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SOLAR ENERGY PROGRAM

CHAPTER FROM THE ENERGY AND ENVIRONMENT ANNUAL REPORT 1979

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SOLAR ENERGY PROGRAM

FY-1979

The research reported in this volume was undertaken during FY 1979 within the Energy & Environment Division of the Lawrence Berkeley Laboratory. This volume will comprise a section of the Energy & Environment Division 1979 Annual Report.

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SOLAR ENERGY PROGRAM

INTRODUCTION

Solar energy has become a major alternative for supplying a substantial fraction of the nation's future energy needs. The Department of Energy (DOE) supports activities ranging from the demonstration of existing technology to research on future possibilities; and at LBL projects are in progress which span that range of activities.

To assess various solar applications it is important to quantify the solar resource. In one project, LBL is cooperating with the Pacific Gas and Electric Company in the implementation and operation of a solar radiation data collection network in northern California. Special instruments have been developed and are now in use to measure the solar and circumsolar (around the sun) radiation. These measurements serve to predict the performance of solar designs which use focusing collectors (mirrors or lenses) to concentrate the sunlight.

Efforts are being made to assist DOE in demonstrating existing solar technology. DOE's San Francisco Operations Office (SAN) has been given technical support for its management of commercial-building solar demonstration projects. The installation of a solar hot water and space heating system on an LBL building established model techniques and procedures as part of the DOE Facilities Solar Demonstration Program. Technical support is also provided for SAN in a DOE small scale technology pilot program in which grants are awarded to individuals and organizations to develop and demonstrate solar technologies appropriate to small scale use.

In the near future it is expected that research will exert a substantial impact in the areas of solar heating and cooling. An absorption air conditioner is being developed that is air cooled yet suitable for use with temperatures available from flat plate collectors. With inexpensive but sophisticated micro-electronics to control their operation, the performance of many-component solar heating and cooling systems may be improved, and work is under way to develop such a controller and to evaluate commercially available units.

Research is continuing on "passive" approaches to solar heating and cooling where careful considerations of architectural design, construction materials, and the environment are used to moderate a building's interior climate. Computer models of passive concepts are being developed in a collaborative project with Los Alamos Scientific Laboratory. These models will be incorporated into public domain building energy analysis computer programs to be used in systems studies and in the design of commercial buildings on a case study basis. The investigation of specific passive cooling methods is an ongoing project; for example, a process is being studied in which heat storage material would be cooled by radiation to the night sky, then provide "coolness" to the building.

The laboratory personnel involved in the solar cooling, controls, and passive projects are also providing technical support to the Solar Heating and Cooling Research and Development Branch of DOE in developing program plans, evaluating proposals, and making technical reviews of projects at other institutions and in industry.

Low grade heat is a widespread energy resource that could make a significant contribution to energy needs if economical methods can be developed for converting it to useful work. Investigations continued this year on the feasibility of using the "shape-memory" alloy, Nitinol, as a basis for constructing heat engines that could operate from energy sources such as solar heated water, industrial waste heat, geothermal brines, and ocean thermal gradients.

Several projects are investigating longer-term possibilities for utilizing solar energy. One project involves the development of a new type of solar thermal receiver that would be placed at the focus of a central receiver system or a parabolic dish. The conversion of the concentrated sunlight to thermal energy would be accomplished by the absorption of the light by a dispersion of very small particles suspended in a gas. Work continued this year on chemical storage processes (such as $2SO_3 = 2SO_2 + O_2$) that could play an important role in providing long-term storage for high temperature power generation cycles. Another project is exploring biological systems. The possibility is being explored of developing a photovoltaic cell, based on a catalyst (bacteriorhodopsin) which converts light to electrical ion flow across the cell membrane of a particular bacteria.

ULTRAFINE PARTICLE SUSPENSIONS FOR SOLAR ENERGY COLLECTION*

A. J. Hunt

INTRODUCTION

Solar energy is being considered as a practical source of high temperatures to operate very efficient heat engines and provide industrial process heat. Many current concepts for conversion of sunlight to heat are based on traditional, nonsolar technologies. This project uses a novel approach to match the characteristics of concentrated sunlight to the requirements of heating a gas.

The purpose of the work is to develop a new type of solar thermal receiver that utilizes a dispersion of very small particles suspended in a gas to absorb the radiant energy directly from concentrated sunlight. The Small Particle Heat Exchange Receiver (SPHER) operates by injecting a very small mass of fine, light-absorbing particles into a gas stream. The air-particle mixture then enters a transparent chamber that forms the solar thermal receiver. Sunlight is focused through the window of the receiver by a concentrating solar collector (a parabolic dish or a field of heliostats). Suspended particles absorb the radiation and, because of their very large surface area, quickly transfer the heat to the surrounding gas. The air-particle mixture heats to the desired temperature until the particles vaporize or oxidize. The gas may be heated to medium or high temperatures as suitable for a variety of power or industrial process heat requirements. Mechanical power can be produced if the gas is compressed before it is heated and subsequently expanded through a turbine or other device such as a Brayton cycle engine. The resulting shaft rotation can be used to turn an electrical generator or provide mechanical power for other purposes.

The most important characteristic of these small particles is their extremely large surface area per unit mass of absorber material. (One gram of particles for this application has a surface area of the order of 100 square meters.) This results in a high absorption coefficient for the incoming sunlight and a high optical efficiency for the receiver. The combination of the large surface area and the small size of the particles insures that the particle temperature stays to within a fraction of a degree of the gas temperature. Thus, the highest temperature present in the receiver is essentially that of the working gas. This results in considerably lower radiant temperatures in the chamber compared to other solar receivers that produce gas of the same temperature. Since the chamber window inhibits infrared reradiation from the heated particle-gas mixture, the receiver has a high overall efficiency.

There are several other important advantages to the use of small particles as heat exchanger elements. SPHER eliminates the need for heavy and complex heat exchanger elements, since its receiver basically consists of a hollow chamber with a window, resulting in a very lightweight structure. Because the heat exchanger is uniformly distributed throughout the chamber, the gas need not be pumped through pipes or small orifices. Therefore the amount of energy required to overcome pressure losses is considerably reduced. Because the heat exchanger is vaporized in the process of performing its function, problems associated with maintenance, failures, heat stress, or corrosion, which occur with conventional heat exchanger elements, are eliminated.

The basic small particle gas receiver can be scaled to any size. Upper size limitations are determined by window design, by the use of multiple windows, a matrix of transparent quartz tubes, or other modular designs; this technique is applicable to sizes characteristic of the solar central receiver program. The concept can also be applied on a small scale by using a parabolic dish concentrator and off-the-shelf gas turbines in the 10 kW size range.

Because there are no temperature limitations on the heat exchanger in the usual sense, SPHER is applicable to the field of high-temperature solar process heat. The ultimate temperatures achievable using SPHER are limited only by the chamber walls, the window (if pressurized operation is desired), and the second law of thermodynamics. It appears that gas temperatures in excess of 2000°C are achievable.

Calculations performed earlier quantify the optical and physical processes of absorption and heating of the particles.[1,2] Related considerations investigated include particle production methods, window and chamber designs, hybrid fossil-solar compatibility, as well as environmental and safety factors. Analyses confirm that the operating parameters are flexible and suitable to a variety of solar thermal power applications. A modest laboratory apparatus built earlier successfully demonstrated the SPHER concept.[3]

ACCOMPLISHMENTS DURING 1979

In FY 1979 the operation of the various subsystems was investigated and the overall efficiency and system parameters were determined. Theoretical work was performed to determine the efficiency and operating conditions of a high-temperature receiver utilizing a transparent window. Two different window designs were evaluated, material and sealing considerations were addressed, and window costs were determined. A new type of heat engine utilizing the SPHER concept was studied to determine its thermodynamic efficiency. An experimental program was initiated to produce and characterize the particle suspensions. A patent application was filed on the SPHER concept with the rights held by DOE.[4]

Windowed Receiver Studies

A study of the optical and thermodynamic efficiencies of single- and double-windowed high-temperature gas receivers was completed.[5] The two-window design utilized a cooling gas flow between the windows. Calculation of receiver performance is based on a detailed window energy balance that includes the energy flows resulting from both radiative and convective transfer to and from the window(s). Equations governing the energy flows were written using conservative estimates for the quantities involved. Parameters were varied by an iterative process until a self-consistent solution was obtained. Once the window temperatures were determined by this process, the total energy loss and the receiver collection efficiency were calculated.

The analysis is based on the assumption that the receiver is sized to 4 MW(t) per module. In the double window design, cooling air flowing between the windows comes directly from the compressor and then passes on to the recuperator. Receiver efficiencies obtained for a gas temperature of 1000°C using high silica windows spanning a 1.7-m opening were 93.8% and 95.4% for the single- and double-window designs respectively. Losses due to each mechanism are computed and their relative contributions assessed.

It is important to consider the overall system efficiency as well as that of the receiver alone. Figure 1 illustrates a Brayton cycle turbine system connected to a SPHER. In the case of a single windowed receiver, the air from the compressor passes directly to the recuperator that recovers heat from the exhaust gases. In the double window design, the compressed air first passes between the windows to provide cooling.

Single and double window systems are compared in overall thermodynamic efficiency (product of the receiver and Brayton cycle efficiencies) as a function of turbine inlet temperature in Fig. 2. Note that the thermodynamic cycle efficiency

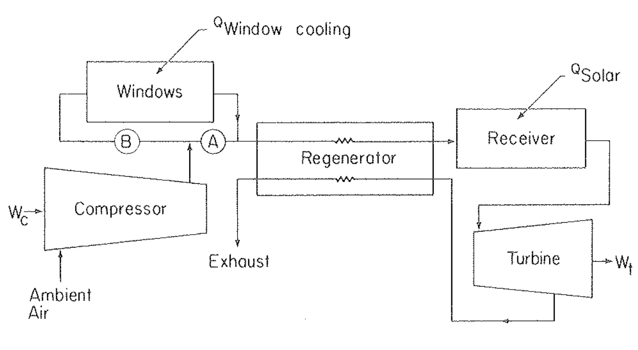

Fig. 1. System diagram for a Brayton-cycle turbine combined with a SPHER. Path A is used for the single-window design, and Path B for the double-window design. (XBL 809-1900)

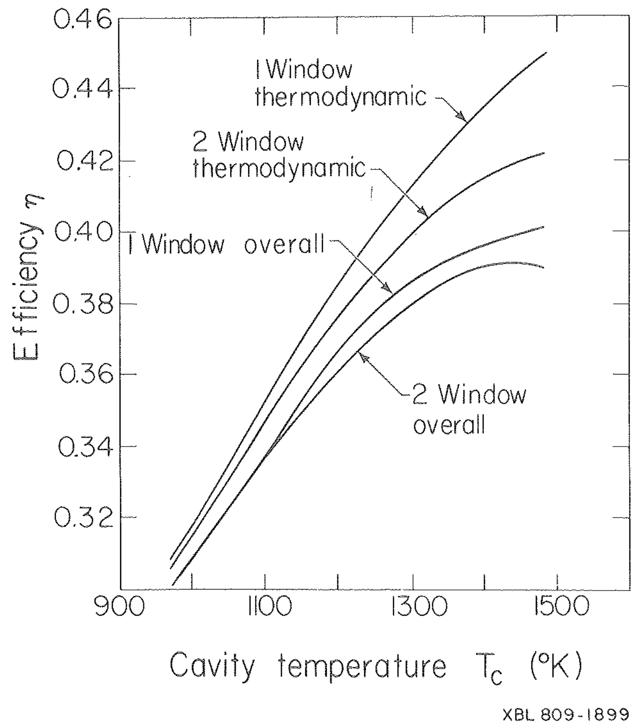

Fig. 2. Thermodynamic and overall efficiencies for one and two window systems. Note: Overall efficiency is defined as the product of thermodynamic and receiver collection efficiency. (XBL 809-1899)

associated with the single window is significantly higher than that for the two-window design. This occurs because the cooling air for the two-window system passes into the recuperator at a higher temperature, reducing the amount of heat recovered from the exhaust gases. The overall effect of this is to make the single-window system more efficient even though the efficiency of the double-window receiver alone is higher.

Sensitivity studies performed by varying each parameter from the baseline design indicate their effects on system efficiency. Techniques used in this analysis are not restricted to receivers of the SPHER type but are general enough to be applied to a number of windowed receiver designs.

Efficiency Study of New Type of Heat Engine

Early in the program, it was realized that the basic concept of the direct absorption of sunlight in a gas could be applied to a number of situations; in particular, it presented possibilities for new types of heat engines. To investigate the feasibility of reciprocating engines in which the solar flux is deposited into the cylinder, a preliminary investigation of the associated thermodynamic cycle efficiencies was initiated.[6] The basic concept is illustrated in Fig. 3. The cylinder induces a charge of cool air that contains a suspension of small heat-absorbing particles. At some point in the cycle, an optical valve opens, allowing concentrated sunlight to be focused through the top of the cylinder by a quartz window acting as a lens.

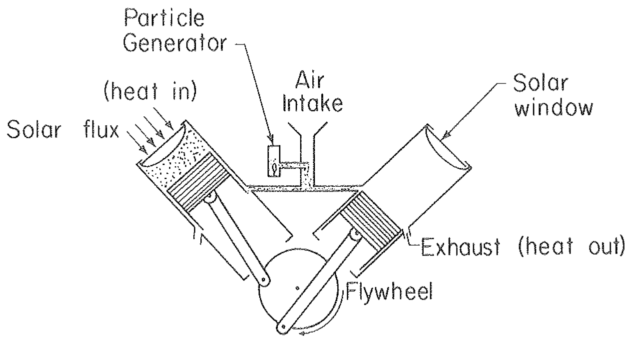

Fig. 3. Schematic view of simple two-cylinder solar engine. Cylinder on the left is near end of compression stroke. At this point, solar flux is directed into cylinder. Cylinder on right is near the end of work stroke. Particles in this cylinder have oxidized. (XBL 809-1897)

The air-particle mixture absorbs the sunlight directly and heats the gas. As the heated gas expands, work is done on the piston providing mechanical power. The cycle efficiency for different periods and phases of the heat injection is being investigated.

The thermodynamic question can be posed as follows: given a constant rate of heat input, and a period equal to the reciprocal of the number of cylinders, what is the optimum timing and the corresponding efficiency? Preliminary results indicate that the efficiency for a two-cylinder engine is about 50% for a compression ratio of 12 when heat injection starts well before the top dead center position of the piston.

Experimental Particle Production

A laboratory has been obtained, equipped, and is in operation. Work has begun on two alternative methods of producing carbon particles suitable for high-temperature receiver work. One method utilizes an enclosed diffusion flame and has successfully produced very dense particle streams. The second method relies on a high-intensity arc in an inert gas atmosphere. Work is under way on the experimental chamber and a set of remotely controlled electrode holders are being fabricated.

PLANNED ACTIVITIES FOR 1980

The experimental program for next year will have three main emphases: particle production, particle characterization, and the determination of the performance of the particle-gas mixture as a heat exchanger. Work will continue on using rich-burning flames with various feed gases and combustion parameters. High-intensity arcs will be used as a means of producing particles of a variety of carbon allotropes. Once good candidates for particle generation are obtained, measurements will be performed to characterize the particles and determine their operating parameters in a receiver.

Opacity measurements will be performed on the particle-gas mixture as well as on collected samples of the particles. Oxidation properties will be determined by optical measurements on particle samples in a high-temperature furnace. Electron microscopy will be used to determine the size, size distribution, and shape of the particles.

An analytical program will be used for guidance and interpretation of the laboratory work. Computer codes to analyze the optical and thermodynamic properties of the system will be written.

A chamber will be constructed to determine the temperature rise and energy exchange to a particle-gas stream. It will utilize a tungsten halogen light source to simulate the sun. The goal is to gain enough experience to design a test receiver to operate with a solar collector. If enough interest is expressed, future plans include the fabrication of a larger SPHER and a testing program at a National Solar Thermal Test Facility.

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*This work has been supported by the U.S. Department of Energy under contract no. W-7405-ENG-48.

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SENSIBLE HEAT STORAGE FOR A SOLAR THERMAL POWER PLANT*

T. Baldwin, S. Lynn, and A. Foss

INTRODUCTION

The energy input to a solar power plant depends on the amount of insolation reaching the collection field. Maintenance of a constant level of power generation through the early evening hours or through a period when the cloud cover varies requires integration of the heat collection and power generation units with some type of energy storage unit.

This work examines in detail one possible configuration for a solar power plant with a sensible-heat storage unit. The proposed flow sheet allows thermal energy storage between the heat collection unit and the power generation unit without a reduction in the thermodynamic availability of the energy supplied to the power turbines. Energy is stored by heating a checkerwork of magnesia bricks. A gas that is circulated from the solar collector through the storage unit and the power plant boiler serves as the heat-transfer medium. A standard steam Rankine cycle is used in power generation. The process configuration is shown in Fig. 1.

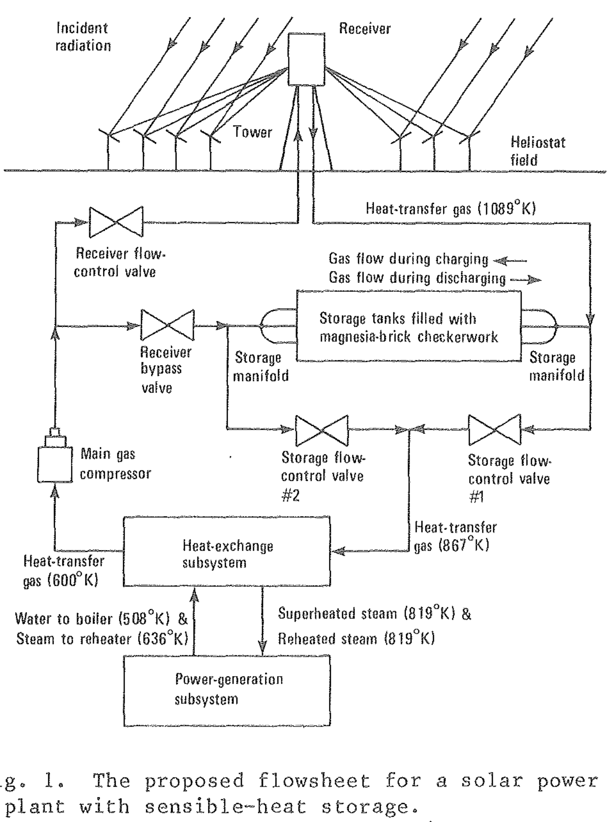

Fig. 1. The proposed flowsheet for a solar power plant with sensible-heat storage.
(XBL 797-2191)

This work was begun in 1977 to compare power costs of a process using sensible heat storage to those of a process using the sulfur-oxide chemical heat storage concept.[1,2]

ACCOMPLISHMENTS DURING 1979

A computer model was developed to predict the behavior of the sensible-heat storage unit and to aid in sizing the storage unit. Procedures were developed to estimate the cost of electricity generated by the solar power plant. These procedures illustrate the effect of changes in the energy storage unit on the cost of electricity. The effects on the storage unit and on the total plant design of changing several process and design parameters were then evaluated.

The proposed configuration for a solar power plant with sensible-heat storage for nighttime electricity generation produces electricity at a cost of 8.7¢/kW(e)-hr. If one forgoes storage for nighttime power generation, the cost drops to 7.6¢/kW(e)-hr. Both of these power plants convert 32% of the energy absorbed by the central receiver into usable electric energy. These costs and efficiencies are more favorable than those of the sulfur-oxide storage system[1] for which the cost was 10.7¢/kW(e)-hr at 25% efficiency, but they are not so favorable as those of Tyson et al.[3] who estimated the cost and efficiency for a sulfur-oxide storage system combined with a hybrid Brayton-Rankine cycle to be 7.7¢/kW(e)-hr and 39%.

Modifications in the sensible-heat storage process to incorporate a Brayton cycle as topping for the steam cycle showed no advantage in power cost.

Because power costs for plants with sensible-heat systems are close to those of sulfur-oxide systems and because the uncertainties in technical aspects are less for the sensible-heat systems, it appears that they will serve best for short-term storage at the present time.

PLANNED ACTIVITIES FOR 1980

This work is completed and no further work is planned.

FOOTNOTE AND REFERENCES

*This work was funded during FY 1979 entirely by the Department of Energy, Division of Energy Storage Systems.

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PASSIVE SYSTEMS ANALYSIS AND DESIGN*

R. Kammerud, H. Akbari, B. Andersson, F. Bauman, C. Conner, M. B. Curtis, M. Daneshyar, A. Gadgil, A. Mertol, W. Place, T. Webster, K. Whitley, and T. Borgers

INTRODUCTION

The Passive Systems Analysis and Design Group began in response to a void in passive solar technical information and passive solar analysis tools. Historically, the primary focus of the program has been computer modeling. This work has been a joint undertaking of the Solar Group at LBL and the WX-4 group at Los Alamos Scientific Laboratory, which had responsibility for the development of the active solar simulation capabilities in DOE-I and DOE-II. Computer work is being coordinated with the conservation group at LBL, which has primary responsibility for the development of conventional building analysis capabilities of DOE-II. Some of the passive solar analysis and design projects are also related to work being done in the Windows and Lighting program at LBL. We are currently shifting the focus of our activities from the residential to the commercial sector.

Recently the group has expanded its efforts to include building design projects. Projects of this nature provide a framework for development of concepts, design tools, and technical information directly related to commercial buildings and the design community's needs. The Passive Solar Program at LBL continues to provide support for related DOE activities in the areas of national program planning, solicitation preparation, contracting, and contract technical monitoring.

ACCOMPLISHMENTS DURING 1979

Heat Transfer Analysis

Theoretical and experimental heat-transfer studies accounting for thermocirculation, single-zone convective heat transfer, and convective heat transfer through doorways and other wall openings were performed.

A detailed thermal analysis of both laminar and turbulent flow in thermocirculation systems was completed, documented, and successfully compared to laboratory data found in the literature. This detailed loop model (DLM) was used to generate simplified algorithms capable of deriving the outlet temperature and flow rate. Specifications were written to include these algorithms in the public domain computer program BLAST (Building Loads Analysis and System Thermodynamics), extending its capabilities to storage walls and massless vertical collectors.

A small-scale experiment designed to measure convective heat transfer was designed and assembled. The apparatus was used to generate data for comparison with the previously cited algorithms. Exploratory studies of the two-zone problem were initiated using the apparatus.

A model designed to simulate the thermal performance of roof pond systems was developed. The model includes options, such as an evaporative water layer over water containment bags; and movable insulation between both the roof pond and the environment, and between the occupied space and the roof pond. Compared to currently available models, this model performs a more detailed analysis of the interaction of water layers and the environment.

Other refinements and extensions of BLAST were completed: successful comparisons were made between BLAST and thermal data from test cells located at LASL; algorithms describing ventilative cooling were inserted; and BLAST specifications were written to include movable insulation.

Building Performance Studies

Building experiments can provide detailed data for validating thermal simulations of well-established passive systems or can serve as a tool for exploring the behavior of new passive concepts. In the former category of experiments, a number of test cells and passive residences in the U.S. have been heavily instrumented for acquiring weather, auxiliary consumption, and internal temperature data. The major unknown in each of these structures is the level of infiltration. In contribution to the national program for passive system data acquisition and thermal simulation validation (more specifically, in support of BLAST validation), the LBL Passive Solar Group has built an infiltration measuring apparatus modeled after a similar device developed by the LBL Building Envelopes

Group. This device will be used on a variety of instrumented passive structures to produce the full complement of data required for proper validation of building energy analysis computer programs. In addition to these validation-related experiments, exploratory studies were initiated on a double-envelope, convective-loop residence in Martinez, California.

BLAST was used extensively to study the sensitivity of residential heating and cooling to structural mass and thermostatic controls.

Plans were made for using BLAST in commercial building parametric sensitivity studies. A review of various commercial building energy consumption studies was made in order to:

- identify the building types which account for sizeable fractions of the national energy consumption.
- identify the nature of the energy demand.

Based on that review, the decision was made to:

- emphasize retail-wholesale, office-public, and educational building types
- give balanced consideration in accounting for space heating, space cooling, lighting and distribution energy.

Passive Solar Building Design and Design Tools

Design and analysis assistance was given in varying amounts to several building projects with the aims of (1) assisting in the design of better passive buildings, and (2) identifying design requirements not fulfilled by commonly understood and available tools.

At the request of the Pittsburgh Energy Technology Center, LBL conducted extensive analysis on a proposed energy conservation building to determine the energy savings of passive design elements compared to those of the original design, and to assist in design refinement. Several helpful design tools were identified, including better methods of displaying weather information, shade design using sun charts and a graphic technique, and analysis of window placement and construction.

Design assistance was given to several projects which asked for help in assessing the energy impacts of their designs, and critiques of their integration of architectural and energy considerations. The designers of the Heavy Ion Institute at Oak Ridge National Laboratory received advice on the architecture, energy design, and instrumentation of their underground/passive building. The designers of a two-unit residential passive retrofit came to us for advice on their own passive design. LBL involvement resulted in a much simpler, less expensive system capable of delivering more heat than the original design.

Members of the Passive Solar Group have worked closely with the design team for the Colorado Mountain College Classroom and Administration building(s). Several important decisions have been made with regard to structure, glazing areas, and mechanical systems as a result of energy analysis by the Passive Solar Group.

All of these passive solar design activities have been used to identify tools useful during the design process. Participation of LBL personnel as designers, experts in building thermal analysis computer programs, and as observers of the design process have highlighted the need for analysis tools and capabilities, simpler design tools, graphic design techniques, and simple calculations. This information allowed the Passive Solar Group to direct its development of BLAST toward these capabilities most needed by passive solar designers, and to encourage the development of building thermal analysis programs suitable to architects' most immediate needs.

Headquarters Support

The year's activities in the area of headquarters support vary from preparation of a marketable products solicitation to preparation and publication of a report on passive and hybrid solar heating[1] to completion by an LBL subcontractor of a passive solar design workbook for residential-scale buildings.

PLANNED ACTIVITIES FOR 1980

Heat Transfer Analysis

The thermosiphon DLM will be completed and used to generate algorithms describing system performance as a function of solar input, ambient weather conditions, load profile, collector characteristics, and heat exchanger properties. Thermosiphon experiments will be used to validate the general behavior of the theoretical models and to establish the effective heat-transfer coefficient for use in those models.

The single-zone room convection model will be extensively explored and sensitivity studies performed to assess the need for more sophisticated convection calculations in the BLAST loads program. Results from the interzonal convective transfer experiment will be used, along with data from related experiments at LASL and NBS (National Bureau of Standards), to generate algorithms for inclusion in BLAST. The roof pond model will be completed and checked, and software written for inclusion in BLAST.

By the end of the fiscal year, the research version of BLAST/Passive will contain the following new capabilities:

- A detailed model describing the interaction of storage roof systems with occupied space.
- A daylighting algorithm. (This project will be performed in conjunction with the Windows and Lighting program at LBL.)
- An algorithm describing convective heat exchange between thermal zones.
- Analysis techniques for shaded roof aperture systems.

- Routines for innovative glazing materials and glazing coatings.

- Algorithms for thermocirculation systems.

A documented version of BLAST/Passive will be made available to the design community. The following capabilities will be included:

- Direct-gain systems with movable insulation.

- Thermocirculation systems with massive and nonmassive absorbers.

- Direct ventilation cooling of the occupied space.

- Direct conductive coupling between thermal zones.

Passive Solar Building Design and Design Tools

LBL will continue its cooperation with the designers of the Colorado Mountain College. Two other case study projects will be added: a small passive solar commercial building in Santa Rosa, CA, which will serve as both office space and laboratory, and a large passive multistory shopping center in Newport Beach, CA. All three projects have received grants from DOE for their passive solar design.

Requirements for an architect's energy analysis tool will be further refined. Informative booklets to assist with design of fixed shading devices and selection of window orientation and construction will be produced and distributed. More design tools will be identified during the case studies, and their development will be pursued.

Building Performance Studies

Infiltration measurements will be made on a variety of passive solar structures and BLAST predictions will be compared to the data from direct-gain and Trombe Wall test cells and residences. Exploratory studies will continue on the double-envelope house; data will be collected on weather conditions, solar radiation, interior temperatures, convective flow rates, infiltration ground temperatures, and auxiliary consumption. BLAST applications for residential parametric sensitivity studies will continue. Thermal mass and thermostatic control studies will be extended to more climates, glazing distributions, shading operations, and building configurations; effects of ventilative cooling and movable insulation will be investigated. Simplified methods will be devised for evaluating the thermal effects of massive construction. Parametric studies will be performed using the thermocirculation, room convection, and roof pond models.

BLAST applications for commercial parametric sensitivity studies will focus on: building size, proportion and orientation; glazing area and distribution; human, lighting and equipment loads; zoning; movable insulation; ventilative cooling; thermal mass; occupant use patterns; and electric lighting control strategies. Daylighting will be investigated for various room geometries and lighting control strategies using experimental models. The output of these experiments will provide instructions to BLAST regarding electric lighting levels for various conditions of sunlight. In addition to energy consumption, considerable attention will be given to the comfort/productivity implications of the factors listed above.

Headquarters Support

A diverse set of headquarters support activities are planned for 1980. These include issuance of the marketable products solicitation written in 1979 and completion of its concomitant proposal review and contract writing tasks; issuance of a basic physical studies research and development solicitation; completion of program area plans for commercial buildings, basic physical studies, products and materials, and commercial building design tools; and completion of the design of a test facility for evaluation of design concepts for commercial passive solar building systems.

FOOTNOTE AND REFERENCE

*This work was supported by the Passive and Hybrid Systems Branch, Systems Development Division, Office of Solar Applications, U.S. Department of Energy, under contract No. W-7405-ENG-48.

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NITINOL ENGINE DEVELOPMENT*

R. Banks, W. Hubert, R. Kopa, M. H. Mohamed, and M. Wahlig

INTRODUCTION

Low-grade heat, in the form of thermal energy at temperatures below the boiling point of water, is a widespread energy resource that could make a significant contribution to worldwide energy needs if an economical technology can be developed for converting it to useful work. The Nitinol Engine Development project is investigating the feasibility of using the thermally-activated shape change phenomenon in certain intermetallic Shape Memory Alloys, particularly the nickel-titanium compound "55-Nitinol", as the basis for thermal-to-mechanical energy conversion at temperatures available from such sources as industrial waste heat, low-temperature geothermal brines, solar-heated water, or the moderate temperature differences that exist in the ocean thermal gradient. An important advantage in using a solid rather than a fluid working medium in such applications is the possibility of eliminating the heat exchangers required by closed-cycle fluid systems, which often constitute major cost and maintenance items in conventional low-temperature energy conversion technologies.

A prototype Nitinol heat engine has been in operation at the Lawrence Berkeley Laboratory since August 1973. Since that time, several iterations of engine design have led to an improved understanding of the important practical considerations in applying this material to energy conversion in continuously cycling heat engines. These studies, as well as experimental and theoretical investigation of the material's thermodynamic and metallurgical properties, have confirmed that Nitinol engines for the recovery of thermal energy from low-grade or waste heat can be constructed; however, the question of economic feasibility is still open.

ACCOMPLISHMENTS DURING 1979

The work of the past year has been focused on experimental investigation of cycling and thermodynamic characteristics of Nitinol through three parallel approaches using specialized test instruments designed and fabricated at the Laboratory during this year and previously. The first of these, an electronically controlled and instrumented Cycle Simulator, was used to compare the effects of performance and lifetime of Nitinol wires cycled under differing thermomechanical conditions (e.g., heating at constant strain versus heating under uniform load.) The Cycle Simulator has the flexibility to vary and control a number of parameters that are critical to practical engine design, particularly in the area of phasing the shape-memory response in the working material with the mechanical response time of engine power take-off components. Based on data derived from the Cycle Simulator studies, comparative efficiencies for the various types of cycles investigated were derived.

A second approach to identifying optimum cycling and work output conditions for Nitinol wires was carried out using a high resolution, laser-beam dilatometer. This instrument, which magnifies axial displacement in a Nitinol specimen by a factor of 200, makes possible observation of variation in the rate of change throughout the complete thermal transition range under controlled and uniform heating rates and stress conditions. Correlating stress and displacement data with calculated heat input values, comparative conversion efficiencies were predicted for a range of thermal cycle conditions.

The third experimental instrument, a Tensile Fatigue Test Stand, fabricated at LBL in early 1979, has subjected Nitinol wire elements to actual engine working conditions for more than one million cycles, the highest limit now known for reproducible cycling of wires working in the mode of linear (axial) strain. This machine, which appears to have overcome many of the problems encountered in previous engine concepts, is the first device since the original 1973 prototype to exceed the million-cycle limit. As in the case of the first engine, systematic improvement in performance of the Nitinol working elements was observed throughout the period of the initial run.

Cycle Simulator Studies

The Cycle Simulator was used this year primarily in the systematic investigation of two types of cycling conditions: the constant strain cycle, and the stress-limited cycle. In the constant-strain cycle, a single Nitinol wire is heated by immersion in a water bath while held at a constant length. Recovery stresses developed in the wire are allowed to come to a maximum before being relieved by controlled relaxation of the simulator mechanism. Stress and strain data are displayed on a storage oscilloscope, and computation of the area enclosed in the oscilloscope gives the work output for that particular cycle. A typical trace for the constant-strain cycle is shown in Fig. 1.

It was found that heating a Nitinol wire through its thermal transformation range prior to initiating shape recovery severely limits the percentage of initial strain that may be imposed on the specimen prior to heating. This also limits the work output per cycle that can be realized over a large number of reproducible cycles. For a wire lifetime expectancy of 10^4 cycles, a strain of 1.0% was found to be the limit for the materials tested, and the maximum calculated conversion efficiency was 1.2% (approximately 6% of the Carnot maximum for the temperatures of the experimental cycle). Limits imposed in heating Nitinol at constant strain have to do with the magnitude of the recovery stresses that develop during the transformation (in excess of 100 Kpsi at 8% strain) and which can effectively exceed the practical yield strength of the material. In addition to being

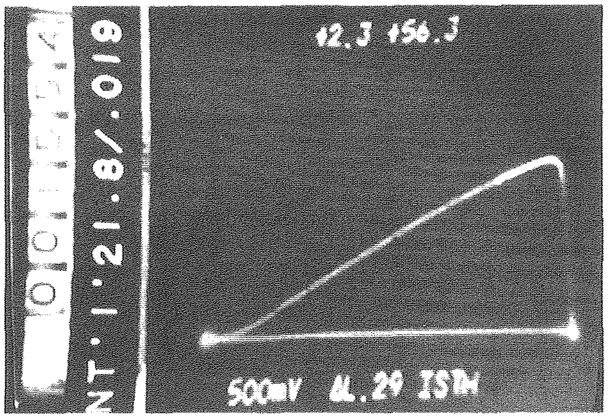

Fig. 1. Video record of a typical constant-strain isothermal cycle. (XBB 786-7388)

an energy transducer, Nitinol is, of course, a realistic engineering material and therefore subject to conventional fatigue constraints like any other metal. The relationship between maximum recovery stress and practical yield strength in Nitinol is closely related to the discrepancy that exists between the calculated strength of pure metals and their observed experimental values. In the case of Nitinol, the recovery stresses generated internally during transformation, must not be allowed to build up to the practical yield strength as a result of external restraining forces, or progressive elongation leading to ultimate failure of the material will result.

For the second series of tests, the Cycle Simulator was modified slightly to apply the shape recovery stress of the Nitinol specimen directly to the lifting of a weight. In this constant-stress cycle, a feasible and reproducible strain limit of 5.0% was observed, with a corresponding increase in indicated conversion efficiency of a factor of ⩾2. To date, these tests have been conducted at a stress limit of 29 Kpsi, substantially below the theoretical practical limit for the material. With increase in applied stress, and resulting increase in work output per cycle, the conversion efficiency of the constant-stress cycle may reasonably be expected to increase even further.

In addition to the simulated engine cycle tests performed on the Cycle Simulator this year, the instrument was also used to evaluate the effects of an alternative approach to heating the wire by controlled electric pulse rather than immersion in a bath. Timed delivery of the electric pulse was adjusted to correspond to the conditions of normal heat delivery (by immersion), and the cycles produced on the oscilloscope were compared. The area of the work diagram for the electric heating technique was found to be almost identical to that produced by continuous heat delivery in the bath. However, in the case of heating the wire with the electric pulse, all of the energy is absorbed by the wire while it is held at constant strain. From this observation, it was deduced that Nitinol wires absorb the latent heat of transformation prior to the shape recovery event, not during the contraction part of the cycle as had been assumed by most prior investigators. This is an important new piece of information in our understanding of the basic mechanism of the shape memory cycle.

Laser Beam Dilatometer

The Laser Beam Dilatometer, shown in Fig. 2, was originally fabricated in 1977 for the purpose of precisely correlating changes in Nitinol thermal transformation thresholds with variation of externally applied stress; it has subsequently proven useful for a number of other applications. Because of the sensitivity of the amplification mechanism of this device, it is possible to isolate macroscopic changes in shape of a specimen due to the shape memory effect from changes solely due to thermal expansion and contraction. Thus it is possible to demonstrate visually that, at the transition thresholds, changes in the thermoelastic properties of Nitinol are essentially discontinuous with continuous variation of stress and temperature.

Of particular interest is the observation that during a complete thermal transformation cycle (complete establishment of the low-temperature phase on cooling, and complete reversion to the high-temperature phase on heating), there is a sensitive region at approximately the middle of the cycle in which the majority of the shape recovery takes

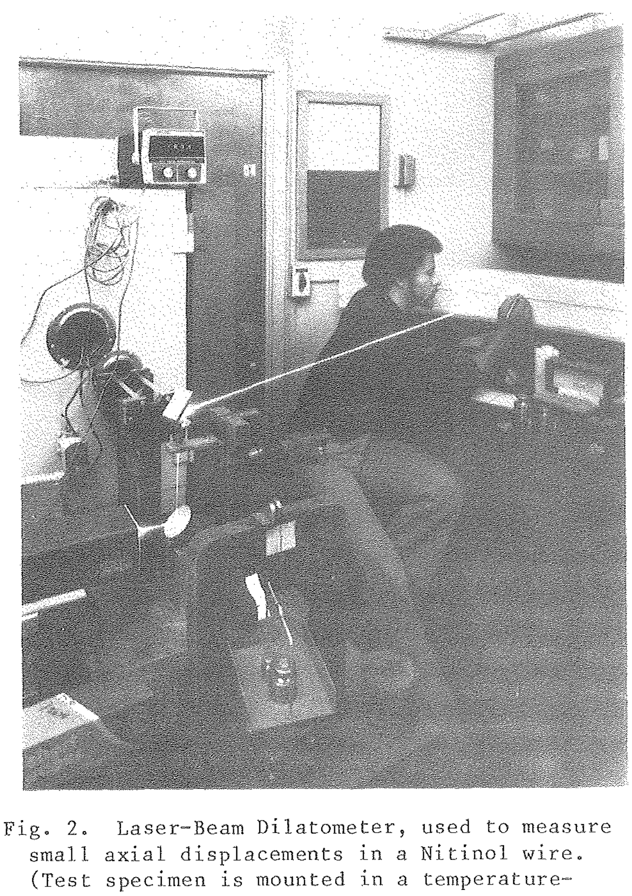

Fig. 2. Laser-Beam Dilatometer, used to measure small axial displacements in a Nitinol wire. (Test specimen is mounted in a temperature-controlled environmental chamber in the background of the photograph). (CBB 796-8367)

place. As heating and cooling is effected (at slow and uniform rates), this most active region is approached by a gradual acceleration in shape-change with respect to rise or fall in temperature, increasing to a change-rate maximum at about the midpoint of the thermal cycle; subsequently, there is again a gradual deceleration in shape-change until the target temperature is reached. This non-uniformity in rate of change, with uniform change in temperature, appears to be enhanced by a directionality that develops in the microstructure of the Nitinol wire. It is a well-known feature of the Shape Memory Effect (SME) in Nitinol that apparent ductility of the low-temperature phase is the result of preferential growth of certain favorably oriented crystal domains (twinned martensite) and shrinkage of others. With repeated cycling (as in the working element of a heat engine), certain of these favored orientations become dominant upon transformation, and the wire develops a "second memory"--a shape change unassisted by externally applied stress--on cooling, a process which has been described as "training". Because transformation threshold temperatures are controlled in part by applied stress, it is to be expected that all martensites of identical orientation (with respect to stress) will be subject to the same local stress conditions, and will transform as a coherent group once the threshold temperature has been exceeded. The appearance of a sensitive thermal region where the SME is at an optimum is therefore interpreted as a reflection of the training process, or a progressive increase in the volume fraction of martensite variants which nucleate in orientations best favored for shape recovery on heating.

After the maximum work output for a "complete" thermal cycle was established by heating and cooling a trained Nitinol specimen to temperatures beyond which there was no observable thermally activated shape change, a series of restricted thermal cycles was performed to determine if work output per cycle would decrease linearly with decrease in ΔT. This was found not to be the case. In a series of experimental trials, the thermal extrema of the cycle were reduced from $\Delta T_{max} = 120^oC$ to $\Delta T = 30^oC$. For the reduced cycle, a work output was achieved that was equal to 51% of the total work of the larger (reference) cycle, although the sensible heat required to produce the work was reduced by a factor of 4. From this it was calculated that the work of the original (reference) cycle could be reproduced by cycling twice the volume of material in the restricted thermal range, but with a net saving in sensible heat input on the order of 50% for the restricted cycle. It thus appears that the work output (and therefore the conversion efficiency) of Nitinol does not increase linearly with increasing ΔT, but that the most favorable range for a practical engine cycle, based on currently available materials, will be in the order of $15^oC \leqslant \Delta T \leqslant 35^oC$. Correlating measured work outputs with calculated heat inputs, conversion efficiencies were predicted for cycles in which $\Delta T = 120^oC$, 60^oC, 30^oC, 20^oC, and 10^oC, respectively. The absolute efficiency attained was 2.6% for the $\Delta T = 30^o$ cycle, which corresponds to 27% of the Carnot maximum for temperatures of 25^o-55^oC. The highest Carnot fraction calculated was 64% for the cycle at $\Delta T = 10^oC$, which had an absolute efficiency of 2.0%. As a corollary to this experiment, a cycle was hypothesized in which $\leqslant$50% of the sensible heat rejected on cooling could be stored and recovered in a regenerator. This component, which has not yet been evaluated experimentally, could theoretically increase the computed efficiency values by a factor of as much as 1.4.

During the latter part of the year, the dilatometer has been used to evaluate changes that have occurred in the performance characteristics of Nitinol wires taken from the Fatigue Test Stand at various intervals. A specimen which had withstood 5×10^5 cycles in the Test Stand at 1.4% strain was investigated, and an increase of >10% work output per cycle was measured as a result of its "training" during Test Stand operation.

Tensile Fatigue Test Stand

The Tensile Fatigue Test Stand was originally constructed with the objective of providing a facility in which the performance of Nitinol wire elements could be observed over many working cycles. Mechanical energy for operation of the test stand comes from the SME recovery stress of a number of Nitinol wires (0.5 m in diameter, 38 cm in length) cycled in parallel between baths of hot and cold water. As a self-powered unit, it is therefore, in a sense, a primitive engine concept as well as a test machine. Mechanical features of interest include relative simplicity of design, and reduction of precision requirements for fabrication by amplification of the modest displacement of the Nitinol wires (approximately 5.3 mm) through a compound lever system. In its present configuration, the machine bears some resemblance to the early steam engines of the 18th century--the walking-beam or Newcomen engine. Heating and cooling of the Nitinol working elements is effected by dipping of the elements in water through front-end reciprocating oscillation of a dynamically balanced pivoting system suspended from above, as a sort of inverted pendulum. Because the rotational momentum of the components carrying the working elements rapidly decreases as soon as the wires reach the surface of the water, parasitic losses due to mass transfer and hydrodynamic friction (a serious limitation to scale-up, if wires are passed continuously through a liquid heat transer medium) are minimized.

Design-point operating parameters for the machine (anticipated cycling rate of 60-80 cpm at a ΔT of approximately 20^oC, under no-load conditions) were not initially achieved. For the initial run-in (early July 1979) it was found that chilled water was required for sustained operation, and water from the engine was put through an ice-water bath. At one point during the early hours of testing, the supply of ice ran out, but the machine continued to operate. It was then switched to the in-house hot and cold tap-water supply ($T_H \approx 42^oC$; $T_C \approx 21^oC$) and a gradual acceleration from about 42 cpm to 60 cpm was observed over the first few thousand cycles. This improvement, due in part to refinements in timing adjustment and mechanical break-in, is also interpreted as an indication of the ability of Nitinol to accommodate, to some extent, to available operating temperatures.

The machine was subsequently installed in a test facility where closed heating and cooling loops are available and tested under various conditions for the balance of the first million cycles. Part of this test included running under load for 250,000 cycles, during which an electric generator was attached to the machine, powering a dial tachometer and conventional flashlight bulb. When the generator was removed, a significant increase in speed of operation (from ~80 cpm to >90 cpm) was observed under no-load conditions and at reduced $\Delta T(T_H \approx 38^oC;\ T_C \approx 20^oC)$. One interpretation of this improvement is that the "training" effects of continuous cycling are enhanced, or accelerated, by cycling under load.

The wire stock selected for fabrication of the first power element had been recycled from experiments in earlier phases of the project, without any attempt to heat treat or reanneal the material. It was known to be embrittled and, in fact, a number of wires were fractured in assembly of the first set before it was even installed on the machine. The rationale for using distressed material for the first run was the anticipation that inadequacies in the machine design (improper provision for the mechanical cycling of the Nitinol wires) would become apparent on the order of thousands of cycles, rather than many millions of cycles. As a result of this initial embrittlement, imperfections in mounting procedures, and maladjustments of the machine during the initial experimental learning period, a substantial number of fractures were encountered in the wires, all occurring at the ends where the Nitinol was pressed into stainless steel ferrules. Although undesirable, these features were anticipated and provided valuable guidelines for the assembly of the second working wire set. Again, recycled and unannealed wire was used (for the same reason as previously), but mounting proedures were modified to reduce point load on the surface of the Nitinol at the fixture end, and to eliminate a bending moment which inadvertently resulted from the geometry of the first mounting assembly. Considerable care was taken to ensure uniformity of length in the wires of the second set, and it has now sustained 2,500 hand cycles, prior to installation on the machine, without mishap.

PLANNED ACTIVITIES FOR 1980

Activities planned for the coming year include broadening of the three main areas of current investigation: cycle simulator studies, dilatometric measurements and wire fatigue lifetime testing. In addition a new research component, the need for which has been increasingly emphasized in this past year's work, will be included: direct experimental measurement of the thermal properties of Nitinol during transformation. In the past, theoretical and experimental determinations of the values for latent and sensible heat transfer in conventional Nitinol materials have been in sufficiently good agreement that they were serviceable to a first approximation for estimates of the properties of relatively uncharacterized commercially available materials. Changes which take place in the performance of Nitinol over the course of many thousands of working cycles, however, indicate that differences in the thermomechanical properties of as-delivered Nitinol materials and partially stabilized, "trained" materials may be sufficiently great that measurements made on uncycled stock may be substantially invalid. As the Laboratory is now in the unique position of having available wires which have sustained over a million cycles in uniform axial strain, investigation of the changes--both structural and thermodynamic--that this cycling history may have produced in the material appears essential. As the thermal and mechanical properties of the material cannot be considered in isolation, this task will require some ingenious modification of standard calorimetric techniques, and various experimental methodologies are currently under consideration.

Cycle Simulator Studies will be continued, especially in the area of stress-limited or constant stress cycles, to identify the practical limits for the work output per cycle that can be realized from both new and stabilized materials. The simulator will also be used for controlled and automated break-in of wire working elements prior to installation on the Fatigue Test Stand.

The Fatigue Test Stand, used this year primarily to assign lower-limit values for the working lifetime of Nitinol wires deformed in axial strain, will be modified to perform direct work-output measurements and empirical efficiency measurements. Modification will include instrumentation of the machine to facilitate direct readout of stress levels, temperature and speed variables, and construction of a simple regenerator chamber to evaluate the feasibility of partial recovery of sensible heat, now largely lost to the atmosphere during transfer of the working element from bath to bath.

Preliminary studies made on the Laser Beam Dilatometer in the past year, correlating specific work output of Nitinol with varied thermal cycling conditions, will be systematically pursued. Tests made on relatively new wires will be reproduced to fill in missing thermal data points, and the investigation extended to include comparative evaluation of properties of cycled wires from the Tensile Fatigue Test Stand.

FOOTNOTE

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APPROPRIATE ENERGY TECHNOLOGY*

C. Case, H. Clark, J. Kay, F. Lucarelli, J. Morris, J. Rees, and S. Rizer

INTRODUCTION

In the spring of 1977, the Building and Community Systems Division of the Energy Research and Development Administration (ERDA), responding to the 1977 ERDA Authorization Act, instructed its San Francisco Operations Office (SAN) to establish a small grants pilot program for appropriate energy technology projects within Federal Region IX (Arizona, California, Hawaii, Nevada, and the western Pacific). Following program guidelines, SAN made these grants available to small businesses, individuals, nonprofit agencies, public agencies, and Indian tribes. The purpose of the grants was to design, construct, and/or demonstrate small-scale energy technologies which conserve depletable fossil fuels or which use renewable energy resources.

With $500,000 to distribute in grants up to $50,000, SAN accepted applications from September to November, 1977. They received 1100 applications requesting $21.3 million. After technical, economic, and peer reviews by a variety of state and university institutions and after receiving an additional $750,000 from other DOE Divisions, SAN awarded 108 grants for $1.25 million in April, 1978. The grants covered a complete spectrum of small-scale energy technologies including solar active and passive systems, wind machines, biomass conversion systems, energy conservation devices, recycling methods, aquacultural and agricultural systems, hydroelectric devices, geothermal systems, and integrated methods.

In the spring of 1979, DOE created the Office of Small Scale Technologies, transferring the program administration to this new office. With a FY 1979 budget of $8.5 million, the program has expanded into all ten federal regions. These regions have received over 10,000 applications requesting $200 million and are just completing their review processes and awarding grants. Federal Region IX received another 1100 applications during the winter of 1979 and has distributed $500,000 in 34 additional grants.

During the late winter of 1980, DOE plans to offer a third national program cycle. Details of this cycle will be similar to the others, and DOE is deciding on the amounts to be distributed for each region.

ACCOMPLISHMENTS DURING 1979 AND PLANNED ACTIVITIES FOR 1980

The LBL role in the Appropriate Energy Technology Program is evolving from a technical advisory one on a regional basis to a policy analysis role on a national level. During 1977 and 1978, we offered technical assistance to the SAN Office; reviewed a sizeable number of applications for technical/economic merit; provided technical assistance to the grantees; and monitored projects in Arizona, Nevada, and the western Pacific. The program has now become a national one, and the Region IX jurisdictions do most of their own reviewing and monitoring; therefore, DOE has asked LBL to change the focus of the work to include various policy studies for implementing the national program. The next sections describe our traditional role and our policy studies for FY 1979 and FY 1980.

Technical Assistance

Since the program's inception, we have been providing DOE with general technical support. This support includes a wide variety of tasks ranging from representing DOE at a Micronesian/Peace Corps workshop in Guam and providing technical backup support and energy efficiency data at regional managers' meetings to designing project evaluation forms. We gave technical advice on the proposed Golden Gate Energy Center and outlined ways for determining which projects have exceptional commercial potential. These tasks will continue with a more national than local perspective as the states assume more technical responsibilities. We will continue helping with logistical chores such as prescreening applications from the program cycles and reviewing applications which the states do not have the technical expertise to evaluate.

Monitoring Projects

During FY 1979 we visited and reviewed 45 projects in Arizona, Nevada, and the western Pacific. During these visits we checked the projects for progress, budget and technical problems, demonstration and commercial potential, and general well-being. In addition, we gathered data for various reports. With encouragement from DOE and LBL, these juridictions have now set up their own mechanisms for monitoring during FY 1980. We will continue to visit various projects in Region IX and other regions in order to compile current data for reports.

Energy Savings Studies

DOE is evaluating the grant program's effectiveness. As part of this evaluation, we have assessed the energy savings potential and cost-effectiveness of 20 projects in Region IX.[1]

The projects in our sample are representative of the 108 projects funded during the first cycle. The projects have developed a variety of energy technologies and have end use applications in the residential, commercial, industrial, and agricultural sectors. Funding levels for the projects vary from $1,995 to $46,874, and average $15,270.

We evaluated the projects for direct and indirect energy savings, defining direct savings as those from the original project and indirect savings as those from secondary applications of the project. We express these savings in terms of end use and primary energy savings. Using a conservative approach for evaluating indirect energy savings, our study estimates these savings at 1.2 trillion Btu annually and 22.1 trillion Btu over the project lifetimes. Primary energy savings from these indirect applications are estimated at 2.9 trillion Btu annually. Over their lifetimes, the 20 projects can save 5.7 trillion Btu of primary energy--the energy equivalent of 9.8 million barrels of oil.

Achieving indirect energy savings requires that each project be cost-effective. To evaluate cost-effectiveness, we compared the annualized cost of producing energy from each project with the annualized price of an equivalent amount of displaced fuel. Those projects which produce energy at a cost lower than the cost of displaced fuel are considered cost-effective. Based on this criterion, 13 of the 20 projects are cost-effective. This conclusion may be overly optimistic because most consumers and businesses do not apply life-cycle costing methods to energy investments. Instead, they use a more stringent test of economic viability, the five-year payback period. If this more stringent criterion is applied, only eight projects are cost-effective.

The study concludes with a discussion of ways DOE can improve the program's effectiveness for saving energy. Specifically, we concluded that for the 20 projects and others to achieve their full energy savings potential, DOE must develop innovative programs to assist with project commercialization and to disseminate information on individual projects.

During FY 1980, we will expand this study to include energy savings of projects from other regions, including projects from the Northwest, Southwest, and East Coast. We also plan to develop standard methods for evaluating the energy savings and cost-effectiveness of additional technologies such as wind and biomass conversion.

Fact Books

We are preparing a series of six reports, or Fact Books, synthesizing the technical and economic data assembled so far from the 108 projects. The purpose of these reports is to assist DOE management in understanding the nature of the projects, identifying constituencies served by the program, quantifying energy impacts of the program, and clarifying objectives for later cycles. In addition, these documents will provide Congress and the public with easy-to-read reports acquainting them with a few of the general and technical accomplishments of the grants program.

We have developed a descriptive format which will be used for Region IX and for all DOE/AET projects nationally. To test this format, DOE, LBL, and the California Office of Appropriate Technology selected 18 projects for the initial report.[2] We used a two-page description for each project, including a diagram or picture. The description includes a simple entry for the project title and number; applicant name, address, and group type; project type; amount of award; project duration, date started, and date completed. One or two paragraphs describe the project in general terms, and another paragraph gives brief technical details. A final section presents project results, including details on direct and indirect energy savings. Also included are information on innovative features, regional or national demonstration possibilities, and aspects of the project which can be replicated elsewhere on either a regional or national scale.

We are issuing a second report describing another 18 projects,[3] and we plan to complete the series, which will describe all 108 projects, by mid FY 1980. We are also developing a loose-leaf notebook format to be used for projects from this and other regions.

California Biomass Potential

We are studying the resource limits and economic feasibility of using California biomass as a source of liquid fuels. The study assesses five categories of biomass for annual yield, seasonal availability, and cost of collection. These categories include municipal, forestry, agricultural wastes, feed grains, and harvest from chaparral and brushland.

Annual yields are estimated for 1976 with projections to 2025. To determine the cost-effectiveness of producing liquid fuels from biomass, we have made two comparisons. The first compares the cost of producing alcohol from biomass to the cost of using biomass for producing alternative fuels, such as low Btu gas, electricity, and steam. The second compares the cost of producing each fuel from biomass with projected prices of fossil fuels. Additionally, the study assesses the environmental impacts of biomass collection and the role that government agencies can play in a large-scale biomass program. The study concludes by discussing the implications for achieving a renewable energy resource future totally reliant on biomass for liquid fuels.

The Labor Impacts of Selected Appropriate Energy Technology Projects

We are beginning a study assessing the labor impacts from a sample of projects funded during the first program cycle. The labor impacts will include four categories: direct, indirect, induced, and employment impacts from respending. We will examine 20 projects, comparing their quantitative labor effects with those of conventional energy systems. To provide data for assessments, we will attempt to identify and use available methods and models. The final report will provide data to DOE for evaluating the program and for clarifying the complex conceptual issues in measuring labor impacts.

Aquacultural Studies

To complement our technical assistance, project monitoring, and policy studies, we have developed a laboratory research component for an aquaculture problem. During FY 1979 and FY 1980, we are studying the laboratory mass cultivation of

Daphnia magna, a freshwater cladoceran, as a potential live food source for aquaculture systems. Attributes such as ready availability, nutritional acceptability, and parthenogenic reproduction allowing for large population accrual in a relatively short period of time, may encourage using Daphnia magna and related genera in small aquaculture systems. However, users have experienced certain problems in mass cultivation. For our research, we performed a number of trials to determine which medium or combination of media provides the best growth of Daphnia magna. We then tested these combinations for two runs of preliminary experiments to evaluate growth and reproduction patterns in a variety of conditions.

Daphnia magna (Straus 1820), reared on a defined medium in 4 liter flasks with controlled light, temperature, and species of algae food, were found to be tolerant to high levels of ammonia, up to 108 μM, at high pH(> 10). Parthenogenic reproduction may be inhibited, though, at these high levels. Scenedesmus quadricada and Ankistrodesmus species were found to be satisfactory food sources. Densities of greater than one animal per ml in culture were attained utilizing Ankistrodemus species as a food source at a pH of 7.7. Maintenance of pH at about 7-8 appears to be important to successful cultures. Therefore, during FY 1980, we plan to undertake our experiments with controlled pH.

Library, Bibliography, and How-To-Books

During the course of our work, we have assembled a library of books on small-scale technology. The library is intensively used by others outside of our program, and in order to facilitate cataloging and browsing, we have developed a simple color-coded system for cataloging the material. In response to a request from DOE, we issued a bibliography listing the books in our library and describing the cataloging system.

For FY 1980, we plan to issue a series of non-technical how-to books or brochures describing how to construct or duplicate some of the successful projects or how to complete successfully some of the paperwork required by the program. A few of the potential topics include how-to build a solar beeswax melter, how-to run a small scale energy workshop, how-to write a how-to booklet, and how-to complete a grants application.

FOOTNOTE AND REFERENCES

*This work has been supported by the Office of Inventions and Small Scale Technologies within the Buildings and Community Systems Division. Office of Conservation and Solar Applications, U.S. Department of Energy under Contract no. W-7405-ENG-48.

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ENERGY CONVERSION BY HALOBACTERIA*

L. Packer, R. Mehlhorn, A. Quintanilha, C. Carmeli, P. Scherrer, N. Kamo, P. Sullivan, S. Tristram, J. Herz, T. Racanelli, I. Probst, and A. Pfeiffhofer

INTRODUCTION

The purple membrane found in the halophilic bacterium Halobacterium halobium contains the simplest biological light-to-electrical energy converter known. The component of this organism responsible for the light energy conversion process is the relatively small and simple protein bacteriorhodopsin. Our understanding of this protein is expanding rapidly, and we now know its complete amino acid sequence, its electron density profile in the membrane, the probable location of the chromophore (retinal), and many details of the photocycle which involves a number of distinct spectral intermediates occurring over a seven millisecond time span at room temperature. Much of the current research on bacteriorhodopsin is concerned with the molecular details of how these spectral intermediates are related to the movement of protons across the purple membrane. Considerable added interest in the halobacteria has been stimulated by the recent discovery that their membranes contain a second light-driven ion pump which accomplishes charge movement without the obligatory participation of protons. Evidence is mounting that this photocatalyst achieves sodium pumping, a hitherto unsuspected biological process. This discovery is of great significance for potential photocell applications because sodium currents can provide considerably more electrical power than protons since the latter eventually give rise to deleterious pH changes in the course of photocurrent production.

In previous years, our laboratory constructed a photocell derived from bacteriorhodopsin, and characterized the efficiency and stability of the cell, thus paving the way for constructing similar devices from other membrane-derived ion pumps. We chemically modified bacteriorhodopsin and showed that the amino acids tyrosine and tryptophan were involved in proton translocation driven by the photocycle, and applied spin label assays for analyzing light-dependent electrochemical potentials on isolated purple membrane surfaces and across sealed membrane preparations.

ACCOMPLISHMENTS DURING 1979

Energy Transduction by Bacteriorhodopsin

To clarify the process of proton translocation by bacteriorhodopsin in purple membranes of halobacteria, we have exploited specific chemical modification of selected amino acid residues.[1,2] The simple amino acid composition of the protein has been a considerable asset for these studies.[3,4] Our attention has been focused on the ionic amino acids, including glutamate, aspartate and arginine, which can be protonated in the physiological pH range, and thus are potential elements of the proton pathway through the protein. The molecular model of the protein revealed a high density of these amino acids at the cytoplasmic membrane interface.

Carboxyl-containing amino acids were specifically modified with water soluble carbodiimides, in reactions which caused their negative charges to be either neutralized or become positive.[5] These modifications caused slowing of the photocycle during the stages corresponding to the uptake of a proton by bacteriorhodopsin. The onset of the photocycle which is related to proton release was unaffected by the modifications. Partial resolution of the carboxyl groups involved in proton uptake was achieved by means of trypsin digestion of a polar fragment of the protein; this treatment has no effect on the photocycle, even though this fragment includes five carboxyl containing amino acids. Positively charged arginine residues were modified with two reagents such that three to five of the seven residues were modified. The general effect of arginine modification was very similar to the effect of carboxyl modification; negative charges were either neutralized or became positive, and slowing of the photocycle was observed during stages corresponding to the uptake of a proton by bacteriorhodopsin (Table 1). These results indicate that both carboxyl groups and guanidinium groups are essential for the proton translocation process.

Previously, we observed that proton pumping by bacteriorhodopsin was affected by iodination of tyrosine residues,[6] although the location of the critical residues could not be ascertained. Tyrosines are of special interest because of the possible involvement of their phenolic hydroxyl group in proton translocation. In the past year,[7] we succeeded in iodinating tyrosines much more specifically with the enzyme glucoseoxidase lactoperoxidase, whose bulk and solubility characteristics should make it mainly a surface specific reagent in the early stages of reaction, and a modifier of hydrophobic tyrosines in the later stages. Experiments in collaboration with Dr. Stanley Seltzer of Brookhaven National Laboratory have revealed that iodination of the lipid of the purple membrane and of the retinal chromophore is insig-

Table 1. Effect of treating purple membranes with carboxyl and arginine specific reagents on photoreaction cycle linked to proton translocation.

Modification	570 nm Chromophore		412 nm Intermediate		
	Absorbance (percent)	Rise ($t_{1/2}$, μsec)	Phase of Decay Initial ($t_{1/2}$, msec)	Phase of Decay Second ($t_{1/2}$, msec)	Photostationary State Absorbance Relative Percent
Carboxyl Specific					
Control	100	40	5.6	-	100
EDC-Treated	85.7	40	15.0	280	527
Arginine Specific					
Control	100	39.2	2.8	-	100
2-3-Butanedione-Treated	91.3	68.4	34.6	174	1922

nificant compared to the iodine labeling on the protein. Using lactoperoxidase on normally oriented and inverted bacteriorhodopsin molecules in sealed vesicle systems, we have been able to show with short reaction times that the most iodine sensitive tyrosines are located on the cytoplasmic membrane surface. This supports our earlier suggestion that proton uptake from the cytoplasm may require a tyrosine residue.

More extensive tyrosine modification eventually causes four tyrosines to become iodinated. Structural information from our schematic model of bacteriorhodopsin shows that several tyrosines are located in close proximity to the region where the β-ionone ring may be located. Extensive iodination slows down the decay, but interestingly accelerates the formation of the M_{412} intermediate. A group of investigators in Cambridge, England have recently made extensive modification of tyrosine residues with tetranitromethane,[8] which also revealed that when up to 30% of the 11 tyrosine residues were altered, an acceleration of M_{412} formation occurred.

Raman spectroscopy is a sensitive tool for studying the environment of the retinal chromophore. Rapid flow techniques were used to measure Raman spectra of both the BR_{570} ground state and the M_{412} intermediate of the chromophore in the laboratory of Dr. R. Mathies, School of Chemistry, University of California, Berkeley. The results were quite different for the two states; there was a considerable alteration in the spectrum of the ground state in the extensively iodinated protein while the M_{412} state was essentially identical to that seen in the untreated protein. One interpretation of this result is that a conformational change occurs in the protein which causes one or more of the iodinated tyrosines to move away from the chromophore in the excited state. Furthermore, since this observation is seen only in extensively modified bacteriorhodopsin, the tyrosine which interacts with the chromophore appears to be distinct from the tyrosine which seems to act as a proton donor.

Surface Electrical Potential Measurements

Previously, we demonstrated that electrical surface potential changes occurred in spinach chloroplasts upon illumination,[9] by means of a new spin probe method developed in our laboratory, based on the partitioning of permanently charged hydrophobic molecules between the aqueous medium and membrane bound populations. This method enabled us to monitor electrical surface charges with high sensitivity and rapid response time.[10,11]

Electrical surface potential changes in purple membranes were of interest because they might provide information about proton binding sites and perhaps conformational changes in the protein.[11,12] We used the amphipathic spin probe CAT_{12}, an analogue of trimethyl dodecyl ammonium bromide to estimate surface charge changes occurring during illumination of bacteriorhodopsin. At room temperature, when purple membranes are illuminated in low ionic strength media, small surface potential changes are observed. However, when the photocycle is slowed, thereby increasing the amount of M_{412} intermediate in the photostationary state, surface potential changes also increase. When the photocycle is slowed by chemical modification of tyrosine, arginine and carboxyl containing residues in purple membranes or by lowering of the temperature, larger surface charge changes are recorded. Figure 1 shows that the partitioning of the probe into aqueous domains (narrow lines) and membrane domains (broad lines) changes slightly under illumination and hence the effective surface potential seen by the probe increases. When these data are interpreted in terms of the Gouy Equation, which relates interfacial charge densities to surface potentials, the changes correspond to about one charge per M_{412} intermediate of the photocycle. The kinetics of the surface potential changes and of the rise and decay of the M_{412} are of the same order of magnitude. The experiments with CAT_{12} suggest that, at low ionic strength and with positively charged purple membranes, the proton leaves the membrane entirely. It is also known that the Schiff base nitrogen becomes deprotonated in the M_{412} state, but it cannot be ascertained if it is this proton which is released from the purple membrane.

Hypothesis for Light Energy Transduction by Bacteriorhodopsin

All data obtained thus far have led us to propose a scheme for relating proton translocation to the photocycle of bacteriorhodopsin (Fig. 2). Based on results of others, theoretical considerations,[13] and our research, we have updated a scheme that attempts to relate the proton translocation by bacteriorhodopsin to its photoreaction cycle. We hypothesize that photon absorption shifts the electron distribution in the polyene side chain toward the Schiff base nitrogen, resulting in a decrease of its positive charge. This results in a structural change of the polyene chain and a charge separation between the Schiff base nitrogen and a nearby R^- group. Charge separation may be the primary event of light energy conversion as it is rapidly (in 30 μsec) followed by proton release from the Schiff base N and at the extracellular surface of the purple membrane. Reprotonation occurs in a relatively slow process (3-5 msec) from the cytoplasmic surface. No precise quantities of absorbed photons and released H^+ have

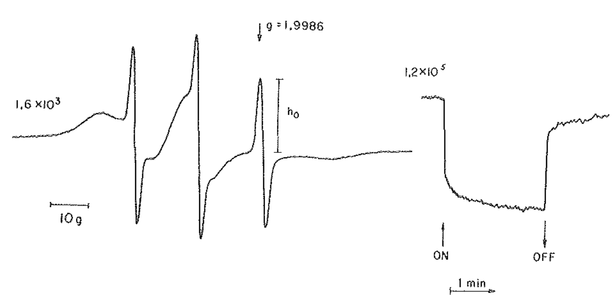

Fig. 1. EPR spectrum and light induced amplitude changes of the high field aqueous CAT_{12} signal, h_o, in a purple membrane suspension. (XBL 797-10700)

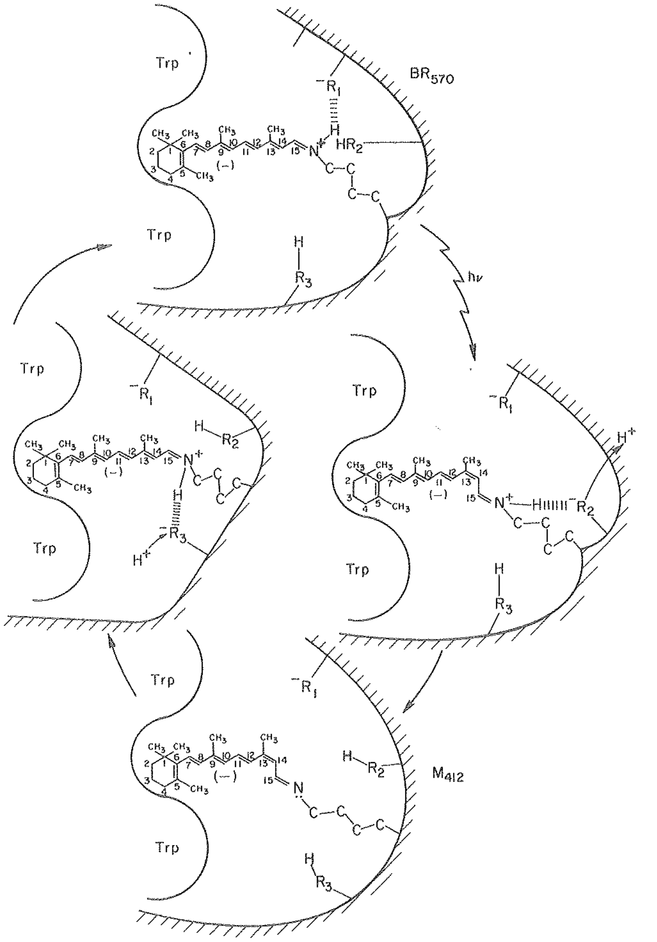

Fig. 2. Light energy conversion by bacteriorhodopsin. Light inititates a chain of events which perturb the structure of this photocatalyst such that protons are released and taken up at different surfaces of the purple membrane in which bacteriorhodopsin is located. When bacteriorhodopsin absorbs a photon, the retinal chromophore isomerizes. This causes a charge separation between a proton on the Schiff base nitrogen ($-N^+$) and a nearby negatively charged group (R_1); this is believed to be how energy is initially conserved. This, in turn, initiates the release and uptake of protons from other groups in the protein (R_1, R_2, R_3, etc.); our studies indicate that tyrosine is one of the important groups in this process. There is evidence that aromatic amino acids like tryptophan (trp) help to form the proper environment for retinal.
(XBL 7911-3903)

yet been established, and no experiments have yet demonstrated whether it is the Schiff base (C=NH) proton which is translocated, or whether proton translocation occurs via another route. Nevertheless, our chemical modification studies reveal that certain groups of charged amino acids are of great importance for the reprotonation process. A precise structural arrangement of arginine and carboxyl groups, probably in complexation with one another, and at least one tyrosyl group near the cytoplasmic surface, is required as are protein conformational changes. The latter has been deduced from chemical crosslinking studies of α-amino groups of lysine which inhibit reprotonation and M_{412} decay. At least one tyrosyl group is also important in the immediate environment of the chromophere, as perturbing it by two methods of chemical modification results in acceleration of proton release. Not enough knowledge is yet available on the tertiary structure and the precise localization of the groups affected to determine whether it is merely configuration of these groups which is important for proton movement through the protein, or whether they participate directly in the precise translocation of protons.

Light-Dependent Energy Conservation in Mutant Strains of Halobacteria

Characterization of the electrochemical gradients developed by halobacteria is essential in understanding how light energy is conserved. We are studying two bacteriorhodopsin-deficient mutant bacteria (red and white strains) in collaboration with Yasuo Mukohata of Osaka University. These strains contain a retinoprotein that results in proton translocation in an opposite direction to that of bacteriorhodopsin.

Critical questions being investigated in our laboratory are: What is the nature of the primary light energy converter in the mutant cells, and what is the feasibility of isolating this converter for subsequent incorporation into synthetic membranes? To answer these questions, it is important to characterize the primary ion pump by identifying pathways of cation movement across the membrane. Identification of these cation pathways will also assist us in moving toward the construction of a photodesalination device.

To monitor proton movements, we are using two independent experimental approaches: (1) pH electrodes which respond to proton concentrations outside of intact cells and cell vesicles, and (2) spin probes which monitor intracellular and intravesicular concentrations.[14,15] The judicious combination of these approaches can give quite accurate information about the salt economy of the cell. A spin-labeled weak acid and amine were used to measure transmembrane pH gradients in H. halobium cell envelope vesicles during illumination. By quenching the probe signal outside the vesicles with the impermeable paramagnetic ion ferricyanide, uptake of the acid and release of the amine were observed (cf. Fig. 2 of Probst et al.[15]). The pH gradients calculated from the data ranged from zero at an external pH of 9.3 to 2.0 at pH 5.0.

Volume measurements are needed to calculate accurately the pH gradients with any method. We have developed a spin probe method which allows simultaneous and accurate cell volume determinations to be made by measuring the intracellular concentration of a permeable probe which equilibrates across the membrane independently of pH and electrical gradients. A perdeuterated, spin-labled ketone nitroxide, designated as ^{2}H Tempone, which exhibits very narrow spectral lines in aqueous environments, has proven most useful for this purpose.

Membrane permeable lipophilic anions and cations can be used for measuring electrical gradients by developing electrodes which measure their external concentrations.[16,17] Upon illumination of intact cells, a potential of about 150 to 180 mV is observed, negative inside. This potential is consistent with electrogenic proton extrusion from the cell which can be simultaneously measured with the pH electrode technique.

To increase the time resolution of the electrical transmembrane potential measurements, spin-labeled permeable cations (phenylated phosphonium derivatives) have been developed. Probes synthesized thus far exhibit considerable membrane binding in their spectra. The spin probe method has a critical advantage over other procedures because binding of the probe can be measured so that this effect can be corrected for in calculations of the membrane potential. Computer interfacing of our EPR instrument this year has made it possible to observe and quantify the population of probe molecules that are bound to the membrane and correct for this common source of error. Computer interfacing is also used to analyze kinetics of the photoresponse, to perform data averaging or subtracting, and to obtain concentrations of the probe in different environments by double integration of the individually resolved spectral components. With these techniques, absolute transmembrane potentials are being determined and the relationship among these gradients elucidated.

PLANNED ACTIVITIES FOR 1980

We will continue to refine our understanding of the molecular mechanism of light energy transduction by bacteriorhodopsin by further exploring the role of specific amino acids in proton translocation. Results of flash photolysis studies of photocycle intermediates will be correlated with measurements of the electrical surface and transmembrane potentials, and direct methods for proton production. These investigations will include more selective chemical modification with emphasis upon protein chemistry and the use of spin-labeled reagents to determine the specific groups modifed; studies on deuterated purple membranes; and the effect of D_2O on light energy conversion in purple membranes and reconstituted proton translocation systems. We expect that these studies will advance to a stage at which we may be able to decide among several alternative hypotheses for the mechanism whereby this photocatalyst generates electrochemical gradients.

The recent discovery of a new retinoprotein pigment with different light energy transduction properties, indicating that it may act as a direct light-energy driven transmembrane device for sodium transport, will be explored in halobacteria cells and vesicles. These experiments will involve simultaneous measurements of changes in parameter of the electro-chemical potentials, ΔpH, and $\Delta\Psi$ by newly developed electrode and spin-probe techniques which will enable us to quantify the converted energy. These studies will be made in mutant species of halobacteria and membrane vesicles prepared from them, in which the function of this new retinoprotein can be distinguished from that of bacteriorhodopsin.

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A SOLAR-HEATED GAS-TURBINE PROCESS USING SULFUR OXIDES FOR POWER PRODUCTION AND ENERGY STORAGE*

G. Tyson, S. Lynn, and A. Foss

INTRODUCTION

If any system of solar power generation is to provide a significant fraction of the power requirements of a community, some means of economical energy storage must be used. The purpose of this study is to develop and evaluate a process configuration using the heat of reaction of:

$$2\ SO_3 \rightleftarrows 2\ SO_2 + O_2$$

for energy storage. The forward reaction is endothermic and is used to absorb energy. The reverse reaction is exothermic and releases the energy that has been stored. This process uses the sulfur oxides directly in a gas turbine in a hybrid Brayton-Rankine cycle to produce electricity. Heat for the system is supplied during sunlight hours by a field of heliostats focused on a central solar receiver. When sunlight is not available, the storage system provides the heat to drive the gas turbine.

This work was begun in 1978 as a natural extension of a chemical storage system[1] which employed only a steam Rankine cycle for power generation.

ACCOMPLISHMENTS DURING 1979

An efficient process configuration for this power cycle was developed, and flow sheets for it are given in Figs. 1 and 2. Detailed material and energy balances were made for a base case that represents a middle range of expected operating conditions. Sensitivity of this process to variations in the key operating parameters was determined. Equipment sizes and costs were estimated for the base case to determine an approximate cost for the electricity produced by this process.

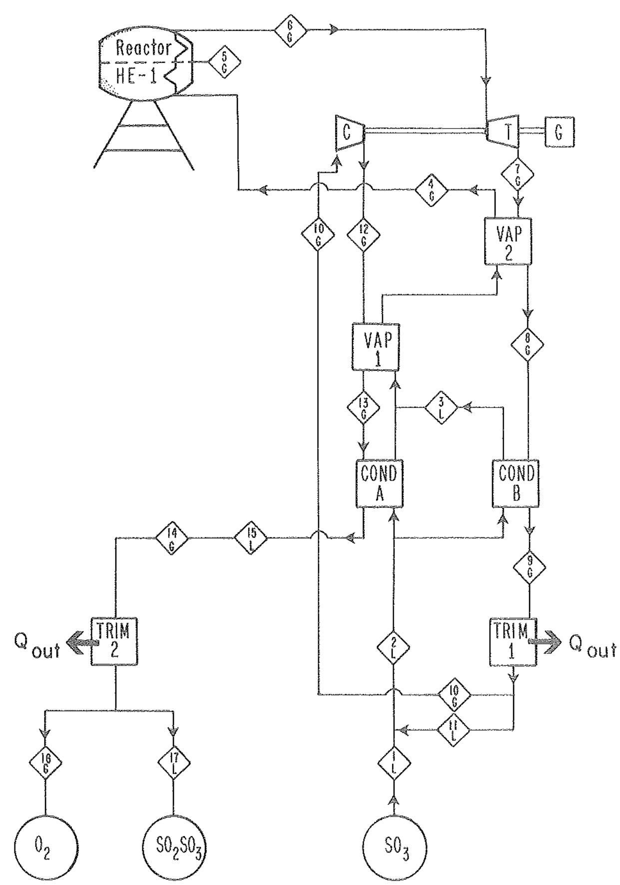

Fig. 1. Block flow diagram of the daytime (charge) process. (XBL 797-2228)

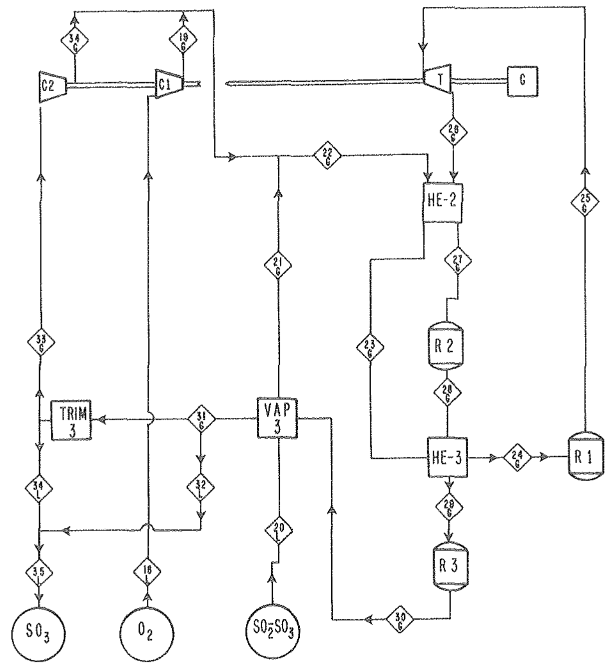

Fig. 2. Block flow diagram of the nighttime (discharge) process. (XBL 797-2229)

In the base case, the solar receiver absorbs heat at a rate of 230 MW(t) for a period of eight hours during the day. Daytime electricity generation is about 52.3 MW(e). Nighttime generation is about 19.0 MW(e) for a period of 16 hours. The overall efficiency of converting heat into electricity is thus about 39%. Total capital cost for the base case is $71.7 million, of which 69% is for the tower and heliostat field. Average cost of the electricity produced is estimated to be 7.7¢/kW(e)-hr.

The economics of electricity production using the gas-turbine process developed in this work appears to be attractive. The estimated power cost of 7.7¢/kW(e)-hr is high compared to current fossil-fuel-fired power sources but only by a factor of about 2. This power cost is substantially lower than the 10.7¢/kW(e)-hr that was projected for a process using the same sulfur-oxide storage concept but using only a steam Rankine cycle for power production.[1]

The principal reason for the improved power cost is an increase in efficiency, 39% in the present process compared to 26% in the earlier process.

The primary uncertainty in the economic estimates presented arises from the corrosiveness of the fluids in the sulfur-oxide system at the temperatures of the process. A developmental program will be needed to determine whether economically as well as technically feasible solutions exist for the materials problems that would be faced in an application of this process.

PLANNED ACTIVITIES FOR 1980

This project is completed, no further funding is sought at the present time, and our activities in this area have ceased.

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*This project was funded during FY 1979 entirely by the Department of Energy, Division of Energy Storage Systems.

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EXPERIMENTAL AND THEORETICAL EVALUATION OF CONTROL STRATEGIES FOR ACTIVE SOLAR ENERGY SYSTEMS*

M. Warren, S. Schiller, M. Martin, M. Wahlig, and G. Sadler

INTRODUCTION

Improved solar energy control systems will reduce the need for using non-renewable fuel sources for heating building spaces and domestic hot water. The LBL solar controls program has four principal objectives: (1) to construct a test facility capable of experimentally evaluating the relative performance of different solar heating and cooling control strategies under a variety of input meteorological conditions and output load demands (performance of control strategies is measured by the ratio of useful heating by solar divided by the auxiliary and parasitic energy required); (2) to use the test facility to test an electronic controller developed at LBL and to evaluate other controllers; (3) to carry out theoretical studies of collector and load loop performance in support of the experimental work; and (4) to perform technical support activities as part of the Systems Analysis and Controls program element of the DOE solar heating and cooling R and D program.

Experimental evaluation of the cost effectiveness of controllers and control strategies is expected to be the primary output of this project.

ACCOMPLISHMENTS DURING FY 1979

In the past year, the test facility has been brought to an operational status with emphasis on refinement of system instrumentation and the development of the necessary computer software to operate the facility and perform data analysis. The test facility is described in detail elsewhere.[1,2,3] Other work this year has included the application of theoretical models to describe dynamic collector operation and building temperature response. The specific building and solar-heating system that will be simulated have also been determined.

Instrumentation and Data Analysis System

A disk drive and operating system for the hp-9825A microcomputer that controls and monitors the test facility was installed this past year and is now operational. Software requirements for data acquisition, adjustment of the load and pseudo-collector simulators, and intermediate data analysis are extensive, exceeding the limits of the computer memory. Therefore, the software has been rewritten in an overlay mode, greatly extending the system capability. Segments containing the main program, subroutines for operation of the data logger and output devices, experiment initiation, data analysis, and control procedures are now stored on different files. Various routines are loaded into memory from the disk as they are required. Auxiliary gas consumption for back-up heat, and parasitic power requirements for the pumps and fans, are now measured electronically.

Solar Input Simulator (Pseudo-Collector)

To make comparisons between alternative control strategies, the heat input and the load conditions must be reproducible. Therefore, solar energy input to the system and building energy requirements are simulated to allow repeated runs under identical external conditions.

The solar input simulator, the pseudo-collector, is a boiler with a controlled mixing valve that allows adjustment of the fluid input-output temperature difference. This year the pseudo-collector solar input simulator has been brought under full computer control. Values of solar insolation, ambient temperature, the boiler inlet temperature and flow rate, along with typical collector parameters, are used to calculate the expected inlet-outlet temperature difference using a steady state collector model.

Figure 1 shows the collector loop. The high- and low-fire gas burners of the boiler, as well as the position of the three-way mixing valve, are all controlled by the hp-9825A. Under no-flow conditions in the collector loop, the value of the collector sensor, TS-4, is set to the calculated

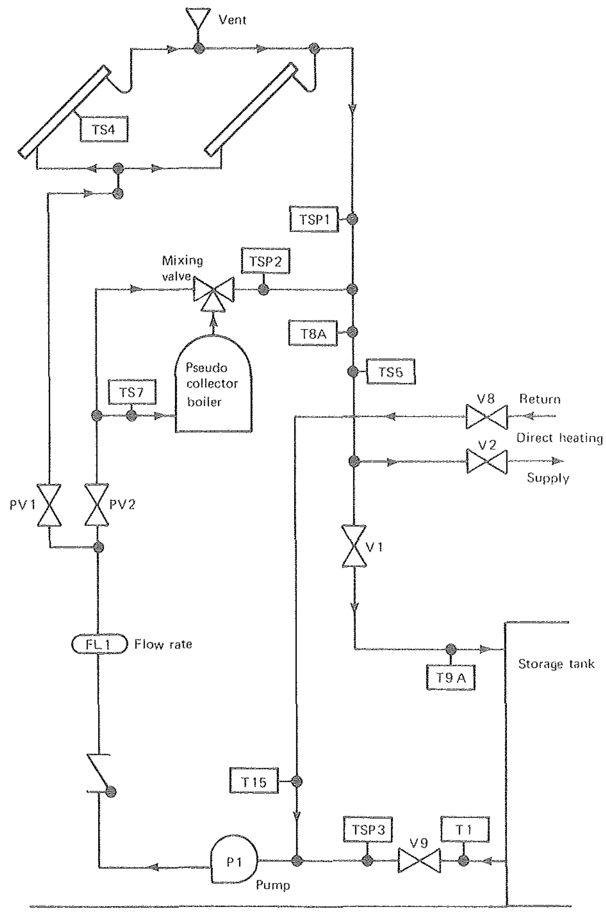

Fig. 1. Solar controls facility collector loop. (XBL 794-1152)

collector stagnation temperature through an output device. When the collector loop pump is on, the collector output temperature is calculated from the collector model, and the boiler output is adjusted accordingly. The apparent collector temperature and boiler control are updated every 60 seconds.

The PROM system controller turns on the collector loop pump, P1, when the apparent collector temperature reaches the "on" set point, given by the storage tank temperature plus a temperature differential, ΔT_{on} of 11°C. The pump is turned off if the collector temperature falls below the "off" temperature, given by the storage tank temperature plus a temperature differential, ΔT_{off} of 2°C.

Figure 2 shows the inlet temperature and the calculated and observed collector outlet temperature over a four hour period of increasing and decreasing insolation. If the collector outlet temperature under flow conditions is less than the "off" temperature and the collector stagnation temperature is greater than the "on" temperature, then the collector loop pump will cycle on and off. Such cycling is typical of solar collector systems. The steady-state collector model does not adequately describe this cycling, and work is continuing to implement a dynamic collector model as part of the solar input simulator.

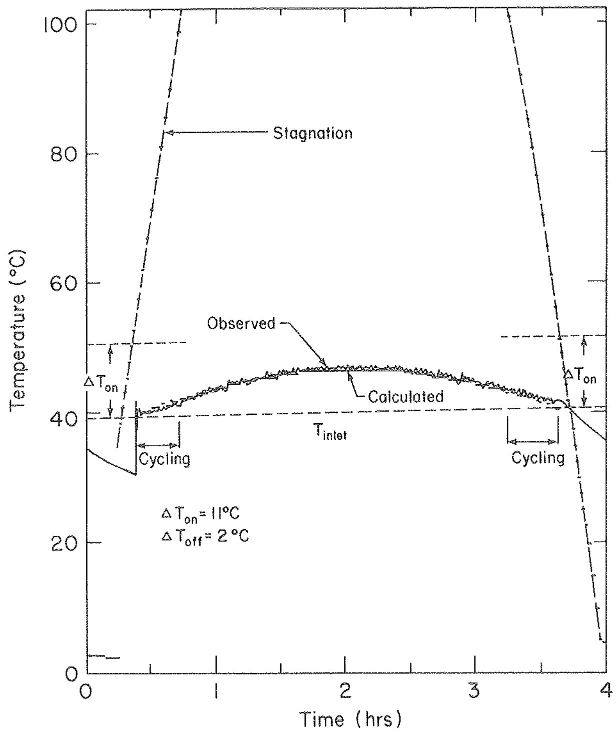

Fig. 2. Pseudo-collector output. Calculated temperature (no flow), calculated outlet temperature (flow), and observed pseudo-collector outlet temperature. (XBL 7912-13155)

Load Simulator

The load simulator is an air channel that simulates a building's heating system, consisting of a return air duct, fan, and heating and cooling coils. The inlet air temperature is adjusted by an electric resistance heater and an air conditioner under the control of the hp-9825a. A schematic of the building load loop and air channel is shown in Fig. 3.

The building heating requirements to be satisfied by the solar energy system are modeled in the microcomputer. A simple thermostat model is used to control the heat delivery system which, as determined by McBride[4] in experimental studies, is on for a fixed interval of about 5 minutes. The energy delivered to the load by the heating coil is measured and compared with the building load to determine how often heat must be supplied and whether auxiliary energy is required.

Energy Balance Tests

Energy balances are performed during the experiment by (1) determining the energy delivered by the pseudo-collector, (2) determining the energy stored at the beginning and end of a period, and deducting estimated losses from storage, (3) determining the amount of energy delivered to the load, and (4) estimating piping heat loss.

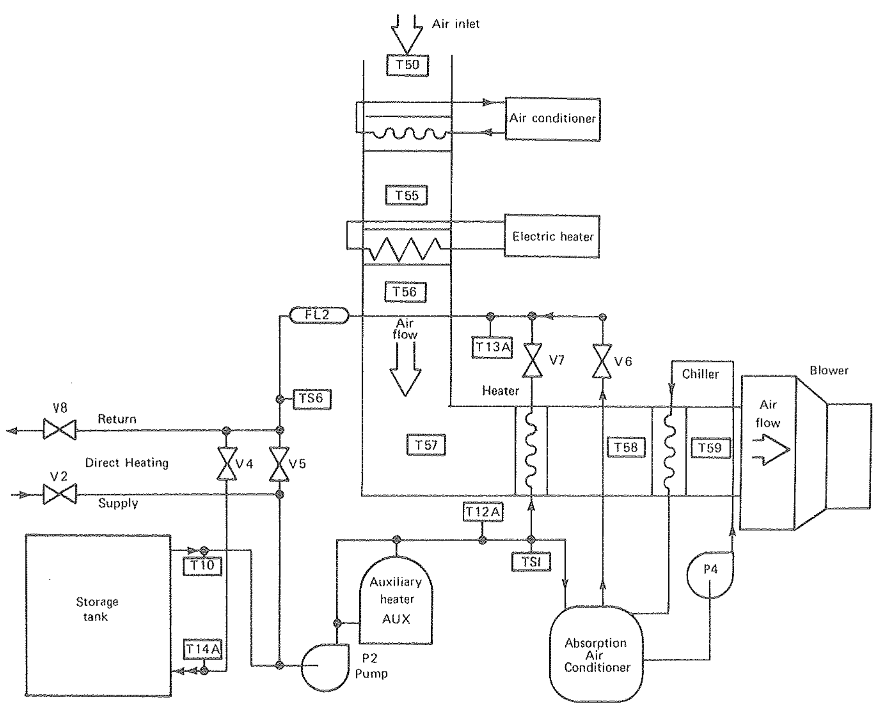

Fig. 3 Solar controls facility load simulator. (XBL 794-1150)

Collector Loop Energy Balance

Preliminary energy balance experiments were done with simulated solar heat input from the pseudo-collector, with the apparent collector temperature determined by the hp-9825a, and with the operation of the collector and load loop determined by the LBL electronic controller. Energy supplied by the pseudo-collector was calculated at 60 second intervals and the amount of energy in the storage tank was calculated at 30 minute intervals as the apparent solar insolation was increased from zero to a maximum of 950 W/m^2 and then back to zero. The duration of each experiment was 4 hours.

An energy balance summary for two 4 hour experiment and for a 22 hour total of successive experiments is shown in Table 1. The measured change in storage tank energy, $\Delta Q_{storage}$, plus the loss from storage during the period, ΔQ_{loss}, gives the total heat input to storage, $\Delta Q_{storage}$. Heat input from the pseudo-collector boiler is calculated using the measured flow rate and the temperature difference between inlet and outlet. Q_2, the total heat supplied to the fluid stream, is calculated using thermocouples just before and after the boiler. Q_4, the heat supplied to storage, is calculated using thermocouples before the boiler, and at the storage return and is slightly smaller because of piping losses. Estimates are made for heat losses from the system piping and from the storage tank, which contains 11,400 kg of water. Previous experiments indicated that the heat loss coefficient should be approximately 25 W/^{o}C for the collector loop piping and 24.6 W/^{o}C for the storage tank. Estimated piping energy losses are indicated in Table 1 and compared with the differences between Q_2 and Q_4. The differences between Q_2 and Q_4 only account for piping losses in the return side of the collector loop. Additional losses are found in the supply side. Energy input during each four hour period was repeatable as shown in Table 1. The energy balance over a single measurement period of 4 hours is not precise primarily because of uncertainty in the storage tank energy measurements. Even though the storage tank energy is calculated from the weighted average of 6 thermocouples, errors of 10 MJ are produced as stratification of the tank temperature changes. However, over a long experimental run of 22 hours, the energy balance is quite acceptable.

Load Loop Energy Balance

Preliminary energy balance experiments were run with heat delivered from the storage tank to the heating coil located in the air duct. Power discharged in the heating coil, Q_H, was measured every thirty seconds using a differential thermocouple, DT13, and the load loop flow measurement, FL2. Power delivered to the load was typically 12 kW. The load loop experiment summarized in Table 2 was run for a period of 18 hours, with the building load calculated for a constant outdoor temperature of 0^{o}C and a building loss coefficient of 500 W/^{o}C. The overall energy balance for the 18 hour run is quite acceptable.

Theoretical Studies to Support Experimental Program

Development of Dynamic Collector Model

The dynamic response of a solar collector was simulated using a collector energy balance equation which accounts for collector thermal capacitance. The equation was numerically solved to describe the

Table 1. Collector loop energy balance summary (in megajoules).

Duration of tests	4 hr	4 hr	22 hr
Storage Tank			
$\Delta Q_{storage}$	113.0 MJ	118.5 MJ	663.9 MJ
ΔQ_{loss}	4.6 MJ	5.6 MJ	28.4 MJ
$\Delta Q_{storage}$	117.6 MJ	124.1 MJ	692.3 MJ
Heat Input			
Q2	131.9 MJ	128.6 MJ	705.2 MJ
Q4	128.6 MJ	126.1 MJ	692.3 MJ
Estimated Piping Losses			
Q2 − Q4	3.3 MJ	2.5 MJ	12.8 MJ
Q_{piping}	3.7 MJ	4.9 MJ	25.2 MJ
Net Energy Balance			
Qstorage	117.6 MJ	124.1 MJ	692.3 MJ
−Q2	−131.9 MJ	−128.6 MJ	−705.2 MJ
$+Q_{piping}$	3.7 MJ	4.9 MJ	25.2 MJ
Net Balance	−10.6 MJ (−9.0%)	−0.4 MJ (0.3%)	12.3 MJ (1.7%)

Table 2. Load loop energy balance summary (in megajoules) for 18 hour period.

Storage tank energy balance	
$\Delta Q_{storage}$	-561.4 MJ
ΔQ_{loss}	21.8 MJ
Piping losses (estimated)	24.3 MJ
Net delivered to load	-515.3 MJ
Measured heat to load, Q_H	-536.7 MJ
Net energy balance	-21.4 MJ (4%)

circulating fluid temperature as a function of time and space. Figure 4 shows a typical collector outlet temperature history derived by the model.

The model is used to evaluate the performance of proportional and on/off collector loop control for various set points, flow rates, insolation levels and patterns (clear and cloudy days), and ambient temperature conditions. In proportional control, the collector loop fluid flow rate is proportional to the temperature rise across the collector. With on/off control, the fluid flow is either on or off. Evaluation of control strategies is based on the following criteria: collection efficiency, percent of maximum steady-state efficiency, pump running time (parasitic power demands), and cycling. Results of comparisons have been presented along with methods for determining controller set points.[5]

Typical results for collection efficiency for a clear day are shown in Fig. 5. Results indicate that the turn-on set point is not always a critical factor in the collection of energy because the collector stores energy while it is warming up and during cycling. This energy is transferred to the storage tank once the fluid begins to circulate.

Figure 6 shows results obtained for an overcast day with lower solar gain. Proportional flow controllers provide improved energy collection only during periods of interrupted or very low insolation when the maximum possible energy collection is relatively low. Although proportional controllers initiate flow at lower insolation levels than on/off controllers, they produce lower flow rates and higher average collector temperatures and thus slightly lower instantaneous collection efficiencies.

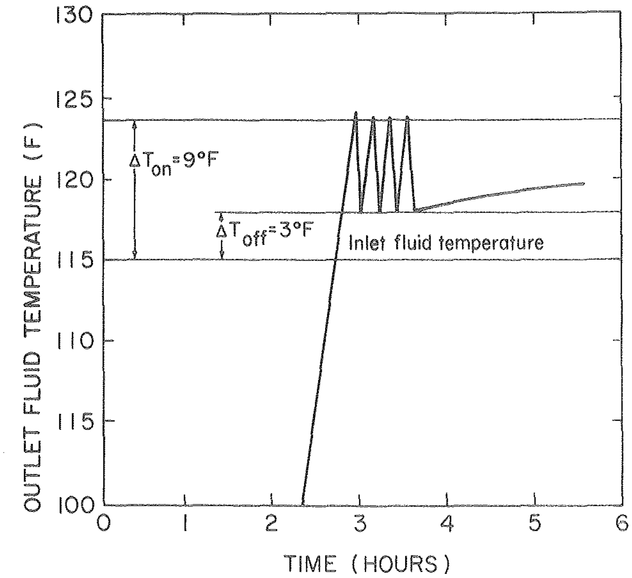

Fig. 4. Collector outlet temperature for a typical day with cycling. (XBL 7911-13120)

Study of Building Load Dynamics

Work has also begun on development of a residential building temperature response model to simulate the effects of heat input on room air dynamics.[6] The model has three nodes: the building shell, the air, and the interior walls. This model gives the short time constant response appropriate for the heating of air within the structure and the long time constant response associated with the building structure. The model will be used in the test facility for evaluating advanced control strategies and controllers.

Technical Support Activities

This past year the Laboratory has been actively involved in proposal review and contract monitoring for the Controls Element of the DOE solar heating and cooling R and D program. Activities have included coordination with SERI on the controls part of the systems plan, conducting site visits, and reviewing the work of DOE controls contractors.

PLANNED ACTIVITIES FOR 1980

Plans for 1980 include a series of experimental tests of on/off control strategies for a variety of meteorological conditions. Experiment modifications are underway to permit variable-flow and proportional-flow control of the collector loop. A series of experimental comparisons of proportional and on/off collector loop strategies are planned. The design of the necessary modifications to test combined domestic hot water and heating systems are also planned. Papers have been submitted for presentation at several energy conferences and for publication in solar energy journals. Technical program support activities, in cooperation with SERI, will be continued.

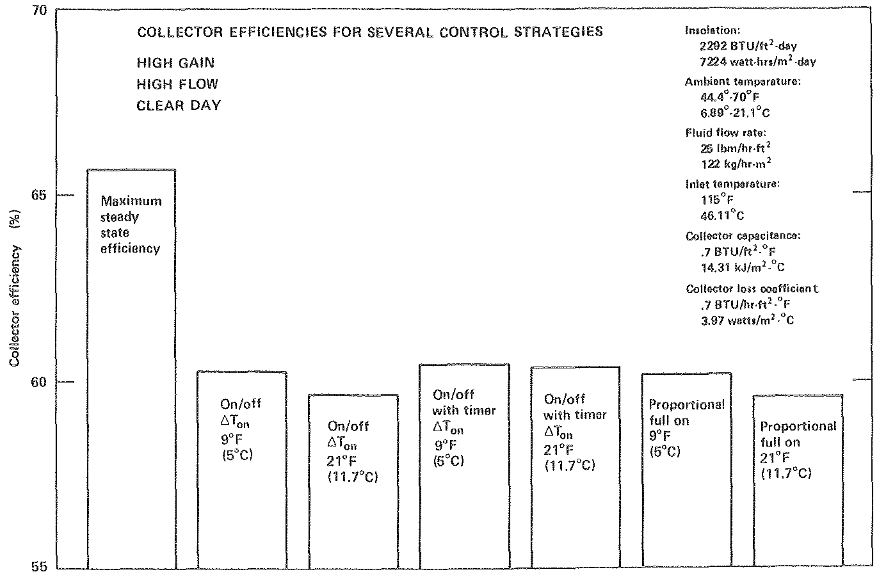

Fig. 5. Collector efficiencies for several control strategies--clear day, high gain cases. (XBL 796-1884)

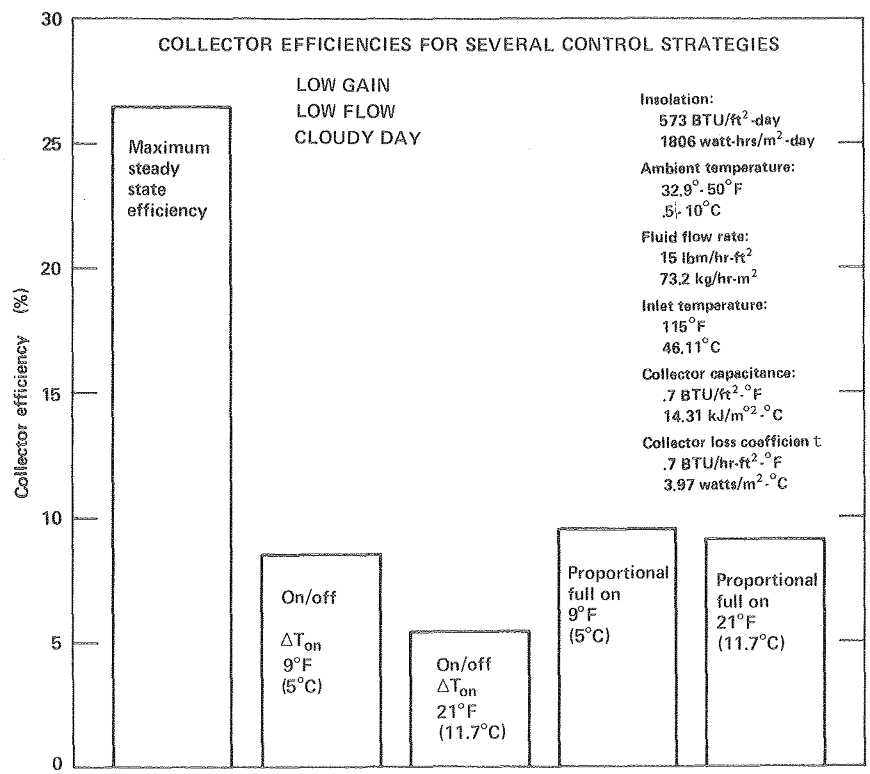

Fig. 6. Collector efficiencies for on/off and proportional control--cloudy day low gain cases. (XBL 796-1891)

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DEVELOPMENT OF SOLAR DRIVEN ABSORPTION AIR CONDITIONERS*

K. Dao, M. Wahlig, and E. Wali

INTRODUCTION

The objective of this project is to develop absorption refrigeration systems for active solar heating and cooling applications. As of the conclusion of the first phase of this project, it has been experimentally demonstrated that the conventional single-effect ammonia-water absorption cycle can be used for solar cooling.[1] Optimum operating temperature ranges for this kind of system are:

- heat source input temperatures: $200^oF < T_S < 230^oF$ (condenser)
- absorber cooling air temperature: $T_0 = 95^oF$ (chilled water)
- output temperature: $50^o > T_E > 40^oF$, coefficient of performance (COP) = 0.65 to 0.70

The second phase of this project explores the commercial potential of the NH_3/H_2O single effect absorption air conditioner. A completely new 3-ton, single-effect unit was engineered and designed to achieve high performance and low cost.[2,3] Key components of this new unit are tube-in-tube heat exchangers for high effectiveness and low cost, and a pair of piston drivers and pumps for recuperation of mechanical energy from the returned weak solution. Estimated production cost of this unit is in the range of \$300-\$500/ton of rated capacity, depending on the choice of materials. The lower estimate applies when all components are made of welded carbon steel tubing. If stainless steel is used for some components, the cost approaches the higher estimate.

Success of the single-effect unit will not obviate the need for development of more advanced chillers with higher COP's compatible with high temperature collectors (above 230°F). Accordingly, the third phase of this project is the development of advanced absorption cycles whose COP increases with temperature, maintaining a relatively constant fraction of the current COP over a wide range of operating temperatures.

ACCOMPLISHMENTS DURING 1979

The fabrication and installation of the new single-effect NH_3/H_2O absorption conditioner has been completed. Preparation is now under way for its performance tests.

The development of the piston circulation pumps has been completed. Vibrations and banging have been reduced to an acceptable level and volumetric efficiency has been improved to above 90 percent. Two of these piston pumps are used to replace the conventional electric diaphragm circulation pump. One pump uses the high pressure weak solution as a driving medium while the other (called the make-up pump) uses high pressure vapor.

Detailed computer analysis of the new advanced absorption cycle (called cycle 2R for double effect regenerative absorption refrigeration cycle), completed this year, served as the basis for the design of the components of the "2R chiller." The configuration of the 2R chiller is shown in Fig. 1; its operation is described below (more details on cycle 2R can be found in Ref. 4).

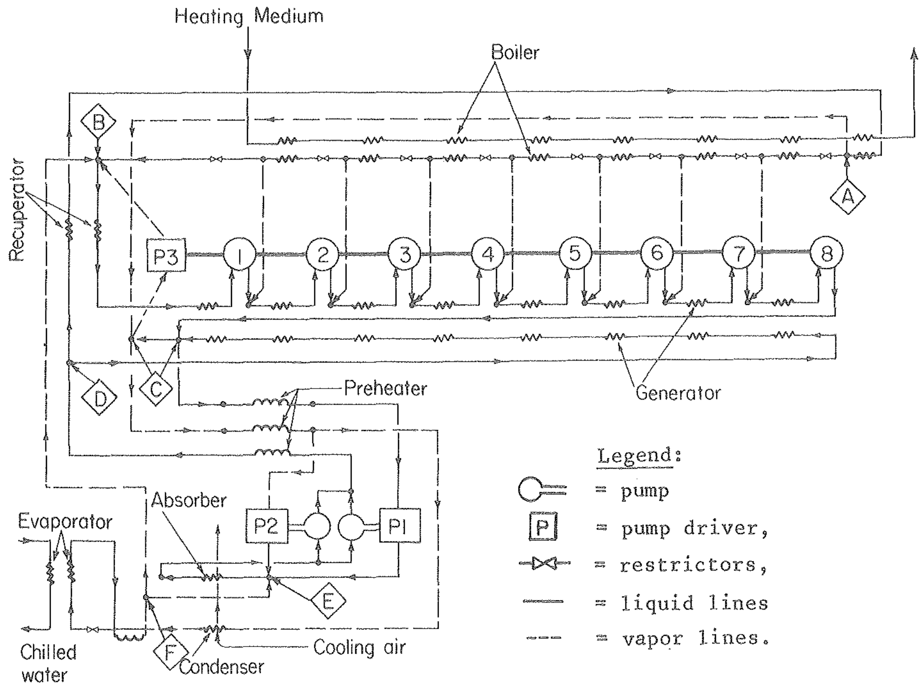

Fig. 1. Schematic diagram of cycle 2R chiller to be developed in phase 3 of the project.

(XBL 809-1894)

Heat is transferred from the heating medium to the ammonia solutions boiling at eight different pressure stages in the boiler. At the end of each boiling, vapor is extracted and reabsorbed in one flow side of the generator. The heat of absorption produced in this side of the generator boils the solution flowing in the other side of the generator. The NH_3 vapor produced by the generator at C is fed to the condenser through the preheater. A small amount of this vapor is bled off to run the piston driver P3 of the multistage pump (stages 1-8). After condensation in the condenser, the liquid NH_3 expands through a restrictor (or expansion valve) to the evaporator where it boils and chills the chilled water. The NH_3 vapor leaving the evaporator at F is absorbed in the absorber at E and in the recuperator at B. The heat of absorption produced in the absorber is rejected to the cooling air. Heat of absorption produced in the B side of the recuperator boils the solution flowing in the D channel of the recuperator. Vapor generated by this boiling process DA is collected at A to be subsequently condensed in the condenser. At the outlet of the absorber, the solution rich in NH_3 is pumped by pumps P1 and P2 to D through the preheater. At D the solution is split into two streams. The first stream (82%) boils in the generator and the second stream (18%) boils in the recuperator. Essentially the cycle 2R is constructed by adding a boiler and a recuperator to the basic conventional single-effect cycle which consists of the generator, the preheater, the absorber, the condenser and the evaporator. Note that the boiler does not directly produce any NH_3 vapors that can be used in the evaporator. The function of the boiler is to transfer heat from the heating medium to the generator and to benefit from the high temperature of the heat source to produce a very weak solution at B.

The amount of heat received by the boiling solution from A to B in the boiler is transferred essentially without losses to the generator in the form of latent heat from the vapors generated by the different stages of the boiler. Upon reabsorption these vapors release their latent heat to the boiler side of the generator.

The very weak solution at B is at lowest pressure and can absorb NH_3 vapor from the evaporator. Absorption of this very weak solution B rejects heat at temperatures high enough to boil stronger solutions in the D side of the recuperator, at condenser pressure. The vapor produced by the boiler solution from D to A adds up to the vapor produced by the generator at C to increase the cooling capacity of the cycle, thus improving the COP. The larger the temperature spread between B and C, the higher the COP. The single-effect cycle part of cycle 2R is designed to operate near cut-off conditions, independently of the heating medium temperature; for instance, the temperature at C is always 216°F when the temperature of the condenser absorber is 110°F and the evaporator temperature is 40°F.

In Fig. 1, all check valves' connections are left out for clarity. With five check valves properly located, the cycle 2R also operates when the heating medium temperature is below the cut-off generator temperature of the single-effect subcycle. This is possible because the boiler and recuperator perform as a heat pump that can pump heat from the low temperature (say 170°F) heat source to a temperature high enough to operate the single-effect subcycle. The design, drawing, and fabrication of the multistage pump P3 has been completed. Performance tests will follow soon. The design and drawing of the remaining components of the 2R chiller is almost 50 percent completed. All heat exchangers are of tube-in-tube configuration.

Design rated capacity is 3 tons; for an anticipated net COP of 0.87, design operating temperatures are:

heat source: 280°F (input to the boiler);
heat source: 95°F (condenser absorber cooling air);
cold source: 45°F (chilled water outlet).

Net COP is defined as the COP obtained after deduction of the amount of generated vapor bled to run the pumps P2 and P3.

Off-design performance of this 2R chiller is summarized in Table 1 and Fig. 2.

PLANNED ACTIVITIES FOR 1980

Reports on the testing of the phase 2 single-effect chiller will be completed in 1980.

The multistage (8 stage) pump (pump P3 in Fig. 1) will be tested, "debugged," and improved during 1980 so that it can be ready for assembly with the cycle 2R chiller in 1981.

The design and drawings of all components of the 2R chiller will be completed in 1980. Fabrication of some components of the 2R chiller may proceed in late 1980.

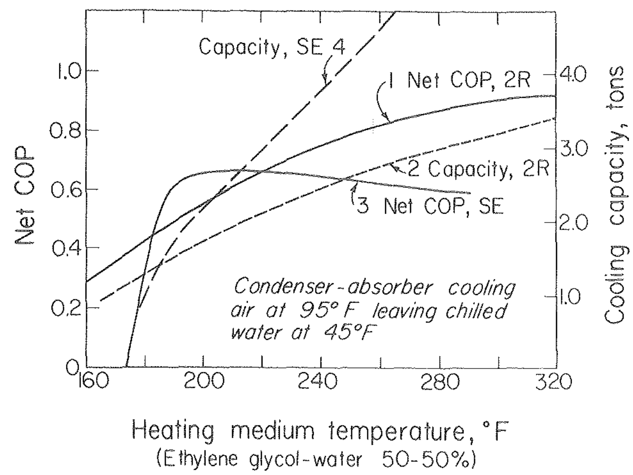

Fig. 2. Estimated performance characteristics of the phase 3 2R chiller as compared to those of the phase 2 single-effect (SE) chiller.
(XBL 809-1895)

Investigations of other possible advanced cycles (such as cycle 1R, Ref. 5), and the search for an advanced cycle that may have better performance and lower production cost than the cycle 2R will continue in 1980.

The search for higher-temperature refrigerant absorbant pairs suitable for advanced cycles (particularly for cycle 1R, Ref. 5) will continue in 1980. The search consists of subcontracting the measurements of key properties of a number of pairs:

- heat of mixing at constant temperature: 25°C;
- vapor pressure of the pure fluids;

Table 1. Off-design performance of 2R chiller.

	Temperature of solution leaving generator at C, °F					
	160	182	210	240	270	300
Chilled water outlet temperature, °F	45	45	45	45	45	45
Cooling air temperature, °F	95	95	95	95	95	95
Condenser absorber temperature, °F	101	103	106	108	110	112
Input temperature, °F	165	190	220	250	280	310
Capacity, tons	0.9	1.5	2.1	2.5	3.0	3.3
Net COP	0.33	0.50	0.67	0.79	0.87	0.93
Cond/absorber fan power, watts	450	450	500	500	500	500

- specific heat capacity of the pure fluids, and mixtures;
- vapor pressure of mixtures over a temperature range.

From the key properties, approximate mixture properties will be calculated over the whole range of interest using appropriate thermodynamic relations. Cycle analysis using the approximate properties will determine the best pair. Properties of the selected pair will then be measured accurately over the whole range of interest. Other properties such as viscosity, thermal conductivity, chemical stability at high temperature, and compatibility with various materials of construction will also be determined.

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PASSIVE COOLING*

M. Martin, P. Berdahl, F. Sakkal, and M. Wahlig

INTRODUCTION

The major objective of this project is to evaluate radiative and passive cooling systems for various parts of the United States. The long-range goal is to displace electricity used for air conditioning. The primary emphasis in this project to date has been infrared radiative cooling.

Infrared radiative cooling systems are composed of a radiator surface which is exposed to the sky, an infrared-transparent windscreen to reduce convective intrusion of heat from the air, and a means for transporting heat from the building's interior to the radiator surface. The current work includes measurement of atmospheric infrared emission characteristics in order to identify geographical regions in which selective and nonselective radiators may be effective. Both atmospheric radiation models and experimental sky radiation measurements are employed in this effort. A computer analysis of radiative cooling will model the entire system, including the atmospheric characteristics, the blackbody or selective radiating surface, and the building load. Promising radiator surfaces and infrared-transparent windscreens will be experimentally evaluated at an outdoor test facility at LBL. Finally, convective and evaporative cooling systems will be integrated into the study so that other aspects of passive cooling will be included.

In order to predict accurately the net heat exchange between the sky and a surface of known infrared characteristics, it is necessary to have a knowledge of the intensity of infrared radiation produced by the atmosphere as a function of both zenith angle and wavelength. Most measurements in the literature pertaining to the spectral radiance of the sky were obtained on one or two nights, or were made only under clear sky conditions. It therefore became necessary to make measurements, day and night, over periods of months, to obtain data on which estimates of cooling system performance can be based. During 1978, a major effort was devoted to construction of four spectral infrared sky radiometers and the siting of three of these instruments at Tucson, San Antonio and Gaithersburg. These sky spectrometers were set up to measure the radiance of the zenith sky at half hour intervals in 6 wavelength bands ranging from 8 to 22 microns. Auxiliary measurements performed consisted of total infrared sky radiance (with a pyrgeometer), air temperature, and dewpoint. Further details of the measurement system may be found in last year's Annual Report,[1] and elsewhere.[2-5]

ACCOMPLISHMENTS DURING 1979

A major activity in FY 1979 was the operation and improvement of the infrared radiometer systems. The fourth system was sited at St. Louis in June. As data acquisition became routine, it was possible to devote some effort to data analysis. A major new activity this year has been the design and construction of the experimental test facility for selective radiative cooling systems. At year's end, the facility was nearly complete.

Spectral Radiometer Measurement Systems

During winter and spring months, efforts were directed toward maximizing the quality and quantity of sky radiance data to be acquired during the summer. Several improvements were implemented.

Radiometer improvements resulted in reduced mirror emissivity corrections. Formerly, a front-surfaced aluminum mirror overcoated with silicon monoxide was used. In the 8 and 9 micron spectral regions, corrections for the mirror emissivity were typically 10%. Although these values are determined automatically during computer processing of the data at LBL, they are not accurately known. New mirrors, with a reflecting surface composed of a thin layer of bare gold, reduced typical emissivity corrections to 3%.

Calibration techniques were also improved. Radiometer calibration is performed by measuring the radiance of a black body of known temperature as it cools from 70°C down to ambient temperature. Formerly, this procedure was initiated manually by personnel at the radiometer site. This function is now under the control of the on-site microprocessor, making it possible to perform calibrations daily. More frequent calibrations aid detection of possible instrument malfunctions.

The most significant improvement implemented was the introduction of new viewing angles. (This extension in capability had been planned from the project inception, subject to the availability of funds.) Prior to this summer, the radiometer viewed only the zenith. However, the hardware and software are now modified so that the instrument can measure the radiance at zenith angles of 0°, 20°, 40°, 60°, and 80°, on an arc from the zenith to the north horizon.

For the summer period, data sets actually obtained range from 67% complete at San Antonio to 88% complete at Tucson. The primary problems which caused loss of data were:

- pyroelectric detector failure;
- rain detector failure (the system "thought" it was raining and did not make measurements);
- rare but recurring hardware failure of unknown origin which interacted with software "bug" to disable microprocessor;
- telephone line failure (data could not be transmitted to LBL);
- broken microswitch; and
- power outages.

Although these problems were significant, they did not substantially impair usefulness of the data.

Analysis of the Sky Radiance Data

Analysis of the sky radiance data to date has provided rough estimates of the resource for radiative cooling. For example, a 100% efficient idealized radiative cooling system with a radiator temperature of 25°C (described in Ref. 3), located in Tucson from August 16-31, 1978, would have rejected an average of 88 W/m^2 to the sky, 24 hr/day.[3] The same system, sited at San Antonio for the last week in September, 1978, would have rejected 69 W/m^2.[3] After further data analysis, estimates such as these will be available for various types of cooling systems, based on longer periods of data.

An important aspect of the data analysis is the verification of the atmospheric model of sky radiance developed at LBL, based on the public domain computer model LOWTRAN 3B.[6] Such a verification is not practical for cloudy skies because an adequate characterization of clounds is not usually available from meteorological measurements. However, for clear skies, it is possible to use radiosonde measurements of the atmospheric profile of temperature and humidity. These measurements are made at 12 hour intervals by the National Weather Service. Incorporating typical profiles for ozone, carbon dioxide, and aerosols, one has enough information to produce a calculated spectrum of the sky radiance. For the 8.1-13.7 micron filter of the spectral radiometer, these calculated radiances are plotted on the horizontal of Fig. 1. (The spectral radiances produced by LOWTRAN have been averaged over the 8.1-13.7 spectral interval, using the spectral transmissivity of the radiometer system as a weighting function in performing the

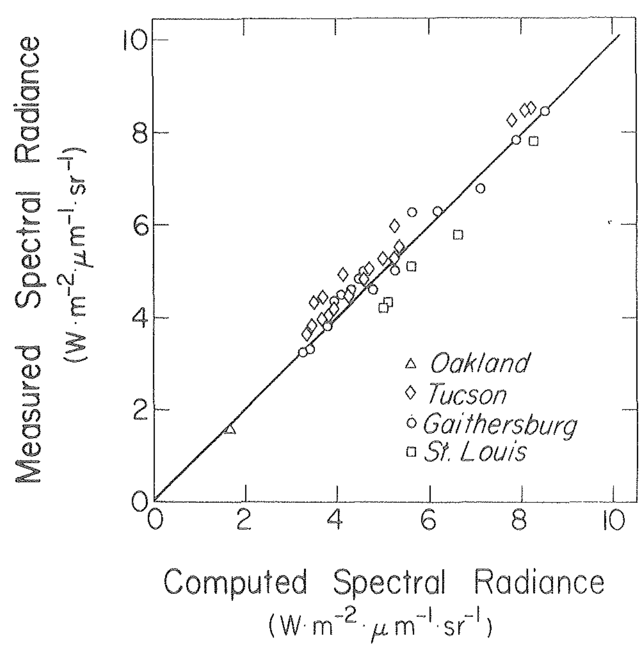

Fig. 1. The measured spectral radiance of clear skies in the 8.1-13.7 band, plotted versus calculated radiances based on measured atmospheric profiles of water vapor and temperature. Except for the single measurement at Oakland, all results are for the summer season. Points to the right in this diagram correspond to measurements near the horizon, where the atmosphere is "warmer". (XBL 809-1898)

average.) The measured values of the average spectral radiance for this filter are plotted along the vertical axis. Most of the scatter in this plot is due to deviations of the radiosonde profile from the actual temperature and water vapor profile along which the radiometer was viewing. To support this contention, Fig. 2 displays the subset of the data in Fig. 1 in which the surface temperature and dew point, as measured at the radiometer site, agree to within ±1°C with the values reported from the radiosonde sounding. The improvement in the data scatter is evident. The computer model verifies that errors of 1-3°C in the dew point temperature are large enough to cause the increased scatter seen in Fig. 1. The small systematic deviation remaining in Fig. 2 between the measured and computed spectral radiance is probably significant; however, more work is required to determine its origin.

Based on the foregoing comparison, one may state that the systematic errors in the radiometer measurements are probably less than 0.3 W/m^2 μsr, for the 8.1-13.7 μ band. The errors in computed estimates of clear sky radiance are also less than 0.3 W/m^2 Mm sr, provided the atmospheric profiles of temperature and water vapor are adequately known.

Experimental Test Facility for Selective Radiative Cooling Systems

This new facility, located on a rooftop at LBL, will permit measurements of the performance of candidate radiator and windscreen materials. Eight radiator assemblies have been mounted on a rooftop rack. Each assembly consists of an insulated Kydex (Acrylic and PVC) box having outside dimensions 108 x 66 x 12.7 cm, as shown in the cross-sectional view of Fig. 3. The insulation, which fills the 10-cm-thick interior of the box, consists of injected styrofoam.

A recess in the upper surface of the box holds a 0.8 mm-thick aluminum radiator plate of dimensions 50 x 90 cm. Convection losses above the radiator are suppressed by means of a 0.050 mm-thick polyethylene windscreen located approximately 3 cm above the plate. A resistive heating element is glued to the bottom side of the radiator plate and the upper side is painted or specially treated to form the radiating surface. The heater capacity is 140 W which allows a maximum net outgoing thermal flux of approximately 311 W/m^2 to be radiated.

A microprocessor-based data acquisition system will be used to control and measure the heater outputs as well as to make measurements of radiator and windscreen temperatures. Auxiliary measurements are to be air temperature, dew point, and total infrared sky radiance using a pyrgeometer.

Preliminary experiments with the test facility have been performed, and results were reported at the Fourth National Passive Solar Conference.[7] More extensive tests will be initiated during the summer of 1980 upon completion of the automatic temperature control and data acquisition system. Improvements on results obtained elsewhere in similar tests[8-15] are expected through the use of more accurate characterization of atmospheric conditions because a pyrgeometer is used to measure infrared sky radiance.

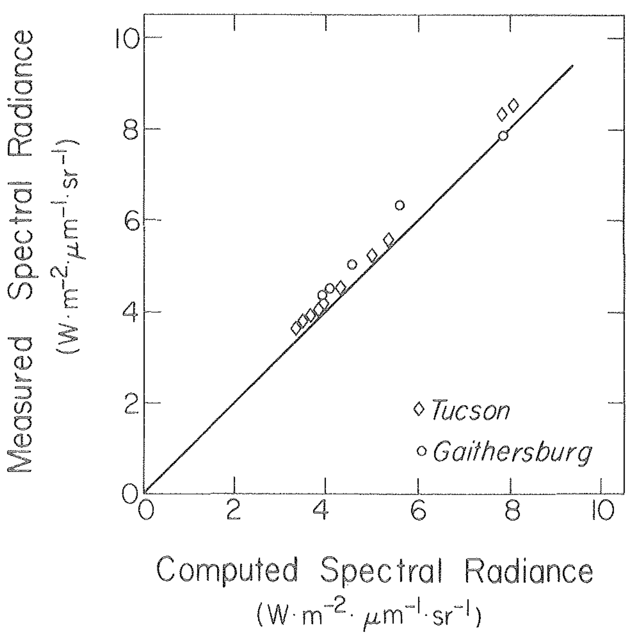

Fig. 2. This figure shows a subset of the points in Fig. 1. Eliminated were those measurements made when the ground level temperature and dew point of the radiosonde measurement did not agree to within 1°C of the values measured at the radiometer. (XBL 809-1896)

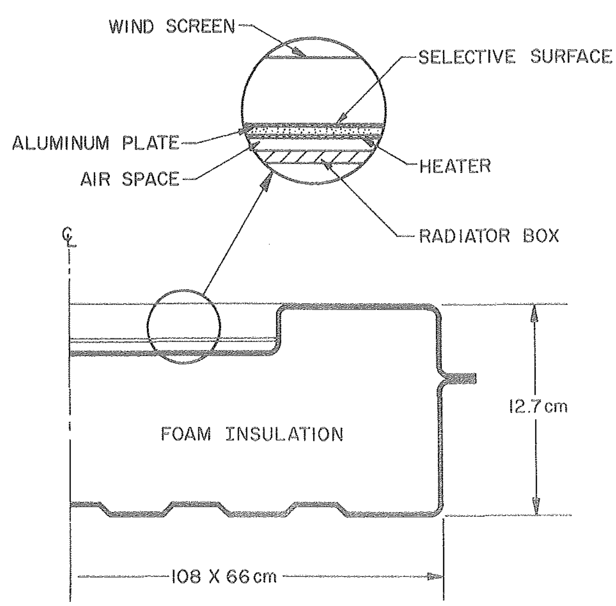

Fig. 3. Radiator assembly showing insulating box, radiator, and windscreen. (XBL 798-10763)

PLANNED ACTIVITIES FOR 1980

All four spectral infrared sky radiometer systems will continue to collect data through the summer of 1980. Two systems have been moved to permit data sets to be accumulated in other (warm) climate regions of the United States. The new sites are West Palm Beach, Florida, and Boulder City, Nevada, which represent extremes of humid and dry climatic conditions.

A major effort in 1980 will be devoted to the analysis of the sky radiance data in order to produce information useful for the design of passive cooling systems which utilize radiative cooling. This effort will have two primary components. First, tabulated values of cooling rates for various systems will be computed, taking into account system operational characteristics, such as the spectral emissivity of the radiator, radiator aspect angle, and whether or not the system will be operated during daylight hours. Second, the radiometer data will be correlated with both meteorological and pyrgeometer data in an effort to establish techniques for estimating spectral data from more conventional measurements.

The experimental test facility for selective radiative cooling systems will be fully operational. The facility will be used to establish the relative and absolute merits of various radiator and wind screen materials. Other issues to be investigated include the effectiveness of honeycombs for suppressing convective losses, the use of infrared reflectors to "concentrate" the cooling resource, the use of infrared-transparent glazings which can reflect sunlight to permit daytime cooling, and the control or elimination of the condensation of atmospheric moisture within the cooling apparatus.

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LBL SOLAR DEMONSTRATION PROJECT*

T. Webster

INTRODUCTION

The LBL Solar Demonstration Project in Building 90 (Fig. 1) is one of eleven projects selected to be part of the FY 1977 Department of Energy (DOE) Facilities Solar Demonstration Program, a pilot program for the Solar Federal Buildings Program authorized by the National Energy Act. The objectives of this pilot program were to establish procedures and techniques for assessing and implementing solar systems for federal facilities, and to assist in energy use reduction within DOE facilities.

The following criteria were used to select projects for this initial program:

- Buildings should be suitable for retrofitting, i.e., their orientation, location and configuration should be suitable for solar energy use.
- Solar space and hot-water heating should be emphasized.
- Buildings should be typical government buildings.
- Design and construction should not cost more than $200,000.

The LBL project was funded by the DOE Solar Energy Division through the Construction, Planning,

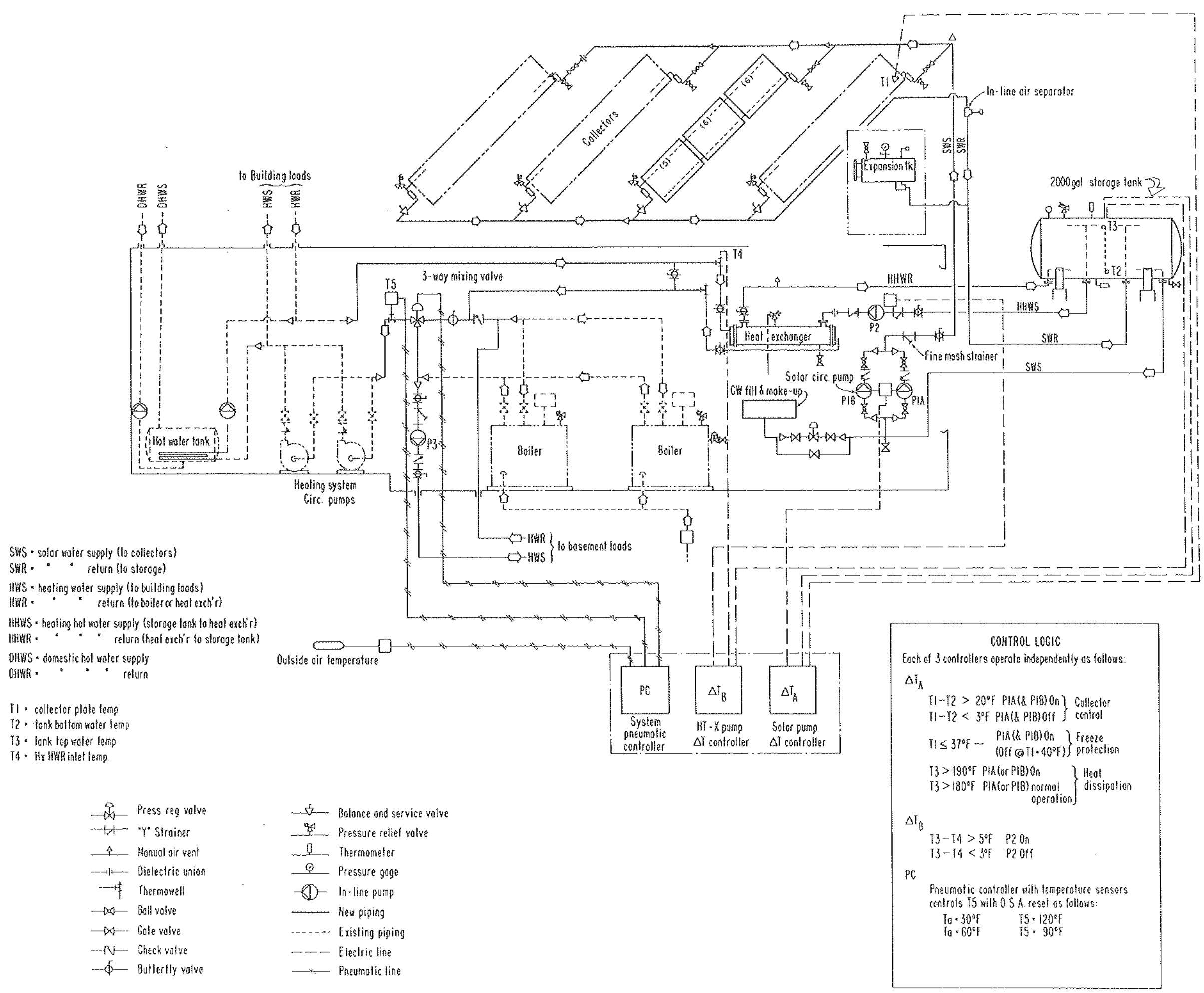

Fig. 1. Building 90 solar retrofit piping and control schematic. Engineering Drawing 4B90-P043-B. (XBL 791-102)

and Support Division. LBL Plant Engineering was responsible for design and construction of the project with assistance provided by the LBL Solar Group. A detailed description of the building, solar systems, preliminary and final design considerations, and initial construction is contained in the 1977 Energy and Environment Division Annual Report, 1978.

ACCOMPLISHMENTS DURING 1979

The solar system construction was completed during 1979. Among significant events and problems during system construction and initial operation were:

- erroneous Unistrut locations (for collector attachment) requiring field modifications;
- rerouting existing piping in the basement to allow installation of solar piping;
- leaking 3-way control valve due to piping misalignment;
- installation of a bulb type collector freeze protection sensor that was unable to take high collector temperatures; this sensor was replaced with an electric, resistance type sensor with a ΔT controller;
- flow anomolies in the heating system which were traced to a check valve that would isolate the boiler from the system in some modes of operation; the valve was found to be unncessary and was removed;
- differential expansion between the urethane foam insulation surrounding the tank and the steel tank shell caused cracking in the tank's insulation and outer aluminum cover. The problem was corrected by resealing the shell.

Construction of the system was completed in April 1979. Preipheral items such as IBM instrumentation and stairs and walkways were completed in September. Although the system is complete and ready to operate, the collector-to-storage loop is the only part of the system currently operating; a return-air recirculating system has not yet been installed, so the solar system is not capable of operating effectively at the temperatures currently required by the heating system. This system is slated for installation soon.

FINAL SYSTEM COSTS

Table 1 is a summary of final system construction costs as reported by the contractor.

Table 1. System costs

Systems	Materials	Labor	Total
Collector Subsystem			40,866
Collectors and mounting	19,123	5,920	25,051
Collector supports	8,762	4,716	13,478
Collector piping		960	960
Collector piping insulation			1,377
Storage Subsystem			8,334
Tank and Installation	4,449	1,130	5,579
Insulation			2,755
Other			36,856
Piping, pumps, heat exchanger	7,255	10,696	17,151
Insulation			2,755
Controls			7,050
Electrical			4,101
Painting			2,200
Contractor overhead and profit			2,799
Total System Costs			86,056
Cost per square foot gross collector area			60.3
Cost per square foot net collector area			67.1
Contract amount			79,700
Extras			6,356

Among the lessons learned (and recommendations for future systems of this type) are the following:

- As shown by the actual costs above, the collector structural supports (at 15%) is a significant part of the system costs. The structure was redesigned three times in an attempt to reduce these costs without much success. Alternative structures that require less structural steel and less reinforcement of building structure beams should be explored.

- While internal collector manifolding is highly recommended, spacing of the collectors should be increased to at least 2 in. to allow easier access for soldering and installation of insulation.

- Expansion joints should be provided when urethane foam insulation is used for tank insulation.

- All minor details, such as valve locations and positions, collector attachment locations and details, insulation details, and clearances should be carefully worked out and double-checked during design and construction to reduce costs and insure durability of the installation.

- Although this was a federal project which usually results in high costs, the overall cost per square foot of collector area is not unreasonable compared with commercial system costs in the private sector. However, the contractor's overhead and profit is quite low at 3%; comparable low bids for this type of work would probably be the exception rather than the rule. On the other hand, because this system is industrial quality and probably is about as difficult a retrofit as is reasonable to undertake, the overall costs are probably typical for future systems of this type.

FUTURE ACTIVITIES

Funding for this project has been terminated as of September 1979. IBM instrumentation will be activated in early FY 80 and performance data collection will commence as soon as the recirculating air system is installed.

FOOTNOTE

*This work has been supported by the Solar Heating and Cooling Demonstration Branch, Office of Conservation and Solar Applications, U.S. Department of Energy under Contract No. W-7405-ENG-48.

SUPPORT FOR COMMERCIAL SOLAR DEMONSTRATION PROGRAM*

F. Salter, S. Peters, and T. Webster

INTRODUCTION

The Solar Applications Group at LBL provides technical consulting and management services to support the DOE San Francisco Operation Office's (DOE/SAN) overall management of commercial-building solar demonstration projects and hotel/motel hot water solar projects located throughout the Northwestern States and Hawaii. These projects are part of the National Solar Heating and Cooling Demonstration Program,[1] whose primary objectives are to stimulate a solar industry and to promote the use of solar energy as a means of reducing demand on conventional fuel supplies.

The group is currently involved in support for projects in this program as follows:

Projects	Program solicitation	
1	NSF-1	Cycle I
13	DSE-76-2	Cycle II[2]
11	PON 4200	Cycle III[3]
3	PON 1450	Hotel/motel[4]

A detailed description of activities of this group is contained in the Energy and Environment Division Annual Report for 1977.

ACCOMPLISHMENTS DURING 1979

Technical consulting and management activities continued on all projects. One Cycle III project was cancelled due to participant funding problems. LBL's participation in these demonstration projects will cease at the end of FY 1980, and accordingly, one Cycle II and five Cycle III projects, which have been delayed primarily because of funding problems and will not be complete by the end of FY 80, have been transferred to Energy Technology Engineering Center (ETEC) in Southern California.

At the end of FY 1979, construction was complete, or near complete, on the following projects:

	Construction Completion	
Program Cycle	100%	>95%
Cycle I	1	1
Cycle II	7	12
Cycle III	1	4
Hotel/motel	2	2

Even on projects that are operational, some consulting and management effort is required to follow the project, deal with occurring operational problems, gather and review Final Reports and Data

Collection Reports. On two Cycle II projects, contracts have been written for refurbishment work to improve the overall systems efficiencies and to make the systems more reliable and serviceable. This work is primarily related to piping, insulation and control modifications. At present, investigations are in progress on three other projects which appear to be potential candidates for similar refurbishment contracts.

PLANNED ACTIVITIES FOR 1980

For FY 1980, activities have been reduced from three to one man-year of effort. LBL's involvement in these projects will cease at the end of FY 1980. Efforts will be directed toward completing as many projects as possible; however, it is likely that additional projects will be transferred to DOE/SAN or ETEC during the course of the year.

FOOTNOTE AND REFERENCES

*This work has been supported by the Solar Heating and Cooling Demonstration Branch, Office of Conservation and Solar Applications, U.S. Department of Energy.

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2. Commercial Integrated Projects for Use in Demonstrations of Solar Heating and Cooling, PON DSE 76-2, ERDA (1976).

3. Commercial Integrated Projects for Use in Demonstrations of Solar Heating and Cooling, PON EG-78-N-01-4200, DOE (1978).

4. Hot Water Initiative for Hotel/Motel Installations, PON EG-77-N-03-1450, ERDA (1976).

MEASUREMENT AND ANALYSIS OF CIRCUMSOLAR RADIATION*

D. Evans, D. Grether, A. Hunt, and M. Wahlig

INRODUCTION

Instrument systems called "Circumsolar Telescopes" are used to measure the solar and circumsolar radiation for application to solar energy systems that employ lenses or mirrors to concentrate the incident sunlight. Circumsolar radiation results from the scattering of direct sunlight through small angles by atmospheric aerosols (dust, water droplets, or ice crystals in thin clouds, etc.). The solar energy system will typically collect all of the direct solar radiation (that originating from the disk of the sun) plus some fraction of the circumsolar radiation. The exact fraction depends upon many factors, but primarily upon the angular size (field-of-view) of the receiver. A knowledge of the circumsolar radiation can be used as a factor in the optimization of a receiver design, as one measure of the suitability of a geographic region for concentrating systems, or as input to comparison studies of competing designs at a particular location.

Design and construction of the circumsolar telescope was one of the first tasks completed in this project. The instrument system has a "scanning telescope" mounted on a precision solar tracker. The telescope mechanically scans through an arc of 6° with the sun at the center of the arc. A digitization of the sun's brightness or the brightness of the circumsolar radiation is taken every 1.5' of arc, with a complete scan taking one minute of time. In all, four such instruments were constructed. Auxiliary instruments include a pyrheliometer, a collimating instrument with a fixed field of view (typically 5-6°) that provides an estimate (called the "normal incidence" reading) of the direct solar radiation. The telescope and pyrheliometer have matched ten position filter wheels: one open position, eight interference filters that divide the solar spectrum into eight intervals of roughly equal energy content, and one opaque filter to monitor detector noise. The data are recorded on magnetic tape, with one tape holding a week's worth of data per telescope.

The telescopes have been primarily operated at locations for which the instruments can play a dual role: (1) characterization of a region or climate, and (2) provision of site-specific data for proposed or actual concentrating solar energy systems.

The data are used at LBL and other DOE-supported institutions [e.g., Sandia Laboratories and Solar Energy Research Institute (SERI)] in consideration of the concentrating system's perform ance. In order to extend the analyses to areas not covered by the instruments, efforts are underway to understand the relationship of the circumsolar radiation to atmospheric conditions and to other, more routine, solar and meteorological measurements.

Details of the instrument system, and examples of the measurements and data summaries have been given in previous annual reports.

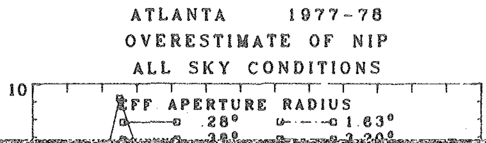
ACCOMPLISHMENTS DURING 1979

Measurement Program

Telescopes were operated this year at Sandia Laboratories, Albuquerque (location of the Central Receiver Test Facility (CRTF) and other concentrating systems); on a Southern California Edison (SCE) building at Barstow, California (near the site of a future 10 Mw(e) Central Receiver Pilot

Plant), and at Atlanta (site of a Georgia Tech central receiver test facility).

The remaining telescope underwent an upgrading program at LBL, with a number of modifications made



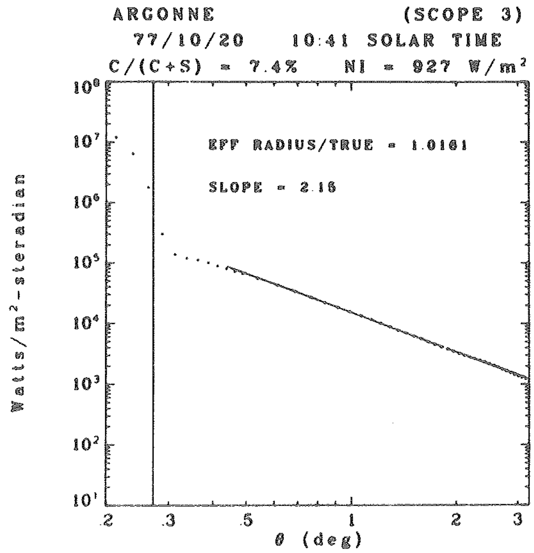


Fig. 2. Sample of a telescope scan in log-log space. The solid, vertical line represents an "effective radius" of the sun. The center of the sun is off-scale.

from Barstow. The dense cluster of points at relatively low slope (~1.5) and low circumsolar ratio correspond to clear-sky conditions. The high slopes (~2.5) are seen to be associated with high circumsolar ratios. In terms of scattering properties of aerosols, a relatively steeper slope indicates that relatively larger particles are responsible for the scattering. The interpretation is that for the atmospheric conditions that give rise

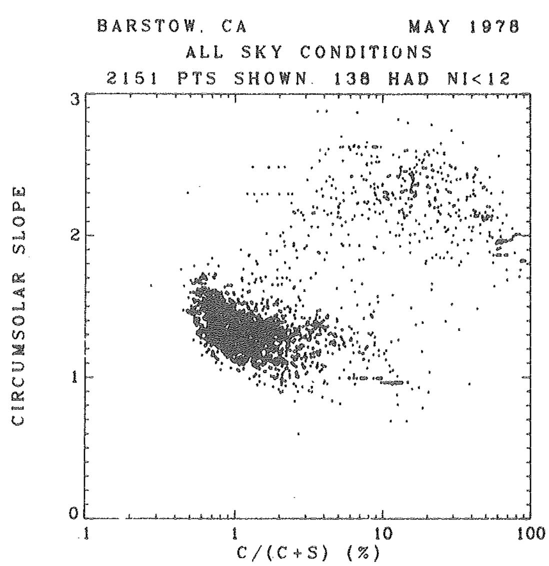


Fig. 3. Plot of the circumsolar slope versus the circumsolar ratio for the month of May, 1978 in Barstow. "138 HAD NI<12" refers to measurements for which the normal incidence reading of the pyrheliometer was essentially negligible. These points are excluded from the graph.

to high levels of circumsolar radiation (e.g., haze or thin clouds) the light-scatterers tend to be rather large.

Some work has been done on comparing these slopes to the predictions of the so-called Mie Theory for light scattering from aerosols, with the aerosols approximated by dielectric spheres of a specified size distribution and complex index of refraction. In terms of this model, slopes on the order of 2.5 would imply that the scattering is dominated by particles with dimensions greater than about 20 μ in diameter.

Colored Filter Data

The emphasis in the project has been on the "clear" filter measurements, because these data are most relevant to concentrating collectors employing thermal receivers (which use black surfaces to absorb the solar radiation). However, there are also applications for which the receiver would be a photovoltaic cell, which is highly wavelength selective. So few systematic measurements of the wavelength dependence of solar radiation are available that the colored filter pyrheliometer data are of considerable interest in themselves, apart from the telescope scans. Thus the first priority has been to extract the normal incidence spectral data. To do this, the transmission of each filter as a function of wavelength must be accurately characterized.

Curves of transmission versus wavelength (obtained on a spectrophotometer) were supplied by the manufacturer when the filters were new. However, such filters may degrade with time. This year, transmission curves were obtained for the filters from one of the telescopes, using an LBL spectrophotometer. These measurements showed that while some of the filters were essentially unchanged, others had a reduced overall transmission and (sometimes) a broader pass band. An effort was then initiated to use the data themselves to track the effective change in filter characteristics between spectrophotometer measurements. The technique (outlined in Ref. 3) would utilize pyrheliometer readings from clear days, when atmospheric conditions are relatively stable and the atmospheric attenuation of the solar radiation is generally thought to be well understood. The computer program Lowtran[4] has been investigated as a model for the atmospheric attenuation.

As a check on the applicability of Lowtran, the model has been compared to actual pyrheliometer values for selected clear days. Figure 4 shows the comparison for Barstow for two filters, one at the blue end of the solar spectrum and the other at the infrared (IR) end. For this comparison, the atmospheric transmission values from Lowtran have been combined with a standard extraterrestrial solar spectrum and with the manufacturer-supplied transmission curve so as to simulate the reading of a pyrheliometer taken through the corresponding filter. As is indicated by Fig. 4, the Lowtran calculation tends to agree with the data at the blue end of the solar spectrum, but to yield higher values towards the red/IR end of the spectrum. A certain number of assumptions were made in order to carry-out the Lowtran calculation, and the validity

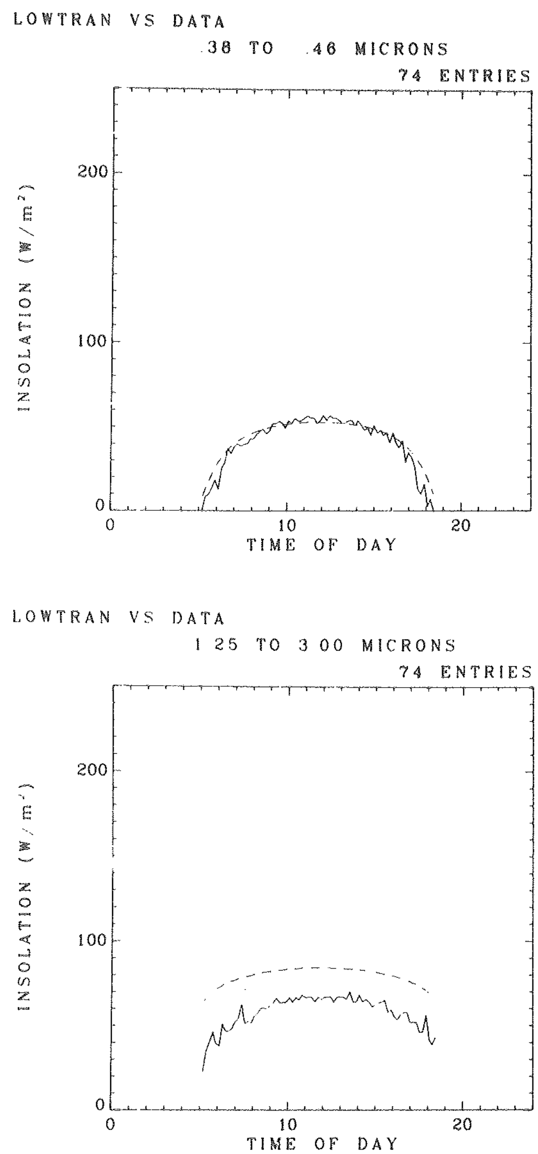


Fig. 4. (a) Pyrheliometer reading versus time of day for July 24, 1978 at Barstow, CA for a filter near the blue end of the solar spectrum. The solid curve is the actual pyrheliometer value, the dotted curve the calculation based on the atmospheric transmission computer program Lowtran. (b) Same as (a), but for a filter at the red/IR end of the solar spectrum.

of these assumptions needs to be examined. However, if the discrepancy holds, then there are implications beyond the immediate problem of filter calibration. In particular, Lowtran has been recently recommended as a suitable tool for calculating the solar radiation available to photovoltaic cells on clear days.[5]

Other Activities

The Solar Energy Research Institute (SERI) is examining the effect of circumsolar radiation on a variety of concentrating systems.[6] As input to this study, LBL prepared selected data in a form usable by SERI.

A DOE-supported engineering firm (Watt Engineering, Limited) is examining the correlations of average values of circumsolar radiation with other solar and meteorological parameters, using data from LBL and other sources. LBL, working with Watt Engineering, prepared several data tapes for use in the analysis.

During actual tests of concentrating systems or components, circumsolar data can be of importance in comparing the actual to predicted performance of the system. Individual scans of the telescopes, taken in parallel with tests of the CRTF at Albuquerque, were provided to Boeing (Brayton cycle receiver tests) and Sandia Laboratory (heliostat tests).

PLANNED ACTIVITIES FOR 1980

The measurement program will continue. Plans originally were for the upgraded telescope to be moved to SERI in Colorado. For various reasons, this move did not prove feasible. Revised plans are for this instrument to be located at the Jet Propulsion Laboratory (JPL) test station at Edwards Air Force Base. The instrument would provide site-specific data for point concentrating collectors (parabolodial dishes) that are undergoing tests by JPL. The instrument would also provide characterization of the Mojave desert area, a role heretofore played by the telescope at Barstow. This latter instrument would then be returned to LBL for upgrading and eventual relocation.

The various analyses will continue with the overall goal of better understanding of the relationship of circumsolar radiation to atomospheric characteristics and to the performance of concentrating solar energy systems. The extraction of the colored filter data will be particularly emphasized.

FOOTNOTE AND REFERENCES

*This work has been supported by the Department of Energy through Conservation and Solar Applications (Systems Development Division of the Office of Solar Applications), and through Solar Geothermal, Electric, and Storage Systems (Central Solar Technology-Solar Thermal Branch, and Distributed Solar Technology Photovoltaics Branch), under Contract No. W-7405-ENG-48.

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INSTRUMENTATION AND DATA PROCESSING MODIFICATIONS IN THE PG&E/SOLAR DATA NETWORK*

D. Anson

INTRODUCTION

A six station network of solar radiation measuring instruments (pyranometers) has been operating in Northern California for the past three years. The network is a cooperative project between LBL and Pacific Gas and Electric Company (PG&E). Each organization contributes its own unique and complementary resources to the implementation of the network. LBL provides technical guidance in the areas of hardware selection, software for analysis and reporting, and calibration and routine maintenance assistance. PG&E coordinates the project and contributes the physical site and personnel to change tapes and check instruments.

Five years have elapsed since the project began, and unfortunately the first two and one-half years were largely consumed by delays caused by funding uncertainties. More recently, though, data has been routinely collected, and, in several locations, has been collected for as much as two and one-half years.

The original purpose of providing quality solar energy research and design data in microclimatic regions with no current or previous solar data records continues to be emphasized by the project. High-quality instruments and data-monitoring practices have also been a high priority with the project. This is important for both system reliability and data credibility.

Considerable interest in the data has been expressed in a variety of ways. A state agency, for example, is eager to include these measurements in a larger, state-wide publication on solar data. A number of colleges have volunteered to operate additional instruments if they become available and assist with certain data analysis functions. There has also been some interest in establishing a "grass-roots" type of network in which responsible and knowlegeable individuals would oversee measurements at their residences and report them each month for publication.

ACCOMPLISHMENTS DURING 1979

Accomplishments during the past year have been in four major areas: (1) improved translation and archival of raw data tapes, (2) receipt of seven new Eppley model PSP pyranometers and a microprocessor-based recorder for testing, (3) arrangements for a number of additional stations, and (4) coordination for acquiring unreported raw data from other agencies.

In the field, all six stations continued to operate routinely throughout 1979. From the perspective of raw data processing at the PG&E general office in San Francisco, a major change occurred in the way the small magnetic tapes were translated and the data transferred onto a 9-track tape. This was significant in almost completely eliminating data losses with respect to computer processing procedures. This consisted of two procedural changes. First, a 9-track tape was established for permanent archival of all unprocessed data. Each new monthly receipt of data is now automatically added onto the tape. Secondly, the erasure and return of the small recorder tapes was delayed until all data had been successfully transferred to the 9-track archive tape, to punched cards, and to a print-out. As much as six months of data had been lost at some stations prior to these new procedures.

Because LBL funding of the part-time network coordinator position ceased, PG&E picked up the person (Dean Anson) who had been coordinating this work. This served to maintain project continuity.

Seven new Eppley model PSP pyranometers were recently received to replace the original units in the network. These first class pyranometers will serve to upgrade the accuracy from that achieved with the second class instruments (Eppley model 8-48) in use. The 6 model 8-48 (also known as "black and white") pyranometers are still quality sensors and will be moved to locations where solar data is not currently available. Also, a complementary instrument has been procured for use in testing, performance evaluation, and measurements of direct solar radiation. This unit is an Eppley NIP pyrheliometer, a device that tracks the sun throughout the day.

A new recorder (Campbell Scientific CR-21) is on order for possible use at each of the stations. This is a microprocessor-based device that can be remotely interrogated by telephone. This is similar to units being used for two other data collection projects managed by LBL.

Preliminary arrangements have been made to add a station in San Ramon, where PG&E's Department of Engineering Research is located. A solar test facility and experienced technicians are available to assure accurate data is collected at the site. Additional sites are being considered at San Francisco City College, University of California at Santa Cruz, and Napa.

A number of organizations are known to collect solar energy data that is not reported or generally available. Lawrence Livermore Laboratory (LLL) has nearly 5 years of quality data available. These data and those from the University of California at Davis, for example, would make valuable additions to a publication of solar data in Northern California.

This project has also done some calibrations of photovoltaic-type pyranometers for local colleges. On one occasion, a spare pyranometer was loaned to a local solar firm for final solar system performance tests after installation.

Overall, the main accomplishments have been in the areas of raw-data processing and new-equipment procurement. The remaining area needing the most attention is in data reduction and reporting.

PLANNED ACTIVITIES FOR 1980

Next year is viewed as one in which final arrangements will have been made for so-called "routine" network operation. With respect to hardware, the final details of pyranometer and recorder installation will be completed, and older units will be relocated.

The highest priority during FY 1980 is to process all solar data as of the end of FY 1979 and, by early 1980, make it widely available.

It is hoped that the concept of a "grass-roots" solar network can be tested using the low-cost and accurate solar-cell-based pyranometer by Li-Cor, Inc. (model LI-200S). This sensor has been carefully tested by the Solar Radiation Laboratory (NOAA) in Boulder, Colorado and was found to perform nearly as well as the Eppley model PSP.[1] A solid state integrator (Li-Cor, Inc. LI-175) is being considered for recording the solar data. It is low in cost and allows a pyranometer-and-recorder combination to be purchased for about $500. This hardware would be supplemented with a user's manual and a contact person to answer questions.

ACKNOWLEDGMENTS

The continuation of the PG&E/LBL solar data network is largely a result of the efforts of Mike Wahlig, Solar Group Team Leader at LBL and of Stan Blois, Technical Services Coordinator of PG&E. I sincerely appreciate their contributions to this cooperative project.

FOOTNOTE AND REFERENCE

*The solar data network project is jointly funded by PG&E and the Lawrence Berkeley Laboratory Solar Energy Program.

1. E. C. Flowers, "Comparison of Solar Radiation Sensors from Various Manufacturers," Annual Report, Nat'l Oceanographic and Atmospheric Administration, Environmental Research Laboratories, Solar Radiation Facility, Boulder Colorado (1978).

SUPPORT ACTIVITIES FOR DOE SOLAR HEATING AND COOLING RESEARCH AND DEVELOPMENT PROGRAM*

M. Wahlig, M. Martin, R. Kammerud, W. Place, B. Boyce, M. Warren, and A. Heitz

INTRODUCTION

This project consists of technical support activities for the Systems Development Division (formerly the Solar Heating and Cooling Research and Development Branch) of the DOE Office of Solar Applications. Areas in which LBL provides program support are controls for solar heating and cooling systems, passive cooling, active solar cooling, and passive solar analysis and design. These activities include the following: (1) peer review of unsolicited proposals; (2) preparation and evaluation of program solicitations; (3) technical monitoring of projects performed both by DOE contractors and by LBL subcontractors; (4) program planning, reviews and summaries; and (5) interlaboratory coordination of support activities. Program responsibilities of the Laboratory have increased due to implementation of a program decentralization plan approved in the fall of 1978. Under this plan, LBL and the San Francisco Operations Office of DOE (SAN) work together to manage the national R&D program in these assigned areas, with SAN providing project management and LBL providing the technical support. DOE headquarters transfers block funds to the SAN office to support outside research and development contracts being performed under these program elements. Most of the staff members of the Solar Energy Group have participated to some extent in this effort during 1979.

ACCOMPLISHMENTS DURING 1979

Review of Unsolicited Proposals

The LBL Solar Energy Group conducted a formal review session for unsolicited active solar cooling proposals at the Solar Energy Research Institute (SERI) in Golden, Colorado in late October 1978. The results of these reviews were then sent to DOE in Washington, D.C. along with recommendations for action. In addition, some nine individual unsolicited proposals for active cooling projects were reviewed during FY 1979. Preparations were begun to develop a standard evaluation process for new proposals (as well as follow-on proposals for contracts in progress) that can be used for making decisions about future funding.

Preparation and Evaluation of Program Solicitations

LBL staff members participated in the development of a computerized evaluation process to evaluate the solar cooling proposals submitted to SERI as part of the joint U.S./Saudi Arabian program (SOLERAS). Additional input was provided to carry out the proposal evaluation and make recommendations for funding. As a result of this program, four contracts were awarded to install solar cooling systems in U.S. locations that have climates similar to those of Saudi Arabia.

LBL staff also participated in the preparation and evaluation of DOE solicitations for Marketing Studies for Solar Heating and Cooling Systems, and for a marketable passive products solicitation.

Technical Monitoring of Projects

Early in FY 79, LBL was given responsibility for the technical monitoring of Absorption and Rankine solar cooling projects that were previously being monitored by Brookhaven National Laboratory (BNL). Initially, five Absorption and four Rankine contracts were included; two additional Absorption contracts have since been added. Project monitoring consists of the continuous technical evaluation of projects being performed by other contractors, including site visits, review of progress reports, and organization of contractor meetings as appropriate. During FY 79, site visits to all active solar cooling contractors were conducted by LBL review teams, whose members included nonLBL technical experts as well as LBL staff. Detailed status reports and action item lists have been generated from these site visits to provide DOE with information on the current condition of each project.

A workbook intended for residential-scale use was developed by an LBL subcontractor under direction of LBL staff. The workbook is slated to be published sometime in FY 80.

Program Planning, Reviews and Summaries

LBL has played an active role in the formulation of three international solar programs during FY 79: the U.S./Saudi Arabia (SOLERAS), U.S./Israel and U.S./Mexico solar programs. The SOLERAS project is mentioned earlier in this article. LBL participated in negotiations in Israel to develop joint active solar cooling and passive cooling projects that would be beneficial to both countries. Both active solar cooling (solar refrigeration) and passive cooling projects were also involved in LBL's negotiations with representatives of the Mexican solar energy program.

LBL has assisted DOE in the formulating and review of a number of program planning and summary documents, including a Decentralized Field Management Plan, Solar Heating and Cooling R&D Project Summary Book, Commercial Readiness Assessments, Multiyear Plans for Active Systems and for Passive Systems for Heating and Cooling of Buildings, and National Program Plan for Passive and Hybrid Solar Heating and Cooling.

The Passive Cooling Program support effort has increasingly shifted from program implementation to program planning. Preparation of a Passive Cooling Area Plan began during FY 1979 and this document is slated to be incorporated into a DOE Multiyear Plan for heating and cooling. Tasks identified in the Area Plan for near-term funding are the subject of three major solicitations to be written by LBL and issued during the spring of 1980. One solicitation is for the construction and operation of a Passive Cooling Experimental Facility in a hot arid climate, and the other two contain numerous tasks covering the entire range of passive cooling technologies. A project management plan is in preparation for monitoring the projects which will result from the solicitation.

LBL involvement in controls program support activities has centered on development of a solar controls program plan that integrates ongoing and planned controls projects into a coherent program. Contact with individual controls projects involved review of periodic progress reports, telephone discussions, visits to contractor sites, and invitations to contractors to come to LBL for project reviews.

Interlaboratory Coordination

A number of meetings have been held during FY 1979 for purposes of program definition, planning, and coordination of activities for both the Active and Passive Heating and Cooling Programs. Included in such meetings have been representatives of many organizations; for example, national laboratories (LBL, LASL, ANL, BNL, LLL), DOE field offices (SAN, CHO, ALO), DOE headquarters, SERI, NBS, NCAT, as well as DOE consultants and support contractors.

LBL has had major input to the controls program planning process in meetings with SERI and SAN in developing and implementing an overall Systems Analysis Program Plan that includes a well-defined controls element and that addresses both currently recognized field problems and longer range research questions. LBL will also be participating in the DOE Technical Managers Coordination Meeting for the Active Solar Heating and Cooling Program, and the DOE Active Systems Contractors Review Meeting, both to be held in March 1980.

PLANNED ACTIVITIES FOR 1980

Activities in all of the above areas will continue throughout FY 1980. Unsolicited proposals will be reviewed and evaluated as they are received. LBL will assist the SAN and CHO field offices in the preparation and evaluation of a number of program solicitations, including those for Passive Products, Passive Manufactured Buildings, Passive Commercial Buildings, Passive Cooling and Materials Studies, and Fluids for Active Cooling Applications. Technical monitoring of projects will likely expand in scope as new projects are initiated as a result of the new program solicitations. LBL will participate in the next round of program planning exercises that will inevitably follow the latest DOE reorganization. A number of headquarters, field office, and laboratory coordination meetings are scheduled for FY 1980, and LBL will take an active role in these activities.

FOOTNOTE

*This work has been supported by the Systems Development Division, Office of Solar Applications, U.S. Department of Energy.

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