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MASTER

APPLIED RESEARCH IN THE SOLAR THERMAL-ENERGY-SYSTEMS PROGRAM

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NOTICE

APPLIED RESEARCH IN THE SOLAR THERMAL ENERGY SYSTEMS PROGRAM

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An important element in accelerating the acceptance of solar thermal energy is innovative design of advanced components. The innovation must address efficiency and durability while anticipating eventual commercial application. This can be best accomplished by defining steps necessary for successful implementation and prioritizing those for which solutions will yield maximum, near-term gains. Confidence in proposed solutions can be best gained through experimental evaluation. Furthermore, the experiments should be of sufficient size so as to permit scaling as in some cases scaling adds complexity.

The categories of solar thermal systems with the potential of contributing to the national goal of deploying renewable resources in the future are central receivers, parabolic troughs, parabolic dishes, hemispherical bowls and solar ponds. It is essential that a strong applied research program be maintained that brings component development to a stage of maturity while addressing material compatibility in order to form a sound technological base.

Within the Solar Thermal Research and Advanced Development (RAD) program a coordinated effort in materials research, fuels and chemical research and applied research is being carried out to meet the systems' needs.

Each of these three program elements will be described in this paper with particular attention given to the applied research activity.

Materials research is aimed at improvement of optical materials and thermal materials. This effort transcends individual systems considerations and therefore is of prime importance to the RAD program. Within the optical materials segment emphasis is placed on innovative concepts that have the potential to produce cost effective concentrators. Within the program development of polymeric materials is being carried out and metallization processes on glass and polymers are being actively explored to satisfy a variety of system needs. Thermal materials are more system specific and, for example, a substantial effort is being devoted to examine suitability of high nickel alloys as containment materials for nitrate salts for central receiver applications. Ceramics are being investigated on a limited scale in order to assess overall technology development needs.

The Solar Thermal Program Branch at the Solar Energy Research Institute (SERI) functions as program manager for DOE/RAD and coordinates the material research effort at several national laboratories. Other laboratories including Sandia (Livermore), Sandia (Albuquerque), Jet Propulsion Lab and Battelle in addition to SERI provide technical expertise in the fields of polymer research, mirror development, thermal containment technology and ceramics research.

Fuels and chemicals research is being directed at selection of technically and economically feasible reactions that will produce valuable product gases and liquids. For example, hydrogen production and biomass solar thermal processing have progressed from preliminary investigations over the last few years and are now being pursued for further process verification. Several dissimilar candidate reactions are currently being researched with the goal to identify a few for which economic and technical feasibility investigations indicate should be carried towards technical readiness.

Applied research within the RAD program is targeted at areas of interest specifically defined by system needs. For example, quantifying the amount of solar energy that is rejected at a solar central receiver through "spill out" by convective and radiative losses is the subject of a continued effort. Two distinct receivers are being analyzed. The external receiver loss program element focuses on a combined analytical/experimental approach with the end goal to define an analytical model capable of minimizing the uncertainties associated with predicting energy losses. The cavity receiver loss program element examines a closed cavity geometry also from a combined analytical/experimental approach. Both activities are well along towards providing valuable insight into this complex, interactive fluid mechanics, heat transfer problem.

Another energy loss problem currently being investigated is the efficient transport of thermal energy over long distances from the solar receiver to the point of end use. Thermal transport, because of the characteristic high operating temperature of the transport medium, requires a large and costly amount of insulation to minimize losses. A possible solution to this problem is the storage of high grade thermal energy temporarily in low temperature chemical bond energy. Transport can then be made at low temperatures and followed by a reversible chemical reaction at the user end the thermal loss problem can be successfully addressed. Experimental investigations have taken place at the White Sands Solar Furnace (WSSF) on CO_2-CH_4 reforming during the past 2 years. As part of a DOE funded program, encouraging progress has been made in thermochemical transport. Tests in January 1981 have demonstrated more than 65% solar to thermal conversion efficiency in the reaction. Detailed analysis is now underway at SERI to examine the technical and economic feasibility of the process beyond the experimental stage and addressing commercial readiness.

The Solar Thermal Test Facilities Users Association (STTFUA) sponsored experiments were managed by SERI. Some of these, recently carried out at the Advanced Components Test Facility (ACTF) operated by the Georgia Institute of Technology for DOE will be described in later sections of this paper. Table 1 summarizes those experiments funded during FY79 and FY80. Although the experiments summarized in the table were conducted at three facilities, the ACTF, WSSF and CNRS, four other facilities are also available to independent experimenters through coordination effort of the STTFUA. The other locations are the 5MW$_t$ Central Receiver Test Facility, Sandia National Laboratories, Albuquerque, New Mexico; the Parabolic Dish Test Site, Jet Propulsion Laboratory, Edwards Air Force Base, California; the CNRS 1000KW$_t$ Solar Furnace, Odeillo, France and the Advanced Component Research (ACRES) facility at SERI.

The experiments to be described within this paper are those conducted recently at the ACTF.

The ACTF is a 325 KW$_{th}$ solar thermal test facility operated by Georgia Tech's Engineering Experiment Station for the U.S. Department of Energy; see Figure 1.

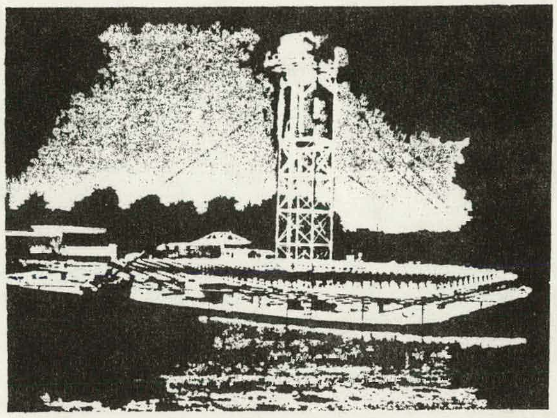

Figure 1. U.S. DOE Advanced Components Test Facility located on Georgia Tech campus.

Its primary purpose is to encourage research and development in high temperature solar thermal technology. It is a flexible and convenient test facility accessible to all qualified research and development organizations--large and small, public and private.

Major elements of the facility include a solar concentrating mirror field, a rigid structural steel test tower located at the geometric center of the mirror field, an experiment support platform (tower deck) mounted on top of the tower, an instrument and control building, a computerized data collection system, and a heat rejection system. The mirror field consists of 550 heliostats (tracking mirrors) that reflect and concentrate direct solar radiation to a stationary focal zone centered in the aperture of the elevated tower deck. The maximum solar radiative flux available at the focus is approximately 125 W/cm^2 (3.96×10^5 Btu/ft^2-hr)* representing a total power input of 325 kW$_{th}$ (1.11×10^6 Btu/hr)* based on a nominal local insolation of 900 W/m^2 (285 Btu/ft^2-hr). The facility is described in more detail in the facilitiy's Users Manual(1).

The FY80 request-for-proposals solicitation by the STTFUA resulted in the conduct of four user test programs at the ACTF in the calendar 1980 time frame. A detailed technical discussion of each test program is beyond the scope of this paper. A summary of program objectives and major results will, however, be presented. The reader is directed to other references for detailed accounts of each test program(2-9).

<u>High-Temperature Solar Steam Generator:</u> A Solar Turbines International 25 kW$_{th}$ high temperature, high pressure solar steam

*Dependent on time of day and season.

generator tested during March and April 1980 demonstrated that steam could be produced at 771°C (1420°F) and 10.7 MPa (1550 psia under steady state conditions. The receiver was of a downward facing cavity design and the design concept involved only the indirect solar heating of the fluid containing heat exchanger. The receiver utilized a Hastelloy heat exchanger tubing in the once-through steam generator design. Numerous thermocouples were used to monitor the location of the water/steam interface and to ascertain the circumferential temperature gradient of the boiler tubing. Total experiment run time was 31.5 hours Experimental details of this test program can be found in references 2 and 3.

Fluidized Bed Solar Receiver: The proof-of-concept demonstration for the application of fluidized bed technology to solar thermal receivers was carried out during May and June 1980. The basic receiver design was of Westinghouse origin and consisted of a 30.5 cm (12 inch) diameter by 1.22 m (4 ft) long transparent quartz tube filled with bed material; see Figure 2. Compressed air,

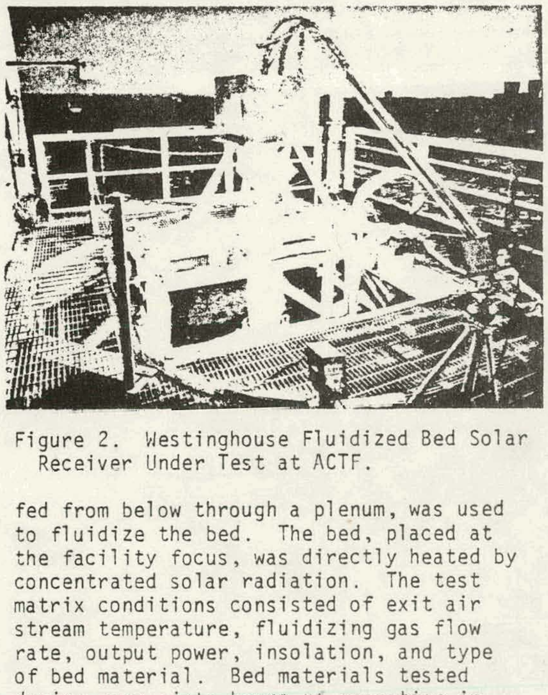

Figure 2. Westinghouse Fluidized Bed Solar Receiver Under Test at ACTF.

fed from below through a plenum, was used to fluidize the bed. The bed, placed at the facility focus, was directly heated by concentrated solar radiation. The test matrix conditions consisted of exit air stream temperature, fluidizing gas flow rate, output power, insolation, and type of bed material. Bed materials tested during over sixty hours of operation included copper shot, various sizes of sand, silicon carbide, alumina, and mixtures of these materials. Exit gas stream temperatures of 538°C (1000°F) were reached within the program. Widely varying optical, thermal and mechanical results were obtained with the different bed materials. Additional details may be found in references 4 and 5.

Flash Pyrolysis of Biomass: The objective of this Princeton University experiment was to gather data on the flash pyrolysis of biomass using concentrated solar energy as the energy source. Of particular importance was the gaseous and liquid product yield as a function of type of biomass, type of carrier gas, solar flux concentration and biomass feed rate. Biomass material was heated directly by allowing it to fall under gravity through the facility focus. The biomass material and an upward moving carrier/reaction gas were contained in a 2.5 cm (1 in.) diameter quartz tube. Gaseous, liquid, and solid samples were collected, analyzed, and used to generate a system mass balance. Four feedstocks were used: wood sawdust, ground corn cobs, cellulose, and lignin. Technical details associated with this work can be found in references 6 and 7.

Heat Pipe Technology: The testing of a representative model of a heat pipe solar receiver under actual concentrated solar flux conditions occurred at the ACTF in October 1980; see Figures 3 and 4.

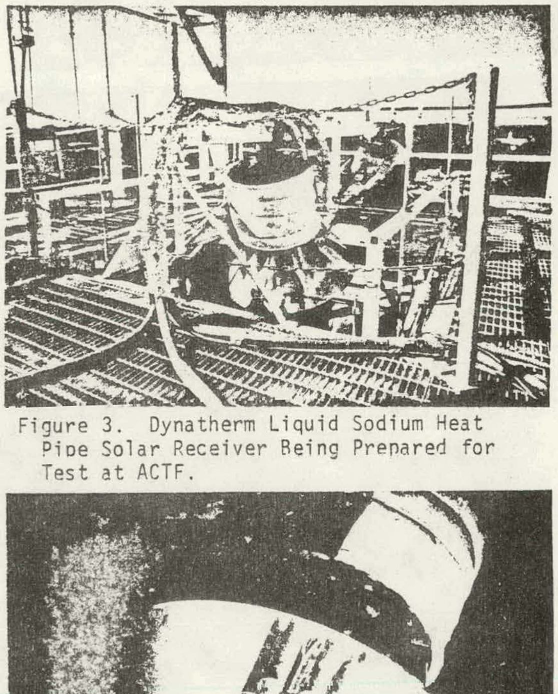

Figure 3. Dynatherm Liquid Sodium Heat Pipe Solar Receiver Being Prepared for Test at ACTF.

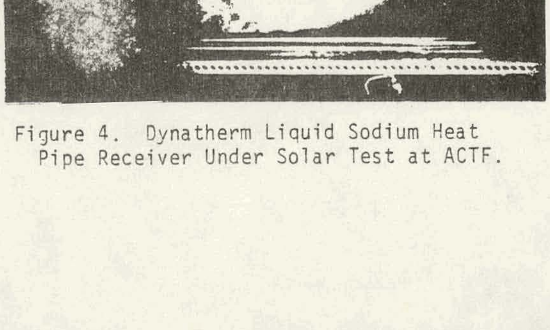

Figure 4. Dynatherm Liquid Sodium Heat Pipe Receiver Under Solar Test at ACTF.

TABLE 1. FY 79-80 EXPERIMENTS

Experiment	Test Location*	Contractor	Performance Period	Budget-$	Objective/Scope
Calcium Carbide Production	CNRS	Institute of Gas Technology	9/79-2/80	37,000	Demonstrate and measure calcium carbide production in a solar facility.
CO_2-CH_4 Reforming	WSSF	New Mexico State University	9/27-12/80	80,000	Quantify solar thermochemical energy capture using CO_2-CH_4 gas reforming.
High Temperature Solar Receiver	ACTF	Solar Turbines International	11/79-7/80	62,000	Design, fabricate, and test a high temperature (816°C) (1500°F) solar receiver/steam generation system for solar central receiver applications.
Heat Pipe Technology	ACTF	Dynatherm	9/79-11/80	66,600	Design, fabricate, test a small representative heat pipe solar receiver.
Fluidized Bed Technology	ACTF	Westinghouse	9/79-9/80	87,300	Investigate application of fluidized bed technology to solar central receivers.
Cadmium Oxide Decomposition-H_2 Production	WSSF	Institute of Gas Technology	9/79-9/80	103,800	Quantify thermochemical conditions in cadmium oxide decomposition as a step in producing hydrogen.
Flash Pyrolysis of Biomass	ACTF	Princeton University	10/79-12/80	109,000	Design and test a vortex flow reactor to process kinetic information in biomass pyrolysis.
Sulfuric Acid Decomposition-H_2 Production	ACTF	General Atomic Co.	5/80-2/81	98,000	Demonstrate use of solar energy in decomposing H_2SO_4 to produce H_2 based on a water splitting cycle.
Coal Gasification	WSSF	Lawrence Livermore Laboratory	6/79-7/79	23,000	Demonstrate production of hydrocarbon rich synthesis gas from coal and biomass exposed to solar energy.
Solar Processing of Ores	WSSF	Los Alamos Scientific Laboratory	2/80-1/81	98,000	Demonstrate feasibility of continuous processing of molybdenum ores in a solar receiver.

* WSSF - White Sands Solar Furnace, White Sands, New Mexico
CNRS - Centre National de la Recherche Scientifique, Odeillo, France
GIT/ACTF - Advanced Components Test Facility, Georgia Institute of Technology, Atlanta, Georgia

An array of seven liquid sodium heat pipes were exposed for a total of 25 hours of operation during which 45 steady state data points were collected. Operating temperatures up to 970°C (1778°F) and output power levels up to 11.5 kW_{th} were realized. The thermal load for the heat pipes consisted of water-cooled gas gap calorimeters. During commercial use, these Dynatherm Corporation heat pipes would be finned on the condenser end and used to heat a compressed gas stream. Applications include Brayton cycle electric power generation concepts and high temperature process heat. Several articles and reports are available describing the details of this program[8-9].

The experiments described above are indicative of the types of programs undertaken at the ACTF. The mission of the ACTF is to work with a wide range of industrial and university workers in search of innovative concepts and technologies which hold promise for scale-up and use.

Concepts and technologies, which after evaluation at the ACTF appear ready for further development, are recommended to DOE for continued support. Larger scale testing of these technologies may occur at the 5 MW Central Receiver Test Facility. At this stage technical feasibility is established through prototype fabrication and testing.

Through experiments of these types an important interface is addressed between research and development and technology development in which innovative, conceptual designs advance to a state of technical readiness.

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