na_2B_4O_7 \cdot 10H_2O$). The most effective method to prevent phase separation is thickening the molten hydrate with appropriate agents.$^{1),2)}$ As a thickener cross-linked polyacrylate is found to be effective.$^{2)}$

Due to its melting point, this matenal is applicable to passive solar systems. It is especially considered promising in Japan to apply the material for heating a greenhouse which is thought to be a kind of passive system. But in this case, the melting point of about 20 °C is considered suitable, so it is needed to lower its melting point. For this purpose, eutectic mixtures of $Na_2SO_4 \cdot 10H_2O$ and $Na_2CO_3 \cdot 10H_2O$, or $Na_2SO_4 \cdot 10H_2O$ and urea ($CO(NH_2)_2$) are developed.$^{2)}$

(2) $CaCl_2 \cdot 6H_2O$

Calcium chloride hexahydrate ($CaCl_2 \cdot 6H_2O$) is also produced abundantly as industrial by-product, and is one of the most inexpensive latent heat storage materials. Its melting point is 29.8 °C and heat of fusion is 180 J/g or 301 J/cm^3. This material also has the problems of supercooling and phase separation. As for the supercooling, barium salts such as $Ba(OH)_2 \cdot 8H_2O$, BaF_2, etc. have been found to be effective nucleating agents. In order to suppress the phase separation, addition of such agents as excess water or sodium chloride is proposed.$^{3)}$ This material is also investigated to lower its melting point to about 20 °C for application to the greenhouse.$^{4)}$

(3) High density polyethylene

High density polyethylene has a melting point of 120 - 135 ℃ and has a heat of fusion of about 200 kJ/kg. It is applicable for high temperature solar heat collecting system (i.e. hybrid solar system supplying heat and electricity, solar absorption air conditioning, etc.) and recovery of waste heat.

This material has the advantages of low cost, safety, no supercooling, no phase separation, no corrosiveness, and so on. On the other hand, it has the disadvantageous properties of low heat conductivity, self-adhesion above the melting point, large expansion during melting, and so on. In regard to these problems, form-stabilized high density polyethylene has been developed using surface-crosslinkage.[5)] It allows direct contact heat exchange with heat transfer fluids such as ethylene glycol.

Durability of the material has been investigated by estimating the extent of thermal oxidative aging.[6)]

(4) Pentaerythritol

Pentaerythritol is a tetrahydric alcohol which is white colored and crystalline. It is widely used as the material of paints, colors and explosives. It is a unique material showing a crystalline transition at 188 ℃ and having a quite large heat of transition (322 kJ/kg) which is comparable to the heat of fusion of ice. As it has the advantages of no smell, no toxicity, small supercooling and being obtainable in large quantity, it is expected to be applied to high temperature solar systems, recovering waste heat, and so on.

As solid pentaerythritol does not change to liquid phase, direct heat exchange with heat transfer media is possible.[7)] The problem of this material is durability. To use pentaerythritol as thermal storage material, the suppression of sublimation, oxidation and radical production are required.[8)]

(5) Paraffins

Melting points of paraffins rise along with the increase of the number of carbons, so the materials having different melting points are obtainable for a relatively wide temperature range. They have excellent properties on supercooling, phase separation, toxity, corrosiveness and stability against heat cycles. But the heat of fusion, specific heat and conductivity are somewhat lower than can be achieved with salt hydrates. Therefore, many studies for paraffins have aimed at improving heat transfer performance. And relatively large heat expansion requires a well-designed heat exchanger and a vessel.

5. Problems for practical utilization

As for the phase change thermal storage materials a lot of researches have been made from the 1920's, and many ideas have been proposed about materials, additives for improving properties of materials, structures of vessels and heat exchangers, and so on. In spite of these efforts, utilization or commercialization of phase change storage materials are still insufficent. The most significant reason is that the thermal storage aims at economical utilization of thermal energy, so that the phase change thermal storage systems are required to be low cost which can compete with the sensible storage systems using water or rocks.

Along with the material cost, the cost of capsules or heat exchangers which are necessary to separate the material from heat transfer media, to improve heat transfer or to prevent corrosion, is considerably high. Therefore, the efforts are focused to the direct heat exchange systems using such materials as form-stabilized polyethylene, pentaerythritol, and so on.

Durability is one of the most significant economical factors for phase change thermal storage materials. But this problem is still uncertain for the most part. Establishing the methods for estimating durability of the materials and ensuring the sufficent life are considered the important subjects to be investigated hereafter.

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Q : Why is NaOAc.3H_2O not included in the group of promising PCM ?

A : Because it is somewhat expensive, compared with $Na_2SO_4.10H_2O$ and $CaCl_2.6H_2O$.

Q : Explain about the use of high density polyethylene.

A : The purpose is to develop the system having no expensive heat exchanger.

Q : Explain the phenomenon of self-adhesion above melting point of polyethylene.

A : Even the crosslinked polyethylene may stick with each other to a large lump when heated to melting, which results in the blocking of the path of heat transfer medium.

SOLAR WATER HEATER USING DIRECT EXPANSION COLLECTOR HEAT PUMP

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Housing Products Research Lab., Matsushita Housing Products Co., Ltd.

ABSTRACT

Super Panasolar* is a hybrid-type solar system embodying the new heat collecting concept that the heat medium flon circulating through a heat collector at a temperature below outdoor atmospheric temperature collects thermal energy not only from solar radiation but also from atmospheric air to make hot water.

The development of an open-type heat collector free of glazing and insulation and a precise refrigerant flow control system was behind this development. This new system has a solar energy collecting efficiency of ca 91%. During spring to fall, it makes 300ℓ of hot water at 45～55℃, 300 days a year. Remarkable reductions have been made in heat collector size and weight (1/5 and 1/11), and many improvements also made in freedom of installation, harmony with home architecture, and ease of installation.

(Keywords: hot watersupply, solar system, heat pump, direct expantion collector)

★ The registered trademark of Matsushita Housing Products Co., Ltd.

INTRODUCTION

Of the devices utilizing solar thermal energy, solar water heaters for home use are the most advanced in the stage of implementation. However, the solar water heaters available today have the disadvantages of unusual dependence on weather, the great bulk and weight of heat collector, and the drawbacks arising from the use of water or antifreeze as heat storage medium, i. e. difficulties in installation and maintenance and the problems of increased roof loads and decreased wind resistance of homes. In addition, the recent upgrading of life has made the public more pleasure-minded than economy-conscious, with the result that in the field of solar water heaters as well as in other fields, there has been a demand for a new solar system that is able to provide a constant and ample supply of hot water.

Under the circumstances, we have developed an all-weather home solar system, "Super Panasolar", which uses flon as a heat medium which circulates through a heat collector at a temperature below the outdoor atmospheric temperature to collect thermal energy not only from solar radiation but also from the atmospheric air. Research has beeo undertaken here and abroad for some time on the utilization of a circulating flon heat collection loop for the collection of solar thermal energy 〔1〕—〔5〕 and this concept has already been implemented in large installations for office buildings, etc.

Super Panasolar, however. represents the first embodiment of the concept in a general home solar system in Japan.

An outline of this new solar system is as follows.

CONSTRUCTION

The schematic architecture and specification of Super Panasolar US-300SA is shown in Fig. 1 and Table 1. This system consists of a fin-type open heat collector (effective heat collecting area 1.0m^2), a heat exchange unit, and a heat storage tank (hot water storage capacity 300ℓ). The heat collector and heat exchange unit are interconnected via heat collecting line, and the heat exchange unit and heat storage tank are interconnected via water distributing line.

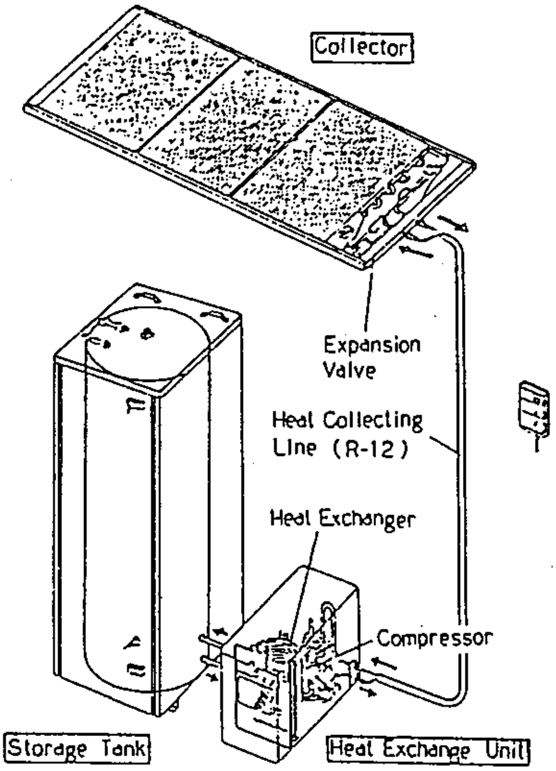

Fig. 1 Schematic architecture of Super Panasolar US-300SA

Heat Collector	Type		Flat plate fin-tube direct-expansion
	Effective heat collection area		1.0 m^2
	Outside dimensions		48 x 1,821 x 759 mm (H x W x D)
	Weight of product		16 kg
	Flow rate control		Thermal auto expansion valve
Heat Storage Tank	Type		Direct connection to city water
	Hot water storage capacity		300 ℓ
	Outside dimensions		1,756 x 698 x 617 mm (H x W x D)
	Weight of product		87 kg (387 with water filled)
Heat Exchanger Unit	Type		Circulation type
	Outside dimensions		530 x 373 x 622 mm (H x W x D)
	Power supply		Single-phase 100 V, 50/60 Hz
	Weight of product		29 kg
	Compressor	Type	Rolling piston rotary system
		Rated output	350 W
	Circulation pump	Type	Magnet drive centrifugal pump
		Power consumed	26/35 W
	Refrigerant		Flon gas R-12
	Heat exchanger		Laminated tube-to-tube double-wall

Table 1 Specifications of Super Panasolar US-300SA

The heat collecting line communicates with a compressor, a heat exchanger serving as a condenser, an expansion valve, a heat collector and an accumulator, and contains the refrigerant Flon R-12 as heat medium, while the hot water circuit comprises a circulation pump, the above heat exchanger and a heat storage tant as connected by a water supply line.

Constructed basically as illustrated in Fig. 2, the new heat collector is a compact plate-type fin tube unit having a heat collecting area of 1.0 m² and capable of collecting heat not only from solar radiation but also from the atmospheric air. Moreover, because of the absence of front glazing, the whole collector weights only 16 kg. Compared with the conventional heat collector (Matsushita SI-3T×3 plates), the new unit is about 1/5 in size and about 1/11 in weight. Improvements have also been made in installation latitude and workability, reliability, and architectural compatibility.

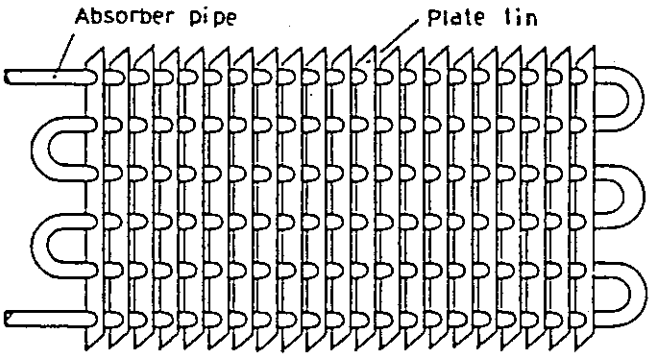

Fig. 2 Basic Structure of heat collector

The expansion valve is a newly developed temperature-type automatic valve which responds quickly to frequent changes in sunshine and wind velocity so that the refrigerant may be fed to the heat collector at the optimum flow rate at all times through the four seasons.

The heat exchanger is of the double-wall construction, built up of laminates of two different flat copper pipes, one for water and the other for flon, which prevents contamination of hot water with the refrigerant.

PRINCIPLE OF HEAT-COLLECTING OPERATION

The flow rate of flon is controlled by the expansion valve in such a manner that the heat collector temperature will be kept below the outdoor atmospheric temperature in accordance with the available amounts of solar energy and atmospheric heat, the latter varying with outdoor atmospheric temperature, humidity and wind velocity. The heat collector thus collects both solar heat and atmospheric heat and the heat so collected is added to the heat of compression generated in the compressor and used to heat the water in the heat storage tank which has been supplied by the circulation pump. The water in the heat storage tank is thus heated to 55℃.

The heat-collecting operation is performed either on the automatic mode or on the manual mode.

At " AUTO " position, it senses the available sunlight and ensures efficient operation.

At " MANUAL " position, it collects heat irrespective of available sunlight.

Usually, with the remote control operation switch set at " AUTO ", the system stops operating after sunset. If the manual mode is selected in order to obtain a larger quantity of hot water, the heat-collecting operation starts as soon as the operation switch is turned ON, irrespective of the level of outdoor sunlight. Therefore, hot water can be obtained even after sunset.

On either mode, the heat-collecting operation stops when the temperature of water in the heat storage tank has reached 55℃ or the flon evaporating temperature in the heat collector has dropped below −10℃.

SOLAR ENERGY COLLECTING EFFICIENCY

Method

The solar energy collecting efficiency η of a heat collector is given by the following equation.

$$\eta = Q_s \ / \ I A_c \qquad (1)$$

where Q_S is the amount of solar thermal energy collected, I is the amount of solar radiation, and Ac is the solar energy collecting area.

In this hybrid heat collector, the total amount of heat collection Q_E is the sum of the amount of solar thermal energy collection Q_S and the amount of atmospheric thermal energy collection Q_A.

$$Q_E = Q_S + Q_A \qquad (2)$$

Therefore, the quantity of solar energy collection Q_S is given by the following equation.

$$Q_S = Q_E - Q_A \qquad (3)$$

Experimental Apparatus and Method

Fig. 3 shows the experimental apparatus used in heat collecting characteristics experiments for determining the amounts of solar heat and atmospheric heat that could be collected.

The surface temperature of the heat-collecting plates is measured in 6 positions by means of C-C thermocouples and the mean of the readings is taken as the surface temperature. As to the outdoor atmospheric temperature, the atmospheric air in the vicinity of the heat collector is guided into a sampling box and its temperature is read with a calibrated bar thermometer. The amount of heat exchange Q_C in the condenser is calculated using the equation:

$$Q_C = 60 \gamma_W C_P\ G_W (T_{W2} - T_{W1}) \times 10^{-3} \qquad (4)$$

γ_W: specific gravity of water (kg/m²)

C_P: specific heat of water (kg/kg·℃)

G_W: circulating volume of water (ℓ/min)

T_{W1}, T_{W2}: water temperatures at inlet and outlet of condenser (℃)

In order to calculate the circulating amount of refrigerant and the amount of heat collected in the heat collector, the temperatures and pressures of flon refrigerant at the inlet and outlet of the condenser and at the inlet and outlet of the heat collector are respectively read by means of C-C thermocouples and Bourdon tubes and the refrigerant entropy is calculated. The circulating amount of flon G_R is determined from the equation:

$$G_R = Q_0 / (i_1 - i_2) \qquad (5)$$

i_1, i_2 : refrigerant entropy at inlet and outlet condenser (kcal / kg)

The total amount of heat collection Q_E in the heat collector is given by the equation :

$$Q_E = G_R (i_4 - i_3) \qquad (6)$$

i_3, i_4 : refrigerant entropy at inlet and outlet of heat collector (kcal / kg)

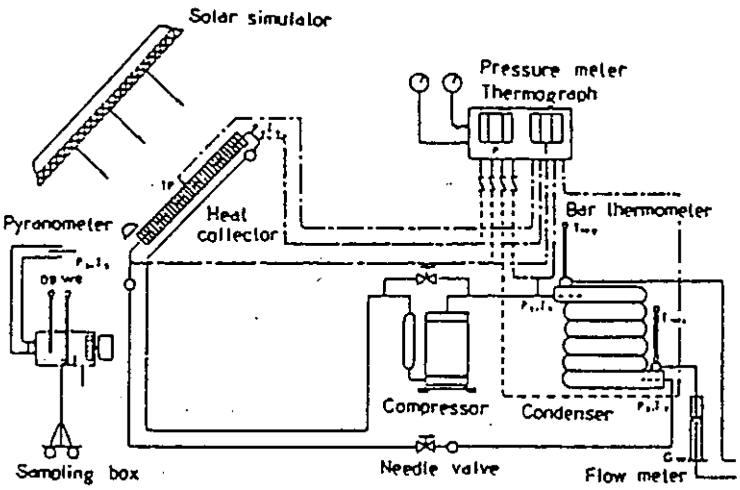

Fig. 3 Test system of collecting characteristics of collector

In order to experimentally determine the solar energy collection efficiency η of the heat collector, first the difference $\Delta T (= t_a - t_f)$ between outdoor atmospheric temperature t_a and heat collector plate temperature t_f is varied in the absence of solar radiation to find the total quantity of heat collection. The quantity of heat collection thus found is the quantity of atmospheric heat collection.

Then, a given quantity of solar radiation I (kcal/m²·h) is applied to the heat collector and ΔT is varied in the same manner as above to find the total quantity of heat collection Q_E. The quantity of heat collection thus found includes the quantity of solar thermal energy collection Q_S and that atmospheric thermal energy collection Q_A. Therefore, the solar energy collection efficiency η of the heat collector can be calculated by means of the above Eq. (3) and (1).

Results

The results of the experiment relating to the heat collection characteristics of the heat collector are diagramatically presented in Fig. 4. Shown are the ΔT values and measured quantites of thermal energy collection when 500 kcal/m²·h and 300 kcal/m²·h of solar radiation were respectively applied to the heat collector. The solid lines indicated by the legends △ and □ pertain to the cases in which solar light was applied in parallel with the heat collecting plates so that a part of the solar radiation passes through the gap between plates (A in Fig. 4.) and the broken line indicated by the legend ◨ represents the case in which solar light was incident on the heat collecting plates at an angle greater than $\theta°$ ($\theta \geqq 17.5$) so that all the solar beams bombarded the heat collecting plates (B in Fig. 4). Referring, further, to Fig. 4, the dot-broken line is a simulation curve tracing the quantities of atmospheric thermal energy collection when the quantity of solar radiation $I = 0$. It is seen that the simulation results are in good agreement with experimental atmospheric heat collection data. For the same value of ΔT, the total quantity of heat collection in the presence of solar radiation is greater than the quantity of atmospheric thermal energy collection, indicating that the thermal energy of solar radiation was added to the heat collector.

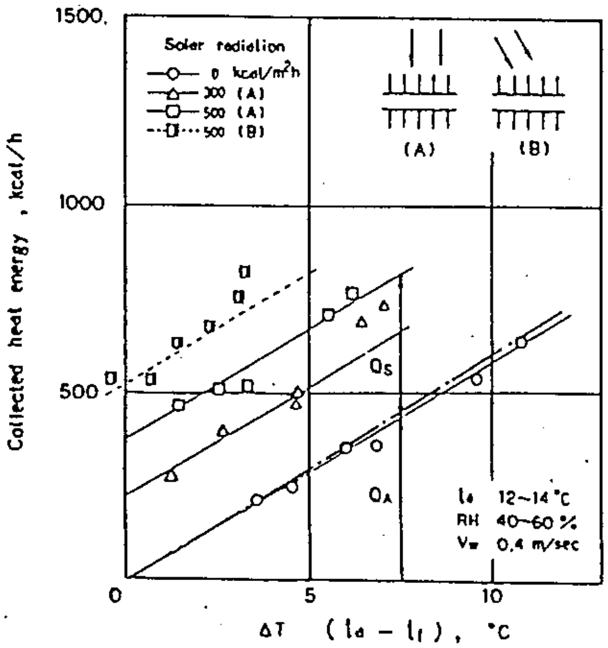

Fig. 4 Heat collection charateristic

In this system where the temperature of heat collecting plates is lower than atmospheric temperature as shown in Fig. 5, the solar energy collection efficiency η in the presence of solar radiation is constant, irrespective of changes in ΔT or in the quantity of available solar radiation, as will be apparent from Fig. 4 and Eqs. (3) and (1). Thus, (1) $\eta = 0.68$ when solar radiation beams are in parallel with the heat collecting plates; (2) $\eta = 0.94$ when the beams are at an angle of $\geqq 17.5°$ with the heat collecting plates.

Therefore, the solar energy collecting efficiency varies within the range of 0.68 to 0.94 according to the angle of incidence of solar beams on the heat collecting surface. However, the situation in which a portion of solar radiation passes through the gap between heat collecting plates to make the relation $0.68 \leqq \eta < 0.94$ hold occurs only during a short period of about 2 hours in the daytime and the average solar energy collecting efficiency for the whole day (0.91) is about twice as high as that of the conventional solar system ($\eta = 0.4 \sim 0.5$).

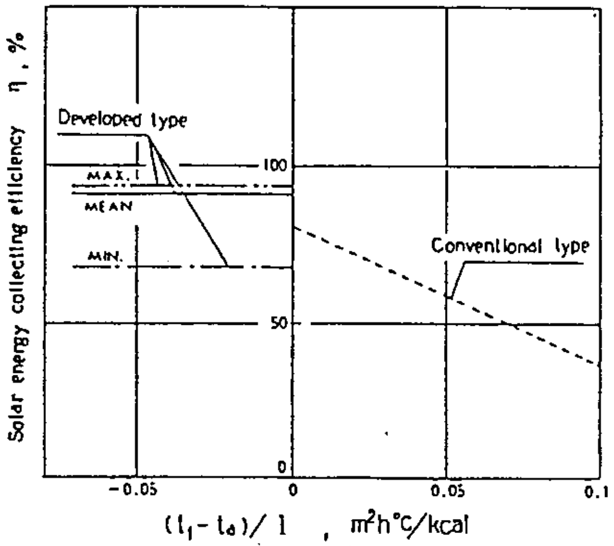

Fig. 5 Solar energy collecting efficiency

HEAT-COLLECTING OPERATION CHARACTERISTICS

Simulation

As the heat-collecting operation characteristic of this new solar system depends much on outdoor atmospheric conditions as well as on water temperature, its annual heat-collecting characteristic varies with different geographic areas. Therefore, an attempt was made at the development stage to predict the heat-collecting characteristic in a simulation model. The characteristics of component parts were experimentally determined and fed back to the simulation model so as to ensure as accurate a simulation as possible for optimization of machine capacity and system control. As an example of heat-collecting cycle operation characteristic, the variation in refrigerant evaporating temperature in the heat collector in response to available sunshine, wind velocity and outdoor temperature is shown in Fig. 6. It will be apparent that with decreasing available sunlight, wind velocity and outdoor atmospheric temperature, the evaporating temperature drops and approaches to the heat-collecting operation stop temperature (−10 ℃).

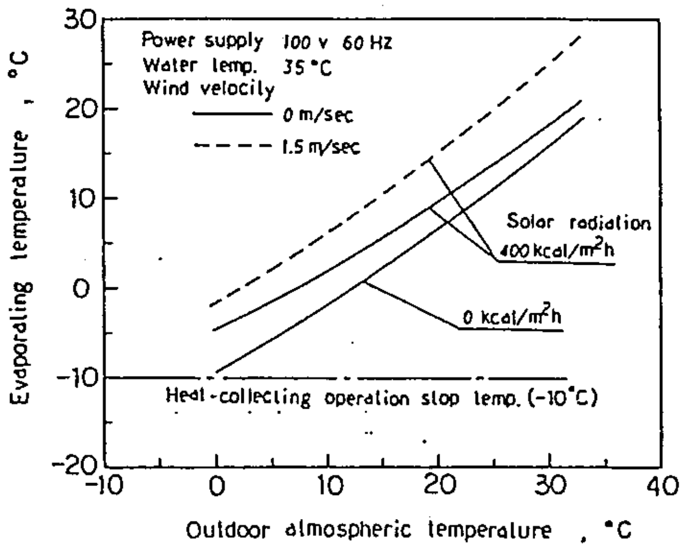

Fig. 6 Heat-collecting cycle operation characteristic (in the absence of frost on heat collector)

Fig. 7 show the product hot water temperature and heat-collecting operation time at a varying outdoor atmospheric temperature with the wind velocity being assumed to be 0 or 1.5 m/sec and the available amount of solar energy to be 0 or 400 kcal/m²·h. Referring to the diagram, at the low outdoor atmospheric temperature with both sunlight and wind velocity being zero, as reperesented by the solid line, the heat-collecting operation time is short and the product hot water temperature is low. This is because frost formson the surfaces of heat-collecting plates and grows with the progress of time to cause the refrigerant evaporating temperature to fall, with the result that the system stops and restarts the heat-collecting operation in frequent repetition. When the wind velocity is 1.5 m/sec. and the available solar energy is 400 kcal/m²·h (10 hours), the heat-collecting operation time is longer and the product hot water temperature is higher.

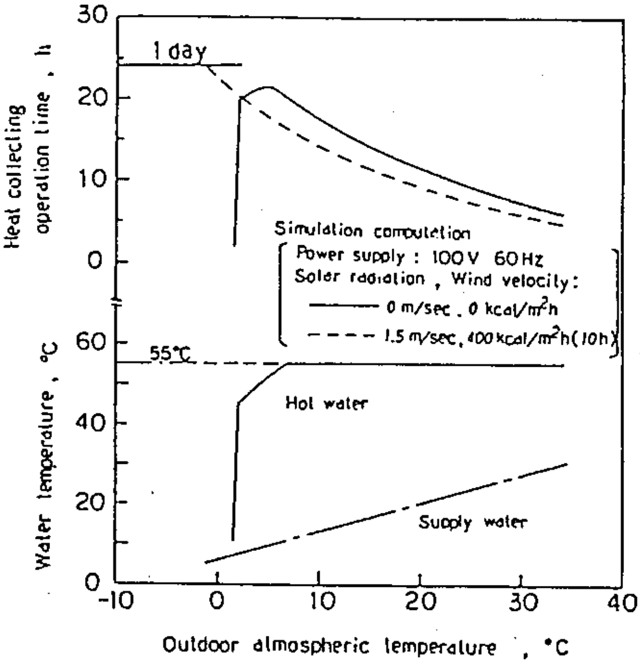

Fig. 7 Heating up characteristics

Field experiment

Fig. 8 shows the results of a field experiment carried out in Yamato-Koriyama City, Nara prefecture, Japan during the period of February to May of the year 1984 when the atmospheric temperature dropped to a record low. As will be seen from Fig. 8, the variation in temperature of hot product water was large during the period from February to the middle of March when the daily minimum atmospheric temperatures were below freezing point. On the 17th day of February when a heavy snowfall left deposits of snow on the heat collector all day long, the heat collecting operation was suspended so that substantially no increase occurred in water temperature. This being an exception, fair degrees of heating effect were invariably obtained even when the daily minimum atmospheric temperature dropped below freezing point, although day-to-day variations were seen according to the daily duration of sunshine, increase of atmospheric temperature, and wind velocity.

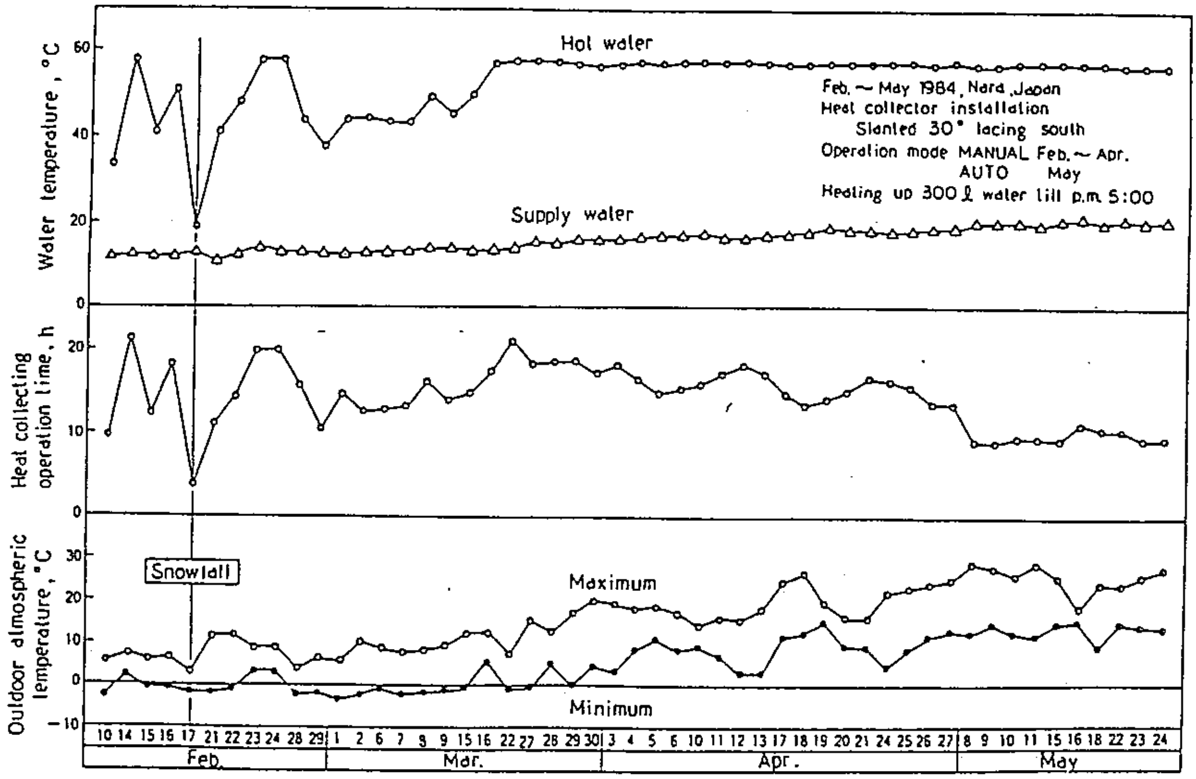

Fig. 8 Results of field heat-collecting operation

In contrast, after the middle of March when the minimum and mid-day atmospheric temperatures exceeded 0℃ and 10℃, respectively, the water temperature reached the maximum temperature to make available a stable supply of hot water on the manual operation mode.

Moreover, as indicated by the data after May when the maual mode was switched to the automatic operation mede, a stable supply of hot water could be obtained by a short time of heat collecting operation.

Fig. 9 shows a comparative plotting of field experimental and simulation data against the mean outdoor atmospheric temperaturc in the heat collecting operatino time zone on the horizontal axis. Simulation computations were made with the initial water temperature and highest product water temperature being respectively equated with those of the actual equipment. In Fig. 9, a variation is found in field data when the mean outdoor atmospheric temperature in the heat collecting operation time zone is up to about 5 ℃. This is because the field data included those measured during the time zone when, despite the mean atmospheric temperature being in the neighborhood of 5 ℃, the outdoor atmospheric temperature dropped still lower (e. g. below freezing point) and the suspension of heat collecting operation owing to the cold and changes in the state of frost resulted in variations in heat collectinf operation time and hot water temperature. Thus, with the outdoor atmospheric temperature of ca 5 ℃ as a inflection point, both the heat collecting operation time and hot water temperature tended to decrease on the lower atmospheric temperature side. On the higher outdoor atmospheric temperature side, a stable product water temperature was obtained, although the heat collecting operation time decreased as the outdoor atmospheric temperature rose. These tendencies were found in both the simulation data and field data. Moreover, it was also observed in both the simulation and field data that depending on the state of sunshine and wind velocity, hot water could be obtained even when the outdoor atmospheric temperature was below ca 5 ℃

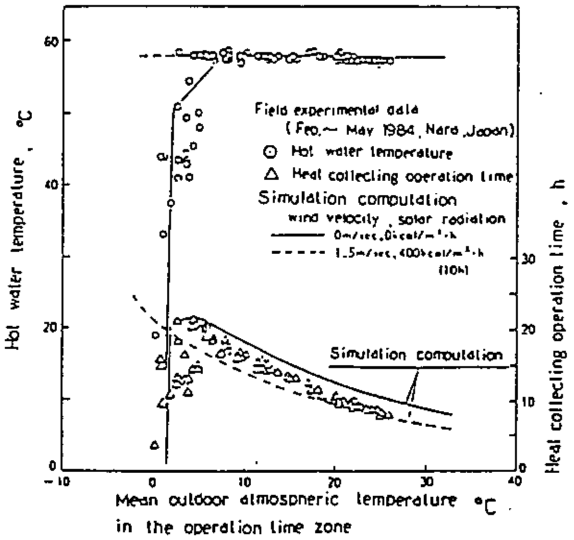

Fig. 9 Comparison of measured and calculated operating time and hot water temperature

Results

Based on the foregoing results, simulation computations of anual heat collection characteristics for the model areas of Tokyo and Osaka were carried out. Under the normal local climatic conditions (HASP weather data), the number of heat collecting operation days supplying 300 ℓ of water at 45－55℃ exceeded 300 days. It is therefore, thought that we can now supply a commercial solar system capable of ensuring a stable supply of hot water throughout most of the year.

CONCLUSION

The new solar system was found to assure effective water temperatures without resort to any auxiliary heat source during the three seasons of the year from spring to fall. This finding has prompted us to develop an allseason water supply system and is also expected to increase the sale of solar systems in urban areas where the utilization of such systems has been so far impeded by the limited availability of installation spaces.

It is our intention to make further improvements in mechanical aspects and develop a still improved system embodying this new solar energy collecting technology.

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〔5〕W. W. S. Charters and C. W. Dixon, "Some performance characteristics of the UNIMELB air source solar boosted heat pump system", Int. Sol. Energy Soc. Silver Jubilee Congr., USA 1979(1), 807－811 (1979).

Q : How is the flow of heat transfer medium determined ?

A : It is controlled by opening the expansion valve as to attain $\Delta T = T_a - T_f = 10°C$. The rate of flow is variable according to ambient temperature, insolation, wind, and temperature of water.

Q : Do you know the solar fraction of this system ?

A : Yearly average of insolation: 200 $kcal/m^2h$, maximum: 600 $kcal/m^2h$ (Tokyo); heat collecting efficiency, 40 %; COP: 3.6(summer, up to 55°C), maximum: 7.0.

Q : How much electric energy do you need yearly ?

A : By simulation at Osaka, 1400 kW/year(capacity for serving hot water, 3.60×10^6 kcal/year).

Heat Mirrors for Passive applications

Sadamitsu Tsuboi

Nippon Sheet Glass Co.,Ltd

1 Introducion

Recently in architectural field, heat mirrors come to be used in buildings. There are two reasons why they are adopted widely. One is color design of walls and windows of buildings. It means that only characteristics of reflection and absorption at visible ray range are required.

The other is to use efficiency of heat mirror and it concerns about energy conservation of buildings.

It means the reduction of cooling load in summer and heating load in winter, however required characteristics are different between them. In the case of reducing cooling load, shading solar radiation through windows is important. In other words, reflection and absorption at wave length range of solar radiation are required. In the case of reducing heating load, heat gain from solar radiation is useful and re-radiation and heat transfer through windows caused heat loss have to be minimized. In other words, high transmittance at range of solar radiation and high reflectance at range of long wave length are required. Later type of glass is called low-E (emissibity) glass.

2 Production Methods and Characteristics

Heat mirror means metal or metal oxide coated glass and there are several production methods.
(Table-1)

Method		Process	Durability	low-E	coating material
Pyrolytic	Spray	on-line/off-line	very good	good	SnO_2, TiO_2
	CVD	〃			
	Dipping	off-line			
Metal ion migration		on-line	not so good	not good	Cu
Wet chemical		off-line	bad	good	Cu, Ag, Au
Vacuum	Electron Bceam	〃	not so good	very good	Ag, Au
	Sputtering	〃	〃	〃	

Table-1

Low-E glass products are mostly manufacturing by pyrolytic method (Spray, CVD) or sputtering method.
In the case of pyrolytic method, film is very stable because of high coating temperature and durability is excellent.
Besides, on-line coating in the glass manufacturing process is possible. Most popular coating material is SnO_2 and its emissibity is about 0.35～0.5 at film thickness 1000～2000 Å.
If the film is thicker, emissibity can be reduced, but cosmetic problem may occur because of interference colors.
Besides, transmittance becomes lower by absorption of SnO_2 film.

In the case of sputtering method, emissibity of 0.06～0.3 can be obtained.
Usually, this kind of film has 3 layers (Fig-1)

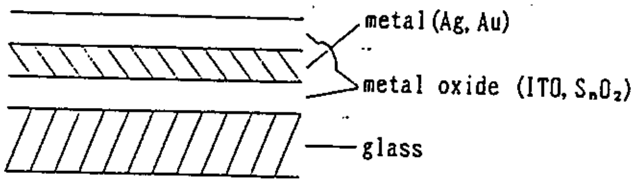

Fig-1

Usually second layer is metal such as Ag and first and third layers are metal oxide for protection of metal.

These composition can be easily made because sputtering is vacuum method. Film thickness is 200 ~ 1000 Å and transmittance is high. It is also possible to make clear coating glass. But durability of sputtering film is not good compared to Pyrolytic film.

(abrasion, scratch, degradation from oxidation of metal)

So sputtering low-E glass is usually used in thermal insulation glass (T I glass). Fig-2 shows a example of spectrotransmittance and reflectance of low-E glass.

Fig-3 shows the relation between emissibity and heat transfer co-efficient of T I glass that uses one low-E glass.

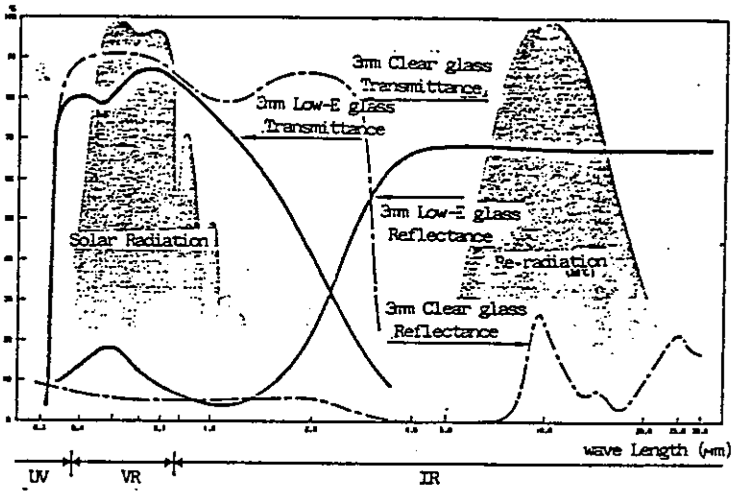

Fig-2

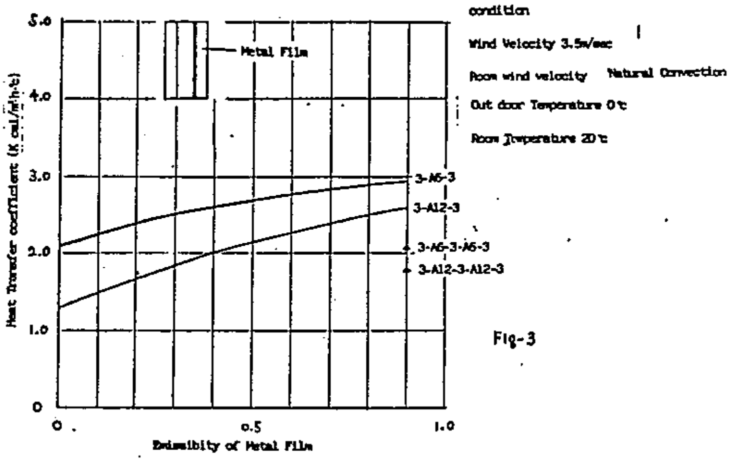

Fig-3

Fig-3 shows the relation between emissibity and heat transfer co-efficient of TI glass that uses one low-E glass.
Double TI glass with low-E glass has good efficiency as same as triple TI glass without low-E glass and this is a strong weapon to reduce heating load in cold district.

3 Energy conservation effect

In Japan, 1980, energy conservation standard for office building was published by the government and it became necessary to submit energy conservation plan to the government when new building which has over 2,000m^2 of total floor is constructed. This standard shows calculation method of annual load for perimeter zone of building and this must be below 80× 10^2 Kcal/m^2.

3.1. Calculation Condition

Fig-4 is model building which has north and south perimeter zone. Windows are fixed and occupy 40% of wall. Heat transfer coefficient K of wall is 1.0 Kcal/m^2℃

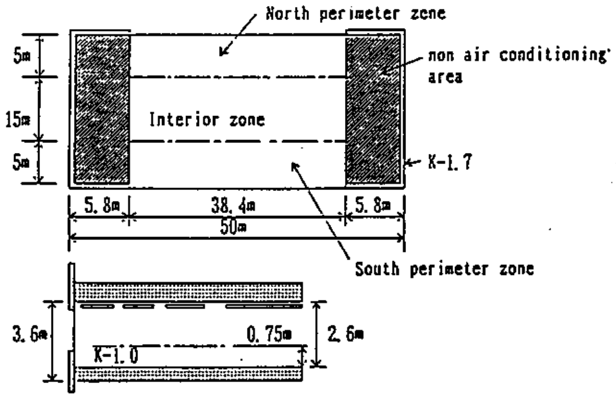

Fig-4

Table-2 shows glass type.and efficiency (kcal/m^2h℃)

glass type	glass thickness (mm)	Shading Co efficient	Heat transfe Co efficient
Clear glass	8	0.92	5.3
Clear TI	6-A6-6	0.81	2.9
SP coating	8	0.40	4.7
SP coating TI	6-A6-6	0.26	2.7
Pyrolytic coating	8	0.75	5.3
Low-E TI	6-A6-6	0.64	2.3

3.2 Calculation result

Fig-5 shows the calculation result in the case of Sapporo city, Hokkaido and Fig-6 shows the result in the case of Tokyo.

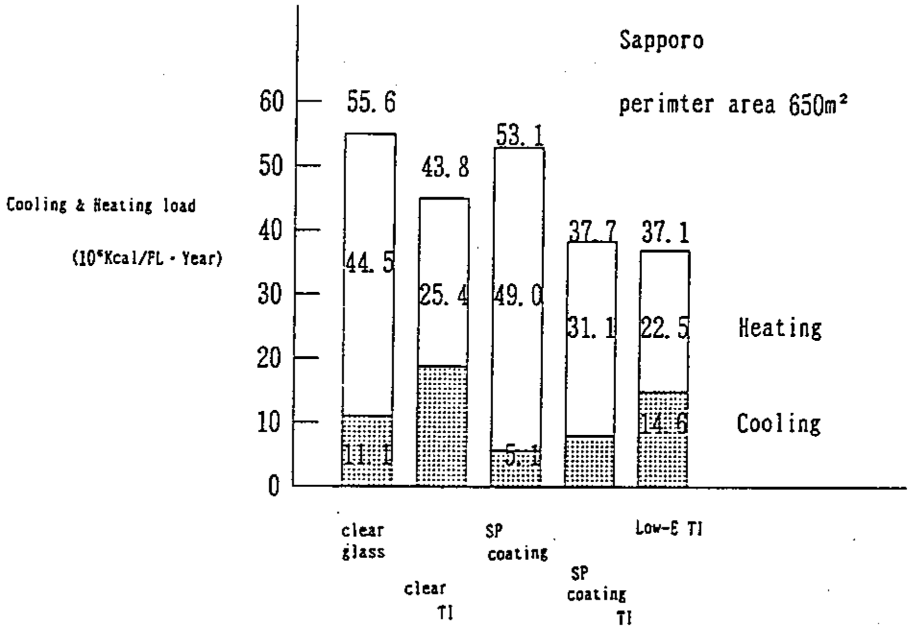

Fig-5

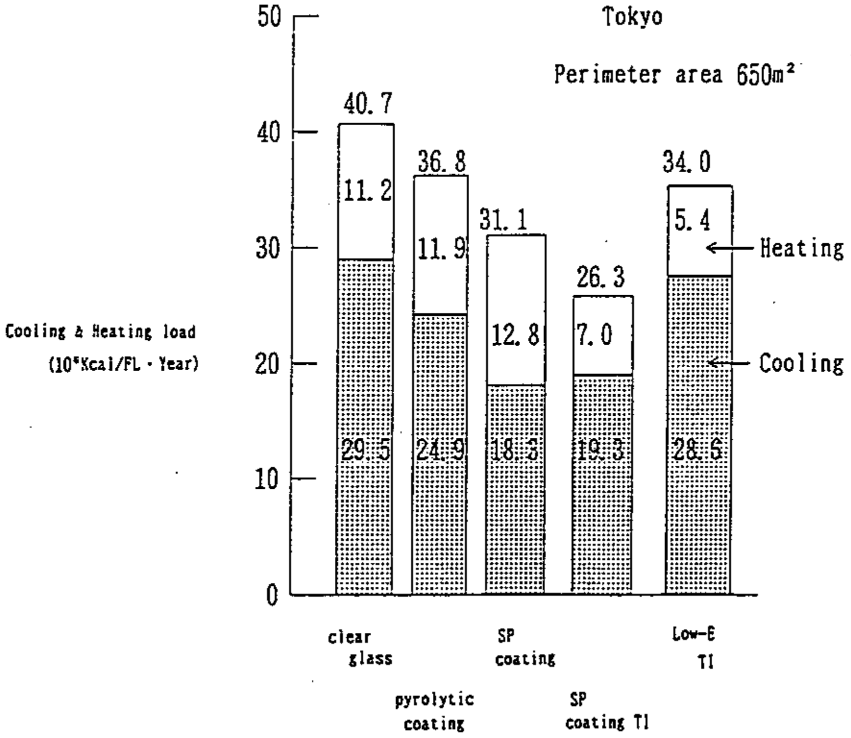

Fig-6

In the case of Tokyo, cooling load occupies large part of annual load. So window glass has to be suitable for it.

Anyway from the view point of heating load, low-E glass is very effective.

4 Conclusion

Heat mirror (low-E) has good characteristics and is attractive materials for passive applications. It will come to be popular to use such glass in residential houses in near future.

Q : What program do you use for calculation of performance ?

A :

Q : What kind of durability test was adopted ?

A : Abrasion test, scratch test, and weathering test.

Glass products for cover glazing

Contribution for IEA X workshop

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INTRODUCTION

Today, float glass is used in most windows. Float glass is a soda-lime silicate glass that is made by the float process, which consists of floating a continuous ribbon of glass on a bath of molten tin. This process leads to a glass with a smooth surface.
Apart from it's use in windows, float glass is an important candidate as cover glazing for flat-plate solar collectors, as encapsulation for photovoltaic cells and as superstrate of solar mirrors.
In view of these solar applications, float glass can be improved with respect to: solar transmittance, mechanical strength, chemical durability and thermal insulation.

IMPROVEMENTS OF GLASS PERFORMANCE

Solar transmittance

The solar absorption of float glass is largely due to iron impurities in the glass. The iron content of standard float glass is about 0.1%; the impurities are primarily Fe^{2+} and Fe^{3+} ions.
The Fe^{3+} ions absorb in the ultraviolet and are of little consequence to solar applications. However, the Fe^{2+} ion has a broad absorption band around 1000 nm, a spectral region in which the solar irradiance is considerable. By reduction of the iron content the solar transmittance can be improved from about 82% to 90% for 4 mm thick float glass.
The solar transmittance can be increased further by lowering the reflectance of the glass surface. This can be realized by coating the glass with an anti-reflective layer, e.g. a MgF_2-layer.
This coating improves the transmittance of glass by up to 6%.
So the upper limit of the solar transmittance of 4 mm float glass amounts to approximately 96%.

Mechanical strength

Generally the strength of brittle materials like glass is reduced by surface flaws or cracks, which are introduced during manufacture, handling and through exposure to the environment (abrasion). These (Griffith) flaws concentrate applied stresses and above a critical value of stress, fracture is initiated at the flaws.
Glass strength can be increased up to a factor of about 10 by tempering methods, including thermal or chemical treatments of the glass surface. The thermal method basically consists of blowing cold air on to the heated glass surface. The chemical treatment involves ion exchange reactions of potassium ions for sodium ions. By both techniques compression layers at the glass surface are produced, which reduce originating of surface flaws. By tempering the thermal endurance of glass is enhanced as well. For example, the themal endurance of a 5 mm normal glass plate is restricted to a temperature difference of 80 ^{0}C at most, whereas the corresponding value of a tempered 5 mm glass plate amounts to 250 ^{0}C.

Chemical durability

Glass has high resistance to atmospheric agencies, but in the long term weathering of the glass surface can occur, due to interactions of alkali ions in the surface layer and atmospheric humidity (alkali-leaching). There are more durable glass compositions than soda-lime-silicate, for example borosilicate and aluminiumsilicate glass.
However, under normal in-service conditions of cover glazing the solar transmittance changes due to weathering of soda-lime glass amounts to a few percents et most. Therefore, common soda-lime glass is usually preferred for economic reasons.

Thermal insulation

The thermal emittance of glass can be reduced by deposition of a transparant conductive coating (low emittance coating) on the glass substrate. Commercially available low-E glass can be divided in:

- noble metal based (multi-layer) coatings, including layers of Cu, Ag and Au.
- semiconductor based (single layer) coatings, including the oxides of Sn and In.

Heat mirror coatings on glass are usually produced by PVD (sputtering) techniques or spray processes (pyrolysis).
The emissivity of commercial low-E glass ranges typically from 0.10-0.15. In practice heat mirror coatings are used in double glass.
The overall thermal conductance (U-value) of double glass (4 mm) is about 3 W/m^2 K. By a decrease of the effective radiative losses, the U-value of a double glass unit with a low-E coating can be reduced to about 1.5 W/m^2 K. However, in evaluating low-E glass as candidate cover material of thermal solar collectors, the decrease in solar energy transmittance due to the low-E coating (reflection-and absorption-losses) should be taken into account as well.

CONCLUSION

A variety of float glass products with improved optical, mechanical and thermal properties is available (see table).
Some of these products offer good prospects as cover glazing of solar thermal collectors in view of collector performance and efficiency.
A future activity of subtask A, IEA X might be to evaluate these glazing materials on behalf of solar collector engineering.

TABLE: Typical values of some glazing properties

Glass type	Solar transmittance	Flexural strength (mean values)	U-value
standard float glass (4 mm)	82%	50 -80 MPa	6 W/m^2 K
low iron glass (4 mm)	90%		
glass with anti-reflective layer	88%		
tempered glass		200 -300 MPa	
double glass (2x 4 mm)	67%		3 W/m^2 K
low-E glass (double)	50 -60%		1.5 W/m^2 K

Q : There is something missing and that is the advent of very thin glass.

Q : How thick is the compression layer of tempered glass ? In our experience the tempered glass was broken in the high temperature weather in the middle east.

COMMENTS ON ESTIMATING DURABILITY OF PLASTICS FOR GLAZING AND ABSORBER

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1. Introduction

According to the preliminary studies hitherto carried out in the scope of IEA Task X, we can recognize that the estimation of durability or longevity in practical use attracts the attention of participating scientists and engineers on all concerned materials. Plastics and rubbers for the solar system cannot be excluded from this fact. But as such organic materials have their own problems which are negligible in other species of materials as metals and ceramics, they had better be treated separately.

In this paper, the durability tests and the prediction of service life of such polymeric materials are discussed. Owing to the lack of enough information on the materials used as parts of a solar collector, most of the following description have been derived from the results on the durability of plastics and rubbers in general sense.

2. Present State of the Art and Performance

Out of various plastics and rubbers as candidate materials for the glazing(transmitter) or the absorber material of collectors(refer the draft of Subtask A), only a few restricted species are used in commercial collectors of DHW. Polycarbonate(PC) for glazing and high density polyethylene(HDPE) for an absorber are sole examples in Japan, respectively. Rubber, once having been used for an absorber, seems to have been withdrawn from the market.

Such a state of affairs may be mainly caused from the lack of reliability, or sometimes from unreasonable presumption of low reliability on organic materials in general. Therefore it is impressed that the problem of estimating the durability or the longevity is especially important for the outdoor use of organic materials.

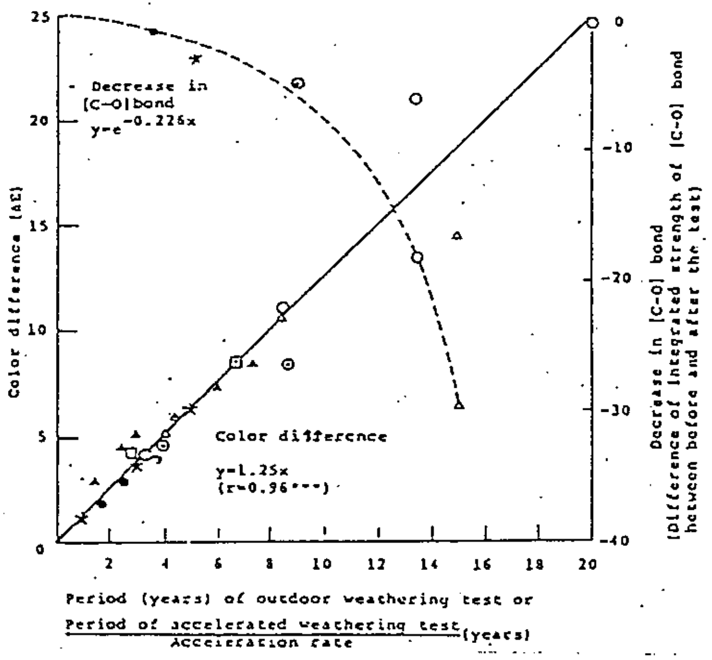
Besides the above two, several polymeric materials like PMMA, PET, PVF, PVDF, FEP, PVC, GFA, GRP, and others are cited as the practical materials for solar applications. PP and EPDM are recognized to be fit for low temperature applications. A polymer film collector developed in BNL looks like an excellent idea, where FEP with a selective coating for an absorber and PVF for a glazing are utilized in the current design. PMMA and PAN are also regarded as the promising materials for the ordinary collectors.

As for the performance, the stagnation temperature is thought to be the most intrinsic for application of plastics. The draft of Subtask A includes very instructive tables and figures on climatic factors and operating conditions. Stagnation temperature was also estimated theoretically.[1]

3. Testing Equipments concerning Environmental Durability

Generally speaking, the artificial irradiation equipments for the accelerated weathering of plastics and rubbers seem to be already settled to a few species. These usages are standardized in various industrial standards, and utilized in many R and D laboratories. Figure 1 shows that various kinds of such standardized artificial weathering devices brought a common deterioration on the coating.[2] To simulate the actual deterioration caused by outdoor exposure, the cooperation with the saline water spray, or the composite cycling, or even the X-ray irradiation[3] was applied.

As criteria for the durability, elongation and transmittance are widely used as the deterministic properties sensitive to the aging. Figure 2 shows a device for tracking the continuous fluctuation of transmittance by scanning.[4] Another kind of equipment to follow continuously the property change by aging is shown in Fig. 3, which can also be used for the accelerated weathering.[5] Recently, the chemiluminescence has been found to be a very sensitive measure of oxidative degradation.[6]



	Condition	Period	Symbol
Sunshine weatherometer test	JIS A 1415 (ASTM D822 equivalent)	8,000hrs	○
Dew cycle weatherometer test	JIS Z 9117	2,000hrs	⊙
Xenon fadeometer test	ASTM G26 (6kw Xenon lamp)	9,000hrs	●
EMMAQUA test	Tested by DSET laboratories, Inc.	150×10^4 langleys	△
QUV test	ASTM G53-77	3,000hrs	▲
High temperature sunshine weatherometer test	Max. temp. of black panel 100°C, other conditions same as JIS A 1415	1,000hrs	▲
Ultraviolet carbon fadeometer test	JIS D 0205	600hrs	□
Composite cycle test	40hrs after dew cycle weatherometer test, SO_2 gas corrosion test(100ppm) for 20hrs(one cycle)	10 cycles	⊡
Outdoor weathering test	JIS A 1410 at Chiba Pref. Japan	5 years	★

Fig. 1. Application of various artificial weathering equipments.[2]

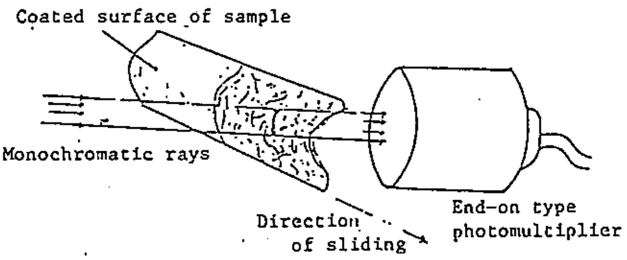


Fig. 2. Device for measuring transmittance continuously along sliding direction.[4]

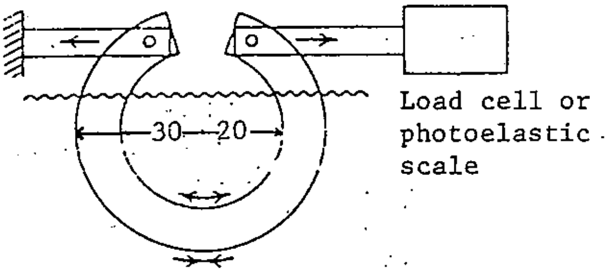


Fig. 3. C-type deterioration tracking device.[5]

4. Prediction of Service Life

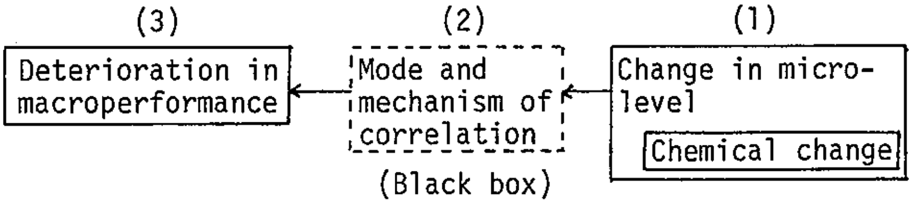
Subtask C aims at the service life prediction. But in fact it cannot be said that a sufficient number of reporting sheets were collected. As we recognize that there is not more precise method than the mathematical one for prediction, the above fact may reflect the present level of the concerned science. It may be worth mentioning that the literature survey for "durability of high polymeric materials" on recent 7 years extracted about 500 literatures from JICST, but the reports regarding prediction of longevity were very scarce. Therefore, the difficulty lies in how to treat the observed aspects of deterioration.

Table 1. Factors affecting the Environmental Durability of FRP

- A. Stresses leading to deterioration from phenomenological viewpoint
  - 1) Deterioration of resin
    - a. Structural destruction and chemical change by UV-rays, heat, water, oxygen and other chemicals in the atmosphere (and their fluctuation)
    - b. Mechanical destruction by heat, water, remnant stress, external force, and dust in the atmosphere (abrasion)
  - 2) Deterioration of glass fibers for reinforcement by water (surface layer), chemicals, and external force
  - 3) Deterioration of interface layer between resin and glass fibers by water, chemicals, heat stress, remnant stress, and external force
- B. Internal factors affecting deterioration
  - 1) Composition of resin
    - kind of unsaturated acid, saturated acid, glycol, and vinyl monomer
  - 2) Secondary materials
    - a. Additives
      - kind and quantity of UV-ray absorber, antioxidant, polymerization catalyst, inhibitor, accelerator, dye, pigment, and filler
    - b. Glass
      - kind of glass and surface treating agent
  - 3) Condition of molding
    - temperature, pressure, time, after-cure temperature and time, and technical skill

When the plastic materials are exposed to outdoor weather, many stresses are considered to act on them deleteriously. Table 1 shows the imaginable factors affecting FRP exposed to environment without estimating the relative importance between them. It is clear that we need to take many factors with their fluctuations into account to discuss the durability. Of course, stresses for glazing composed of a polymer of a single composition are much less. It looks to be, however, impossible or meaningless to treat all the factors mathematically in order to predict the longevity. Moreover, the technology of prediction itself may sometimes be worse than nothing because of excess expectation paid on the remaining longevity.[7] But if we do not agree to alter the philosophy of current technology, the prediction of service life should remain as the principal theme requisite for the usage of the said material.

It is commonly recognized that the change of macro-level property is essentially caused by that of micro-level or mainly by that of chemical nature.



In spite of such unanimous recognition, however, the deterioration of macro-level properties(3) is directly described by the terms of stress, and usually no plunging consideration is paid on the change of micro-level(1). As far as the mathematics for longevity prediction stays in this phenomenological stage, it may be impossible to generalize the results so as to be applicable even to plastics made of the same material but of different recipe. Because the complexed materials will be more widely utilized in future, the study on correlation of macro-level property change(3) to micro-level affairs(1), or correlation of deterioration of the total system to the changes at the unit level is urgently necessitated.

Another problem which obstructs the progress of prediction technique is that the change in property is often not sensitive enough and the fluctuation of data is too big to allow the precise treatment of data by affording physical and chemical meanings to them.

Current ways of service life prediction for plastic materials in environment would be divided into three categories. As the brief review has been presented elsewhere, only a few of notices are described below.

1) From artificial accelerated tests

There would be no widely accepted method in this category except the famous Arrhenius plot[8] and Eyring model[9]. But we can find a few interesting and promising examples of prediction, into which the micro-climatic factors[10], or chemical kinetics[11] were successfully incorporated, though to a limited extent.

2) From the correlation between the artificial accelerated tests and outdoor exposure tests

Figure 1 shows an example of such a treatment. The recommended acceleration ratios, which naturally vary with the species and composition of polymeric materials and also with the equipments, are shown in industrial standards[12]. In Japan the comparative studies on the environmental durability of plastic materials were carried out by the cooperation of many research workers belonging to AIST of MITI, and the equations led to service life prediction were derived[13].

Principally this method allows the introduction of any kinds of acceleration if the deterioration similar to that of the practical outdoor exposure is attainable. Many of engineers engaging in this matter, however, regard this kind of prediction technique as of low confidence for practical purpose, presumably.

3) From the extraporation of outdoor weathering data

A significant success was achieved in incorporating the macroscopic climatic factors into the formula of prediction[14]. The technique of multivariate analysis would be requisite for generalization[15]. But it is a well known fact that the starting season of exposure affects the deterioration in outdoor considerably. When the concerned stresses differ in their intensity, the order of appearance of stresses should be taken into account.

5. Expected Progress in Prediction of Longevity

1) Although it may be unclarified yet whether the deterioration can be treated purely chemically, the service life prediction based on chemical reaction mechanism should afford an interesting direction of progress. In this respect we notice the work carried out at Sandia NL[11].

2) Prediction on composite materials may offer a new field of study. In spite of their complex structure, the prediction has so far been performed according to the same theorem with that for materials of simple composition. Novel idea on interpretation of micro-level affairs is expected[16].

3) The nature of deteriorated surface and the effects of oxygen and water on it are insufficiently known. For instance, we have no good clue at present to explain the difference in aspect of oxidative degradation between HDPE and LDPE.

4) Synergistic and antagonistic effects in every combination of stresses need to be elucidated. In this connection HDPE offers a good problem. Even though HDPE has obviously no photo- or thermo-labile or hydrolyzable group, it rapidly deteriorates in the outer atmosphere. Synergistic effect of light and heat is suspected.

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Q : Are you studying the degradation modes of polyethylene ?

A : The photo-oxidation of PE is very difficult and complicated problem. We are studying the combined effect of light and heat.

Q : What is the influence of moisture ?

A : Not examined yet.

Q : What about the synergistic effect ?

A : Usually the stresses are related to macroperformance by their linear combination, ΣX_i, but it may be necessary to adopt the mutual synergistic relation like XY.

EVALUATION OF MATERIALS BY THE ENERGY YIELD OF AN ACTIVE SYSTEM

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BACKGROUND

The suitability of materials for solar energy applications is often evaluated according to the engineering properties of the materials, such as yield strength, durability, or maximum operating temperature. However, the use of different materials can affect the energy yield of the solar energy system. It is therefore desirable to estimate the impact of new materials on the energy yield of systems. This paper will review the energy impact of materials on active systems for hot water and space heating of buildings. A separate paper in this conference will review impacts for passive systems. The energy impacts of absorbers, heat transfer fluids, and thermal storage materials on active systems are well understood, and will be described only briefly. The study of energy impacts of glazings has just begun, and initial results will be presented below.

ABSORBERS

Selective absorber coatings for flat plate collectors and for evacuated tube collectors are commercially available in many countries. These coatings usually have emissivity (ϵ) near 0.1, and absorptivity (α) greater than 0.9. Little additional energy yield would result from additional reductions in ϵ or increases in α. Altering the absorber coating usually produces changes in both α and ϵ. A person who develops new absorber coatings may need to know if changes in α and ϵ cause a decrease or an increase in energy yield of the collector. The impact of α and ϵ on energy yield depends in a complicated way on the operating conditions, so a single rule does not apply to all cases[1]. As a rough approximation for solar energy systems used in buildings, one should examine the ratio of the changes in α and ϵ, $\Delta\alpha/\Delta\epsilon$. For insolation near 750 W/m^2, glazing temperature near 40 °C, and absorber temperature near 80°C, the energy yield will usually be increased if $\Delta\alpha/\Delta\epsilon$ is > 0.5, and decreased if this ratio is < 0.5.

HEAT TRANSFER FLUIDS

The common heat transfer fluids used in active systems are water, water-glycol solutions, oils, and air. Water and water solutions provide the best heat transfer. A small reduction in collector efficiency occurs when oils are used. Oils provide protection against freezing, corrosion, and boiling, but require more pumping power. Collectors using air as a heat transfer fluid have roughly 20% lower efficiency than collectors using water. Rock bins usually provide the thermal storage in air systems for space heating. The temperature stratification in rock bins is usually much better than the stratification in water tanks used for thermal storage in liquid systems. Therefore, the energy yields of liquid and air systems are often comparable, in spite of the lower collection efficiency of air systems. The use of air requires much larger electrical power for circulation of the fluid than the use of water. The use of air eliminates the problems of freezing, corrosion, and boiling, and reduces the concern with leaks.

In a few commercial systems, the heat transfer occurs by evaporation of a refrigerant in the collector, and condensation of the refrigerant vapor in the thermal storage unit. Boiling heat trasnfer provides a collector efficiency slightly larger than that obtained with water, and a significant reduction in pump size and pumping power. Current research on refrigerant-charged systems proves that these systems can utilize the vapor pressure to return the condensed liquid to the collector, eliminating the need for an electrically powered pump[2,3].

THERMAL STORAGE MATERIALS

In a system using sensible heat storage, the temperature must rise as energy is stored, resulting in decreased collector efficiency. The energy yield of a system should be increased slightly if a phase-change material (PCM) is used for thermal storage because the storage remains at one temperature. However, the major effect of PCM storage is to reduce the volume of storage. Because the thermal conductivity of the PCM is usually low, the material must be encapsulated in containers with large surface/volume ratio to provide adequate heat transfer between the moving fluid and the PCM.

GLAZINGS

At Los Alamos, we are currently studying the energy benefits of various glazings. In general, any assembly of materials into a glazing for a flat plate collector can be represented by three characteristic numbers. It is most convenient to consider the properties of the glazing-absorber combination, although the selective properties of the absorber have little influence if the glazing has large thermal resistance. The glazing (or glazing-absorber combination) can be described by its thermal conductance (U_t), its solar heat gain coefficient at normal incidence (SHG_n), and by the incidence angle modifier (K) of the solar heat gain coefficient. The U_t of the glazing/absorber combination is the top heat loss coefficient for the collector. For many collectors, the total heat loss coefficient (U_L) is approximately $1.6U_t$. In our study we assume that the back and edge insulation of collectors will be increased so as to maintain the ratio $U_L/U_t = 1.6$ when improved glazings are used.

The solar heat gain coefficient represents the fraction of solar radiation incident on the collector that is deposited in the absorber. This is often regarded as the transmittance-absorptance product. However, the solar heat gain coefficient includes the effects of transmission <u>and</u> absorption within the glazing unit. Composite glazings with infrared-reflective layers or other internal materials may absorb some radiation within the glazing, and a portion of the absorbed energy is conducted inward to the absorber. At an angle of incidence, θ, the solar heat gain coefficient is given by:

$$SHG(\theta) = SHG_n \cdot K(\theta),$$

in which

$$K(\theta) = 1 - b_o\{1/\cos(\theta) - 1\}.$$

This form of the incidence angle modifier is used for flat plate collectors with layered glass glazings, and we assume it will also be appropriate for other glazings. The term b_o is a constant for each glazing. The table below shows sample values of U_t, SHG_n, and b_o. We are investigating the total system energy yield as a function of these three parameters.

PROPERTIES OF SAMPLE GLAZINGS

GLAZING ABSORBER	Single glass selective	Double glass flat black	Multi film flat black
U_t ($W/m^2{}^\circ C$)	3.2	3.2	0.6
SHG_n	0.9	0.8	0.5
b_o	0.1	0.17	0.5?

The expression for the instantaneous energy yield of a collector is:

$$\dot{Q} = F_R\{\Sigma\, SHG(\theta)\cdot I(\theta) - U_L(T_i - T_a)\},$$

in which F_R is the heat removal factor (which depends on U_L), I is the incident insolation, T_i is the fluid temperature at inlet, and T_a is the ambient air temperature. The sum is over the three components: beam, diffuse, and ground-reflected radiation. Each component has its corresponding angle of incidence. The average efficiency for the year is the sum of energy yield for all hours of operation divided by the total annual incident insolation. It can be shown that the average annual efficiency (η_{yr})should have the form:

$$\eta_{yr} = F_R\cdot SHG_n\{C_1 - C_2 b_o\} - C_3 U_L ,$$

in which C_1, C_2, and C_3 may depend strongly on climate and weakly on the collector parameters.

The linear behavior of η_{yr}/F_R as a function of SHG_n is shown in Figures 1 and 2 for the city of Albuquerque, which has a warm, sunny climate. In Figures 1 and 2, it can be seen that, at fixed SHG_n, a collector with $U_t = 0.6$ $W/m^2{}^\circ C$ has better energy yield than a collector with $U_t = 3.2$ for all $b_o > 0.4$. It can also be seen that decreasing U_t from 3.2 to 0.6 $W/m^2{}^\circ C$ has the same effect as increasing SHG_n from 0.7 to 0.9. This provides an initial estimate of the benefits of relative changes in U_t and SHG_n. It appears that each reduction of U_t by a factor of two would permit a reduction of SHG_n by approximately 0.1, for equal energy yield. For the climate of Albuquerque, $0.80 < C_1 < 0.95$, $0.3 < C_2 < 0.5$, and C_3 is in the range 0.03-0.05°C m^2/W. We are attempting to find simple rules for C_1, C_2, and C_3 so that the energy impact of almost any glazing can be easily predicted for any climate.

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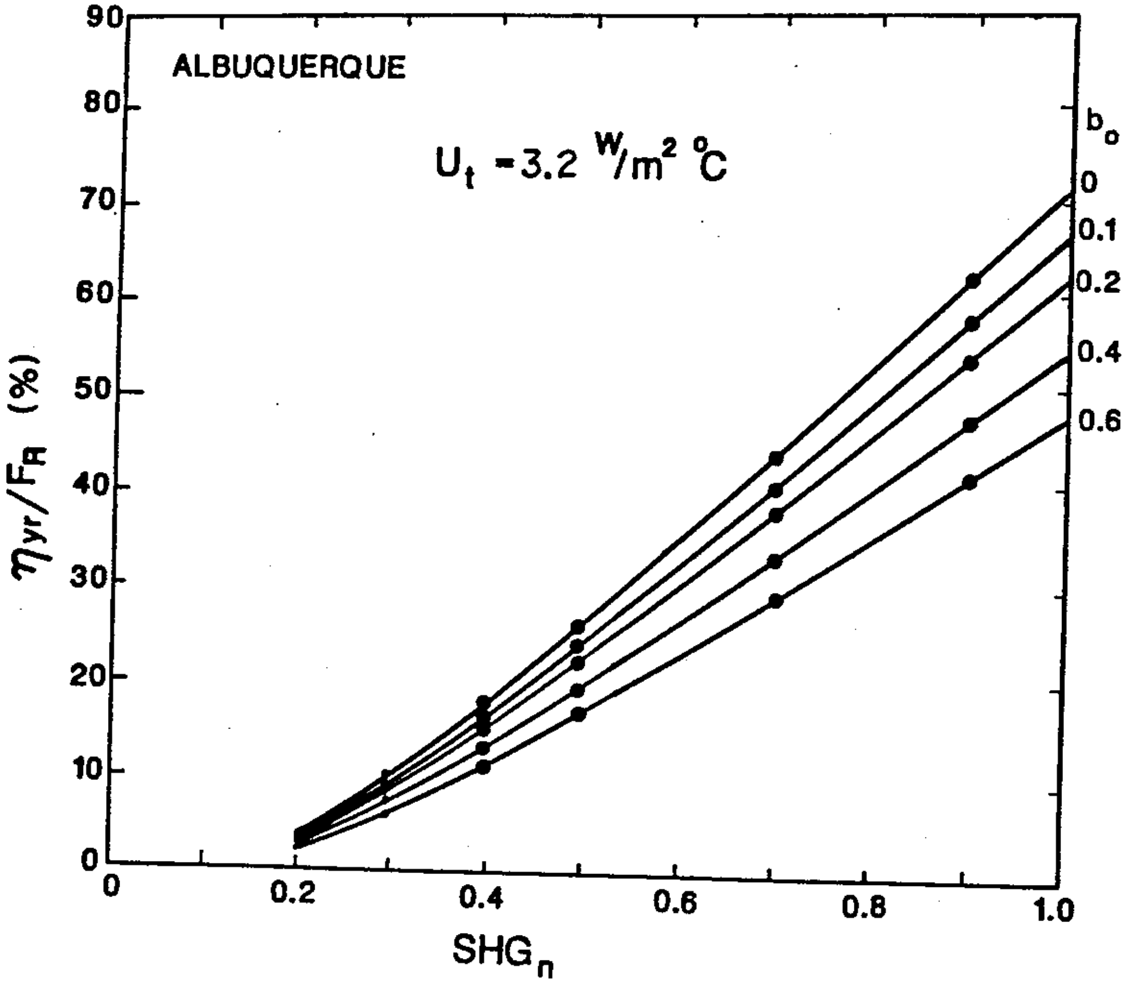

Figure 1. Water-heating collector: average annual efficiency divided by F_R as a function of the solar heat gain coefficient at normal incidence. The inlet temperature is 50°C and U_t is 3.2 $W/m^2 °C$.

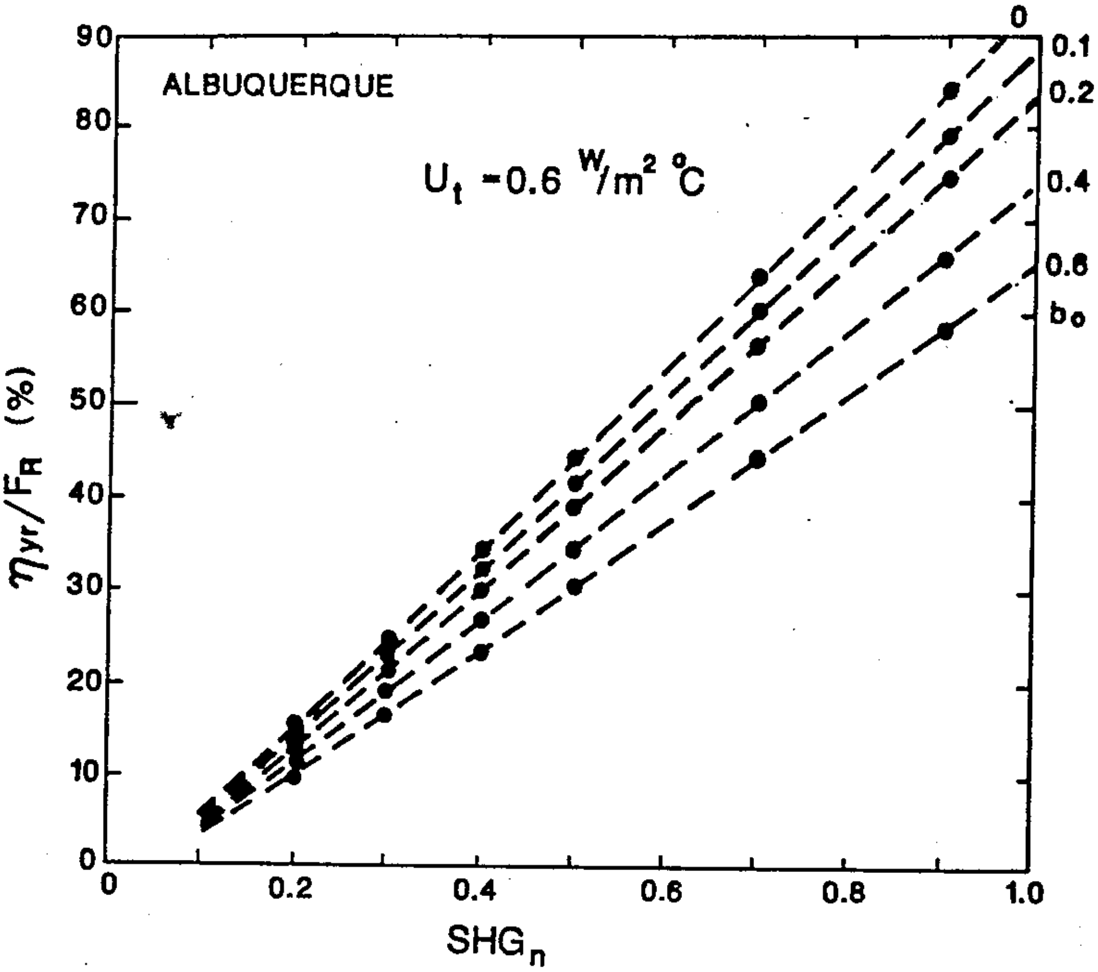

Figure 2. Water-heating collector: average annual efficiency divided by F_R as a function of the solar heat gain coefficient at normal incidence. The inlet temperature is 50°C and U_t is 0.6 $W/m^2 °C$.

Q : What is the presumed inlet temperature ?

Q : Are you looking at honeycomb risings ?

EVALUATION OF MATERIALS FOR PASSIVE SYSTEMS

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BACKGROUND

The suitability of materials for use in architectural passive space heating and cooling systems is usually evaluated according to strength, durability, fire safety, and other properties by which construction materials are judged. However, new materials could increase the energy savings or other performance qualities of passive systems, particularly if those materials permit more of the building to be used for energy gain, storage, or heat rejection. IEA Task X is concerned with heat transfer fluids, absorbers, thermal storage materials, and glazings. Heat transfer fluids are rarely used in passive systems. The energy benefit of selective absorbers has been established for storage wall passive heating systems (Trombe walls and water walls). New glazings and phase change (PCM) thermal storage materials may greatly enhance the performance of passive heating, cooling, and daylighting systems. Therefore, it is appropriate to evaluate materials according to the performance benefits that they may provide. This paper will review the known energy benefits of selective absorbers, glazings, and thermal storage materials.

ABSORBERS

Extensive computer analyses for many climates[1], validated against test cell experiments, predict that the use of selective absorbers with <u>single</u> glazing on masonry Trombe walls and water walls will provide a larger annual fraction of heating from solar energy than would be obtained with a flat black absorber and double glass glazing. For a building that obtains approximately half of its heating from a Trombe wall or water wall, the solar fraction with single glazing and selective absorber is greater than the solar fraction with double glazing and flat black absorber by a factor between 1.2 and 1.6. Rolls of thin metallic foil with a selective surface on one side and an adhesive on the other side are commercially available in the United States. This material is pressed onto the irradiated side of a water wall or Trombe wall. Water tanks usually have smooth surfaces, but a masonry wall must be prepared with a very smooth plaster surface, so that air gaps are not left between the absorber foil and the masonry wall.

THERMAL STORAGE MATERIALS

Moisture dynamics. Recently, it has been discovered that architectural surfaces can adsorb and desorb moisture. Passive cooling with night ventilation permits moisture to enter the building where it is stored in the surfaces and later released during daytime dehumidification, causing an increase of air conditioning loads in humid climates. It may be possible to change this apparent problem into a benefit by utilizing the natural desiccant properties of building materials to generate cooling in a two-stage desiccant cycle. A study of the moisture dynamics of materials is under way at the Florida Solar Energy Center.

Trombe walls with PCM. The optimal thickness of a masonry Trombe wall is approximately 300mm. A Trombe wall made of PCM can be much thinner. The annual fraction of heating supplied by solar energy will be only slightly larger than that of a masonry wall[3]. Commercial products containing between 2 and 15 kg of PCM are available in the U.S.

Direct gain with PCM. Direct gain and sunspace passive heating systems utilize masonry walls or floors of buildings for thermal storage. Analysis has shown that the important property of these architectural surfaces for thermal storage is the ability to gain and lose heat on a 24-hour cycle. The 24-hour (diurnal) heat capacity of different thicknesses of various materials has been calculated[2]. For high density masonry with the heat flux into and out of the same surface, the optimal thickness of material is about 100mm. For a large solar heating fraction, the exposed area of masonry should be at least six times the area of the direct gain glazing. These requirements for thickness and area present no difficulty if the building and its internal partition walls are constructed of masonry. However, the interior wall and ceiling surfaces of most small buildings in the U.S. are constructed of gypsum wallboard, 13mm thick, nailed to wooden frames. This amount of gypsum provides inadquate thermal storage for passive heating or cooling. The addition of masonry to a new frame building is usually expensive, and it is difficult to add masonry when an older building is remodeled for passive solar energy. Therefore, it is attractive to consider PCM thermal storage for both new and older buildings.

Although current commercial PCM products work well as Trombe walls, the surface area/volume ratio is usually too small to provide adequate heat transfer if these products are used for thermal storage in direct gain systems. Furthermore, these products are expensive because they are small modules that must contain corrosive chemicals. Recent experiments indicate that the gypsum wallboard can be impregnated with waxes, fatty acids[4], or solid-state PCM material. The impregnated wallboard can provide up to $400kJ/m^2$ of latent heat capacity. The wallboard would provide the building with sufficient thermal storage for a large solar heating fraction with direct gain or sunspace systems. Calculations indicate that the natural heat transfer coefficient at the wall surface ($\sim 5W/m^2{}^\circ C$) will provide adequate heat transfer for passive heating, for heating with active collectors that deliver warm air directly to the interior of the building, and for night-ventilative cooling. PCM wallboard would not necessarily enable a larger solar heating fraction, but it could enable almost any small building to be a solar building. Calculations indicate that PCM wallboard may enable night-ventilative cooling in climates where the night minimum temperature is 22°C, because latent heat storage does not require a large temperature change. Sensible thermal storage would require a night temperature below 17°C for storage of ventilative cooling.

GLAZINGS

Electrochromic glazings. Because daylighting from vertical windows is adequate only at distances less than 5m from the window, large windows are not beneficial for daylighting in large commercial buildings. Windows may, in fact, increase the cooling load more than the lighting load that they replace. However, for the top floor of a building, daylighting from roof-apertures can provide uniform illumination. With ordinary glazings, the aperture must be sized to provide full daylighting only on the brightest days. If the aperture were large enough to provide adequate lighting on dim days, the excessive solar gain on bright days would make the cooling load larger. A complete study on the benefits of electrochromic glazings has not been published, but one theoretical analysis of an office building predicted the following results for tilted roof apertures. Dimmable glazings:

- reduced the cooling load by 40-50%, independent of climate; and
- reduced the chiller capacity by 40-50%.

Another unpublished study indicated that dimmable glazings might eliminate the summer cooling load induced by passive heating systems.

Thermal glazings. Glazings with reduced heat transfer coefficient (U-value) offer an opportunity for increased energy saving with passive heating systems. As with glazings for active collectors (see our other paper, this conference), the energy benefits of new glazings for passive systems depend on a tradeoff of solar gain and U-value. Los Alamos is presently conducting a study of the energy impacts of glazings in passive systems. At present, we can show sample results of the winter energy impacts of different glazings when used in windows. For windows, it is assumed that all solar energy transmitted by the glazing is useful for heating. During the winter period of November through March in the U.S., the average angle of incidence is approximately 55° for beam, diffuse, and ground-reflected radiation; therefore, the value of the solar heat gain coefficient at this average angle was used for each glazing. The seasonal efficiency of a glazing is the total energy fluence through the glazing, divided by the total incident radiation. Figures 1 and 2 show the seasonal efficiency for vertical windows of several actual and hypothetical glazings. Efficiency is plotted as a function of the average indoor-outdoor temperature difference ($\overline{\Delta T}$), divided by the average incident solar flux ($\bar{H}$). Arrows on the horizontal axis indicate values of $\overline{\Delta T}/\bar{H}$ for north- and south-facing orientations in several U.S. locations.

The vertical intercept of each line is the solar heat gain coefficient, and the slope is the U-value of the glazing. The line for an insulated opaque wall is shown for comparison. The vertical intercept of this line is zero, and the efficiency is always negative, because the wall cannot gain solar energy. An extra vertical axis for each location and orientation represents the efficiency multiplied by the total incident radiant energy. These axes enable reading of the seasonal energy fluence directly from the graphs. The glazing layers are defined in the table below.

The figures show that double glass has better energy benefits than most of the advanced glazings for a south-facing window in a warm, sunny climate (Albuquerque). However, the advanced glazings are superior to double glass in cold, cloudy climates. For north-facing windows, some of the composite glazings of Fig. 2 are superior to an insulated wall! We are attempting to derive a method for accurate comparison of the energy benefits of glazings when used in passive heating systems with thermal storage. Figures 1 and 2, which apply only to windows, are presented to illustrate the type of simple comparison that we are attempting to develop.

DEFINITION OF LABELS FOR GLAZING LAYERS AND GLAZING UNITS†

g	3mm inch float glass.
l	3mm inch low-iron glass.
p	0.10mm polyester;
a	0.10mm polyester with antireflective surfaces.
h	A low emittance coating, emittance = 0.15.
A	Antireflective surface, normal reflectance 1%.
20LowP	Aerogel 20 mm thick at reduced pressure near 100 Torr.
HITS	Proprietary unit with two coated polymer inner panes.
V10	Vacuum that provides U = 0.56 W/m^2°C insulation when used in combination with low emittance surfaces.
R18	An opaque wall with U = 0.31 W/m^2°C insulating value.

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† Airspace between layers is 13mm except for vacuum, aerogel, and HITS.

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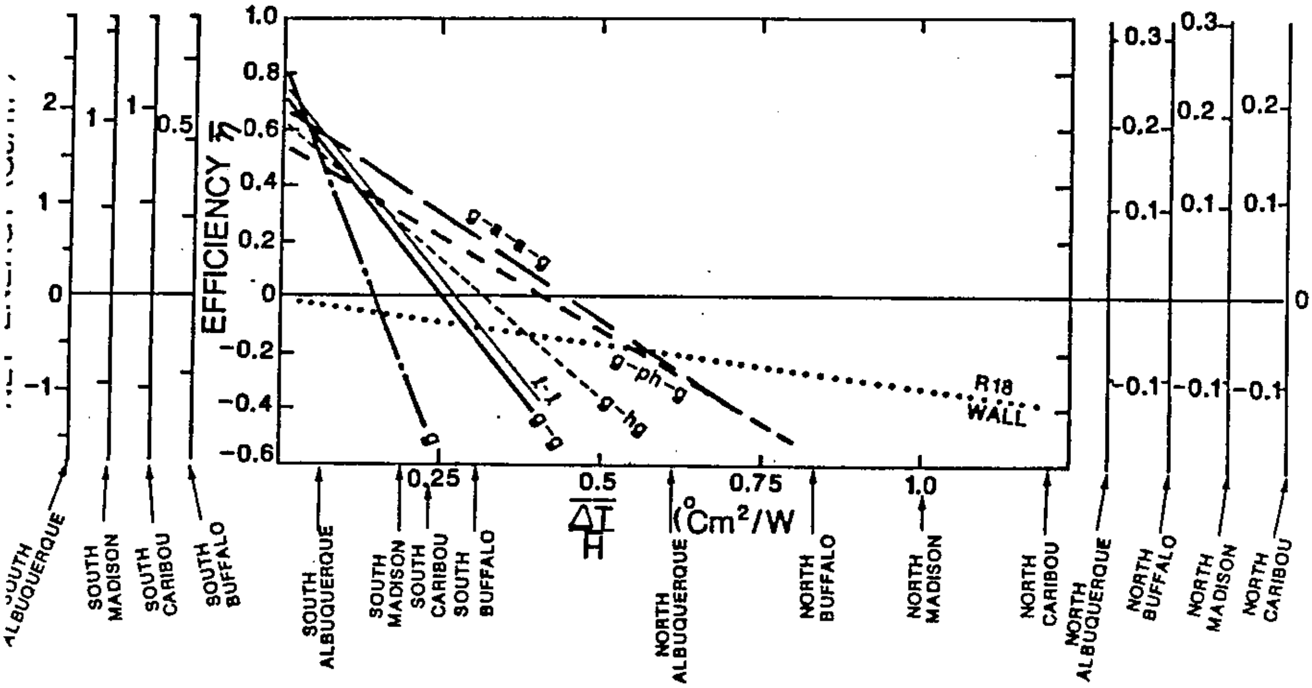

Figure 1. Window efficiency and net energy fluence for the November-March period, as a function of the climate parameter, $\overline{\Delta T}/\overline{H}$.

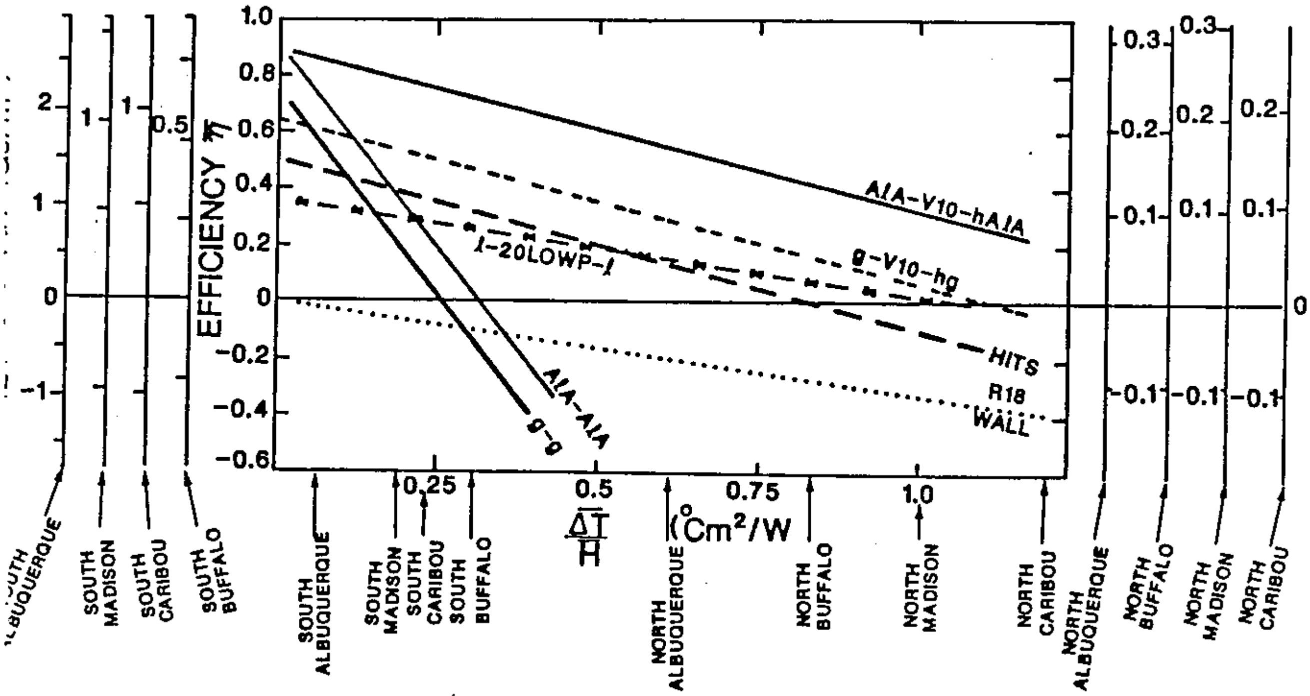

Figure 2. Plot similar to Figure 1, but for different glazings.

Q : Windows we know have to get collective properties. Is there a standard to get collective properties ?

Performance of PCM and chemical heat storage materials

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In this paper, latent heat storage, chemical heat storage and desiccant air conditioning for solar heating and cooling (SHW) and for domestic hot water supply (DHW) are described briefly.

1. Latent heat storage materials (Phase change materials, PCM)

Latent heat storage has advantages that compact heat storage unit is available because of higher heat storage density compared with sensitive heat storage, and that it can store heat at constant temperature. Although solid-solid phase change materials such as pentaerythritol have been studied, most of studies have been done on solid-liquid phase changes. Especially, in the temperature level of SHW and DHW, most of efforts have been concentrated to development of parraffins (include polyethylene) and salt hydrates. Therefore, characteristics and problems of these two kinds of materials are discussed hereafter.

1a. Paraffins (include polyethylene)

Paraffins (include polyethylene) have heat of fusion in the range 180 ∿ 210 J/g, 125 ∿ 200 J/cm^3. Melting points of paraffins vary 6 to 80°C with number of carbon atoms and these of polyethylenes vary 80 to 140°C with degree of polymerization.

Paraffins have the following advantages compared with salt hydrates: (1) No problems of supercooling and phase separation. (2) No corrosivity to the vessel. (3) Direct contact heat exchange with water which is the most general heat transfer fluid is capable.

However, they have the following disadvantages compared with salt hydrates: (1) More expensive. (2) Smaller heat of fusion. (3) Lower thermal conductivity. (4) Combustible.

Because of low thermal conductivity, large heat exchange area is needed. For this reason and to gain high heat storage capacity per volume, it has been proposed that one fills a large number of small pellets of polyethylene rather densely in heat storage vessel, then flows heat transfer fluid through the space of the pellets and make direct contact heat exchange, if polyethylene are used as heat storage material. However, if normal polyethylene is used, small pellets become large clods by adhesion in melting-freezing cycles. Consequently, the performance of the heat storage unit deteriorates because of aggravation of heat exchange.

In order to improve them, form stabilized polyethylene, of which the surface region remains in solid state even at the condition that the inner region melts, have been developed. γ-ray crosslinking, and metallic or powder coating have been investigated for stabilizing the form, and good results has been obtained.

1b. Salt hydrates

Salt hydrates have heat of fusion in the range 150 ∿ 280 J/g, 250 ∿ 400 J/cm^3, so the heat storage capacity per volume is almost twice of that of paraffins. However, salt hydrates, which have desirable melting point for SHC and DHW, and which are inexpensive and available in large quantities, are rather a few. Glauber's salt ($Na_2SO_4 \cdot 10H_2O$), calcium chloride hexahydrate ($CaCl_2 \cdot 6H_2O$), sodium acetate trihydrate ($NaCH_3COO \cdot 3H_2O$) and etc. have been investigated powerfully. The problems that these PCM include are mainly supercooling and phase separation.

Supercooling means the phenomenon that the melt doesn't freeze even cooled under melting (freezing) point. It is not unusual that salt hydrate indicates 10°C of supercooling. Especially, under the condition that small amount of pure hydrate is cooled without moving, 25°C of supercooling for $CaCl_2 \cdot 6H_2O$ and 40°C of it for $Na_2S_2O_3 \cdot 5H_2O$ are observed.

As the methods to avoid supercooling, it has been investigated that the seed crystal of heat storage material itself were added, and that cold finger, where the crystal remained at all times by cooling, were set up in the heat storage vessel. However, these methods make a heat storage unit more complicated. On the other hand, nucleating agents which acted as seed crystal by mixed with heat storage material have been investigated. Borax ($Na_2B_4O_7 \cdot 10H_2O$) for $Na_2SO_4 \cdot 10H_2O$ and $SrCl_2 \cdot 6H_2O$ for $CaCl_2 \cdot 6H_2O$ are the examples of the nucleating agents. The nucleating effects of these materials could be explained by the reason that the crystal structures of these materials are simular to that of the heat storage materials. However, nucleating agents of which effect could not be explaind by simularity of crystal structure were found. Examples of these agents are $Sr(OH)_2$ and $Ba(OH)_2$ for $CaCl_2 \cdot 6H_2O$. The studies to understand the mechanism of nucleation and the developments of new nucleating agents are carried out.

Phase separation produces deterioration of heat storage capacity in melting-freezing cycle. It is caused by that most of salt hydrates have a peritectic point and melt incongruently.

For the example, the case of Glauber's salt would be explained. The melting point of Glauber's salt (32.4°C) is peritectic point in truth. At this temperature, $Na_2SO_4 \cdot 10H_2O$ decomposes to saturated solution of Na_2SO_4 and anhydrous Na_2SO_4 crystal. The anhydrous Na_2SO_4 crystal does not dissolve even if the temperature are raised. (Solubility of Na_2SO_4 decreases with increase of the temperature.) Subsequently, when this mixture is cooled, $Na_2SO_4 \cdot 10H_2O$ crystal grows around anhydrous Na_2SO_4. Consequently, for the anhydrous crystal changes to $Na_2SO_4 \cdot 10H_2O$, water has to diffuse through $Na_2SO_4 \cdot 10H_2O$ crystal, so, it rate is too slow, then actually it can't proceed.

In order to avoid the problem, the use of the composition added water of which amount anhydrous Na_2SO_4 dissolved completely was proposed. However even using this composition, if heat cycles are undergone without stirring, $Na_2SO_4 \cdot 10H_2O$ crystals produced in freezing cycle settle at the bottom of the vessel (or capsule), and in subsequent melting cycle, anhydrous Na_2SO_4 crystals precipitate at the bottom, the intermediate layer becomes saturated solution of Na_2SO_4, and the top layer becomes dilute soultion of it, by the difference of density. With increase of the number of heat cycle, the amount of anhydrous Na_2SO_4 crystal increases, so that deterioration proceeds. Following methods have been investigated to avoid this deterioration.
(1) Rolling heat storage vessel is used for stirring. (2) By adding a thickener such as attapulgite clay, viscosity of the melt is increased, so that PCM are protected from phase separation. etc.

However, these methods seems still insufficient to protect salt hydrates from deterioration.

2. Chemical heat storage

Chemical heat storage is a heat storage method that heat of reversible chemical reaction is used for heat storage, and has following advantages.
(1) Long period storage without insulation. (2) High storage density.
(3) Possibility to use as heat pump.

In the temperature range for SHC and DHW, candidate reactions are hydration-dehydration reactions, alcoholation-dealcoholation reactions of salts as described $S \cdot nH_2O \rightleftarrows S \cdot (n-m)H_2O + mH_2O$, $S \cdot nC_2H_5OH \rightleftarrows S \cdot (n-m)C_2H_5OH + mC_2H_5OH$ (S: salt) respectively, and etc..

For a example, $Na_2S \cdot 5H_2O \rightleftarrows Na_2S + 5H_2O$ reaction has about 310 kJ/mol of heat of hydration.

But most of studies on this storage method have been carried out on beaker scale, and reaction is complicated because it needs heat and mass transfers. As candidate reactions are solid-gas reactions, reaction rate control becomes important factor.

It seems that basic researches especially on reaction rate sould be continued for this method.

3. Desiccant air conditioning

This is an air conditioning method that uses the adsorption of water on adsorbent, and has following advantages: (1) Relatively low temperature level of heat can be used compared with other air conditioning method. (2) No corrosivity. etc..

The mechanism of the air conditioning are described briefly. In cooling operation, the air passed through the adsorbent and heated by heat of adsorption is cooled by ambient air or cooling water. Then water is sprayed to this dry air, and by evaporation heat of the water the temperature of the air is dropped. In heating operation, the hot dry air passed through the adsorbent and heated by heat of adsorption is humidified and is supplied to load. The adsorbent is regenerated by heating with batch operation.

The adsorbents generally used for this method are silica gel and zeolite. Silica gel has larger adsorption capacity than zeolite has. However, adsorption capacity of silica gel varies significantly with temperature change. Therefore, in air conditioning operation, according as the temperature of silica gel rises by produced heat of adsorption, its adsorption capacity may decrease, and so the performance of the system may varies. Meanwhile zeolite has fairly constant adsorption capacity in usually operated temperature range.

Bench scale experimental equipment which had two adsorption towers in which about 150 kg of synthetic zeolite was filled each for continuous operation (but electric heater were used for regeneration) were constracted in our laboratory. Cooling, heating and dehumidification experiments have been carried out. The load was 6m x 5m x $4m^H$ of the laboratory room. In cooling operation, at 33 ∿ 35°C of outdoor temperature, 3 hours continuous cooling with keeping the load room temperature at 25 ∿ 26°C were established by one tower. The thermal efficiencies of that case were ∿ 0.22 for cooling only, and ∿ 0.68 for including the heat of hot water obtained from heat-exchanged cooling water etc. for hot water supply. However, about 4m x 3m x $2.5m^H$ of space were needed for the equipment, since large amount of zeolite had to be used etc..

Therefore, it is desirable that the adsorbents which have large and temperature independent adsorption capacity below regeneration temperature are developed.

DURABILITY ASSESSMENT AND MICROSTRUCTURAL CHARACTERISATION OF SELECTIVE SOLAR ABSORBER SURFACES

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1. INTRODUCTION

Durable and reliable solar energy systems and components are highly important for a technology which for economic acceptance must necessarily function effectively for many service years. Solar collector thermal performance is greatly enhanced through the use of selective solar absorber surfaces which minimise radiative heat losses from the receiver surface and hence, from the collector to its environment. The solar absorber is subject to exposure to solar radiation and prolonged thermal cycling, often in the presence of humidity and/or atmospheric contaminants. Selective absorber surfaces are often a complex system of a thin-film coating on a reflective, metallic substrate. The thin-film may be particulate, porous and inhomogeneous. The absorber coating system is seldom a single phase material and degradation may occur in the coating, substrate or both. Possible degradation mechanisms are many and are more fully described elsewhere [1]. A principal aim of present studies is to quantify absorber surface degradation through the identification of failure modes in order to predict useful in-service lifetimes with respect to the performance criteria established for a particular application [2]. To assist in meeting this aim a combination of natural outdoor exposure and laboratory accelerated ageing tests are being carried out [3]. The work presents difficult individual problems that we are seeking to solve, i.e. the design of appropriate accelerated ageing tests that effectively simulate in-service conditions; the measurement of induced degradation and the identification of failure mechanisms; the calculation of degradation rates and prediction of service lifetime. Beyond these problems it would be beneficial to correlate durability results with the surface deposition process parameters with the aim of improving surface performance and/or reliability.

Selective absorber surfaces are often categorised in terms of the physical processes responsible for their optical properties, e.g. tandem structures, interference multilayers, graded index films, intrinsic absorbers etc. Since in many practical cases more than one physical process is responsible for absorptance, in durability examinations we consider it is more appropriate to classify the absorber system in terms of its composition, microstructure and substrate. We have adopted the categorisation first proposed by Smith [4] which employs composition, microstructure and homogeneity as the key identifiers of surface type.

Many selective absorbers have solar absorptance, α , > 0.94. These high values are not normally realisable unless the surface microstructure has roughness dimensions of the order of incident solar radiation wavelengths. Such a coating then contains many surface voids and absorption is thereby enhanced through multiple cavity reflection events, resonant scattering and a lowering of the effective air-film refractive index and hence a reduction of the Fresnel reflection loss [5,6].

Thermal emittance, ε , is a measure of the radiative loss from the coating and is dependent on film thickness and hence surface volume, substrate infrared reflectance and the infrared absorptance properties of the surface film.

In this paper we examine results obtained for a number of commercially available selective absorbers which have been subjected either to exposure to elevated temperatures in air or to prolonged thermal cycling in the presence of moisture under the controlled conditions of a climatic cabinet. In addition we present our first results which quantify the scale of microroughness in the surface film. It is shown that close examination of the uv/vis/nir spectral reflectance curve and the measurement of surface roughness can be used as sensitive indicators of surface change in durability testing.

2. EXPERIMENTAL

2.1 Accelerated Ageing Tests

Four commercially available selective solar absorber coatings were chosen for the laboratory accelerated ageing tests.

Sample A : Cusorb - black nickel on nickel on copper [7].
Sample B : Maxorb - black nickel on nickel foil [7].
Sample C : Skysorb - oxidised stainless steel [7].
Sample D : Sunstrip - Ni in Al_2O_3 on Al [8].

All samples are prepared using chemical conversion based deposition processes.

A number of representative samples for each surface type were subjected to one of two principal tests :

(a) Furnace exposure in air at atmospheric pressure for each combination of 1h, 10h and 100h at temperatures of 150°C, 200°C and 300°C.

(b) Thermal cycling in the presence of controlled humidity for 10 cycles using the cycle

6h at 30°C, 95% R.H.
6h at 60°C, 95% R.H.
with a transition time of 6h.

The individual cycle time was 18h. This is a derivative test of US MIL STD 810D.

The optical properties, α and ε, and the surface microstructure of control samples were first measured. For the test samples spectral reflectance curves were recorded before and after testing and in some cases samples were re-examined by scanning electron microscopy (SEM). The spectral reflectance curves were measured using a Beckman 5240 uv/vis/nir integrating sphere spectrophotometer and values of α were then calculated using a 20 selected ordinate numerical integration for air mass 2 [9]. Values of total near-normal thermal emittance, ε, were measured before and after testing, the latter not in all cases, using an in-house developed pyroelectric radiometer [10]. Surface microstructures were examined by secondary electron microscopy using a Jeol JSM840 scanning electron microscope.

2.2 Stereo-pair electron microscopy

The microstructural dimensions of two types of surface (a) a cobalt metal film produced in-house by cathodic deposition [6] and (b) a commercially available black chrome on copper surface [11] were examined by stereo-pair secondary electron microscopy. These images were subsequently digitised and calculations performed to produce values for a r.m.s. surface roughness and an autocorrelation length, a spacing parameter, using the methods described in previous studies [12,13]. Values of spectral reflectance were then calculated and compared with experimentally measured curves [14].

3. RESULTS

3.1 Accelerated ageing in air

Measurements of α and ε of tested surfaces revealed only small changes in surface optical properties following testing even under the severest exposure of 100h at 300°C. A summary of the most significant changes measured is shown in Table 1.

Sample	Control α ±0.02	Control ε ±0.03	Exposure Temp	$\Delta\alpha$	$\Delta\varepsilon$
Cusorb	0.94	0.11	200°C	-0.02	+0.07
			300°C	-0.03	+0.07
Maxorb	0.94	0.10	200°C	0.00	0.00
			300°C	0.00	+0.02
Skysorb	0.80	0.16	200°C	-0.01	+0.02
			300°C	-0.02	-0.07
Sunstrip	0.90	0.09	200°C	-0.01	+0.02
			300°C	-0.01	+0.01

Table 1. Measured changes in surface optical properties of four selective solar absorber surfaces subjected to elevated temperatures in air for 100h exposure time.

The small changes in the integrated values of α were surprising since marked colour changes could clearly be seen to have taken place in Samples A,C and D. The integrated values of α and ε by themselves provided little information on surface degradation or the physical or chemical nature of the induced change. The uv/vis/nir spectral reflectance curves for the four samples are shown in Figs.1-4 in each case for the control, 100h at 200°C and 100h at 300°C. In each case reflectance shifts are observed and consistent trends evident of changes in effective film thickness are present. The interference shifts in Cusorb and Skysorb are consistent with an increase in film thickness whilst the shifts in Sunstrip and Maxorb indicate an effective decrease in active film thickness. Comparison of Table 1 and Figs.1-4 underlines the importance of close examination of spectral reflectance data in durability testing and casts doubt on methods which simply adopt a policy of comparing optical properties before and after testing as the diagnostic variables. The complete results of this ageing study are presented elsewhere [15].

3.2 Accelerated ageing under controlled conditions of temperature and moisture

All surfaces subjected to the thermal cycling/humidity test showed no significant change in either the integrated values of α and ε or the respective uv/vis/nir spectral reflectance curves. Some evidence of microstructural changes at localised sites in the Cusorb sample were observed in the SEM studies. Full results of these tests are presented elsewhere [16].

3.3 Stereo-pair electron microscopy

Fig.5 presents a stereo-pair image of a black chrome surface. Fig. 6 shows the derived linescan profile for a representative portion of the surface. The r.m.s. surface roughness was found to be 0.09 μm with a correlation length of 0.12 μm. For the tested cobalt surface these values were found to be 0.17 μm and 0.22 μm respectively. Calculated spectral reflectance curves were found to exhibit similar trends to measured profiles. The agreement was of the order of 10-20%. Improved agreement, especially at shorter wavelengths, could be obtained through the use of effective medium theories.

4. DISCUSSION

Accelerated ageing in air at elevated temperatures induced measurable changes in the uv/vis/nir spectral reflectance curves for all four samples tested. The integrated solar absorptance values were insensitive to small changes which could readily be observed by examination of the uv/vis/nir spectral reflectance curves. These observable changes would permit changes in effective film thickness to be derived if surface optical constants are known. Accelerated ageing under controlled conditions of temperature and relative humidity induced no measurable changes in the four samples tested. Current investigations are in hand to continue this testing whilst exploring different combinations of temperature, relative humidity, cycle duration and number of cycles. Stereo-pair electron microscopy has been found to provide quantitative information on surface microroughness and particle spacing using a mathematical method that is not over complex. Predicited surface reflectances using these numerical parameters have been found to be in broad agreement with experimentally measured data.

We are currently carrying out a set of experiments of furnace heating in air for more prolonged exposures on a wider number of surfaces. Surface microroughness parameters are being determined before and after testing. From particle size changes and measured changes in film thickness we shall attempt to propose degradation mechanisms and calculate degradation rates using published mathematical techniques [17]. These results will be presented shortly [18]. The combination of stereo-pair electron microscopy and reflectance spectrophotometry may permit a more quantitative assessment of selective surface degradation than has presently been achieved.

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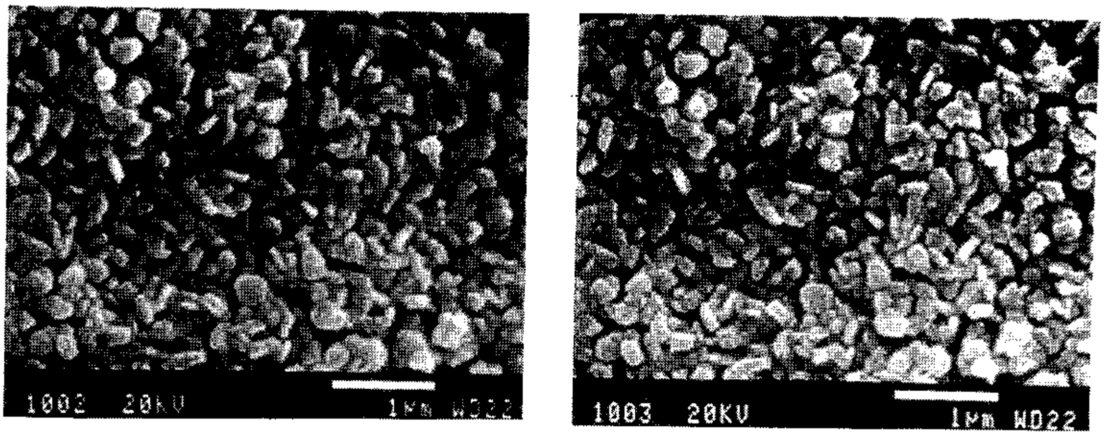

Figure 5. Stereo-pair secondary electron micrograph of MTI Solar black chrome selective absorber surface.

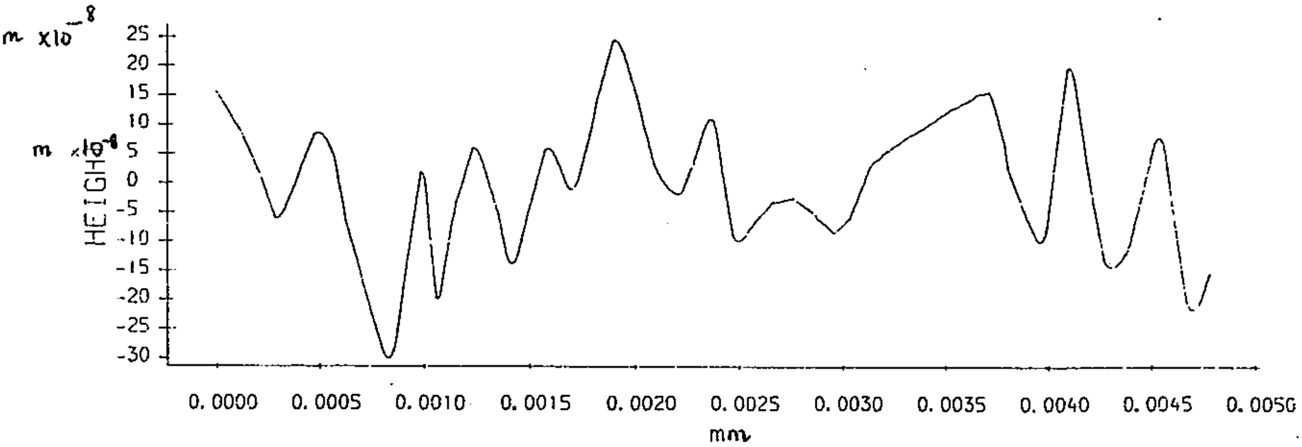

Figure 6. Calculated line scan profile obtained from stereo-pair electron microscopy for the MTI Solar black chrome surface.

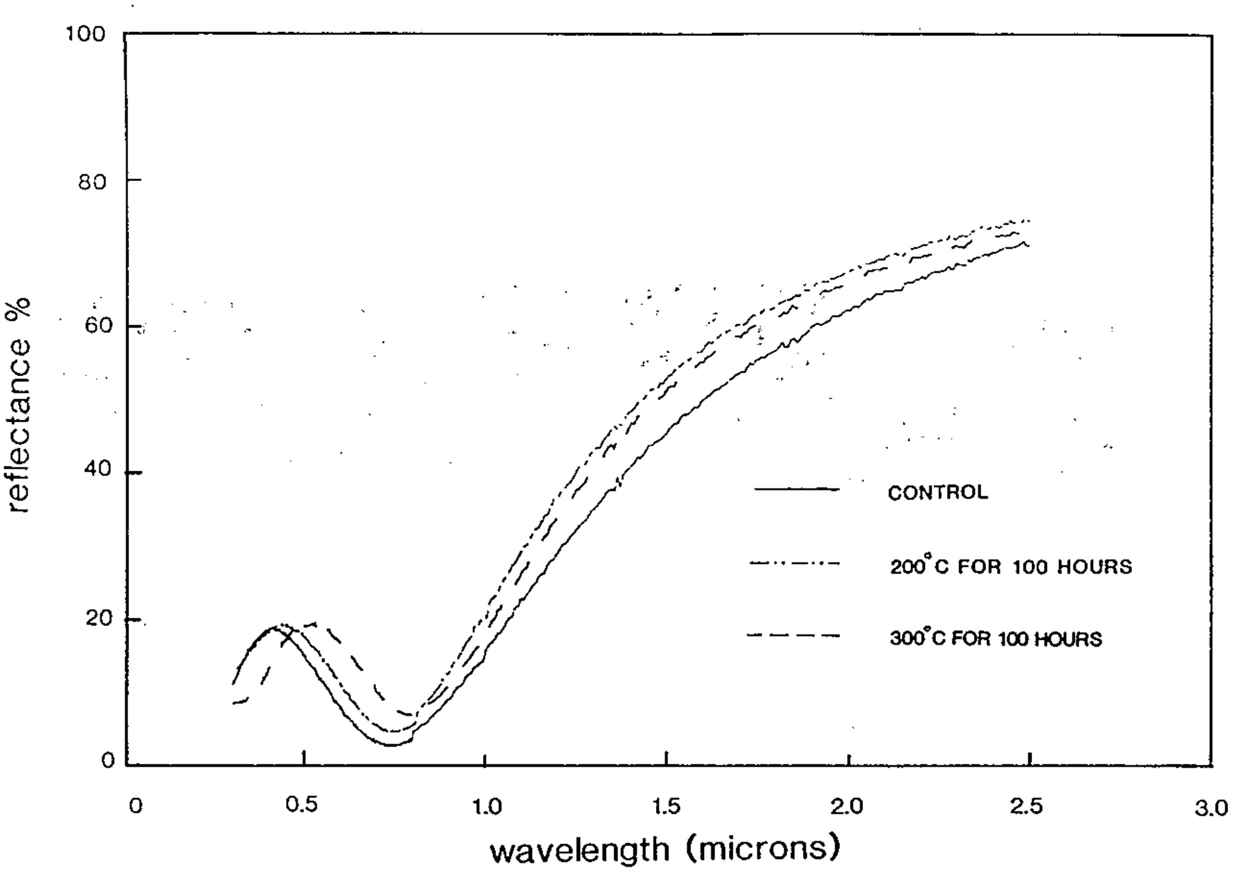

Figure 3. Spectral reflectance of Skysorb samples following constant temperature exposure in air.

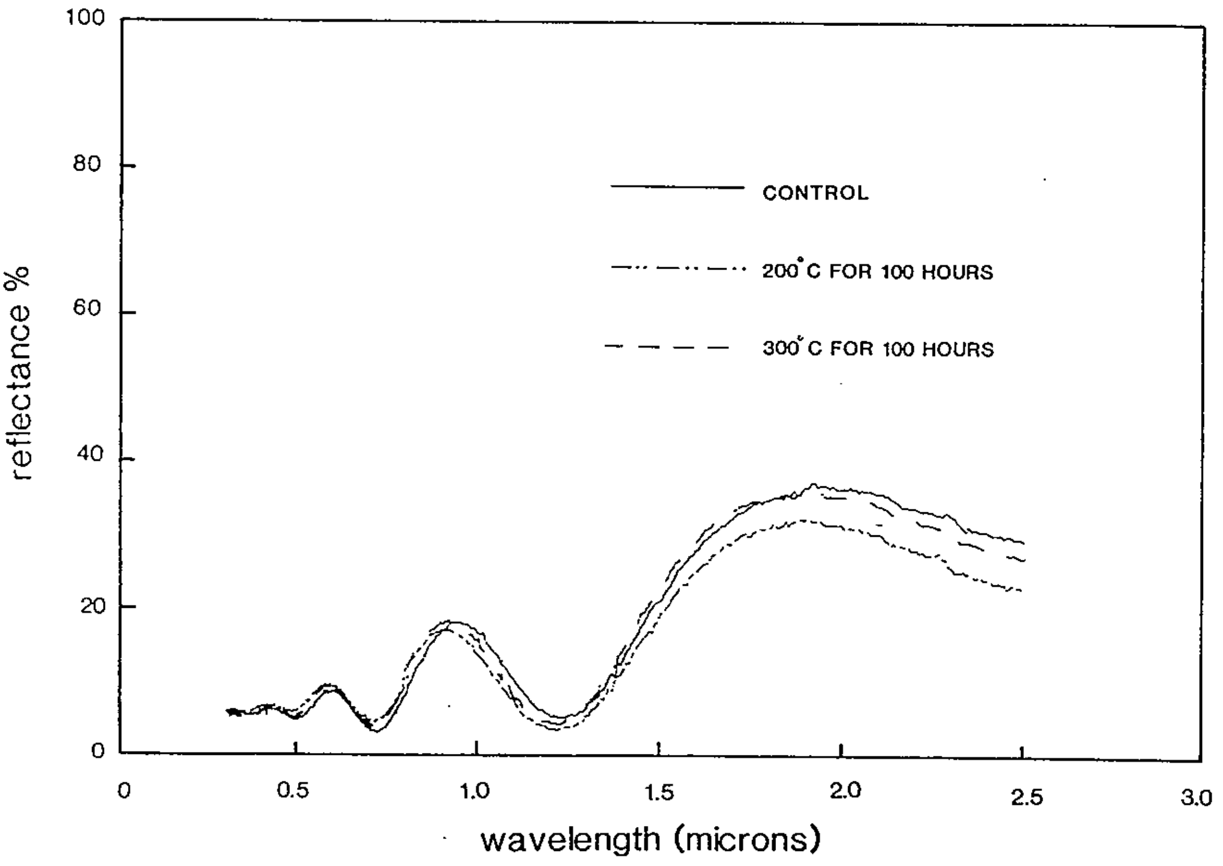

Figure 4. Spectral reflectance of Sunstrip samples following constant temperature exposure in air.

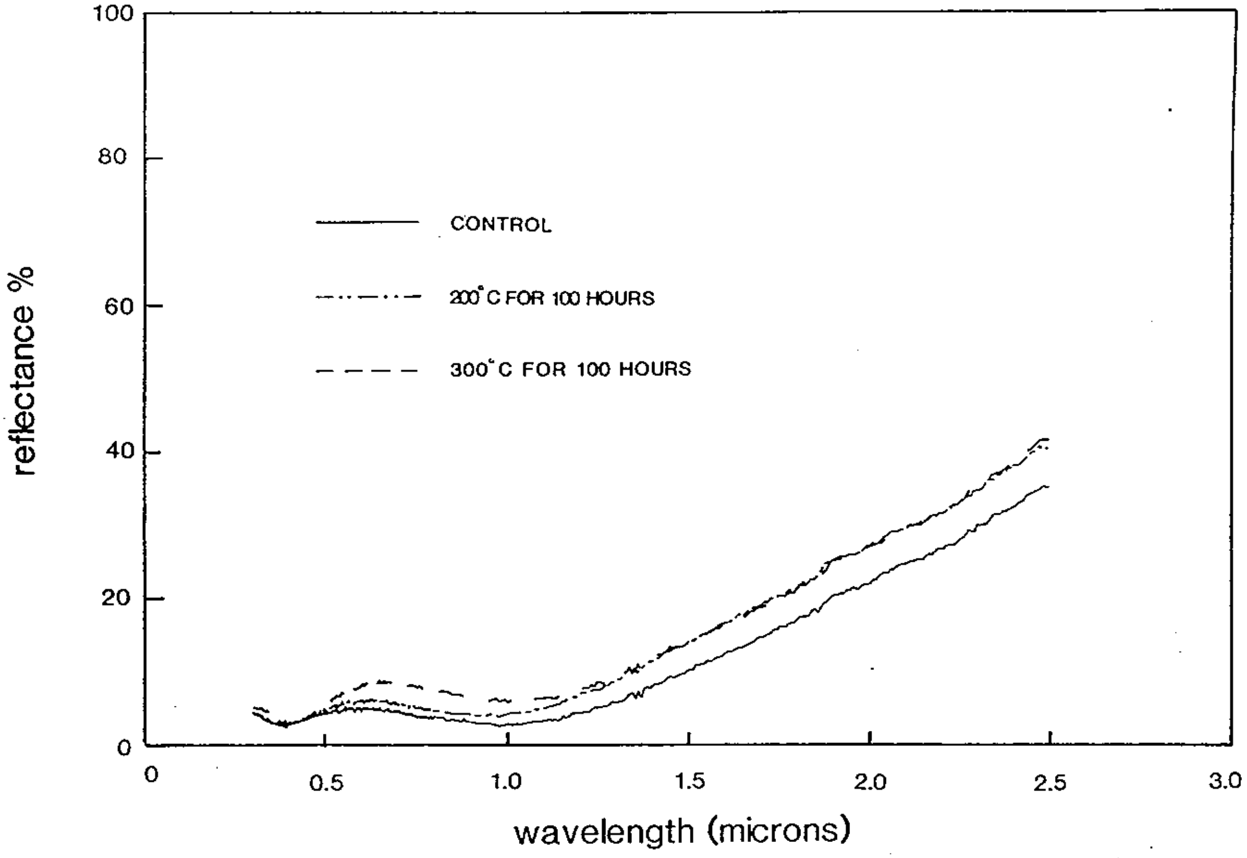

Figure 1. Spectral reflectance of Cusorb samples following constant temperature exposure in air.

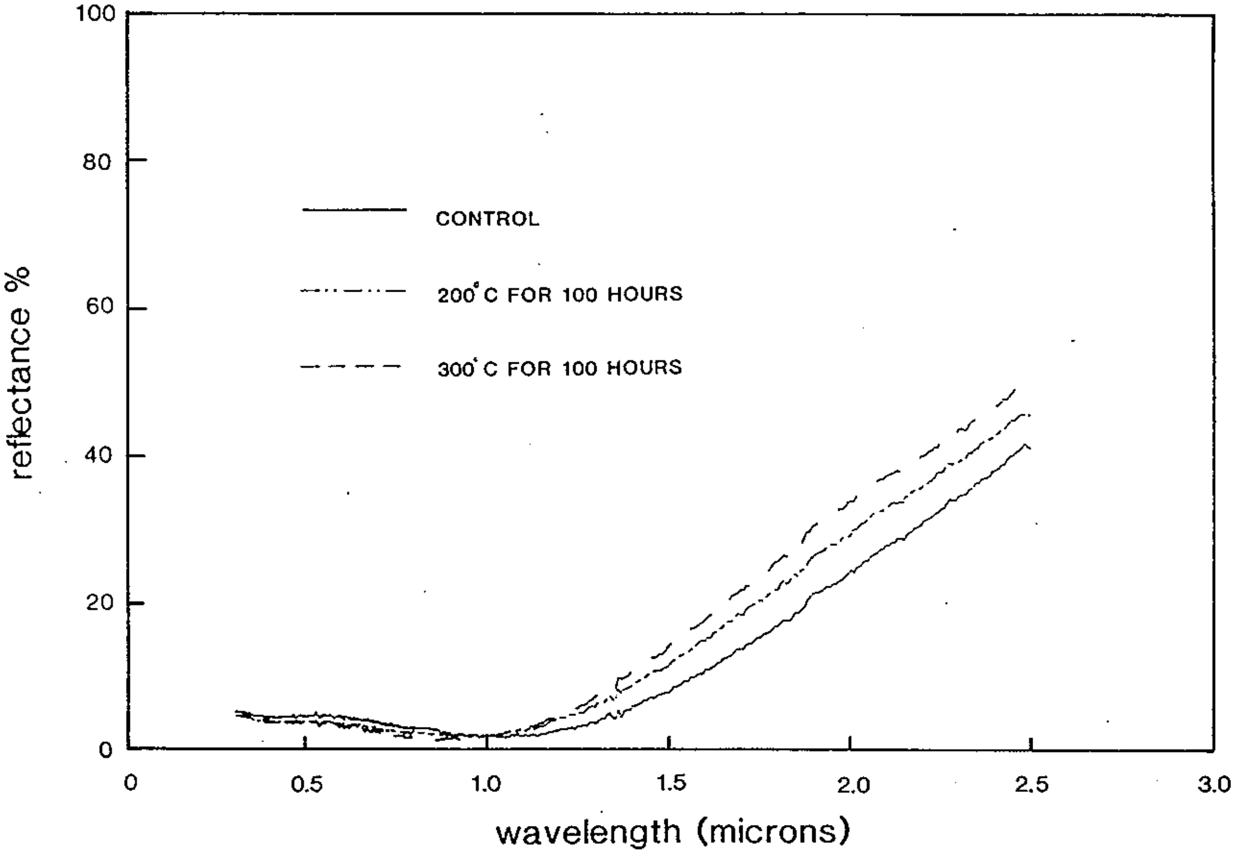

Figure 2. Spectral reflectance of Maxorb samples following constant temperature exposure in air.

Q : What method did you adopt for thickness measurement of the layer ?

Q : What about the long term suitability ?

Ageing Investigations of Solar Absorber Coatings

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1 Introduction

Solar absorber coatings are essential components of solar-thermal systems. Since they are either new products developed for this special application or products now used at unconventional working conditions, informations about their durability during an expected service life time of 10 years or more are needed.

The optical performance of a solar absorber is characterized by the solar absorptance and the thermal emittance. The efficiency of the collector is directly proportional to the solar absorptance of the coating. Therefore the absorptance should be as high as possible for all absorbers. The minimum requirement and so the maximum allowable decrease by degradation during the expected life-time of the absorber, should be specified from an economical point of view.

The energy loss of the absorber due to the emission of thermal radiation can be reduced by the use of spectrally selective absorber coatings, which have, besides a high absorptance in the wavelength range of the solar irradiation, a low emittance (or a high reflectance, respectively) in the wavelength range of the thermal radiation (above about 2,5 µm). The importance of a low thermal emittance grows with increasing operating temperature and decreasing solar irradiation.

Another generally important requirement is a durable adhesion of the absorber on the substrate (collector), which is necessary for a good heat-transfer to the fluid.

The loads of the absorber strongly depend on the type of collector, the local climate and the type of the solar system. Three types of collectors can be distinguished from the point of view of durability:

Absorbers of unglazed collectors, mainly used for swimming-pool heating, work at low temperatures (to 40°C), but they are exposed to the environmental weathering.

In flat-plate collectors, mainly used for domestic hot water or heating systems, the absorbers are more or less shielded from the climate outside by one or more transparent covers , but they are working at a medium temperature (40°C - 90°C).

The temperature load might be higher at high-efficient evacuated tube collectors, used for domestic hot water or heating systems mainly at cites with low solar insulation, as well as for industrial high-temperature applications with and without concentration of the solar irradiation, but they are not exposed to atmospheric components.

2 Ageing Properties

Degradation factors

As mentioned above the stresses of an absorber layer depend qualitatively as well as quantitatively on the local climate, the solar system, and the collector. The degradation factors, which are unavoidable for all solar absorbers are, of course, the temperature and the solar irradiation. The temperature load depends on the local climate, the working temperature of the collector, the heat transfer from the absorber to the fluid, and can reach a maximum, if the collector is out of order and runs into stagnation. The frequency and the amplitude of temperature cycles depend on the same parameters and vary seasonally.

The solar irradiation primarily causes a temperature load. But moreover photolytic degradation may occur. The concentration factor in concentrating systems and the ultraviolet transmission of the glazing influence the grade of the load.

In non-evacuated collectors, components of the atmosphere surrounding the absorber can act as reaction partners in degradation processes. The concentration of these degradation factors depend on the collector design and the local climate. Mainly oxygen, humidity and moisture and pollutants (salt, sulphur-dioxide, nitrogen-oxides) have to be taken into account.

Degradation mechanisms

The optical properties of an absorber-coating depend on the physical and chemical composition of the absorber. The degradation factors acting upon the absorber set up or accelerate degradation processes, which change the absorber composition (with regard to materials and morphology). This yields, in general, changes of the optical properties, too. The kinds of degradation processes and the extent of their effect on the optical properties depend on the materials and the applied physical principle providing the desired optical behaviour.

In the following only selective absorbers applied on a metal substrate (aluminium, copper or steel) are considered. Except of selective paints a large spectrum of metals, semiconductors and dielectric materials have been used for the realization of selective absorber coatings /1/, according to the following physical principles /2/, /3/, /4/:

1. Intrinsic selectivity of materials (mostly not sufficient).

2. Interference stacks (known from other optical applications).

3. Combination of an absorber layer with a selectively transmitting coating (e. g. SnO, In_2O_3).

4. Microrough surfaces ("wave-front discriminators").

5. Combination of an infrared reflector (metal) with a layer absorbing the solar radiation and transmitting the infrared radiation.

6. Metal/dielectric composites (cermets).

The best performance of absorbers has been achieved by combinations of several principles, as can be seen exemplarily at some commercially available coatings: The combination of a cermet with an IR-mirror is realized by nickel-pigmented aluminium-oxide on aluminium. Blue stainless steel is a semiconducting interference layer on the metal mirror. Absorbing semiconductors with a surface roughness on an IR-mirror are used for black nickel, black zinc and black copper. The combination of a microrough cermet layer with an IR-mirror forms black chrome. Often the metal substrate is used as IR-mirror and must be considered as a part of the absorber coating in this case.
These few examples give an impression of the broad spectrum of materials used in absorbers with different physical and chemical properties.

The degradation processes, also called degradation modes, vary from coating to coating and moreover depend on the degradation factors. In evacuated collectors the temperature load might accelerate internal diffusion, internal chemical reactions or desorption (outgassing) and might cause recristallization or phase transitions. Additional mechanical degradation (microcracks, blistering) might occur due to the cycling of the temperature.
The solar irradiation firstly causes a temperature load with the respective degradation modes, but can moreover accelerate these processes or set up new ones by photocatalysis.
An environmental atmosphere can provide to external diffusion and external chemical reactions, in addition.
The combination of the different degradation factors can yield

synergetic effects leading to other degradation modes than the single degradation factors applied separately.

A detailed discussion of the degradation modes is given in /2/.

Accelerated ageing tests

An acceleration of the ageing can be obtained by a quantitative increase of the degradation factors, usually at small samples in the laboratory.

Elevated temperature tests in air can be easily performed in ovens. Eespecially at high temperatures attention should be paid to possible deviations of sample temperature from the temperature of the test atmosphere caused by radiative heating, if the thermal radiation heats well absorbing samples more than the environment (especially the temperature sensor).
The temperature tests of coatings used in evacuated collectors should be carried out in vacuum, of course.

The influence of the solar irradiation can be investigated with solar simulation lamps, which should provide a flux higher than the solar constant. Special attention should be paid to the UV-radiation (mainly is responsible for degradation), which depends on the type of the lamp and on the used optics and windows.

The acceleration of degradation caused by interaction of the materials of the absorber with parts of the atmosphere can be achieved either by an increase of their concentrations or by an increase of the temperature. The first way is suitable for pollutants occuring in very small concentrations. The second way must be gone for humidity and moisture, which may occur with maximum concentrations in collectors, or should be gone for oxygen, for which a high increase of the concentration cannot be achieved.

The performance of combined accelerated tests, giving a true image of the reality, is difficult. There is no commercially available climatic cabinet which allows a controlled enhancement of all degradation factors, and it must be supposed that the requirements to the corrosion resistance of such a chamber could be hardly accomplished.

Another possiblity could be the use of the collector itself as a climatic cabinet, operating at high temperatures provided by a heated fluid. But then the effects of condensation must be investigated in special heating and cooling-cycles.

Degradation indicators

The degradation of an absorber primarily means a change of the optical properties. The spectral reflectance or the spectral absorptance and emittance, respectively, are much more sensitive to changes of the absorber composition than the integral values of the solar absorptance and the thermal emittance.

Changes of the spectral reflectance in the visible often can be seen visually by changes of the colour of the absorber, even if the solar absorptance remains nearly constant. On the other hand, ageing often affects first of all the spectral absorptance in the near-infrared, also without severe changes of the solar absorptance. Both of these possibilities might be evaluated as degradation indicators, though they strongly depend on the absorber materials and their composition.

3 Methods in present use for service life prediction

Accelerated ageing tests have been carried out mainly during the research and development of new absorber coatings. Recently some laboratories focussed their activities on the investigation of the durability of commercially available absorbers. Nearly all tests have been restricted to the comparison of the ageing resistance of different coatings or of coatings with different production parameters with respect to the applied test conditions, and have not been carried out for service life prediction.

Ageing at a constant temperature in air is the most popular test. References can be found in /2/ and in the state-of-the-art report of Subtask D. For heating in vacuum different approaches were reported:

- electrical heating in a pumped high-vacuum system, see e. g. /5/, /6/, /7/
- electron beam heating in a UHV-system /8/ - samples heated by IR-radiation in an evacuated quartz encapsulation /6/,
- photothermal sample heating with solar simulation lamps /9/.

The last mentioned study represents one of those concerned with the effects of ageing by solar irradiation using quartz halogen lamps providing a maximum flux of 3,3 kW/m^2. A considerably higher flux (350 kW/m^2 - 2,5 MW/m^2) was achieved by a field of heliostates /10/. The irradiance achieved by xenon-arc used in another laboratory has not been specified /11/.

The investigation of the ageing due to humidity recently have been part of durability programme. The samples mainly were exposed to 95% relative humidity at 90°C /11/, /12/, /13/, /2/.

A combined test with UV-radiation, humidity and moisture in a so called QUV-Weatherometer had been proposed for polymeric coatings by ASTM /14/, but was sometimes also applied to metallic absorbers /9/, /11/, /12/, /15/.

The influence of pollutants has not been investigated intensively. Besides salt spray tests /16/ only one laboratory concerned with sulphur-dioxide tests in a humid atmosphere /12/ could be found.

A combination of all possible degradation factors in one laboratory test have not been realized to this date. The common practice is the outdoor exposure of either complete collectors (e.g. /11/, /12/, /13/, /15/) or the exposure of the absorber mounted in a standard collector box, as it had been proposed in ASTM Practice E 781 (e. g. /11/, /12/, /17/, /18/). The advantage of outdoor stagnation tests is their accordance with the real climate. Disadvantages are the unreproducibility, the uncontrolled dependence of the load on the local climate and on the performance of the samples. Only the effect of the temperature is slightly accelerated, and it must be assumed, that the moisture content of the collector is diminished by the higher temperature level.

Qualification testing

Qualification practices for solar absorbers generally include the measurements of the solar absorptance and the thermal emittance before and after some ageing tests (e. g. according to ASTM E 744).The results of these shortened ageing tests may be useful for the evaluating of solar absorptive materials, but are useless for a description of the ageing behaviour not to mention for lifetime prediction methods.

Other qualification tests are applied to the whole collector. The absorber is partially affected by the following tests :

- High temperature stagnation test (according to standards or laboratory procedures existing in several countries)
- Short term ageing test (according to standards e. g. ASTM E 823)
- External thermal shock (spraying water on the collector at stagnation temperature; here only relevant for unglazed collectors)
- Internal thermal shock (Empty collector at stagnation temperature is cooled by a cold fluid)

Mathematical analysis of life data

At accelerated ageing procedures the life time is shortened by an elevation of the load. The mathematical analysis requires a set of data in the form of a table of the performance over time at different levels of the load. With a given performance limit, which defines the lifetimes for the respective loads, the performance table can be reduced to a set of lifetime/load pairs. The representation of those pairs by an appropriate function lifetime versus load (time transformation function) allows the extrapolation to the in-use conditions and the estimation of the corresponding lifetime.

The determination of the time transformation function can be carried out by means of two different approaches /19/:

1) A best-fit approximation of the data by a suitable arbitrary mathematical function is called "non-parametric method". A kind of coarse approximation of this method is implied in all accelerated ageing tests by concluding from a short term stability at high loads to a long-term stability at low loads.
2) The "deterministic method" makes use of basic physical laws, according to the degradation modes for the selection of the suitable function.

The latter approach was applied to the life-time estimation of black chrome /20/ and black copper /21/ both limited to the temperature resistance. Arrhenius'law was used as basic law for the time transformation function assuming, that the degradation modes are either chemical reactions (the temperature influences the reaction velocity according to Arrhenius'law) or diffusion processes (the diffusion "constant" is temperature dependent similar to Arrhenius'law) and also assuming, that the degradation modes will not change in the temperature range from working temperature to the maximum test temperature.
The same method has been appplied to studies of the degradation of the performance of evacuated tubes collectors /5/. The temperature dependence of the desorption of Argon from the

absorberlayer, which leads to a decrease of the collector performance caused by the enhanced pressure in the tube, obeys Arrhenius' law, too.
The other degradation factors have not been taken into account to this day.

4 Summary

Great efforts have been focussed on the investigation of the durability of solar absorber coatings. Emphasis has been lying on testing of their thermal stability in air, while the other degradation factors have been considered seldom. Combined tests, taking all degradation factors into account, have only been performed outdoors in collectors or standardized collector-boxes at stagnation conditions. Nearly all of these more or less accelerated ageing tests have been carried out either as qualification tests or in a comparative manner for the selection of the most stable coatings, or in order to get a coarse idea about the stability of the absorber, or for the identification of a special susceptibility of the absorber to certain degradation factors, but finally no informations about the durability at working conditions could be achieved from these tests.
Methods for service life prediction have been only applied to temperature tests of black chrome and black copper as well as to the outgassing of Argon in evacuated tubes. Their suitability for other materials and the development of adequate life tests for the other degradation factors and their combination should be subject of future research work.

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METHODS FOR SERVICE LIFE PREDICTION OF POTENTIAL INTEREST FOR THE APPLICATION AREA OF SOLAR HEATING AND COOLING

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Abstract:

Many general methodologies and mathematical models for service life prediction which might be of potential interest for the application area of solar heating and cooling can be found in the literature. However, only a few of them are directly applicable for materials used in this area. Present review discusses different general methodologies for service life prediction proposed for building materials in general. It also presents different deterministic and probabilistic mathematical approaches to analyze accelerated life test data for service life prediction.

1. INTRODUCTION

The concept of durability of a material is generally qualitative in nature and most often thought of as the ability of a material to withstand deterioration caused by exposure to the environment. The sense of the word environment then includes all external factors which may influence the performance of the material under service conditions. The time aspect of durability is related to the concept of "performance over time" i.e. variations with time of specific material properties of importance for the performance of the material. The "service life" of a material is then defined as the period of time after installation during which essential properties of the material meet or exceed minimum acceptable values.

Data on service lives of materials can be obtained from different kinds of soarces as

- feed-back from practice
- long-term tests under in-use conditions
- accelerated tests

For traditional materials in traditional applications feed-back data from practice are often available in the form of actual service lives. Although in many cases poorly documented or incomplete such data can serve directly as an aid . A problem that may arise, however, is that all environmental factors of importance for material degradation are not thoroughly characterized. This makes data sometimes difficult to transform into in-service performance of different climates.

Long-term tests under in use conditions is one alternative in generating service life data for new or substitutional materials or for traditional materials in new applications. For this type of test, however, it may take a long time to obtain results unless property change of the material can be detected at an early stage of degradation. One problem associated with this type of tests is also that it is often difficult to measure the degradation factors acting on the material under in-use conditions in particular on micro-level. It may therefore sometimes be difficult to identify true mechanisms of degradation.

An alternative to long-term testing under in-use conditions is accelerated testing. This means that the stress level of one or more degradation factors during the test is kept higher relative to the situation in use. Service life data prevailing for in-use conditions have to be calculated by extrapolation in this case. The advantage is of course here that such a procedure saves considerable time. Moreover as concerns development of new materials accelerated testing is the only realistic way sometimes to get information on durability properties of materials before they are introduced on the market.

For the application area of solar heating and cooling there is a strong need for use of service life prediction methods based on accelerated testing because the technique is new and feed back data on service lives of materials in this case therefore limited.

As the literature contains little information on accelerated life testing related to materials used in solar heating and cooling the purpose of the present short review, based on the survey work of IEA Subtask XC [1], is to discuss currently available methods which might be of potential interest for service life prediction in this area of application.

2. SYSTEMATIC METHODOLOGIES FOR SERVICE LIFE PREDICTION

Despite the great number of laboratory based test methods for determining durability properties of materials, only a few exist which are adequate for reliably predicting service lives. Among the problems associated with finding methods for predictive service life testing the following can be mentioned as are listed in [2]:

> Most short-term durability tests that exist are intended only for comparative testing i.e. comparing only qualitatively the results of a test material with the results of a similar control material when exposed to identical conditions. Moreover, recommendations are seldon made as how to relate the results of those short-term tests to in-service performance.

- In the laboratory materials and components are frequently tested in configurations far different from in-service configurations making the results from the laboratory tests difficult to transform into in-service performance.

- The degradation mechanisms of materials are complex and not well understood so that it is difficult to design meaningful short-term tests

- The degradation factors affecting service life are difficult to quantify expecially those involving natural weathering. Many existing tests do therefore not include all factors of importance and factors that are included are seldom related quantitatively to in-service exposure conditions.

- Methodologies, e.g. mathematical models, for relating results of laboratory tests to in-service performance are hard to find because of the high complexity of the mechanisms leading to material degradation.

Many efforts have been made to develop systematic approaches to service life prediction, so that all essential aspects of the problem will be taken into consideration. Such a methodology should serve, as summerized in the working document of CIB W80/RILEM 71-PSL [2], the following purposes:

1. It must be generic

2. It must lead to identification of all data needed for service life prediction, e.g. environmental degradation factors in service, possible degradation mechanisms for the material or component, quantitative performance requirements, internal maintenance methods, design features etc.

3. It must be based upon the use of reliable test methods or feed back data. All tests must be designed and be of relevance for the requirements dictated by item two above.

4. It must provide guidance on interpretation of data. Suitable methods and tools for this purpose, e.g. mathematical models, must be specified

5. It must lead to documentation of all assumptions made

With special reference to building materials many examples of systematic methodologies for service life prediction can be found in the literature, see Table 1 below

Table 1 METHODOLOGIES FOR SERVICE LIFE PREDICTION OF BUILDING MATERIALS

A	Methodology of RILEM TC 31-PCM on Performance Criteria for Materials [3]
B	Methodology of Australian Standard 1745 Part 2: Outdoor Weathering of Plastics in the Australian Environment - Guide for Design Purpose [4]
C	The Application of Encapsulation Material Stability Data to Photovolaic Module Life Assessment; Jet Propulsion Laboratory [5]
D	Standard Practice for Developing Accelerated Tests to Aid Prediction of the Service Life of Building Components and Materials; ASTM E 632-82 [6]
E	Methodology of Centre Scientifique et Technique du Batiment (CSTB) on service life prediction [7]
F	Methodology under consideration in RILEM TC 60-CSC on Corrosion of Steel in Concrete [8]
H	Methodology under consideration in CIB W 80/RILEM 71-PSL on Prediction of Service Life of Building Materials and Components [2]

Within almost all the methodologies of the table, four basic themes appear. Not unexpectedly, these themes are also essentially the same as the items of Task X within the IEA Solar Heating and Cooling Program [1].

PERFORMANCE ANALYSIS	Subtask A: Performance levels and evaluation criteria for selecting materials
FAILURE ANALYSIS	Subtask D: Failure and degradation modes
LABORATORY TESTING	Subtask B: Test procedures and measurement techniques
MATHEMATICAL MODELLING FOR SERVICE LIFE PREDICTION	Subtask C: Service life prediction methods (mathematical models)

As concerns performance analysis this is an essential part in all the methodologies. In most of them failure analysis is also an important element and is treated in considerable detail in the scheme used by Jet Propulsion Laboratory. Guidelines for developing accelerated laboratory tests for service life prediction is the main item of the ASTM and the CSTB precedures. As concerns mathematical modelling most of the methodologies considered are, however not particularly detailed with exception of the RILEM TC60-CSC and Jet Propulsion Laboratory schemes in which the need for mathematical models is identified at each stage of evaluation. The ASTM standard only treats the most simple case of mathematical modelling, i.e. when the rate of degradation is constant.

3 MATHEMATICAL MODELS FOR SERVICE LIFE PREDICTION

For mathematical modelling of life data two different kinds of approach can be found in the literature - the deterministic and the probabilistic of statistical. The difference between the two, however, seems merely to be a question of how to formulate the service life requirement for the pertinent material.

The service life requirement can be formulated such as the average service life should be of a certain value and, consequently, a so called deterministic approach is the right level of mathematical modelling. But, the service life requirement may be formulated such as that a certain population fraction should survive beyond a certain age and in this case a probabilistic approach has to be used taking into account the distribution in service lives also.

Among the deterministic mathematical models you can distinguish two main categories - the non-mechanistic and the mechanistic. The first places main emphasis on numerically fitting the experimental life data in terms of all stress factors which might be of importance for the degradation of the material and is not in general based on a physical and chemical model of the degradation process. An exemple from the literature on the very complex problem of accelerated aging of plastics by weathering will illustrate the concept. The degradation of polyethene and polyvinyl chloride was described by Leikina et al [9] by the following property-versus-time relation:

$$P = b_o + \sum_{i=1}^{N} b_i x_i + \sum_{j=1}^{N} \sum_{i=1}^{N} b_{ij} x_i x_j \qquad (1)$$

Four experimental parameters X_i;s related to weatherometer testing were considered, namely, irradiation, intensity of a Xenon arc, specimen surface temperature, fraction of time exposed to water during test cycle, and total test time. The b_i;s are material specific parameters fitted by way of multiple-linear-regression analysis. The equation illustrates the high complexity needed for describing mathematically a degradation process in terms of stress factors without taking into consideration the possible mechanisms of degradation. Furthermoore, the fitted equations could be used best for interpolations to conditions not actually evaluated but within the limit of the design. Extrapolation outside of the design limits to service conditions result in a high level of uncertainty.

If the degradation process can be described in terms of a mechanistic model on the other hand extrapolations can be made more accurate. Failures of materials caused by mechanical fatigue without or in combination with stress corrosion cracking or corrosion fatigue can favourably be analyzed in terms of fracture mechanics and the process of crack groth be described by the Paris-Erdogen-relation, see e.g. [10]

$$\frac{da}{dN} = C\ (\Delta K)^m \qquad (2)$$

where

$$\Delta K = \Delta\sigma\ \sqrt{\pi a} \cdot Y \qquad (3)$$

ΔK is the stress intensity, N the number of cycles, a the crack length, Y a geometry factor and C and m are material constants. The corrosion effect can be taken account of by expressing the constant C as

$$C = C_i \cdot C_{corr} \qquad (4)$$

where C_i is valid for an inert environment and C_{corr} is a correction factor for the effect of corrosion. In connection with solar applications it can be mentioned that the Paris-Erdogen relation has formed the basis for the following equation for life time predictions of solar mirror glasses

$$Y_s = B \cdot \sigma^{-n} S_s^{n-2} \qquad (5)$$

where Y_s is the service life, B and n are material/environment constants, S_s the initial strength of component and σ applied mechanical stress [11].

To be able to reach a mathematical description of the performance-versus-time relation, requires that you have detailed knowledge of the material and its physical and chemical properties during aging. However, when accelerated testing is used as an aid for service life prediction the functional form of the performance-versus-time relation has not to be fully known. Of importance is of course that the material degrades by the same mechanism during the accelerated test as occuring under service conditions. The simplifications that can be made are commonly referred to as the acceleration factor approach. The basic idea is here that the ratio between the service life, y_s, and the time to failure in an accelerated test, y, called the acceleration factor, A, can be expressed as

$$A = \frac{y_s}{y} = \frac{g(\bar{S})}{g(\bar{S}_s)} \tag{6}$$

where $\bar{S}$ is a vector describing only the external stress factors acting on the material. The equation is best suited for cases when only a single stress factor causes degradation.

To accelerate the degradation process by increasing the temperature is the far most applied method in accelerated life testing. Most often the results are analyzed in terms of the Arrhenius equation:

$$A_T = \exp \quad -E(\frac{1}{T} - \frac{1}{T_o}) \tag{7}$$

E = constant
o indicates a reference state.

Examples of materials that can be tested and evaluated this way constitute elastomers, amorphous plastics and even metallic materials undergoing corrosion.

If the service life requirement is formulated in terms of a distribution in service lives, analysis of life data must be based on a statistical approach. Such an approach is above all used in high technologies where it is well established. Many text books can be found on the subject, see e.g. [12] and [13].

The point of departure for statistically treating life data is either to look at the spread in failure times see eg. [12], [13] and [14] or to look at the spread in some material property being important for the durability of the material, see e.g. [10]. The first mentioned approach seems more common, however, mainly because the mechanisms of degradation have not to be fully known. Consequently failure distribution functions play an important part in statistical life data analysis and in particular the exponential, normal, lognormal and Weibull life distributions, see e.g. [13]. The basic idea when using these life distributions in connection with accelerated life testing is that the parameters of the life distribution functions may vary with the stress level but the functional form will be the same. Accordingly, the reliability function R(y) of the Weibull life distribution can be expresse as:

$$R(y) = \exp \left[-(\frac{y}{\alpha})^{\beta}/8)\right] \tag{8}$$

where α and β are parameters which can be related to the stress levels of different degradation factors, see e.g. [12] and [14].

To go further into the details of statistical analysis of accelerated life data falls however outside the aim of this short review and the reader is referred to the references given in the text. However, the success of statistical life data analysis in advanced technologies points at the need also for other technologies to develop service life prediction methods based on this approach. For the new technology of solar heating and cooling such methods should therefore be of great interest.

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Q : Are there any experiences in industry for use in these ?

Q : If choice is allowed, which do you choose, mechanistic models or statistical models ?

Q : Can you put chemical factors into your mathematical models ?

Application fields and Operating conditions

Task X

Subtask A

Performance Levels and Evaluation Criteria for Selecting Materials

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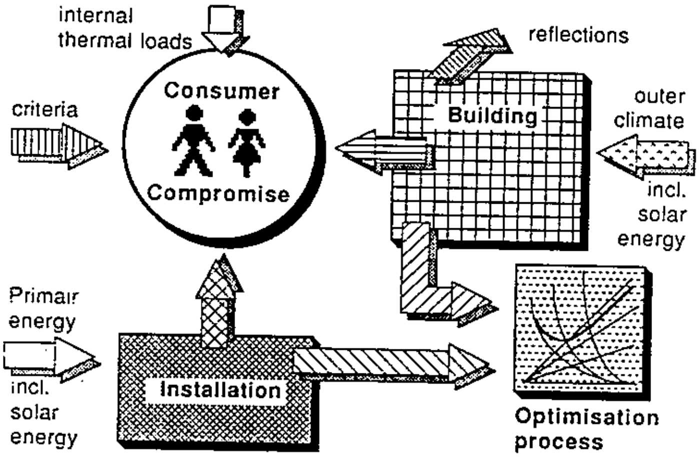
1. Introduction.

Fundamental criteria for solar heat utilisation.
Consumers in different application categories utilise in a passive and more active way solar heat as an uncontrolled perception in positive or negative sense. The application c.q. climatisation of swimming pools, of buildings etc., requires specific optimal criteria, which will generally contribute to maximal results.
The building structure is attacked by the outer climate and solar heat is absorbed and accumulated. Taking into account the internal thermal loads the added installation tries to make a compromise for the consumers' climate in the building.
This results in an optimisation process expressed in scheme 1 in which a maximum of solar energy can be used, viz.

a. active systems by means of solar collector installations and
b. passive systems by means of building structures, in this case only windows.



Scheme 1

The prime function of a solar system is to simultaneously absorb and transform solar radiation to heat and lead this heat to a heat storage medium or directly to the consumer. For active systems the heat losses from the absorber are reduced by using a transparant cover, spectral selective coating(s), elements for suppression of convection or specific insulation supplies.

Depending on the local climate factors during a year and the different local applications for the use of solar energy (e.g. heating, cooling, natural lighting and dehumidification) conditions arise to which materials of the solar energy installation have to be tuned.
Each material in an application field functions with and suffers from the ambient climate leading to the operating conditions.
To facilitate the selection of materials and to weigh the importance of test results, -procedures and -conditions evaluation criteria will be established.
These criteria, which have the potential to improve the performance, durability, reliability, safety and cost effectiveness of solar energy systems, cover on the one hand

- operating conditions and on the other hand
- material properties.

The performance criteria for solar energy systems exist within a context of requirements that increase in scope from the application (e.g.building) for which the system is designed, to the site, to the region and its climate, up to the scale of national energy goals. Regional climate conditions may exert a strong influence on designs, components and systems, but also on material selection.

The designated materials, cover, absorber, heat transfer medium and heat storage medium can be used at different locations around the world and for different applications.

Due to the performance and the economic feasibility for a state or country realisations in a specific application field are justified. E.g. considerable absence of direct solar radiation during summer is not worthwhile to install a solar system for cooling. The local climate conditions, the local heat demand and the governmental rules and permissions (health, savety, fire resistant) justify a specific solar energy application and are fundamental firs criteria before selecting materials in a more technical way.

So the first conditions for selection are:

a. Local application fields of solar systems, and natural conditions The perspectives of these application fields, common dimensions and potentials with respect to the local climate, the topography, and vegetation.
b. The local building codes and national standards, attention for physical hazard and toxicity, structural safety, fire resistant.
c. Climatic factors. Solar radiation, ambient temperature, hours of exposure, humidity.

After this global evaluation materials of a solar system in a specific field are selected by considering the operating conditions and the boundary conditions with respect to the engineering properties.

2 Application fields and Solar Systems.

The different application fields with their specific working temperatures require an adaption of the construction of the componen or the solar system.

Solar collectors for swimming pools mostly have not been covered, whereas cooling systems ask for very sophisticated solar collectors. Some areas at different performance levels of the active and the passive solar systems have been distinguished as stated in scheme 2 . More in detail each application category and system type is shortly described hereafter.

2.1 Application Categories.

SWIMMING POOLS. The watertemperature in swimming pools normally varies between 21 and 25 degrees Celcius. Due to this low systemtemperature low performance solar collectors are economically incorporated in solar systems for pool heating. In northern countries especially in outdoor swimming pools, which are only used in summer, there exists a big heat demand. The collectors with large dimensions, generally made of plastic or metal, are situated in the neighbourhood of the swimming pool, that acts as the heat storage of

the system.
The higher temperature of shower water (about 35-40 degr. C) asks for better collectors and an additional heat storagetank.
DWELLINGS. The heat demand in dwellings covers:

a) domestic hot water preparation: about 60 degr. C during the whole year, solar heat is stored for 1 or 2 days,
b) heating: during winter system temperatures are required from 30 till 80 degr. C. Due to the lack of solar heat during the period of heat demand important attention has to be paid on the storage of solar heat. In spring and autumn short time storage (some days) and in winter long term storage (some months) can be considered. To achieve a better performance low temperature heating systems are much more appreciated in comparison with high temperature.
c) cooling: during summer solar heat with a high temperature (about 80 degr. C) is used. These systems are only justified in southern countries where abundant solar energy can be captured.
   For heating purposes very simple collectors (oncovered,unisolated) in combination with a heat-pump can be used. Heat from solar radiation and ambient air with a low temperature is transformed into usable heat with a temperature of about 50 degr.C.
   With passive solar systems heating is achieved by directly capturing solar heat through windows of e.g. dwellings, in conservatories (serres), and by means of Trombe constructions.

AGRICULTURE. Solar Energy for fish basins acts as solar energy for swimmingpools. Depending on the fish culture the temperature of the basins will differ (eel 25 C, tarbot 18 C).
Hot water is needed for food preparation, cleaning of equipment and drinking in the livestock sector. During the whole year water-temperatures of 40 till 80 C are desired.
Potential applications for solar energy in livestock house conditioning are mostly in pig en poultry rearing.
Solar drying is practised in countries with more sunny climates.
The relationship between the parameters concerning the energy requirement in a drier is relatively complex.
The desired temperatures depend on the products.
Mostly air collectors are used. Greenhouses generally have to be cooled in southern countries (summer) and to be heated in northern countries (winter). Most important is the balance of a high solar light transmission for plant growth and the capured heat.
INDUSTRY. Industrial proces heat e.g. food industry big amounts of hot water with temperatures from 40 uptill 100 C are needed during the whole year.
HOTELS, RESTAURANTS. Especially for kitchens in hotels and restaurants in all kind of buildings hot water with a temperature of about 60 C is used during the whole year.
UTILITY BUILDINGS. Cooling as well as heating is needed for climatisation. Cooling, mostly during sunny periods, with absorption cooling machines ask for heat with a temperature of about 80 C. Heating mostly during winter, however asks for temperatures of about 30 till 80 C. As already mentioned for heating of dwellings here the storage of heat is more complex.

2.2. Natural Factors.

The local applications of solar systems have also to be justified b) the following natural factors. (ref.2).

(a) Sun altitude and declination - for consideration of collector aperture tilt and shading, etc.
(b) Orientation - due south vs. magnetic south - to determine orientation and building geometry.
(c) Topography - for consideration of building into slopes, earth berming, and otherwise maximizing southern exposure and minimizing others.
(d) Altitude - for the effects of atmospheric density.
(e) Vegetation - as it affects shading, reflection and air movement.
(f) Ground temperature - as it affects ground water temperature and earth exchange cooling.
(g) Water table height - for considerations of excavation, burying of storage elements, earth contact housing, and wetting insulation.
(h) Water quality - its mineral content, pH, etc., when used for heat transfer fluid or thermal storage.

3. Building codes and infra structure.

Due to non-technical and also technical reasons local governmental institutes prohibit the application of some materials or components. If there are any special allowances (acts, codes, etc.) it is recommended to consider. Important is an early presentation of the designs of systems and components to the local authorities. Some factors in this field are the following(ref.2).

(a) Density and growth of development - in consideration of solar rights, shading, glare, obtrusive installations.
(b) Pollution of air - as its affects insolation, corrosion on exposed parts, stain and dirt deposits on collector cover plates, or glazing.
(c) Building materials and architectural character - consideration of mass and geometry or prevalent building types.
(d) Building codes - to the extent that they constrain solar applications.

4. Climate factors.

The most important factor of the climate factors for solar systems, passive as wall as active, is the solar radiation. The use of solar radiation in an optimal way for typical applications is the principal feature of such a system. However climates are quite different on earth.

To consider in this IEA-study for all participating countries each specific local climate will be an enormous work due to these differences in solar radiation and the very different applications of utilizing solar energy. Therefore the climate factors are divided in two groups:

the macro-climatic and the micro-climatic factors. The macro-climatic factors are generally well-known in wheather forcasting institutes of the countries.

The micro-climatic factors differ slightly or more from the macro-climate and focus the local situation.

Macro-climatic factors have a direct influence on solar H/C/HW systems. Typical sources of climate data are the Climatic Atlas.

Following is a tabulation of typical climate factors (ref.2).
(a) Temperature (annual average, seasonal, and daily).
(b) Solar radiation (annual, monthly, daily, hourly). Note: data on weekly basis would offer many advantages but is usually not tabulated in that form.
(c) Wind or air movement (direction, velocity, frequency).
(d) Relative humidity.
(e) Rainfall and snow.

Micro-climatic factors are those of specific interest to an individual building, site, and immediate surroundings.

Climatic characteristics become more focused at this scale and may be tempered or exaggerated by local features, creating weather characteristics unique to the site.

The characteristics unique to the site may be caused by its topography, landscaping, and proximity to surrounding buildings, hills, lakes, or open plains. The following characterictics should be considered at this scale (ref 2).
(a) Shading - time, duration, and season of occurence are important for heating as well as cooling.
(b) Air movement (direction, velocity, frequency).
(c) Atmospheric quality (fog, haze) and direct vs. diffuse solar radiation.
(d) Relative humidity.

By taking into account only a selective number of climate areas, representing with a certain accuracy most regions on earth, the development of performance levels and selecting criteria for materials will be conveniently arranged. The climate areas have been specified in the annex and represent weather data of many years. As an example one climate area Phoenix, Arizona, U.S.A. has been described now. For this site hours of exposure according to intervals of 100 W/m2 insolation and intervals of 5 C of ambient temperature have been given in table 1.

5. Operating conditions.

To design solar systems and to select materials for these components operating conditions should be the most important criteria.

They not only justify the application of such systems in local regions but they also bound the selection of materials with the respect to their properties.

Scheme 2 already showed the application categories and the type of solar system which is preferred. For the designated materials the operating conditions caused by the climate factors have been derived. Table 2 shows this relation. For the selection of materials not only the conditions in normal operating of the system are used, but also the maximum and minimum conditions and the time duration of such phenomena.

Each of the four designated material groups functions on a different way in the solar system.

So the actual operating conditions, but not always the boundary conditions,,will differ for each material of the solar system as visualised in the table 2

As far as possible for this moment the table can be used for each location. In the same table is shown which climate factors expose the designated materials.

The items on which materials are selected have been mentioned in table 3.

Table 1

Outdoor exposure conditions (example ref. 1)

PHOENIX, ARIZONA Lat= 33,43

PHOENIX elevation = 339m .
this is a sunny desert climate that is really warm.
Annual Heating Degree days (below 18,3 °C):862.
Snow may occur once in five or ten winters, and lasts only a few hours when is does occur. Cooling, rather than heating, is the dominant problem for buildings. Summer temperatures often reach 40 °C, even at night. Direct evaporative cooling was formerly adequate for residential buildings, but is now inadequate due to the humidity caused by nearby irrigated agriculture.

Number of hours of exposure under typical conditions in one year:

ambient °C temperature	Insolation W/m² 700 - 800	800 - 900	900 - 1000	1000 - 1100	1100 - 1200	
15 - 20	36	25	8	1	0	
20 - 25	55	49	41	7	0	
25 - 30	83	63	67	44	0	
30 - 35	112	115	82	58	0	collector is horizontal
35 - 40	58	112	115	74	0	
40 - 45	15	21	24	14	0	
45 - 50	0	1	0	0	0	
15 - 20	95	91	4	0	0	
20 - 25	70	63	11	0	0	
25 - 30	50	19	0	0	0	collector is vertical - facing south
30 - 35	39	11	0	0	0	
35 - 40	1	0	0	0	0	
40 - 45	0	0	0	0	0	
45 - 50	0	0	0	0	0	

Table 2

Global Operating Conditions.

Application categories	Components	Max.* temp.°C	Actual* temp.°C	Durability exposure to					
				UV	rain	wind	moist.	hail	poll.
Active systems Solar collectors									
1. low performance, [uncovered coll.] -swimming pools -energy roofs	absorber medium storage	Ta+40	10-30	x	x	x	x	x	x
2. med. performance, [single covered insulated coll. normal black] - swimming pools	cover	Ta+30	10-30	x	x	x	x	x	x
- hot water in dwellings, restaurants, agriculture	absorber medium storage	Ta+90 100 90	10-70				x		
3. high performance, [as 2 with improvements as sp.sel.coatings, double glazing]	outer cover inner cover	Ta+30 Ta+80	10-60	x	x	x	x	x	x
- hot water in dwellings, restaurants, agriculture, industry - heating - cooling	absorber medium storage	Ta+120 100 90	20-80				x		
4. very high performance [as 3 with extensive improvements as vacuum, honeycomb etc.]	outer cover inner cover	Ta+30 Ta+90	10-60	x	x	x	x	x	x
-heating -cooling	absorber medium storage	Ta+190 100 90	20-100				x		
Passive systems -direct gain -Trombe wall	windowglass	Ta+30	10-40	x	x	x	x	x	x

* depending on the local climate
minimal temperature = ambient temperature Ta=ambient temperature

Table 3 LIST OF ITEMS for Material Selection and Testing Requirements.
ⓧ items of first interest.

	1 th.	2 th. importance	only degradation.
1. <u>COLLECTOR COVERS</u>			
.Thermophysical.			
1.1 .Solar Transmission	ⓧ		ⓧ
1.2 .Solar Absorptance		x	ⓧ
1.3 .Emittance		x	ⓧ
1.4 .Heat conductance		x	
.Structural			
1.5 .Flexural (wind load)	x		
1.6 .Fatigue (wind load)		x	
1.7 .Impact (hail)	x		
.Environmental			
1.8 .Operating temperature		x	x
1.9 .Temperature (extreme)	x		x
1.10 .Thermal Cycle	x		
1.11 .Thermal Shock	x		
1.12 .Solar Radiation (UV)		x	x
1.13 .Humidity, Moisture		x	
1.14 .Air Pollution		x	
1.15 .Flammability		x	
2. <u>COLLECTOR ABSORBERS</u> (S=substrate, C=coating)			
.Thermophysical			
2.1 .Solar Absorptance (C)	ⓧ		
2.2 .Emittance (C)	ⓧ		ⓧ
2.3 .Specific Heat (S)		x	
2.4 .Thermal Conductivity(S)	ⓧ		
.Structural			
2.5 .Internal Pressure(S)		x	
2.6 .Flexural (S)		x	
2.7 .Vibration (S)		x	
.Environmental			
2.8 .Operating temperature		x	x
2.9 .Temp. (extreme)(S,C)	x		x
2.10 .Thermal Cycle (S,C)	x		
2.11 .Thermal Shock (S,C)	x		
2.12 .Solar Radiation (C)	x		x
2.13 .Humidity (C)		x	
2.14 .Air Pollution (if no cover)(C)		x	
2.15 .Flammability		x	
3. <u>HEAT TRANSFER MEDIA</u>			
.Thermophysical			
3.1. .Operating Pressure Limits		x	
3.2 .Maximum and Minimum Temperature Limitations	x		
3.3 .Operating Temperature	x		x
.Environmental			
3.4 .Compatibility materials/			
3.5 .Heat Transfer Fluid	x		
3.6 .Operating Flowe rate	x		
3.7 .Dissimular metals	x		x
3.8 .Toxicity	x		x

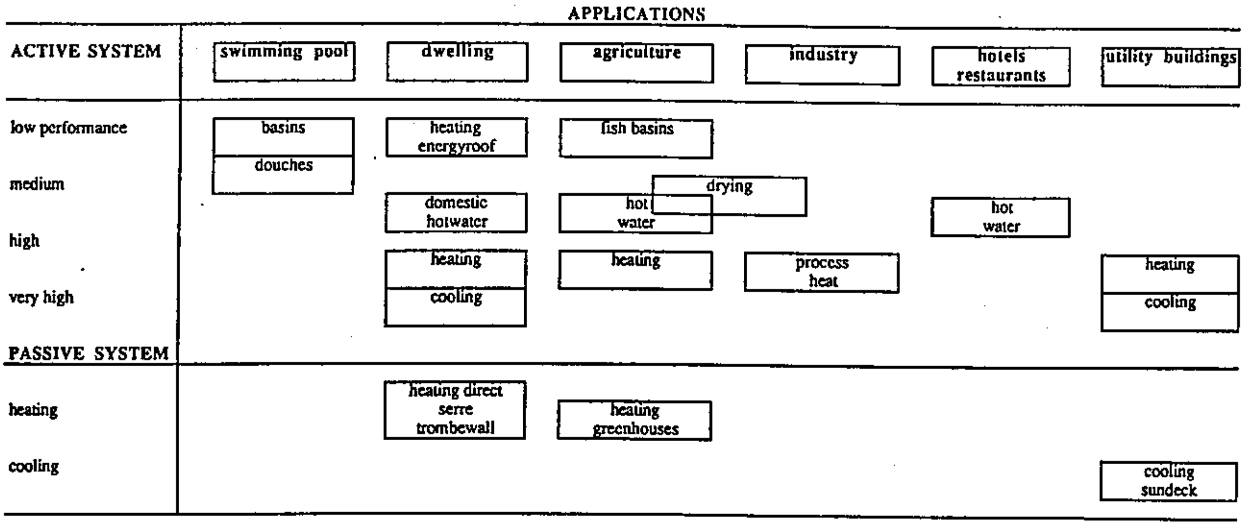
4. THERMAL STORAGE MEDIA. (L=liquid,S=solid,PCM=phase change material)

.Thermophysical			
4.1 .Phase change temperature or operating temp. (L.S.PCM)	x		x
4.2 .Specific heat	x		x
4.3 .Latent heat	x		x
.Maximum and minimum temperature level (L,S,PCM)	x		
.Environmental			
4.4 .Moisture (S)		x	
4.5 .Cycling (L,S,PCM)		x	x
4.6 .Chemical compatibility dissimular materials (L,S,PCM)		x	

5. References.

1. Information D.A. Neeper. Los Alamos National Laboratory New Mexico, Oct. 1986.

2. Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings. NBS technical note 1187, april 1984.



scheme 2

Components, Technical Analysis and Thermal Performance

Task X

Subtask A

Performance Levels and Evaluation Criteria for Selecting Materials

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Holland Solar

the Netherlands

May 1987

The cooperative activities of Task X concern solar energy systems employed for heating, cooling, natural lighting and dehumidification.
Each designated material endures operational conditions in a wide range even if applicated in one employment.
Not only the climatic conditions but also the coverage of the energy demand by solar heat plays an important role.
If the system fails even higher conditions occur than during normal operation.
These factors have to be considered in the design phase of the project.

Design-path solar energy systems.

Step 1	Heat load calculation
Step 2	Insolation and climatic effects
Step 3	Solar system design passive, active
Step 4	Components choice efficiency, dimensioning collectors storage control auxilliary heating
Step 5	Solar heat calculations month, year
Step 6	Economic evaluation, optimisation

Materials have to be related to the use to which it is to be put, namely its utilization as a constituent of some specific structure or component.
Referring to the prime function of the solar system moreover the evaluation criteria have to be brought in relation to the complete system.
From the analysis of solar systems results a general scheme where all systems have been incorporated (scheme 1).
The system analysis focusses on the components in which the 4 designated materials have been emphasized: solar collector (cover and absorber), heat transfer medium and thermal heat storage.
However materials degradate during life time and the performance of components decrease less or more in relation to the local climate and application.
Therefore allowable boundaries and minimum property guidelines have to be denoted to 'feel' this decline.
Only the most significant materials, systems and applications have been covered.

The products on the solar energy market are fully in development not only due to the effects of low economic feasibility.
In a number of figures some installation types and component types have been shown for different application fields.
Swimmingpool heating, domestic hot water, space heating, agricultural application as hotwater for fattening calves, drying;
installations with air- or liquidcollectors, with single or double heat

exchanger, consisting of several components as collector, storage, pump, control, pipes and so on or consisting of one unit with all functions integrated in one compact system and systems with a solar assisted heatpump.

Though this survey is not complete at all it shows the big number of possibilities that components and materials have to withstand operational conditions.

In the future research plan of subtask A this analysis will be carried out and will lead to practical guidelines for the selection of materials.

The thermal performance of solar systems is influenced by climatic, consumer- and systemconditions.

Some examples have been given in the next figures.

From this big number of variables the most important ones have to be considered for evaluating their influence on the system performancy (e.g. a performance decrease of 10%).

This parameter study will be carried out by the use of computer programs.

Results from experiences with these components, failures and degradation effects will also be used.

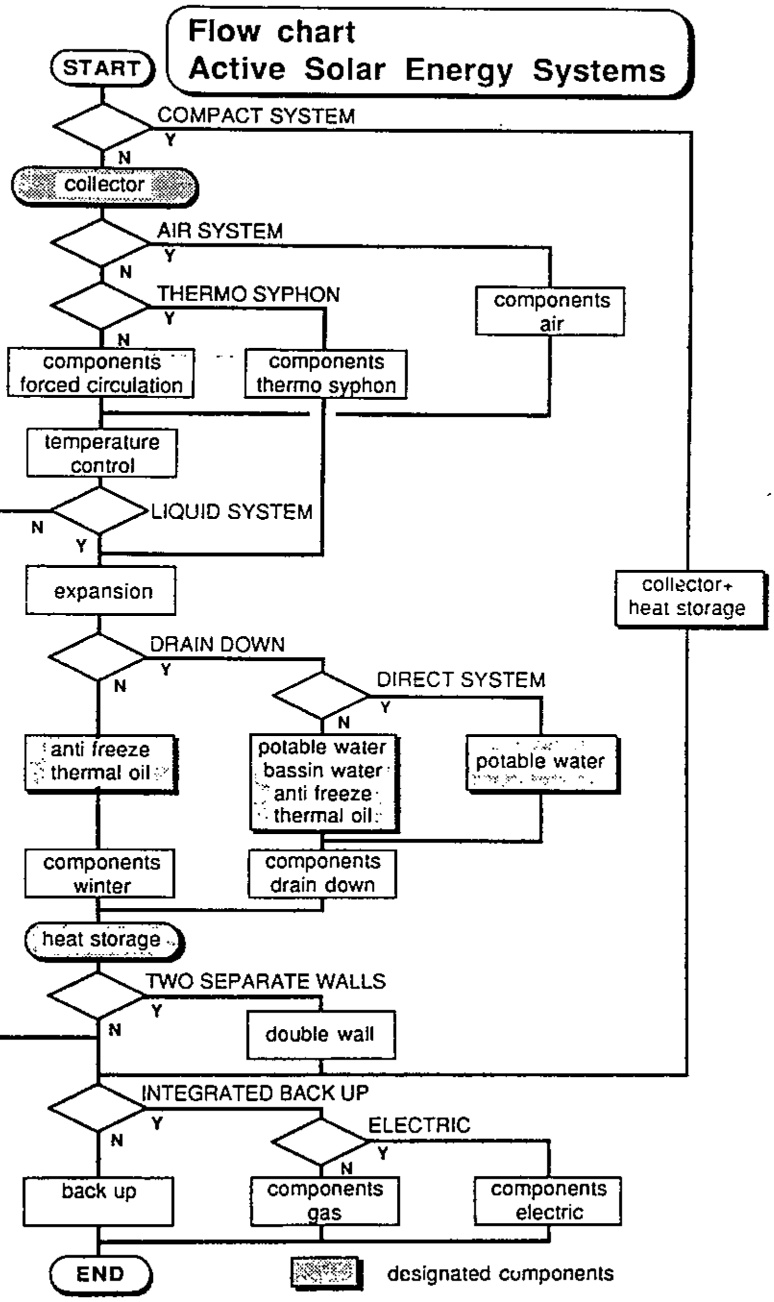
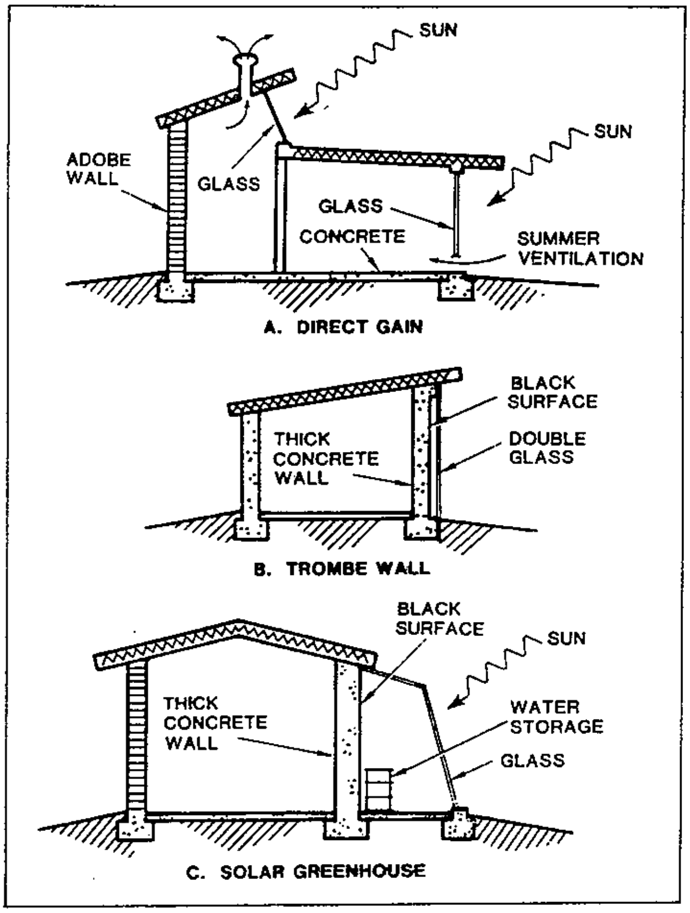

Flow chart
Active Solar Energy Systems
START
COMPACT SYSTEM
Y
N
collector
AIR SYSTEM
Y
N
THERMO SYPHON
Y
N
components air
components forced circulation
components thermo syphon
temperature control
LIQUID SYSTEM
N
Y
collector+ heat storage
expansion
DRAIN DOWN
Y
N
DIRECT SYSTEM
Y
N
anti freeze thermal oil
potable water bassin water anti freeze thermal oil
potable water
components winter
components drain down
heat storage
TWO SEPARATE WALLS
Y
N
double wall
INTEGRATED BACK UP
Y
N
ELECTRIC
Y
N
back up
components gas
components electric
END
designated components

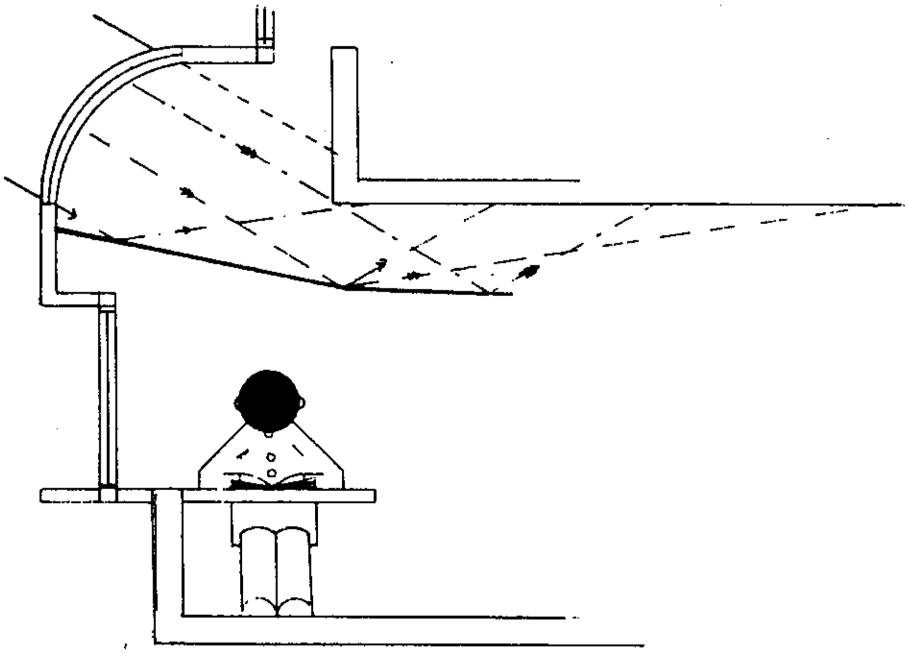
Figure 1

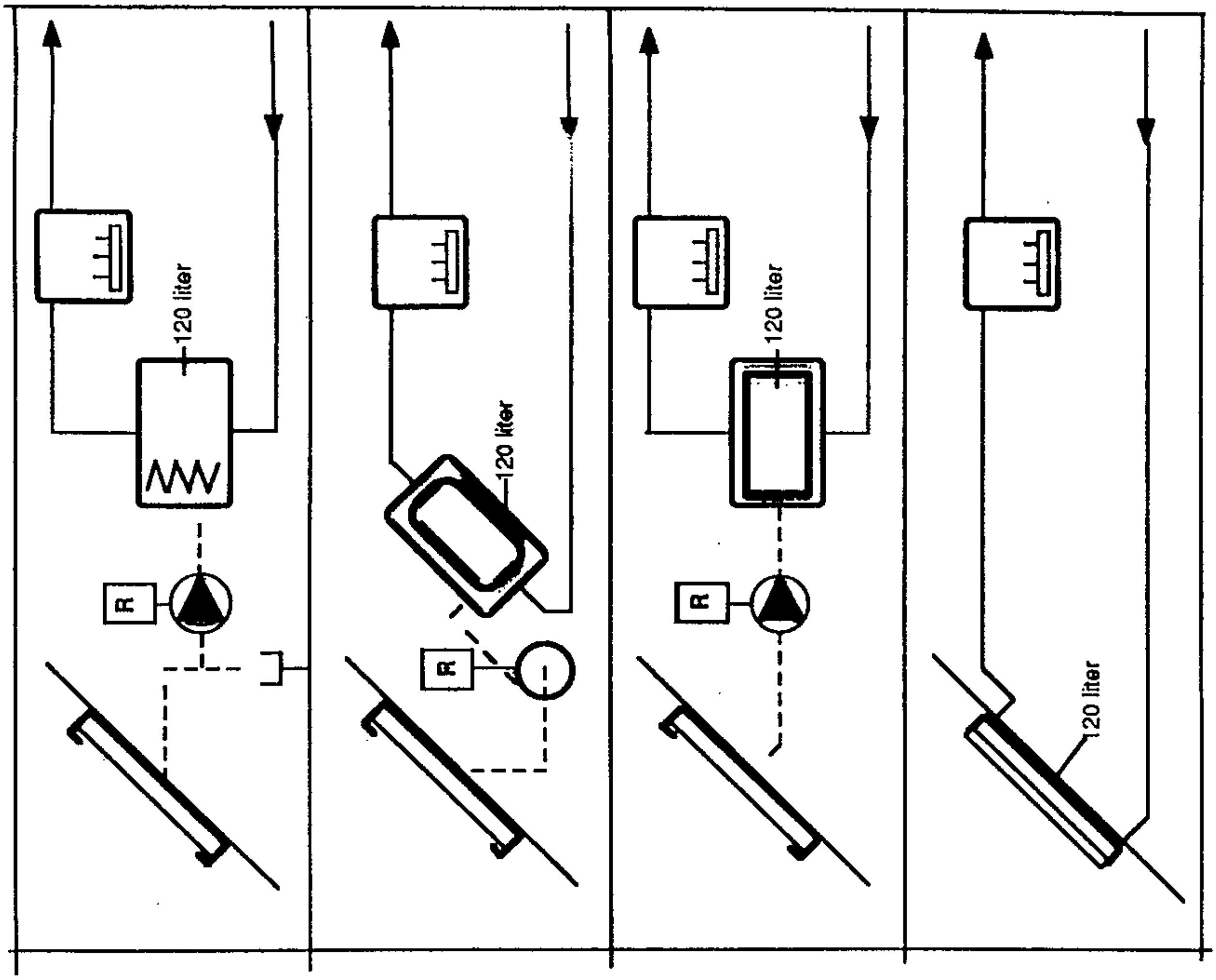


A. DIRECT GAIN

B. TROMBE WALL

C. SOLAR GREENHOUSE




120 liter
R
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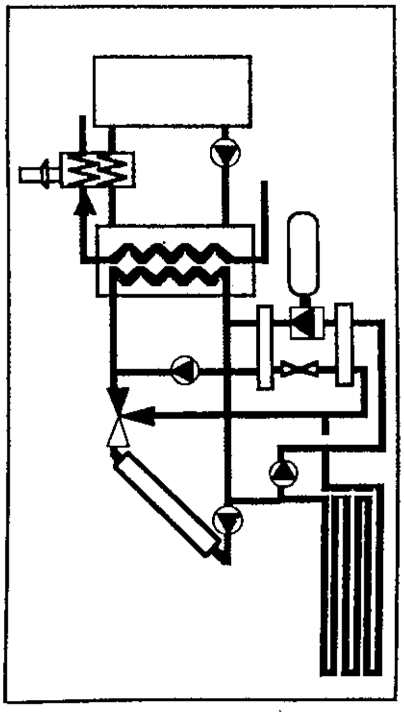
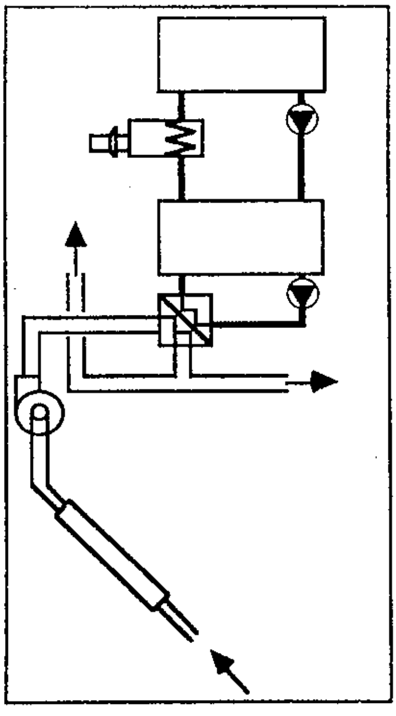
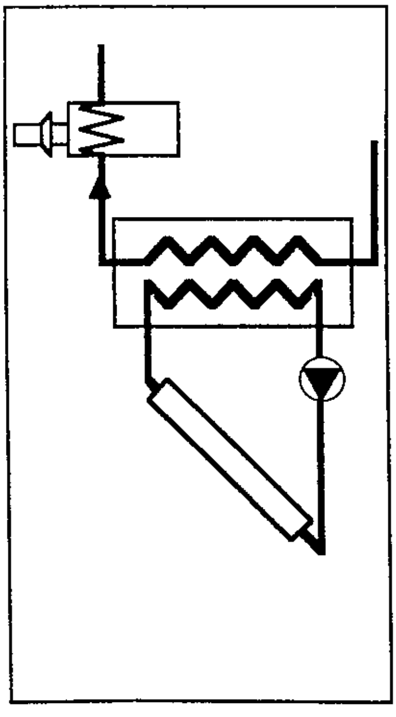
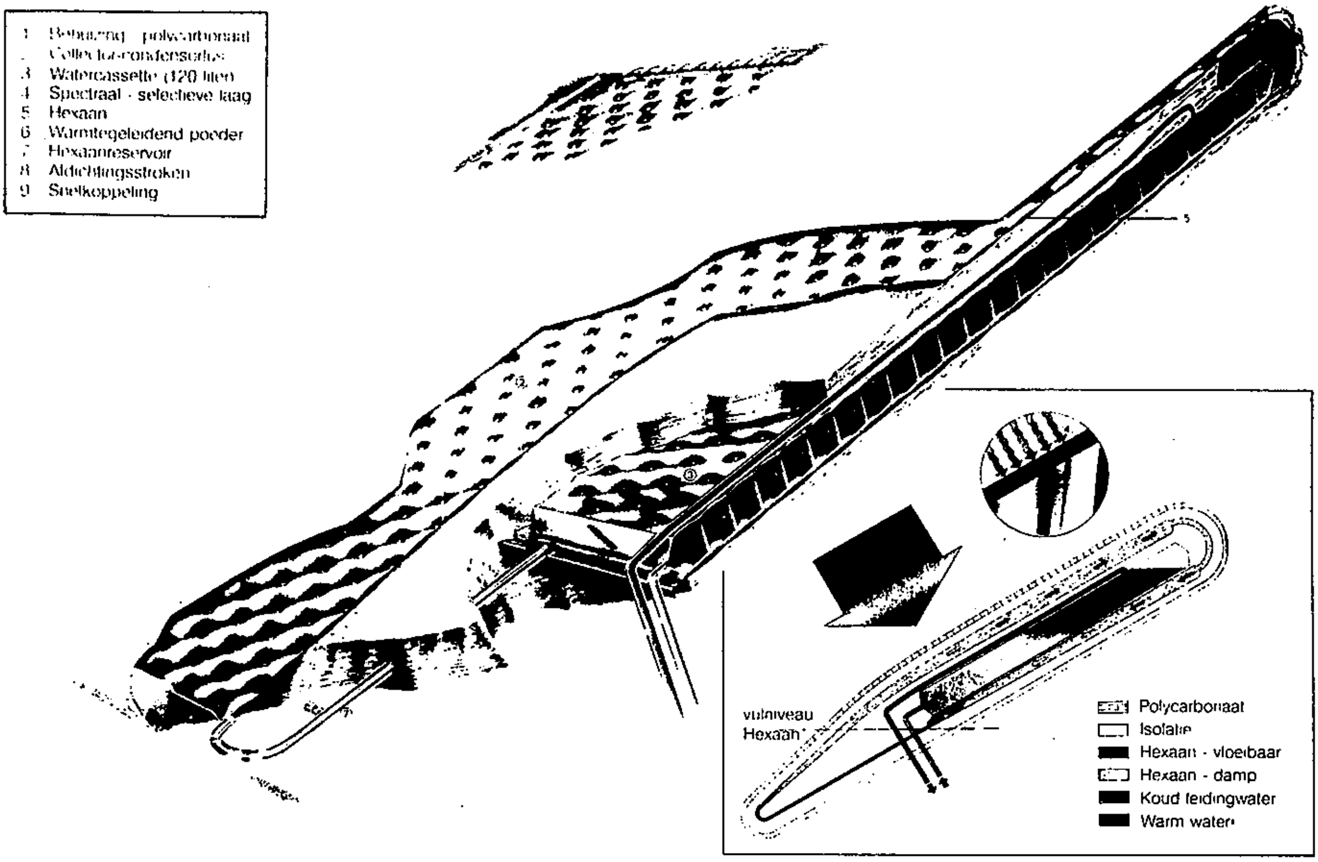
120 liter

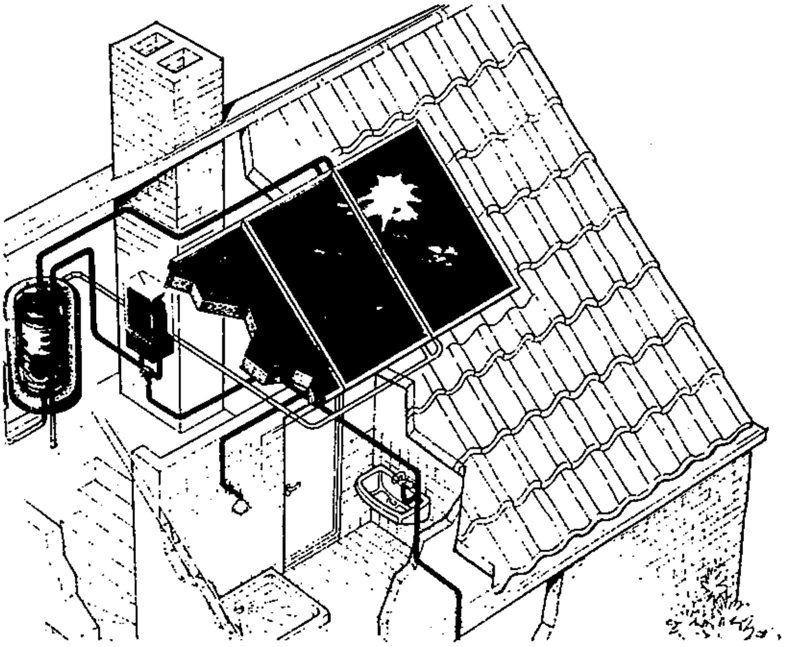








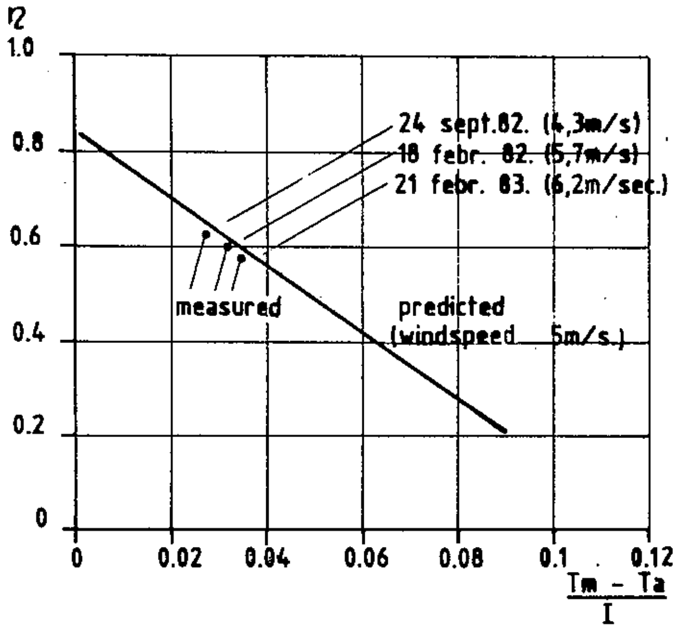
Nagron



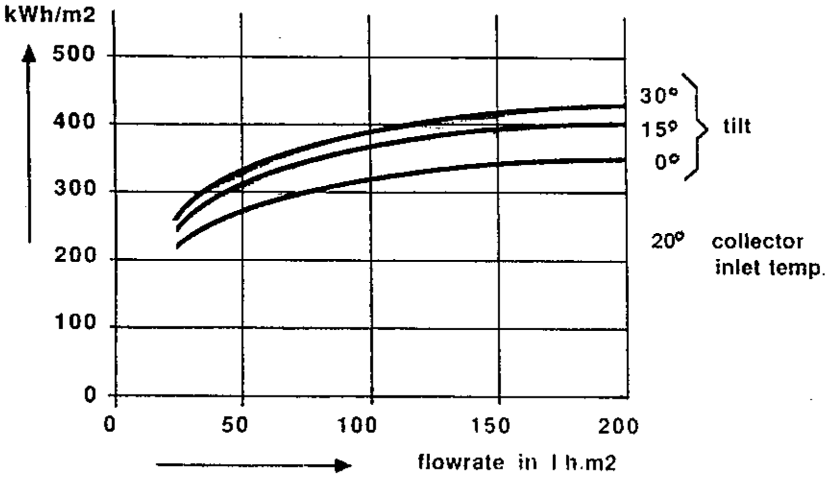
Zonnevang

Domestic Hot Water Solar Systems

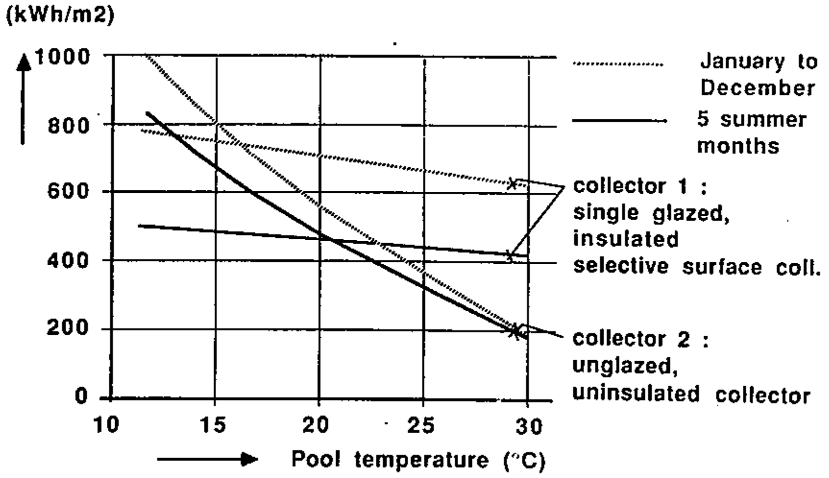
INSTANTANEOUS EFFICIENCY CURVE



Heat recovered in summer (5 months)



Collector energy output



Anodized Aluminum as Absorber Material

Kazuo TAGA

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In 1974 SHOWA aluminum has developed the method of a selective coating treatment through the special anodizing process on the surface of aluminum. With this result SHOWA was invited to take part in "SUNSHINE PROJECT" which is a Government-sponsored project to develope how to utilize the solar energy practically and SHOWA has been engaged in the studies on consignment of the Japanease Gorvernment for the improvement of selective performance,durability and economics. The selective coating with good performance was completed and technology for the mass-production has been also established. We first started the studies for the developed of a selective coating that satisfies these requirements of

a) absorptance (α) of 0.9 and over, emissivity (ε) of 0.1 and below.
b) adaptation to mass producing.
c) durability against temperatures over 250°C.
d) treatment cost no more than black paintings.
e) durability under the conditions of practical use.

Figure 1 shows cross section of anodized aluminum with selective surface. The thickness is about 1 μm to top porous layer from Aluminum base metal. The consistuent of deposited metal is nickel.

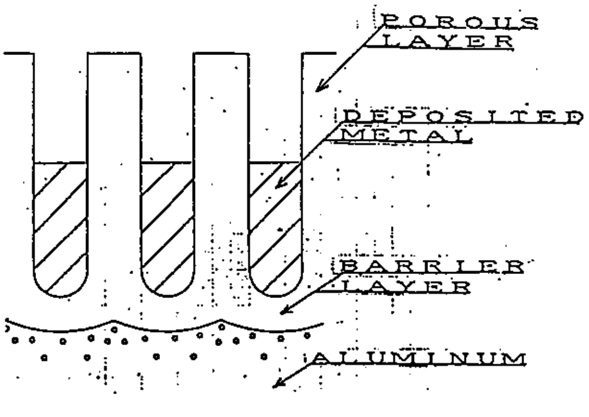


Fig 1 CROSS SECTION OF ANODIZED ALUMINUM as ABSORBER MATERIAL

Figure 2 shows the flow chart which is a selective surface treatment process on aluminum. First of all, aluminum base metal is cleaned in a weak alkalin solution bath. And then, it is rinsed in a water bath. Next it is anodized. By this treatment porous layer is formed on the surface of aluminum base metal. After this treatment this metal is rinsed in a water bath and then electrolytic pigmentation treatment is done in solution contained nickel ion for depositing nickel in porous layer. By this process of treatment our selective coating is formed and efficiently absorbs the sun's rays and suppresses the radiation of infrared rays.

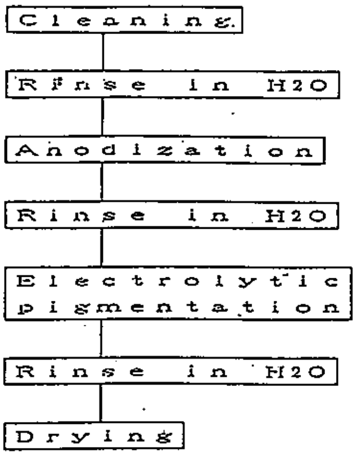


Fig 2 TREATMENT PROCESS

Figure 3 shows the spectrum reflectances of selective coating of anodized aluminum and black paint coating. According to this chart reflectance of selective coating is low up to 2 μm. In the case of black paint the spectrum reflectance is low in all range of wave length.

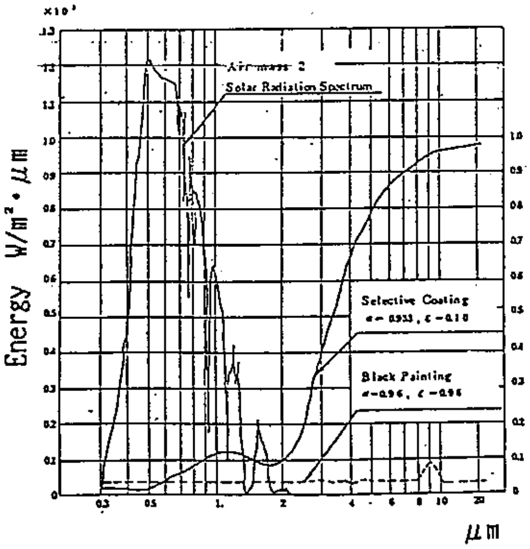


Fig 3 THE SPECTRUM REFLECTANCE OF SELECTIVE COATING

Durability of selective coating is necessary, because collectors are used for a long term. For the durability of our coating we tested about five items, heat resistance, humidity resistance, corrosion resistance, weather resistance and humidity & heat cycle resistance. Table 1 shows the results of these tests. The solar absorptance and emissivity of the specimen were measured before and after the tests. From this table we understand the changes of both the absorptance value and emissivity value are within 0.04 before and after the tests.

1. Heat Resistance

Selective coating must be durable against high temperature, because in case of a flat type collector it's temperature becomes about 200°C under the stagnation condition. Selective coating showed no deterioration in selectivity by the accelerated test held under 350°C within 1000 hours.

Testing Items		α·ε	before test	after test
Heat Resistance (350°C × 1000Hrs)		α	0.93	0.92
		ε	0.10	0.06
Humidity Resistance (98% RH·50°C × 3000Hr-s)		α	0.92	0.92
		ε	0.08	0.10
Corrosion Resistance (Water dipping) (room temperature × 1000Hrs)		α	0.95	0.94
		ε	0.09	0.10
Weather Resistance (Outdoor exposure)	with glass cover (1 year)	α	0.93	0.93
		ε	0.09	0.09
	without cover (1 year)	α	0.93	0.90
		ε	0.08	0.09
Weather Resistance (Sun shine carbon arc. with glass cover, 1000Hrs)		α	0.94	0.92
		ε	0.14	0.17
Humidity & Heat Cycle (10°C·1Hr=70°C·1Hr, 250cycles)		α	0.94	0.91
		ε	0.06	0.07

TABLE 1 DURABILITY OF ANODIZED ALUMINUM as ABSORBER MATERIAL

2. Humidity Resistance

Solar absorber plates are usually enclosed in a collector with a little ventilating and a little humidity. Selective coating hardly presented deterioration in selectivity by the accelerated test held under 50°C and 98% RH.within 1000 hours.

3. Corrosion Resistance

Since solar collector is installed outdoors, atmospheric moisture or rains fall may enter into collector and moisture may be condensed in collector case. Durability against water is desired in this sense. Selective coating hardly presented deterioration in selectivity by the accelerated immersion test under room temperature for 1000 hours.

4. Wether Resistance

In case glazing are broken, selective coating will be exposed directly to atmosphere. Assuming these conditions, the six months out door exposure test was performed, but deterioration of selectivity was hardly observed. It was also confirmed that the deterioration of the surface without glazing was the little decrease of absorptivity during the one year out door exposure test.

Figure 4,5,6 are absorber plates manufactured by SHOWA. Figure 4 is absorber plate welded by means of brazed Therma Fin process. Therma Fin process is a revolutionary new high-speed high-frequency welding technique permitting continuous welding of fin and tube into one-piece solid-body construction. By this process the different or same types of metals can be welded together. Figure 5 is absorber plate connected with fin and tube by means of hammering. This fin is extruded aluminum. Figure 6 is Roll-Bond absorber. Roll-Bond means a roll-bonded sheet. The sheet has a hollow circuit between two pieces of rolled aluminum. Now SHOWA is producing heat pipe type domestic solar water heater utilized Roll-Bond absorber plate.
These absorber plates are treated the selective coating on one side. We are fabricating solar collectors using these absorber plate.

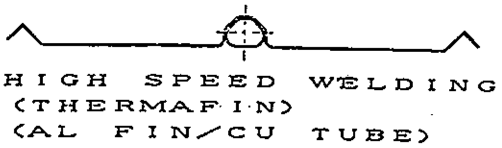


Fig 5

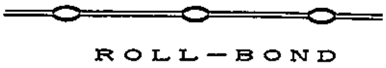
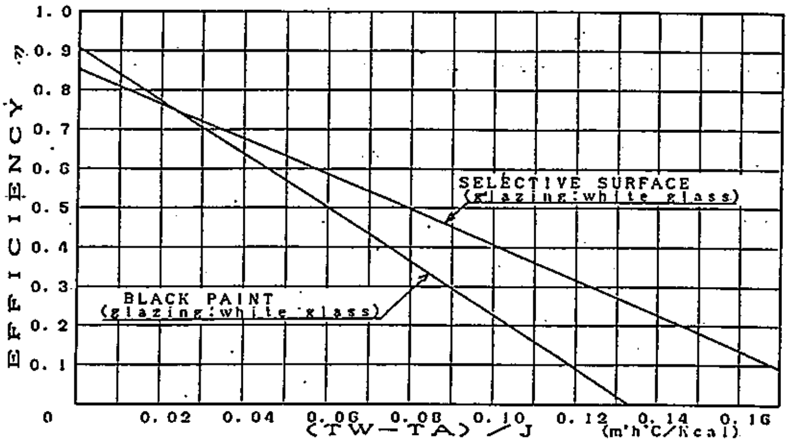


Fig 6

Figure 7 shows the difference of solar collector performances between selective coating and black painting absorber plate. Two type collectors are same specifications except coating of the absorbers. Glazing is a single white glass. Bottom insulation is a glass fiber which thikness is 50mm. Collectors treated with selective coating show significantly higher thermal efficiency than those using black paint.



TW : mean water temperature =(Ti−To)/2 (°C)
TA : ambient temperature (°C)
J : solar radiation (Kcal/m²h)
η : collector efficiency

Fig 7 COLLECTOR PERFORMANCE CURVE

Q : In production process, don't you apply ceiling process ?

A : We are not using ceiling process.

Q : Do you wash it in cold water or in hot water ?

A : Cold water.

Q : Can you provide samples ?

A : Yes.

Notice :

Each "Q and A" was edited according to the reporter's declaration after the workshop. Therefore incomplete description of Q and A was unavoidable for reports on which no declaration was made by authors.