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Solar Industrial Process Heat (IPH) Project Technical Report

October 1981–September 1982

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SOLAR INDUSTRIAL PROCESS HEAT (IPH) PROJECT TECHNICAL REPORT

October 1981-September 1982

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ABSTRACT

This document contains a report of the work performed in the Solar Industrial Process Heat Project during FY 1982. The work consisted of solar energy experiments at eight industrial sites, performed under separate DOE contracts by seven different prime contractors. The eight experiments were active projects receiving DOE funding during FY 1982 and constituted the remaining portion of a broader program of experiments some of which had been completed in prior years.

Construction was essentially complete for the solar energy systems, and the experiments were entering into the operational phase. The report contains a description of each of the experiments and a discussion of system performance and operation and maintenance experience.

The project is sponsored by the Systems Test and Evaluations Branch of the Division of Solar Thermal Technology, Department of Energy.

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Introduction

The Solar Industrial Process Heat (IPH) Project was begun in 1976 for the purpose of evaluating solar energy applications in industrial settings. The project consists of three phases: design, construction, and operation of solar energy systems located at industrial sites throughout the United States. The project is sponsored by the Systems Test and Evaluation Branch of the Division of Solar Thermal Technology. It is conducted through contracts with major systems integrators, industrial participants, research and development firms, and federal laboratories. Upon completion of the operating phase, normally one or two years, ownership of the solar energy systems is transferred to the industrial participant. The systems are a continuing source of energy for the industrial plants and serve as examples of solar energy applications for other prospective users.

The project was conducted in 4 cycles, each beginning one year apart. The cycles were for applications using (1) hot air or hot water up to 100°C (212°F), (2) low-temperature steam up to 176°C (350°F), (3) mid-temperature steam up to 268°C (550°F), and (4) cost-shared steam and hot water. Collectors used in the project include flat plates, evacuated tubes, parabolic troughs, and multiple reflectors.

This report describes the work accomplished during FY82 for projects operating under DOE support. Projects that have been completed and that are no longer funded by DOE are not discussed.

Objective

The objective of the solar IPH project is to evaluate the technical feasibility of solar thermal energy for industrial process heat applications. To accomplish this objective, solar IPH systems have been installed at industrial sites as described above and are being operated in experiments to provide long-term (at least one year) data on performance, operation, and maintenance. The objectives of these experiments are to evaluate performance against predicted performance and to determine the extent and cost of operation and maintenance.

Overview - FY82

In April 1982, management of the project was moved from the DOE San Francisco Operations Office to the DOE Albuquerque Operations Office (ALO). Sandia was assigned lead laboratory responsibilities. In addition, in March, technical management of the Capitol Concrete point focus project was transferred from the Jet Propulsion Laboratory to ALO and included in the IPH project. Technical advisory and monitoring support is provided by the Energy Technology Engineering Center (ETEC). Reporting guidelines for performance data were developed by SERI and distributed to the projects in September of 1980. SERI provides performance predictions for the IPH project, consulting for data acquisition and instrumentation, and general technical support.

The original program included projects selected to cover a wide range of process heat applications. Capitol Concrete was added this fiscal year. The projects are as follows:

Company	Application
Capitol Concrete Topeka, Kansas	Steam for curing concrete blocks
Caterpillar Tractor San Leandro, California	Hot water for washing machined pieces
Dow Chemical Company Dalton, Georgia	Process steam for latex production
Home Laundry Company Pasadena, California	Hot water and steam for laundering

Company	Application
Lone Star Brewery San Antonio, Texas	Steam for washing cans
Ore-Ida Foods Ontario, Oregon	Steam for frying potatoes
Southern Union Refining Company Lovington, New Mexico	Process steam for refining operations
U.S.S. Chemicals Company Haverhill, Ohio	Process steam for phenol plant

A comparison of the IPH projects in terms of size and process demand temperatures is shown in Figure S-1.

By the end of FY82, construction was complete for all projects, and the solar IPH systems had been checked out. Two of the projects, Lone Star Brewery and Southern Union Refining Co. operated for significant periods during FY82, 10 and 7 months respectively. Four others, Capitol Concrete Products, Caterpillar Tractor Co., Home Laundry, and Ore-Ida Foods operated for lesser periods and were able to report short-term performance. Two projects, Dow Chemical Co. and U.S.S. Chemical Co., were operational producing useable steam, but were not reporting performance because of problems with their data acquisition systems. At the end of the fiscal year all systems were operational. However, two were shut down for repairs. Caterpillar Tractor Co. was awaiting installation of collars to prevent interference between the collectors and their pylons. Ore-Ida Foods was awaiting repair of its main circulating pump. All of the projects required longer-than-planned shakedown periods to correct equipment problems.

Activities completed during FY82 are shown in Figure S-2. Figure S-3 is the multiyear schedule.

System Performance

FY82 was a year of transition from construction to operation for the IPH projects. All of the systems experienced equipment problems.

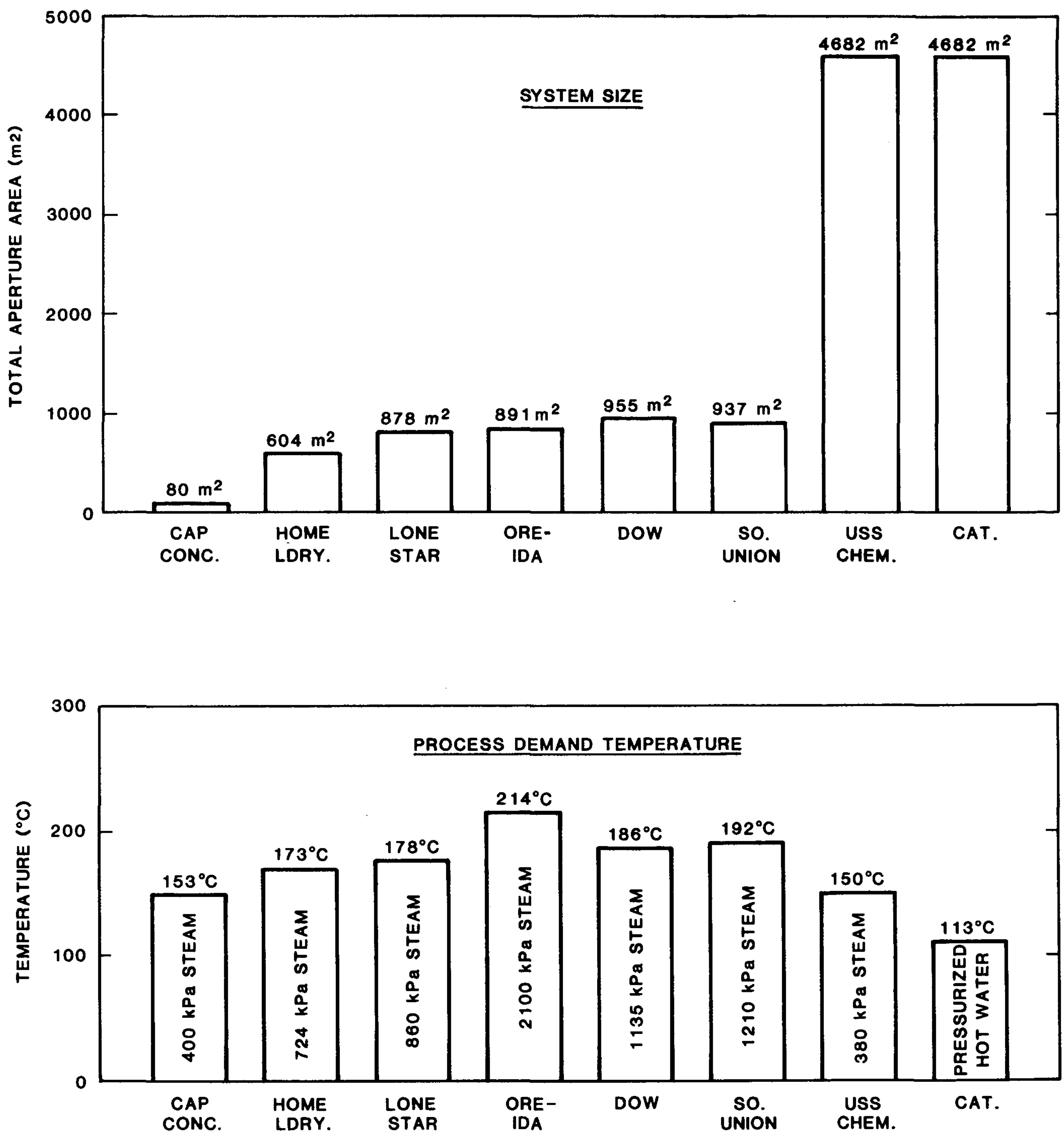

Figure S-1. Comparison of the IPH Projects in Terms of Their Size and Output

SOLAR INDUSTRIAL PROCESS HEAT PROJECT	FY 1982											
	O	N	D	J	F	M	A	M	J	J	A	S
CAPITOL CONCRETE PRODUCTS		A									B	
CATERPILLAR TRACTOR CO.							A					
DOW CHEMICAL CO.				A				B				
HOME LAUNDRY							A				B	
LONE STAR BREWERY			A	B								
ORE-IDA FOODS (ACCEPTED IN FY 81)												
SOUTHERN UNION REFINING CO.				A	B							
USS CHEMICAL CO.						A		B				

A - CONSTRUCTION COMPLETE
B - ACCEPTANCE TEST

Figure S-2. Solar Industrial Process Heat, Activities Completed - FY82

	FY 1981				FY 1982				FY 1983				FY 1984				FY 1985				FY 1986			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SOLAR INDUSTRIAL PROCESS HEAT PROJECT								A								B								C

A. CONSTRUCTION COMPLETED FOR ALL IPH PROJECTS
B. OPERATION COMPLETED FOR ALL IPH PROJECTS.
C. CONTINUED MONITORING OF OPERATING IPH PROJECTS.

Figure S-3. Multiyear Milestone Chart

As a result long-term performance was less than predicted. Nevertheless, performance in terms of energy delivered to real life industrial processes was measured. Two of the systems, Lone Star Brewery and Southern Union Refining Co., reported long-term data (Table S-1).

Table S-1

Long-Term Performance - IPH Projects FY82

Project	Output (MBtu)	Term (Months)	System Efficiency (%)	Fossil Fuel Displaced (BBL x 10^3)
Lone Star Brewery	323	10	19	79
Southern Union Refining Company	148	7	17	32

Peak or instantaneous efficiencies were reported for Capitol Concrete Products, Caterpillar Tractor Co., Home Laundry, and Ore-Ida Foods (Table S-2).

Table S-2

Peak Efficiencies - IPH Projects FY82

Project	Collector	Peak Efficiency (%)
Capitol Concrete Products	Power Kinetics Inc. Point-Focus Fresnel Concentrator	80
Caterpillar Tractor Company	Solar Kinetics Inc. Parabolic Trough	33
Home Laundry	Jacobs-Del Parabolic Trough	50
Ore-Ida Foods	Suntec Parabolic Trough	33

Conclusion

This report covers the transition from construction to operation for the industrial process heat experiments active during FY82. Although there were many equipment problems, an effort has been made to report the operational data that was collected. Measurements of instantaneous and peak energy output conformed well to predicted values, but long-term performance did not meet expectations. The results of the experiments should not be considered final nor should they be interpreted as "what solar will do." The results do show that additional effort needs to be applied to quality in engineering and manufacturing and to the improvement of reliability for solar energy components and subsystems.

SOLAR INDUSTRIAL PROCESS HEAT (IPH) PROJECT
TECHNICAL REPORT

October 1981 - September 1982

1. CAPITOL CONCRETE PRODUCTS, INC.

TOPEKA, KANSAS

The Capitol Concrete project was an experiment planned by the Jet Propulsion Laboratory (JPL) of the National Aeronautics and Space Administration (NASA). The purpose of the project was to evaluate a point focus collector designed and built by Power Kinetics, Inc. (PKI) in a process steam application. Applied Concepts Corporation was the prime contractor for this project. In addition to the contractor and the collector manufacturer, the project team consisted of JPL and a consultant to the user, the University of Kansas Center for Research, Inc. The solar energy system is shown in Figure 1-1.

Applied Concepts received the contract to install and evaluate the steam plant in December 1980. In June 1982, management of this project changed from JPL to the Department of Energy (DOE). In addition, the project was assigned to DOE's Albuquerque Operations Office (ALO) with technical support from Sandia National Laboratories, Albuquerque. It joined seven other projects under the Industrial Process Heat program.

Operation of the solar energy system began in July 1982. The Inspection and Acceptance tests were conducted by Sandia on August 17.

The project produced both component and system information and a small amount of performance data. At the end of FY82, the system was producing steam and had operated continuously without incident for the last 29 days.

Figure 1-1. Solar Energy Collector at Capitol Concrete Products Inc., Topeka, Kansas

Description

Capitol Concrete Products, Inc.

Capitol Concrete Products produces concrete blocks for the construction industry. The blocks are cured by pressurized steam in two autoclaves in which the blocks are subjected to 414 kPa as a final process before sale. A plant boiler provides 2631 kg/h (5800 lb/h) of steam to the autoclaves.

Solar Energy System

The solar energy system at Capitol Concrete consists of a point focus Fresnel concentrator designed, built, and field tested by PKI. The concentrator has an aperture area of 80.3 m^2 (864 ft^2) and is mounted atop an elevated platform. Sunlight is reflected to a receiver where feedwater is converted directly into steam. Freeze protection is provided by automatically draining the fluid loop in the event of temperatures below 4.4°C (40°F). The solar energy system is shown schematically in Figure 1-2, and its characteristics are summarized in Table 1-1. There is no thermal energy storage in this system.

Interface -- Feedwater is brought to the solar receiver/boiler by the main circulating pump. The water is heated and leaves the receiver as steam at 153°C (308°F) and 414 kPa (60 psig). Condensate is drained from this line through a steam trap. The steam is routed at a maximum rate of 79.2 kg/h (174.5 lb/h) either to the plant steam line or to the main feedwater preheater when the autoclaves are not receiving steam.

Process Utilization -- The concrete block plant operates 5 days per week, 50 weeks per year on a variable shift arrangement. The curing process operates for 16 hours. The maximum plant demand for energy is 8.2 GJ/h (7.6 MBtu/h). The solar system at peak efficiency conditions can supply 0.22 GJ/h (0.21 MBtu/h) of steam or 3 percent of this demand. The annual solar energy system contribution has been projected at approximately 106 GJ (100 MBtu) per year.

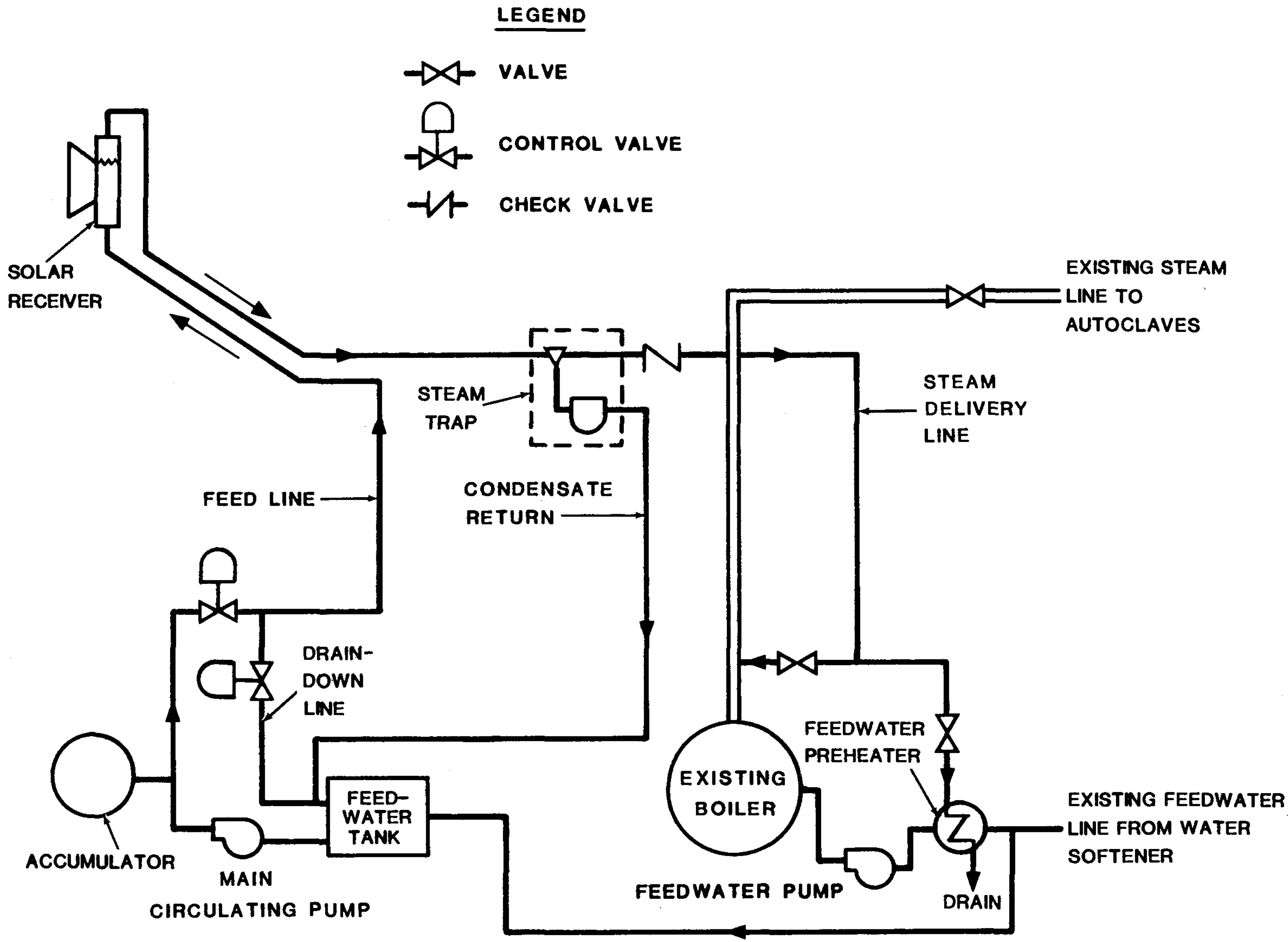

Figure 1-2. Schematic of the Capitol Concrete Products Solar Energy Steam System

Table 1-1

Capitol Concrete Products, Inc.
Solar Energy System Characteristics

General	
Site:	Topeka, Kansas
Demand:	Steam at 207-414 kPa (30 - 60 psig)/135-153°C (274-308°F); 79.2 kg/hr (174.5 lb/hr) max
Process Schedule:	Cement block curing in autoclaves; 16 hours per day, 5 days per week, 50 weeks per year
Collector	
Type:	Movable slat, point focus Fresnel concentrator, Power Kinetics
Area:	80.3 m^2 (864 ft^2) of reflector surface
Mounting:	Elevated platform
Mirror Module:	Back silvered glass tiles, mounted on movable slats on frame
Receiver:	Cavity with vertical tube boiler inside
Solar Tracking:	Shadow band with computed azimuth back-up
Working Fluid	
Type:	Water/steam (boils in receiver)
Control:	Liquid level switch in receiver
Temperature:	153°C (308°F) (maximum)
Flowrate:	1.32 x 10^{-3} m^3/s (21 gpm) (max)
System	
System Interface:	Delivers steam to autoclave or to a boiler feedwater pre-heater
Auxiliary Fuel:	Natural gas
Design Energy Delivery:	60 kW maximum, 106 GJ/yr (100 MBtu/yr) or about 3% of plant load
Thermal Storage:	None

<u>Collector</u> -- The PKI collector has three primary subsystems: the Fresnel concentrator, the receiver, and the control system. It is 10.1 m (33 ft.) by 9.14 m (30 ft.) with a gross aperture area of 92 m^2 (990 $ft.^2$) of which 80.3 m^2 (864 ft^2) or 87% is reflecting surface.

The concentrator consists of 864 flat, one-foot-square, second-surface, silvered glass mirrors. The mirrors are fixed to rows of identical curved supports positioned in a faceted Fresnel design.

Each mirror assembly rotates through its center of gravity to provide elevation tracking. Two drag links interconnect the mirror assemblies. Each drag link is moved by a lead screw worm gear drive, which is mechanically connected to the elevation drive motor.

The concentrator is supported by a lightweight frame structure composed of steel tubing members and steel plate joints. This structure distributes all wind and gravity loads to the base supports.

The base of the structure is a circular track, inverted to eliminate problems of dirt and ice build-up. The track rides on wheels mounted on concrete piers and is motor-driven by a simple, sprocket/ roller chain assembly. The rotation of the entire collector on its base provides azimuthal tracking.

The receiver is a small vertical tube boiler inside of an insulated cavity with a square aperture. The boiler consists of two rows of close-packed, staggered, carbon steel tubes connected at the top and bottom by headers. Boiling takes place within the tubes and a liquid level float switch maintains liquid in the bottom half of the tubes. The boiler is mounted on an 11-meter (36 foot) boom holding it at the focal point of the concentrator. The nominal focal length of the collector is 10.1 m (33 ft).

A unit similar to the one installed at Capitol Concrete Products, Inc. was tested at Sandia National Laboratory in Albuquerque. At an insolation level of 980 W/m^2 (311 $Btu/hr\text{-}ft^2$) and operating with a steam outlet temperature of 149°C (300°F), the collector had an efficiency of approximately 80 percent. The rate of energy production during the test was 60 kW.

Controls -- The collector is controlled by a microprocessor which provides automatic two-axis tracking and operational control of the collector system. Signals for tracking during clear weather are sent by a shadowband detector mounted on the collector. Azimuthal tracking during cloudy conditions is programmed in the control unit. This allows energy collection to begin immediately when the sun reappears, even after an extended period of cloudiness. The control system also includes a real time, clock, digital display and an integral digital voltmeter.

Automatic shutdown results from a number of malfunction and environmental signals such as boiler overheating, low feedwater pressure, high winds, user-initiated manual stow, controller failure, AC power loss, low focus, and activation of low limit switch on the elevation drive. The fluid loop is drained automatically when the temperature falls below 4.4°C (40°F).

FY82 Progress

Construction at the Capitol Concrete site was completed in November 1981. From that time until May 1982, the project underwent checkout and testing under a Phase II contract. During this testing, changes were made in the elevation drive, in the control system, and in fluid loop components.

Phase II was completed in May 1982, and program control was transferred from JPL to DOE in June. While awaiting final acceptance, the system was struck by lightning in July causing the system controller to fail. Following repair of the controller, the system was operated for 12 days in July and 26 days in August 1982. The final acceptance of the system took place in mid August.

The system operated 29 days in September. However an accurate measure of performance was not obtained because of malfunctions in the flow meters. Flashing of the hot condensate to steam as it passed through the flow meter was the suspected cause. To correct this problem the amount of make up water was measured and used to calculate steam rates.

By the end of the fiscal year the system was operating well.

Data Presentation and Analysis

The amount of data generated in FY82 was limited by both program delays and system component failures. In addition, flow measurement problems invalidated much of the data collected from July through September. However there are valid data with which to evaluate the system's performance. Typical performance for this period is shown for selected days in Table 1-2.

System performance for July 28, 1981 is shown in Figure 1-3. The maximum system output was 53 kW (1.8×10^5 Btu/hr) at which time the instantaneous system efficiency was over 80%.

Table 1-2

Typical System Performance Data for Capitol Concrete

Date	Weather	Incident Solar Energy (GJ)	Energy Delivered (GJ)	System Thermal Efficiency
9/3	Partly Cloudy	1.96	1.53	78%
9/21	Partly Cloudy	2.19	1.32	61%
9/24	Fair	1.88	1.02	55%
9/25	--	1.50	.25	17%

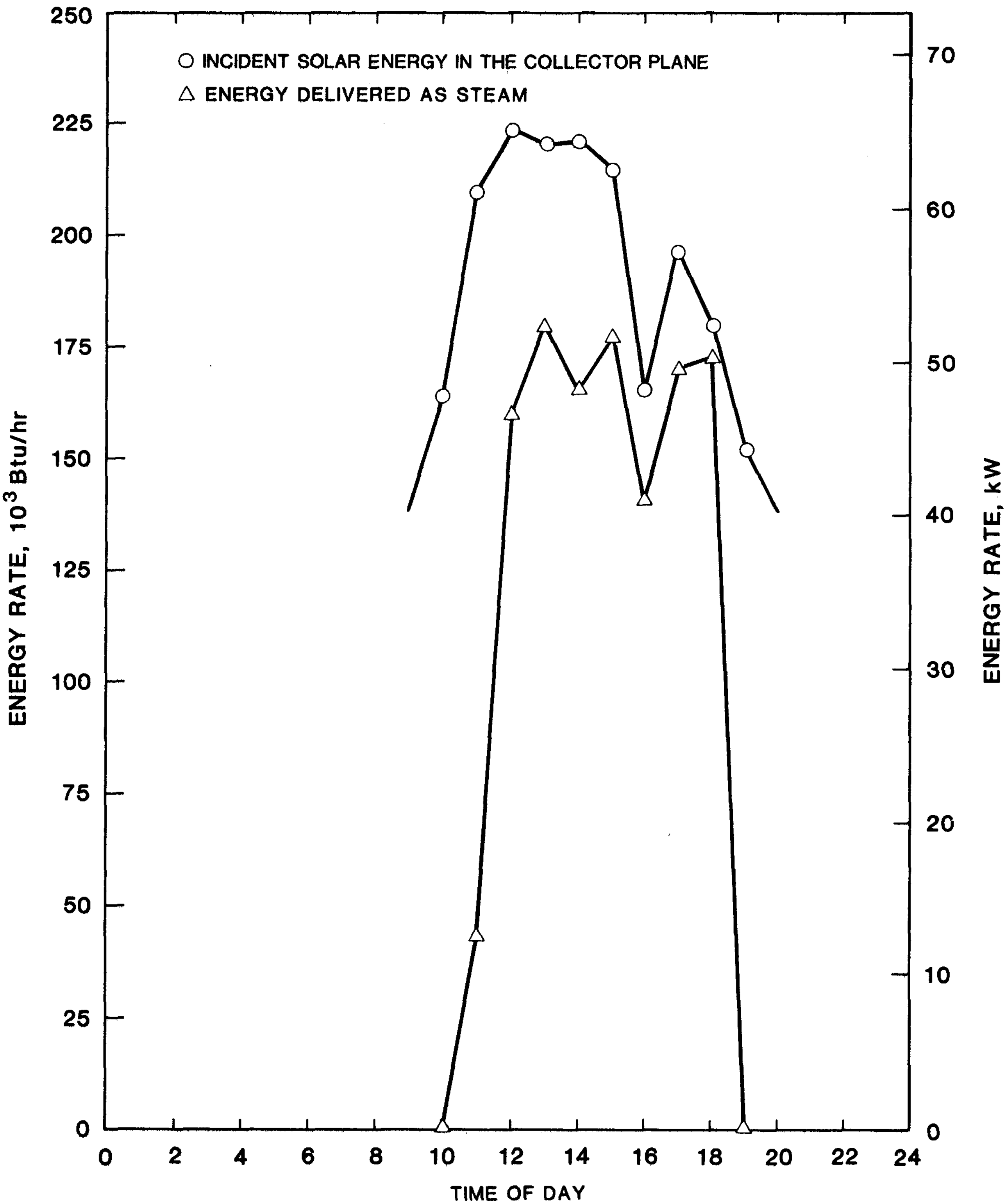

Figure 1-3. Capitol Concrete Products System Best Day Performance - July 28, 1982

Future Plans

The solar energy system was operated under DOE support through December 1982 at which time it was transferred to the cwner of Capitol Concrete Products, Inc. Future operations of the system will be monitored and reported by Sandia with the cooperation of Capitol Concrete Products, Inc.

2. CATERPILLAR TRACTOR COMPANY

SAN LEANDRO, CALIFORNIA

The Caterpillar Tractor Company solar project is one of two large 4680 m^2 (50,400 ft^2) systems in the industrial process heat program. It is a cost sharing agreement between Southwest Research Institute (SWRI) and the Department of Energy (DOE). Under this agreement, DOE is funding 75% of the project, and Caterpillar Tractor Co. through SWRI is funding 25% plus cost overruns. Construction was completed in FY82. Southwest Research Institute (SWRI) designed and built the project and was working as the fiscal year ended to bring the project to operational condition.

The solar energy system provides pressurized hot water to the plant for washing manufactured parts and for office space heating. Figure 2-1 is a photograph of the system and the facility which it serves.

A series of problems prevented beginning the operational phase during FY82. However, construction was complete by the end of the fiscal year and the acceptance test was scheduled for early in FY83.

Description

Plant Description

The Caterpillar Tractor Company's San Leandro facility requires a maximum rate of thermal energy of 34.3 GJ (32.5 MBtu/h), with an additional reserve of 3.2 GJ (3 MBtu/h). Because portions of the process equipment are used at different times, the design energy demand is

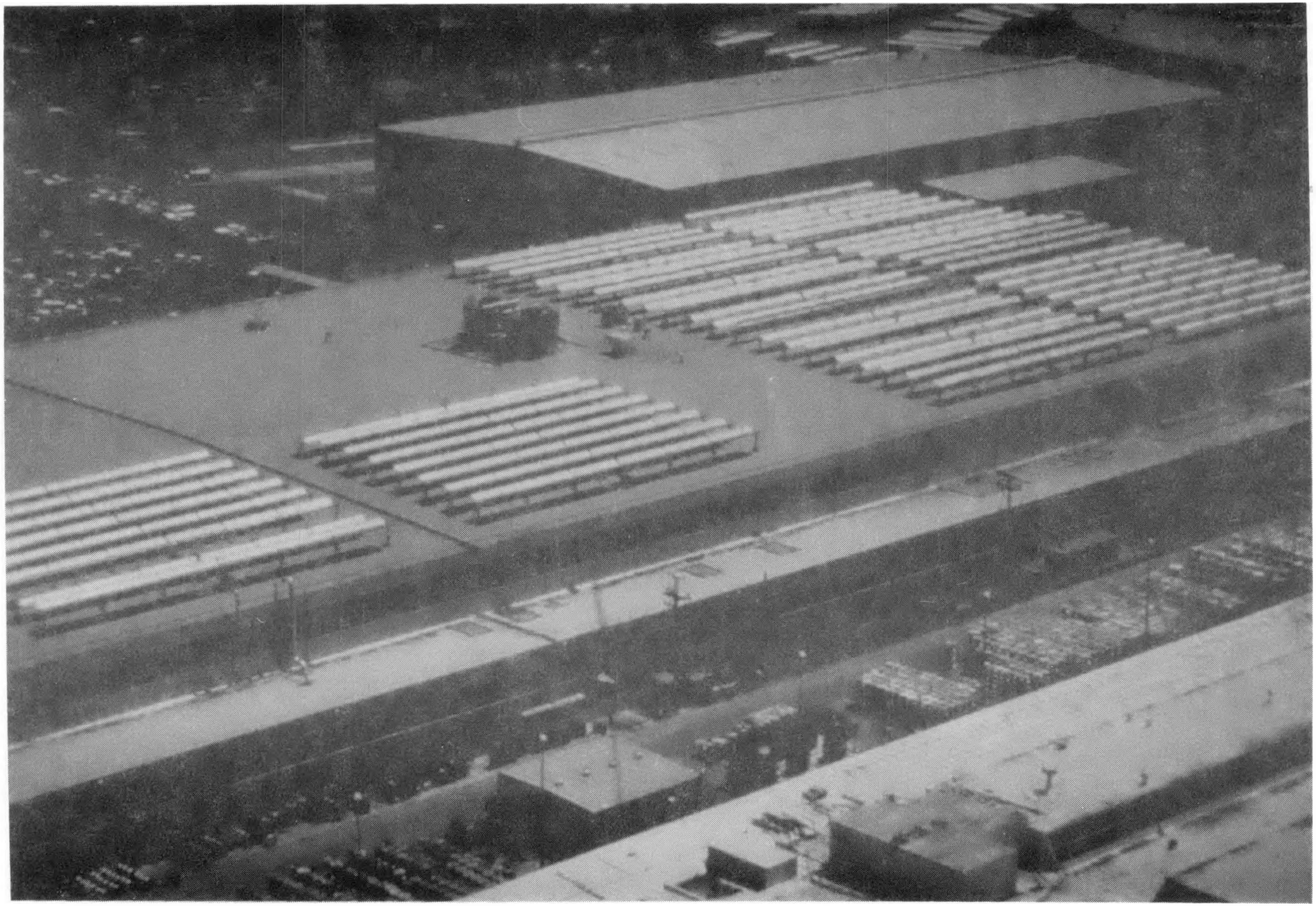

Figure 2-1. Solar Collector Array at Caterpillar Tractor Company, San Leandro, California

4103 kW (14,000 x 10^3 Btu/h). The existing thermal energy system consists of two natural gas fired boilers, each rated at 4905 kW (16,738 x 10^3 Btu/h). Hot water leaves the boilers and is pumped around the manufacturing facility through a hot water supply header with outlets connected to heat exchangers in various pieces of process equipment. A return line recirculates the water back to the boilers by means of a pumping system. The pumping system consists of four hot water pumps connected in parallel. The solar energy system supplements the boilers.

Solar Energy System

The solar energy system at Caterpillar Tractor Co. consists of 4682 m^2 (50,400 ft^2) of Solar Kinetics T-700 parabolic trough solar concentrators. They are located on the roof of the factory building in two segments; a north field of 16 rows and a south field of 44 rows. The total aperture area of the north field is 1248 m^2 (13,440 ft^2) and the remaining 3434 m^2 (36,960 ft^2) is in the south field. The tracking axes of each row are aligned in the north-south direction. The collector rows are spaced 4.08 m (13.4 ft) apart (because of I-beam purlin spacing) giving the system a 0.52 packing factor. The physical characteristics of this system are summarized in Table 2-1.

There are 360 modules, each 6.1 m (20 ft) long with an aperture width of 2.13 m (7 ft). Six modules are connected together in a drive string and are positioned by a hydraulic drive and shadow band tracking system. The receiver tubes of two drive strings are connected in series to form a 73.1 m (240 ft) long delta-T string. There are 8 delta-T strings in the north field and 22 in the south field.

The heat transfer fluid in the collector receiver tubes is boiler grade (treated) hot water pressurized to 310 kPa (45 psig). It flows through the combined collector field at a constant flow rate of 28.4 x 10^{-3} m^3/s (450 gpm). At this flow, under maximum insolation conditions the system will raise the water temperature 19°C (34°F). Under design load conditions, water enters the solar energy system from the hot water return line at 90.5°C (195°F).

Table 2-1

Caterpillar Tractor Company
Solar Energy System Characteristics

General	
Site:	San Leandro, California
Demand:	Hot water at 113°C (235°F)
Collector	
Type:	Solar Kinetics T-700 parabolic trough
Area:	4682.2 m^2 (50,400 ft^2)
Mounting:	Roof-mounted, N-S orientation, arrayed in 2 fields; North field - 16 rows; South field - 44 rows
Mirror Module:	Aluminized acrylic (3M FEK 244) on monocoque-stressed skin face sheet
Receiver Tube:	41.3-mm (1-5/8 in) o.d. carbon steel tube plated with black chrome and covered by a 63.5 mm (2-1/2 in) Pyrex glass tube
Solar Tracking:	Shadow band sensor; hydraulic collector positioning
Working Fluid	
Type:	Treated water, pressurized to 310 kPa (gage) (45 psig)
Control:	Constant flow rate
Flow Rate:	28.4×10^{-3} m^3/s (450 gpm)
Outlet Temperature:	113°C (235°F) (maximum)
System	
Interface:	Open loop, preheating water entering fossil fuel fired water heaters
Process Schedule:	Intermittent hot water demand to parts washer heat exchanger, 40 hours per week, all year
Auxiliary Fuel:	Natural gas
Thermal Storage:	None
Design Energy Delivery:	14800 GJ/yr (14×10^9 Btu/yr), SOLIPH model estimate: 10,170 GJ (9.64×10^9 Btu/yr)

The fluid loop, shown schematically in Figure 2-2, is an open-loop preheat system which takes part of the water being returned from the process heat exchangers and preheats it before it enters the natural gas boilers. Two main circulating pumps are used for redundancy. Each is capable of providing the full flow rate, but only one operates at a time. Freeze protection is provided by operating the main circulating pump intermittently when a potential freezing condition is sensed.

To minimize thermal shock on the plant system, a temperature regulating valve and a bypass valve set for 10% of design flow are located at the exit of each bank of collectors. When the system starts in the morning, cold water leaves the field at 10% of its normal flow. This continues until all of the cold water in the field has been replaced by hot water from the process return line. The temperature regulating valve then opens completely and full design flow is allowed.

Interface -- Water from the plant process return line is circulated through the solar collectors. The solar heated water reenters the hot water process return line, and the total flow goes to the two gas fired boilers. After leaving these boilers, the hot water is pumped through the plant hot water header.

The flow through the hot water process return line is nominally 12×10^{-3} m^3/s (836 gpm) for a 22.2°C (40°F) temperature difference across the boilers. The amount of flow diverted from this line to the solar energy system is 28.4×10^{-3} m^3/s (450 gpm). Control is provided by the fossil fuel boiler controls which maintain the hot water outlet temperature at 113°C (235°F). As plant load decreases, the temperature of the return water increases so that the solar energy system supplies a larger percentage of the demand.

The temperature of the water in the hot water process return line, downstream of the point where the solar heated water reenters, is monitored. This temperature could exceed the boiler set point in

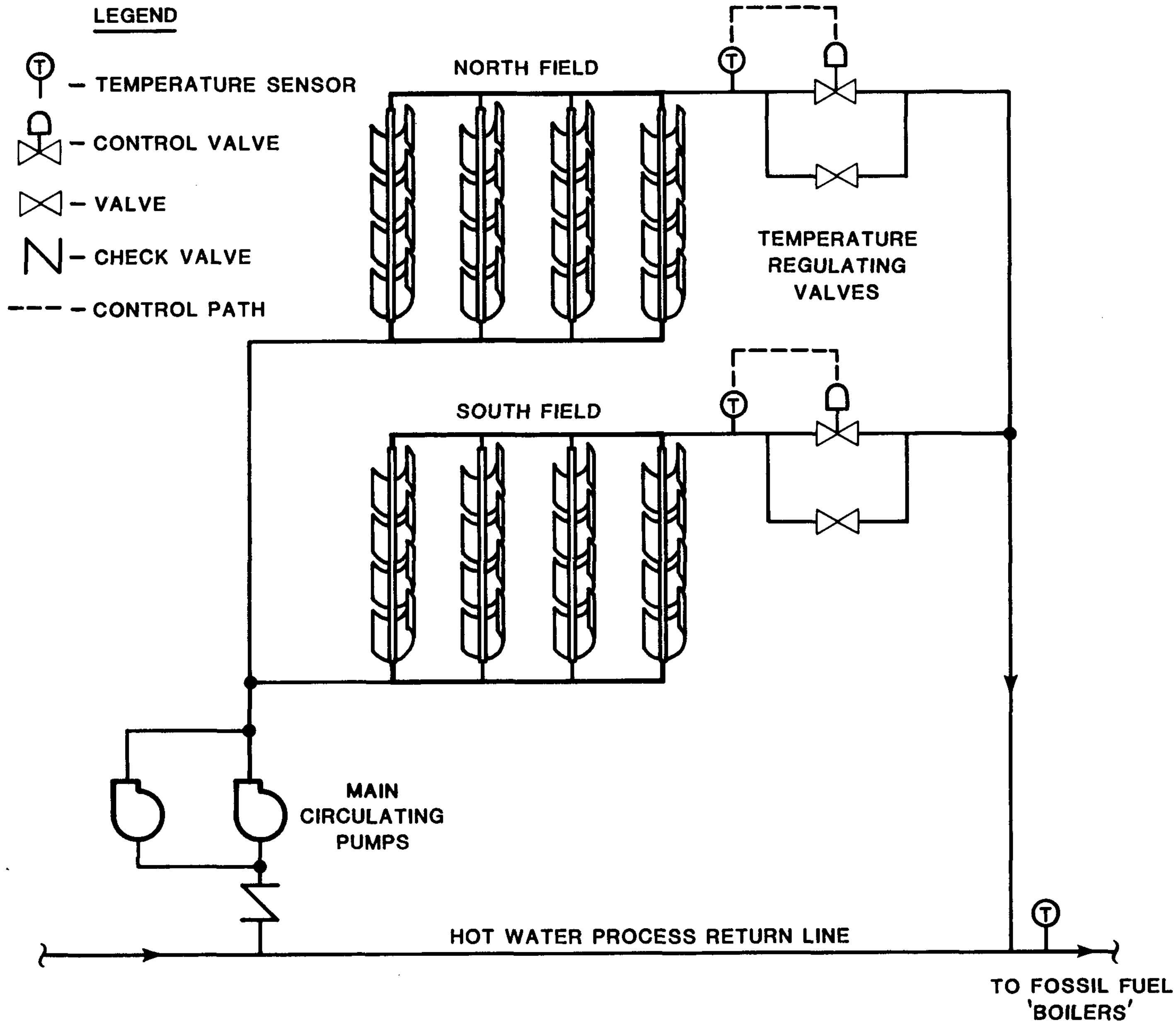

Figure 2-2. Schematic of Solar Energy System at Caterpillar Tractor Company

the event of low process heat loads. When this occurs, collector rows are defocused until the return line water temperature drops to its proper level.

Process Utilization -- The peak thermal energy requirement for this application is 2,638 kW (9 x 10^6 Btu/hr) of hot water at 113°C (235°F). This demand has been reduced from the original design value due to active energy conservation efforts. The demand normally is for 24 hours, 5 or 6 days per week. Under optimum conditions, the solar energy system will deliver energy at the rate of 2520 kW (8.6 x 10^6 Btu/hr). The yearly design energy delivery by the solar energy system is 14,800 GJ (14 x 10^9 Btu).

Collectors -- The collectors used in this system are Solar Kinetics T-700 parabolic trough concentrators. Their physical characteristics and their performance are described in Appendix A.

Hot Water System -- Two 20 hp circulating pumps are used in this system. They provide a flow of 28.4 x 10^{-3} m^3/s (450 gpm) at a pressure head of 414 kPa (60 psig). The pumps are switched so that each is used on alternate days.

Controls -- A central controller operates the system. When its light switch indicates adequate insolation for a period of five minutes, it issues a command to start the circulating pumps. After a 2 minute delay, the controller directs the collectors to come out of the stow position. The controller also provides control functions for low level insolation shut-down and emergency stow due to overtemperature or inclement weather.

Data Acquisition System -- A computer based data acquisition system (DAS) is used to monitor the performance of the solar energy system. The system consists of a PDP 11/23 computer, LA-36 line printer, two disc drives for data and software storage, and a modem for off-site monitoring. An uninterruptible power supply is used for greater DAS reliability.

Analog to digital converters are connected to each sensor in the system and the digital signal is transmitted to the computer. Direct normal insolation is measured by the difference between a shaded and an unshaded pyranometer mounted on one of the collector rows.

FY82 Progress

The fiscal year began with the final stages of construction nearing completion. Originally, the final inspection and acceptance test was planned for May 1982, however a series of minor problems led to rescheduling the acceptance test to early FY83.

Following a delay in shipment of receiver tubes in January, it was discovered in February that the trackers could not be installed in the north field. These units had been wired backwards. Following rewiring and installation, the collectors were aligned, and the field was completed. Some of the receiver tubes that were received were found to be defective and were shipped back to the manufacturer, causing a delay in the final work in the south field.

Installation in the south field began in March; the north field system was filled with water; and the collectors and instrumentation were checked out. The DAS and system controller were also checked out. During checkout 16 of 60 overtemperature switches were found to be defective and had to be replaced. As the month closed, only electrical and control wiring remained incomplete.

Preoperational checkout continued in April. The south field had become operational, but only the north field was operated because the main plant was shut-down and the energy could not be used.

More problems were encountered with temperature switches in May, with switching being actuated at below set point again causing inappropriate stowing of the collectors. The manufacturers shipped new switches to replace the faulty ones, and their installation was started early in June.

By July, the north field had been operating for 2-1/2 months, and the south field was operational as well, following the switch replacements. The DAS was also working well. Unfortunately, a new problem was beginning to develop that would be the most serious encountered during the year. A collector struck its own pylon. When the second instance of this occurred, both fields were shut down to prevent further damage. To correct the problem, the design was changed to include spacers that would maintain the clearance between the collector and the pylon. Both the north and south fields remained shut down awaiting installation of the spacers throughout August.

In September, welds on the receiver support arm assemblies began to fail spontaneously, dropping the receivers and thus breaking the receiver tube jackets. SKI agreed to replace the 720 support arm assemblies while they were installing the collector shaft collars. Work was scheduled to begin in October.

In spite of these difficulties, the north field had operated successfully during the year. The DAS was also functioning as the year closed.

Data Presentation and Analysis

The Caterpillar Tractor Co. project remained in Phase II throughout FY82. However, the north field operated for approximately 2-1/2 months, and the south field was operational for a short time providing tentative performance information. Instantaneous field efficiencies of 33.0% and 29.5% were measured for the north and south fields respectively. These were based on total horizontal insolation readings of 690 W/m^2 (219 $Btu/hr/ft^2$) for the north field and 675 W/m^2 (214 $Btu/hr/ft^2$) for the south field.

Future Plans

The system is operating routinely producing hot water in excess of plant demand which has been reduced because the plant is operating below capacity. It is anticipated that problems experienced with the SKI collectors at other locations will require further attention at Caterpillar Tractor Co. These problems include low reliability of the hydraulic drives and faulty operation of the control system. Corrective actions in process at other IPH sites will be applied at Caterpillar as necessary. The experimental phase is scheduled for completion at the end of FY84.

3. DOW CHEMICAL COMPANY

DALTON, GEORGIA

Dow Chemical Company, one of the four largest chemical manufacturing companies in the United States, produces more than 1000 chemical products. It is the largest cogenerator of steam and electrical power in the United States and produces approximately two-thirds of its steam and electrical power through cogeneration. The company has conducted research in several alternative energy systems appropriate to its needs for steam. Through contracts with Foster Wheeler Development Corporation and the Department of Energy (DOE), a solar energy system was designed to produce steam for the Dow plant in Dalton, Georgia. Figure 3-1 is an aerial view of this system.

The design phase began in September 1978 and was completed in June 1979. The following September the construction phase began and was officially completed in January 1982 following the Acceptance Test in November 1981. Phase III, Operations, will be completed in 1983. The system was operating and producing steam in September as the 1982 fiscal year closed.

Description

Dalton Plant

The Dalton plant uses steam to heat its latex reaction kettle and for steam distillation of unreacted monomer from raw latex. The annual plant demand for steam is 108,700 GJ (103 x 10^9 Btu), 50% of which is used by the latex stripping process. The steam is produced from fossil fuels, of which 75% is natural gas and 25% No. 2 fuel oil.

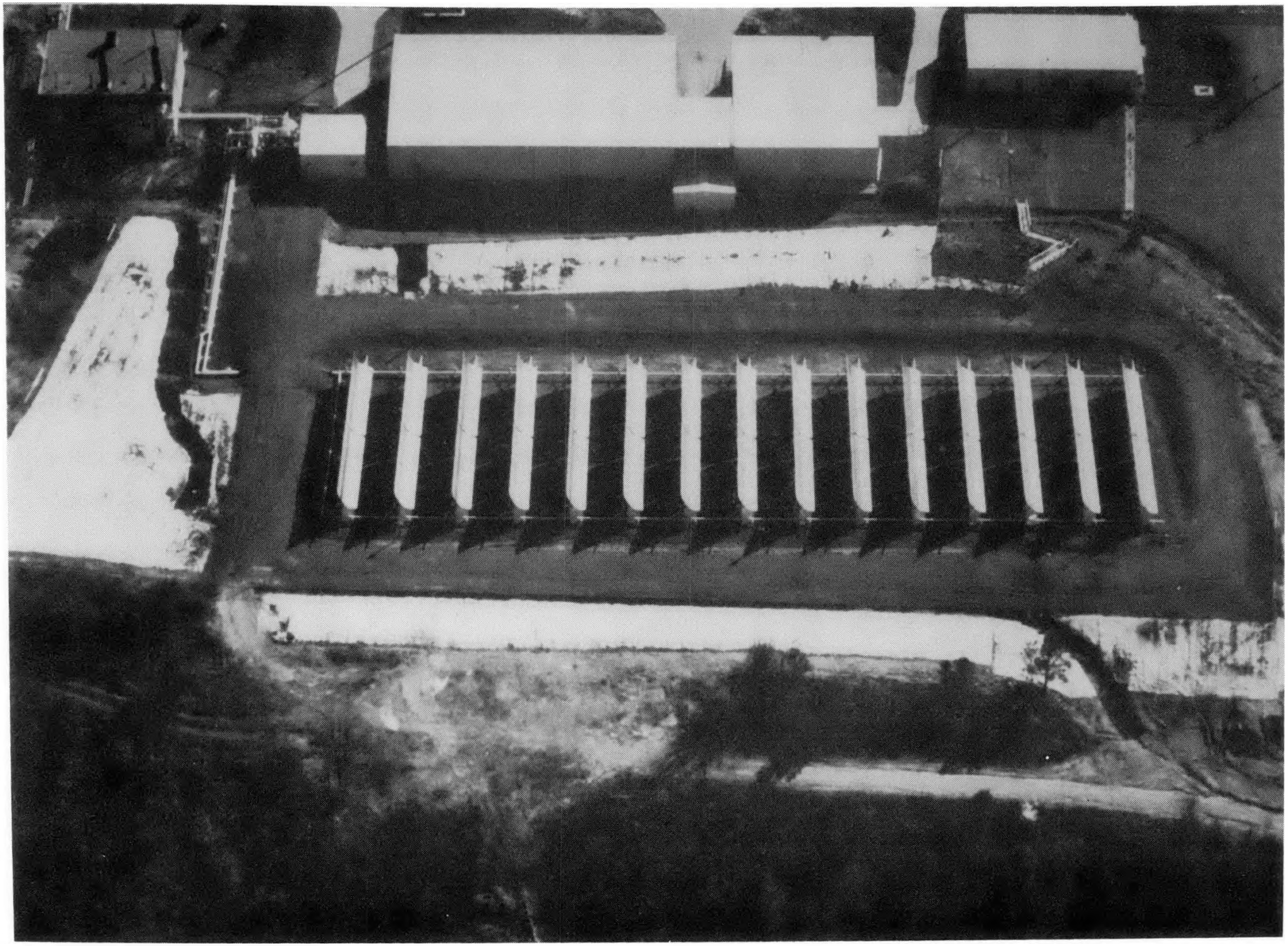

Figure 3-1. Solar Collector Array at Dow Chemical Company, Dalton, Georgia

The plant operates 24 hours a day, 365 days a year. Each pound of styrene-butadiene rubber latex requires approximately 0.53 MJ (500 Btu) for production. The pressure of the steam needed for the process is 1034 kPa (150 lb/in^2). Two fossil fuel fired package boilers with capacities of 9000 kg/h (20,000 lb/h) each provide this steam at an average rate of about 4990 kg/h (11,000 lb/h). Boiler efficiencies are estimated at 70%. The solar energy system supplements the fossil fuel energy supply.

Solar Energy System

The solar energy system at Dow is shown schematically in Figure 3-2. It consists of Suntec/Hexcel parabolic-trough, line-focus collectors arrayed in 15 rows in a north-south orientation. The field on which these are installed slopes downward to the south with a 10° tilt. The total collector aperture area is 922.5 m^2 (9,930 ft^2) with a gross collector field area of 2093 m^2 (22,525 ft^2). The packing factor is 0.46.

The collector field consists of 60 collector modules. Four modules are connected together in a drive string and are positioned by a single tracking drive. There are 15 drive strings connected in parallel to form 15 fluid flow loops (delta-T strings).

The system uses Dowtherm LF oil as the heat transfer fluid. The fluid circulates in parallel through the collector rows at a constant flow rate of 0.22 m^3/s (57 gpm). The maximum design fluid outlet temperature is 265°C (510°F) when the inlet temperature is 190°C (325°F). It is then pumped to an unfired steam generator where it produces 1034-kPa (150-lb/in^2) saturated steam.

In addition to the collectors and boiler described above, the system includes a 1.2 m (4 ft) diameter x 2.4 m (8 ft) long accumulator tank. This serves as both an expansion tank and a dump tank. The tank has a pressure relief valve, low-level alarm, level gage, and nitrogen purge. The circulation pump is a centrifugal pump rated at 2.24 kW (3 hp). A summary of the system characteristics is shown in Table 3-1. There is no thermal energy storage included in this system.

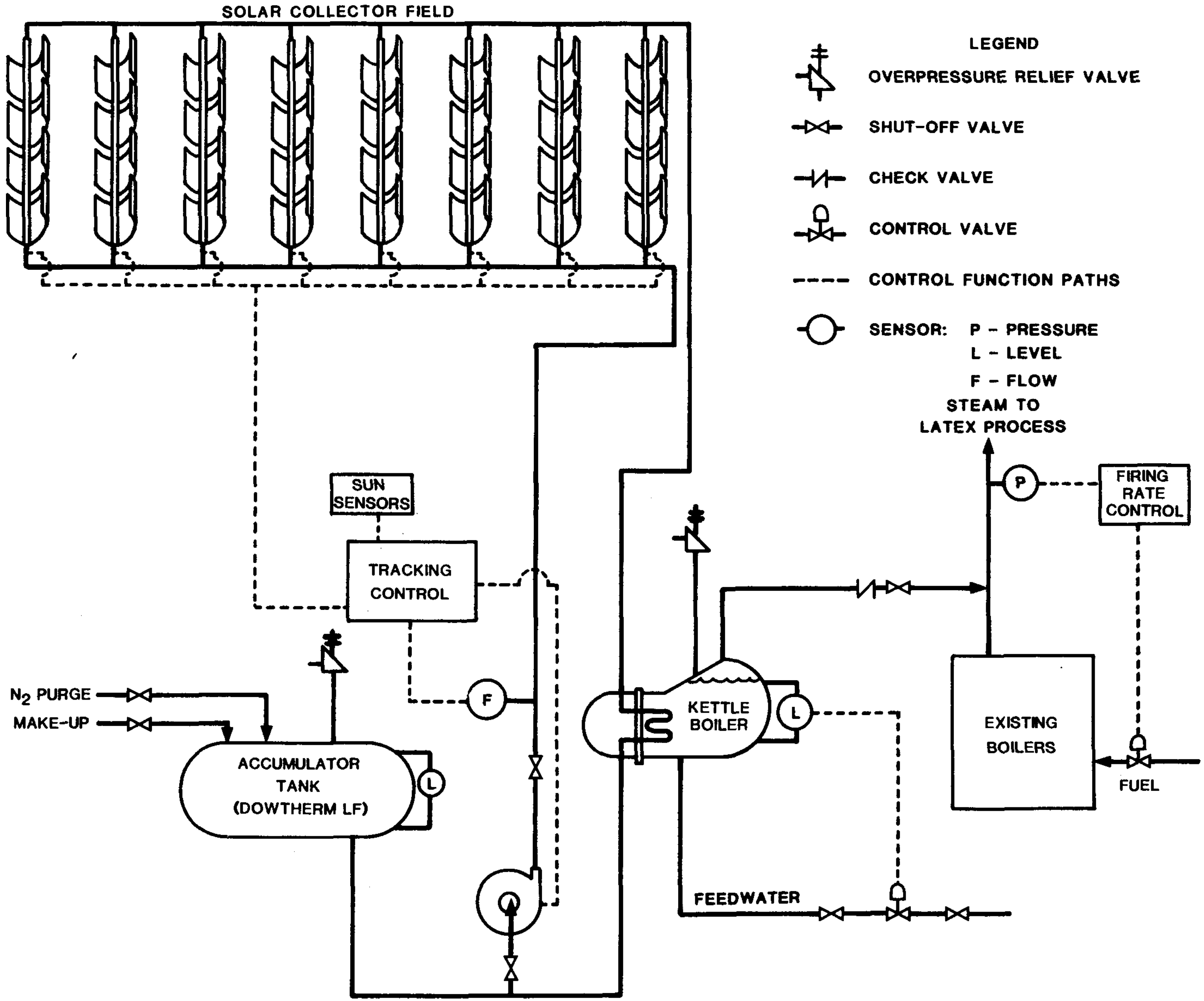

Figure 3-2. Solar Energy System Schematic for the Dow Chemical Company Installation at Dalton, Georgia

Table 3-1

Dow Chemical Company Solar Energy System Characteristics

General	
Site:	Dalton, Georgia
Demand:	Steam at 186°C/1135 kPa (367°F/150 psig); 680 kg/h (1500 lb/h) max
Collector	
Type:	Suntec/Hexcel SH-1655 parabolic trough
Area:	922.5 m^2 (9,930 ft^2)
Mounting:	Ground level, N-S orientation, 10 degree tilt, facing south, arrayed in 15 rows
Mirror Module:	Aluminized acrylic (3M FEK 244) on aluminum honeycomb core panels
Receiver Tube:	38.1 mm (1-1/2 in) o.d. tube, black chrome coated, bottom-half glass enclosed, top-half insulated
Solar Tracking:	Shadow band sensor, geared electric drive motors with chain drive
Working Fluid	
Type:	Dowtherm LF (Dow)
Flowrate:	3.6×10^{-3} m^3/s (57 gpm)
Outlet Temperature:	265°C (510°F) (maximum)
Control:	Constant flow rate
System	
System Interface:	Hot Dowtherm LF boils water in a kettle boiler for steam to plant steam line
Process Schedule:	Styrene Butadiene rubber production; 24 hr/day, 365 days/yr
Auxiliary Fuel:	75% natural gas, 25% No. 2 fuel oil;
Design Energy Delivery:	440 kW (1.5×10^6 Btu/hr) max 2,675 GJ/yr (2.53×10^9 Btu/yr); 5.0% of annual stripping process demand (SOLIPH model estimate: 698 GJ/yr (662×10^6 Btu/yr))

Interface -- The primary loop carries the heated Dowtherm to the kettle boiler where the steam is generated. The steam is fed from the boiler into a steam line connecting the main plant boilers to several demand points. Feedwater at 96°C (205°F) is returned to the main boilers and to the kettle boiler. The kettle boiler has a heat transfer surface area of 23 m^2 (250 ft^2), a pressure relief valve, low and high level alarms, and a level transmitter to the feedwater flow-control valve.

Dowtherm LF coming from the collector system arrives at the boiler inlet at a maximum temperature of 265°C (510°F). The flow rate is a constant 0.22 m^3/min (57 gal/min) and the system is pressurized with nitrogen to 207 kPa (30 lbs/in^2) (gage). Feedwater entering at 95°C (205°F) is heated by the Dowtherm LF into steam which leaves the boiler at 1135 kPa (150 psig) and 186°C (367°F). Design peak steam output flow rate is 680 kg/h (1500 lb/h). The steam system pressure is controlled by a check valve at the interface between the solar and conventional steam systems.

Process Utilization -- The latex plant uses two strippers, a batch stripper in Plant 1, and a continuous stripper in Plant 2. These units use steam at different rates. The solar-produced steam is piped into the main steam line and is delivered to the continuous stripping operation in Plant 2 which has a minimum steam flow requirement of 1575 kg/h (3500 lb/h) and a maximum of 1800 kg/h (4000 lb/h). Since the solar energy system is capable of producing up to 675 kg/h (1500 lb/h), all solar generated steam can be used in Plant 2, which operates continuously all year. This potentially provides up to 37.5% of latex stripping process hourly demand at peak solar collection conditions with an annual contribution of 5% of total process demand.

Collector -- The collectors used in this project are single axis tracking parabolic trough concentrators, Suntec-Hexcell model SH-1655. The physical characteristics and performance of these collectors are described in Appendix A.

Controls -- Master control for the solar system is provided by a Data General NOVA 4/c central processing unit with 48k word memory. The collector drive controls consist of an electronic tracker control feedback sensor and travel limit switches, all connected to the master controller. Each of the drive strings of collector modules is driven by a chain drive connected through a gearbox to an electric motor. Tracking and safety controls and electric controls at the motor drive, interface with the executive command controls.

The system is brought into operation by a signal to the master controller from a field-mounted photocell when sun intensity is adequate for start-up. This activates the collectors and brings them out of stow. Tracking begins when the sun centers on the tracker head, located on the receiver. Other weather sensors, responding to low-level insolation, send signals to the master controller to restow the collectors. The motors are connected to a remote battery pack, which is charged by an online 110-volt ac trickle charger.

Safety functions operating through the master controller prevent damage when (1) ac power is lost, (2) fluid flow ceases, (3) insolation level falls below minimum, (4) high winds occur, or (5) energy demand ceases.

Data Acquisition System -- A passive microcomputer-based data acquisition system (DAS) collects data which is used to evaluate solar energy system performance. A computer program calculates the performance of the solar system and provides information on incident solar energy both in the collector plane and in the horizontal plane.

FY82 Progress

The solar IPH system at Dow was in Phase II construction as FY82 began. Construction was completed, and the Acceptance Test was performed in November 1981. After system repairs and modifications, Phase II was completed in January and operation commenced in May of

1982 and continued through the end of the fiscal year. Solar equipment and DAS problems persisted and energy production was severely limited. FY82 was a period of extended shakedown and startup activities. Following is a description of these activities.

During October 1981, when the new north-side flex hoses were installed, they would bend out of the rotation plane and under the reflector surface. This interfered with the tracking movement of the collector. The 10° slope of the field, not the design of the hoses, was identified as a source of the problem and the hoses were reinstalled closer to the receiver as a corrective measure.

The system was shut down in December because the feedwater line to the solar steam generator froze and ruptured in several places. It was subsequently found that the trace heaters were out-of-specification and that a thermostat control had been omitted during construction. In addition to repairing the pipes, defective insulation was replaced.

A month of data had been obtained between the November start-up and the December freeze shutdown. This enabled the contractors to analyze the data acquisition system (DAS) output. It was planned to have the DAS fully operational when the system began operating in March.

The pyrheliometer, which had malfunctioned, was repaired by the manufacturer in March. Two design modifications were also made during this month: (1) the mechanical limit switches which were originally activated by a spring wire were changed to a new design using a mercury bulb limit switch and (2) a design change was made to the motor gearbox to prevent oil loss.

During April five limit switches malfunctioned preventing the collectors from going into the fully stowed position. The problem was caused by a defective batch of epoxy used during their manufacture. In midmonth, a DAS local control board failed precluding further operation of that row in April.

The system was put into operation in May, however a faulty control board prevented operation of one collector row. Recording of performance data was modified to use measures of insolation in the plane of the collector for determining efficiency. Also, some of the receiver tube glass covers were broken during the month.

The erratic collector behavior first noted in May was traced to defective drive module circuit boards. After the boards were replaced, some tracking and start-up problems continued to occur. Other minor problems with glass breakage continued, but the system operated throughout June, producing 270 to 319 kg/h (600 to 700 lb/h) of steam, approximately half of the design steam production rate.

During July the check valve to the main steam plant line malfunctioned, allowing the solar boiler to fill with water during the night. A shut-off valve which activates upon stow of the collectors was installed ahead of the check valve.

During most of August, operation was limited by work on instrumentation and the DAS. Foster-Wheeler visited the site in August to determine the cause of the data problems observed during July and to check and recalibrate instrumentation and sensors. They also adjusted the tracking and focusing equipment. The pyrheliometer was removed for recalibration.

Debugging of software began in September. In addition, flex hoses were starting to fail on the south side of the field, and a decision was made to replace all south-side hoses.

At the close of the fiscal year the pyrheliometer had been reinstalled, the DAS was functioning properly, and most other problems were resolved. Part of the flex hoses had been replaced. The system operated for 10 days during the final month.

Data Presentation and Analysis

No data were received from the Dow project during the fiscal year. However, there was considerable undocumented operation of the system throughout the year, as well as documented but unreported performance data.

Future Plans

The Dow project was in Phase III for most of FY82, but operated in a shakedown and start-up mode. Operation under DOE support will continue through FY1983 after which the system will be operated by Dow Chemical Co. Performance of the solar IPH system is low because of high thermal losses in the system. The thermal losses are caused by high heat losses in the insulation and pipe supports. Funding is being allocated to correct these problems so that the system will operate as efficiently as possible when it is transferred to Dow.

4. HOME LAUNDRY COMPANY

PASADENA, CALIFORNIA

The Home Laundry solar steam system, located in Pasadena, California, consists of parabolic trough collectors arrayed on an elevated frame structure which covers the laundry and a parking and storage area. The system provides steam and hot water for operation of the laundry. The system was designed by Jacobs Engineering Co., and the collectors were manufactured by the Del Manufacturing Co. Figure 4-1 shows the solar collector array.

The Design Phase for this system began in September, 1977, and was completed in January, 1981. Construction was completed in April, 1982, with the Acceptance Test being conducted the week of 12 April. Due to the necessity for further modifications, the Phase III (operational) period did not begin until the final month of FY82. At the close of FY82, the system was operating at full capacity, producing hot water for laundry operations.

Description

Plant Description

Home Laundry Co. serves both as a laundry and dry cleaning facility, and uses steam and hot water in these processes. The energy used by Home Laundry over a period of one year is as follows:

Energy Required--Hot Water	1209 GJ/yr (1146 MBtu/yr) (15%)
Energy Required--Steam	6854 GJ/yr (6497 MBtu/yr) (85%)
Total Boiler Energy Required	8063 GJ/yr (7643 MBtu/yr) (100%)

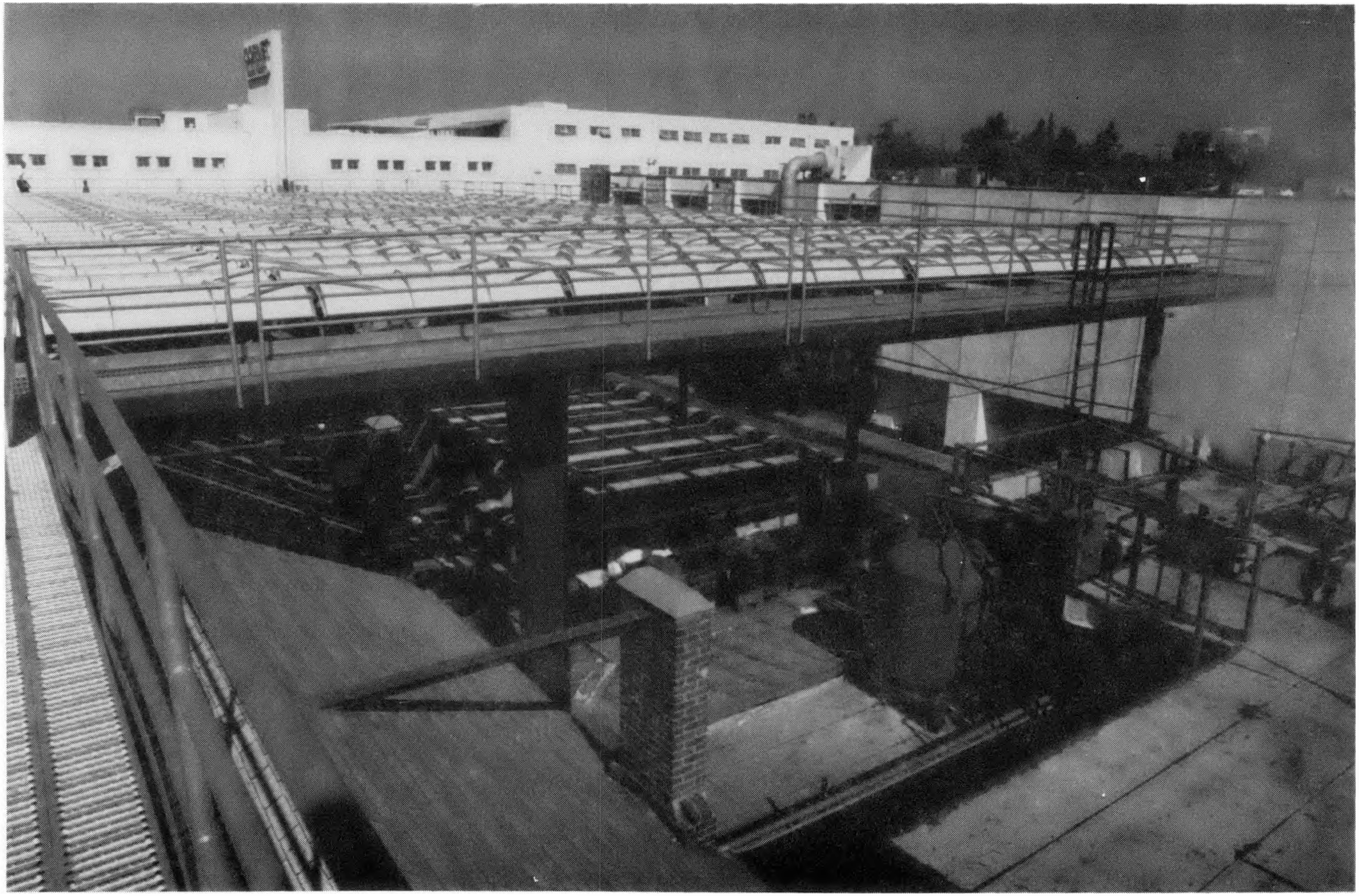

Figure 4-1. Solar Collector Array at the Home Laundry Company, Pasadena, California

Home Laundry uses a higher percentage of steam than most laundries because it does a greater-than-average amount of dry cleaning. Thus, it represents a good opportunity to demonstrate the ability of a solar system to generate both steam and hot water. At the time the solar energy system was designed, the plant had an existing steam-generating boiler rated at 149 kW (509,000 Btu/hr). The fuel used to fire it is natural gas, and the steam produced is 0.69 MPa (100 psig).

The steam is used to heat water for wash cycles by means of a heat exchanger, a steam injector, and a 5,678 liter (1500 gallon) tank in the boiler room. The tank is equipped with a circulating pump. Steam is also used in special washers that require water above 65.6°C (150°F) and in equipment such as dryers, pressers, and ironers, which require finishing heat.

The peak energy demand at the laundry occurs at 6 a.m., when the boiler is fired and the storage tank water is heated. Operation continues until 3:30 p.m. The facility does not operate on weekends.

Solar Energy System

The collector field consists of two banks side-by-side, the north side with 26 rows and the south side with 32 rows of Jacobs/Del parabolic trough concentrators. The tracking axes of the collectors are oriented in the north-south direction. The total collector aperture area is 603.5 m^2 (6496 ft^2). The collectors are mounted on an elevated frame having a total area of 1,489 m^2 (16,025 ft^2). The packing factor is 0.41.

The field consists of 406 collector modules. Seven modules are connected together in a delta-T string. Four 7-module delta-T strings are positioned by a single electric tracking motor by means of a drive shaft and worm gears. The collector fluid flows in parallel through 58 delta-T loops. There are two delta-T strings in a row connected by end feed, center return fluid piping.

The heat transfer fluid flowing through the collector field is water, pressurized to 1.66 MPa (240 psig) to prevent boiling. The water circulates through the field at a constant flow rate of 0.004 m^3/s (70 gpm). The maximum temperature of the pressurized water leaving the collectors is 210°C (410°F) when the water entering the field is 195°C (383°F). After being heated in the collectors, the water goes to either the steam generator, the domestic hot water tank or the high-temperature storage tank. The water is returned to the collector field in a closed loop system.

A small, high-temperature storage tank can be included in the loop. The tank has a volume of 1.14 m^3 (300 gal). It is used as a buffer tank for over-temperature protection or as a storage tank both for collector preheat during start-up and for production of domestic hot water during periods of low insolation. Figure 4-2 is a schematic of the solar energy system. Table 4-1 gives the characteristics of the system.

Interface -- The Home Laundry solar energy system is a closed loop system and therefore interfaces with the existing process through heat exchangers. Steam is produced in a tube and shell steam generator. Hot water for laundry use is normally produced in a steam to water heat exchanger. However, a heat exchange tube is included in the domestic hot water tank so that the solar energy system collector loop may also be used to heat this water.

Solar produced steam is generated at 0.73 MPa (105 psig) at a design flow rate of 424 kg/h (935 lb/hr). This pressure is slightly higher than the 0.69 MPa (100 psig) pressure of the fossil-fired boiler to ensure that, when solar steam is available, it will go into the plant steam line.

Process Utilization -- The process schedule and load profile at Home Laundry are such that for the five operating days of the week, all of the solar derived energy produced can be utilized. The time of peak demand, when the boiler is fired at 6 a.m., precedes the normal

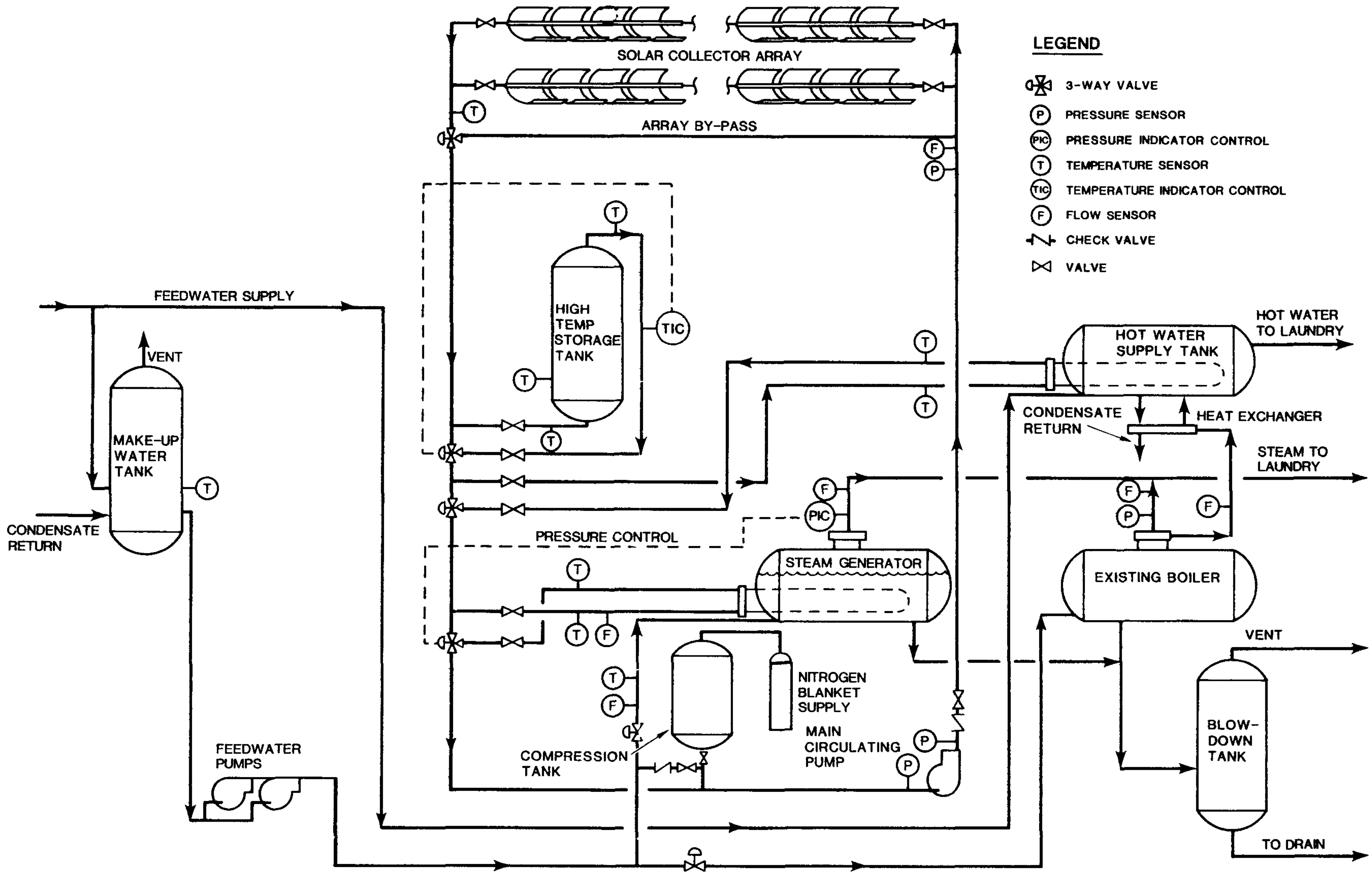

Figure 4-2. Schematic of the Solar Energy System at Home Laundry Company, Pasadena, California

Table 4-1

Home Laundry Company
Solar Energy System Characteristics

General	
Site:	Pasadena, California
Demand:	Steam at 724 kPa (gage)/173°C (105 psig/344°F); 424 kg/h (935 lb/hr) max; or hot water at 71.1°C (160°F)
Collector	
Type:	Jacobs/Del Parabolic Trough
Area:	603.5 m^2 (6496 ft^2)
Mounting:	Elevated platform, N-S orientation, arranged in two banks.
Mirror Module:	Back-silvered sagged glass
Receiver Tube:	Steel receiver tube, 1.9-cm (3/4-in) O.D., plated with black chrome over dull nickel, surrounded by 38-mm (1.5-in) O.D. pyrex glass tube
Solar Tracking:	Delavan shadow band sensor, electric motor driven tracking
Working Fluid	
Type:	Pressurized water (pressurized to 1.66 MPa (gage) (240 psig))
Control:	Constant flow rate
Flowrate:	4.42×10^{-3} m^3/s (70 gpm)
Outlet Temperature:	216°C (420°F) (maximum)
System	
Interface:	Tube and shell steam generator or heat exchange hot water supply tank. (Closed loop) Both supply to existing plant steam and hot water lines.
Process Schedule:	Cleaning and laundry operations; 7 a.m. to 3:30 p.m. Monday through Friday, weekend heat storage
Auxiliary Fuel:	Natural gas
Thermal Storage:	1.14 m^3 (300 gal)
Design Energy Delivery:	274 kW (935×10^3 Btu/hr) max 1,266 GJ/yr (1.2×10^9 Btu/yr) or 21.2% of annual steam and hot water requirement for process. (SOLIPH model estimate: 765 GJ/yr (725×10^6 Btu/yr))

start-up of the solar energy system. The predicted percentage of annual energy which could be provided by the solar energy system is in the range of 21 to 25% of the plant process heat requirement. The estimated annual solar contribution based on a five-day work week was 1,266 GJ (1,200 x 10^6 Btu).

During FY82 the system was used largely for producing hot water, despite the original intent to use it for producing steam. This was caused by failure of the laundry's in-line direct hot water heat exchanger and the consequent need to provide solar heated water to meet normal demand.

Jacobs/Del Concentrator -- The Jacobs/Del parabolic trough concentrator was manufactured by the Del Manufacturing Co. of Monterey Park, CA, and was marketed jointly with Jacobs Engineering of Pasadena, CA. The modules have an aperture width of 0.61 m (2 ft) and length of 2.44 m (8 ft).

Each module is a rigid welded structure built from rectangular steel tubing and sheet steel ribs. Within this structure are attached eight sagged glass mirror segments. These segments are sagged from 69 mm (0.27 in) thick glass sheets at high temperature into either an inner or outer segment parabolic shape. A second surface silver coating is applied to the back of these panels and then a protective coating. The eight segments are clipped into the frame, two across the aperture and four along the length.

The focal length of the collector is 114 mm (4.5 in) providing an f/d ratio of 0.188. The collector has a rim angle of 106.4 degrees.

The steel receiver tube has an outside diameter of 19.1 mm (3/4 in) and is plated with black chrome over dull nickel. It is covered by a 38 mm (1.5 in) o.d. borosilicate glass tubing with 2 mm (0.8 in) thick walls. The internal flow passage is smooth and unobstructed.

The receiver tube is fixed and does not move or rotate with the reflector panels, which rotate about the focal line. This elminates most of the relative motion between the ends of the receiver tubes and fluid piping experienced with most concentrators of this type. Flex hoses are used with these collectors to compensate for the linear thermal growth of the receiver.

Performance Characteristics -- The Jacobs/Del collectors were tested at Sandia National Labs-Albuquerque and reported, in part in SAND79-0515 dated April 1979. Data from these tests predicting noon time performance are presented in Figure 4-3. The abscissa parameter is the difference between the average fluid temperature in the receiver minus ambient temperature, divided by the direct normal insolation.

Steam System -- The steam generator is an Ace-Buehler generator rated at 421 kg/h (934.5 lbs/h), of 0.79 MPa (115 psig) steam and 0.0037 m^3/s (58 gpm) water ranging in temperature from 210° to 186°C (410° to 367°F). The main circulating pump has a capacity of 0.0032 m^3/s (50 gpm) with a 50 hp motor and is made by Dean Brothers.

The high temperature storage tank is a 1.14 m^3 (300 gal) steel tank. It is jacketed with 5.1 cm (2 in.) of fiberglass insulation.

Controls -- The tracking system used with the Del collectors is a Delavan Sun Tracker Sun Loc 1 with a Delavan photoelectric sensor. The sensor is mounted in the plane of the collectors and utilizes a dead band and two phototransistors in a bridge circuit. When the sensor is not aligned with the sun, it activates a reversible, 0.12 kW (1/6 hp) motor in the control box. The motor drives a shaft that transmits rotary motion through worm gears, thus moving the collector until it is realigned with the sun. The worm gear locks the collectors in position and prevents vibration and wind response. The drive system itself is sealed to keep out dust and water.

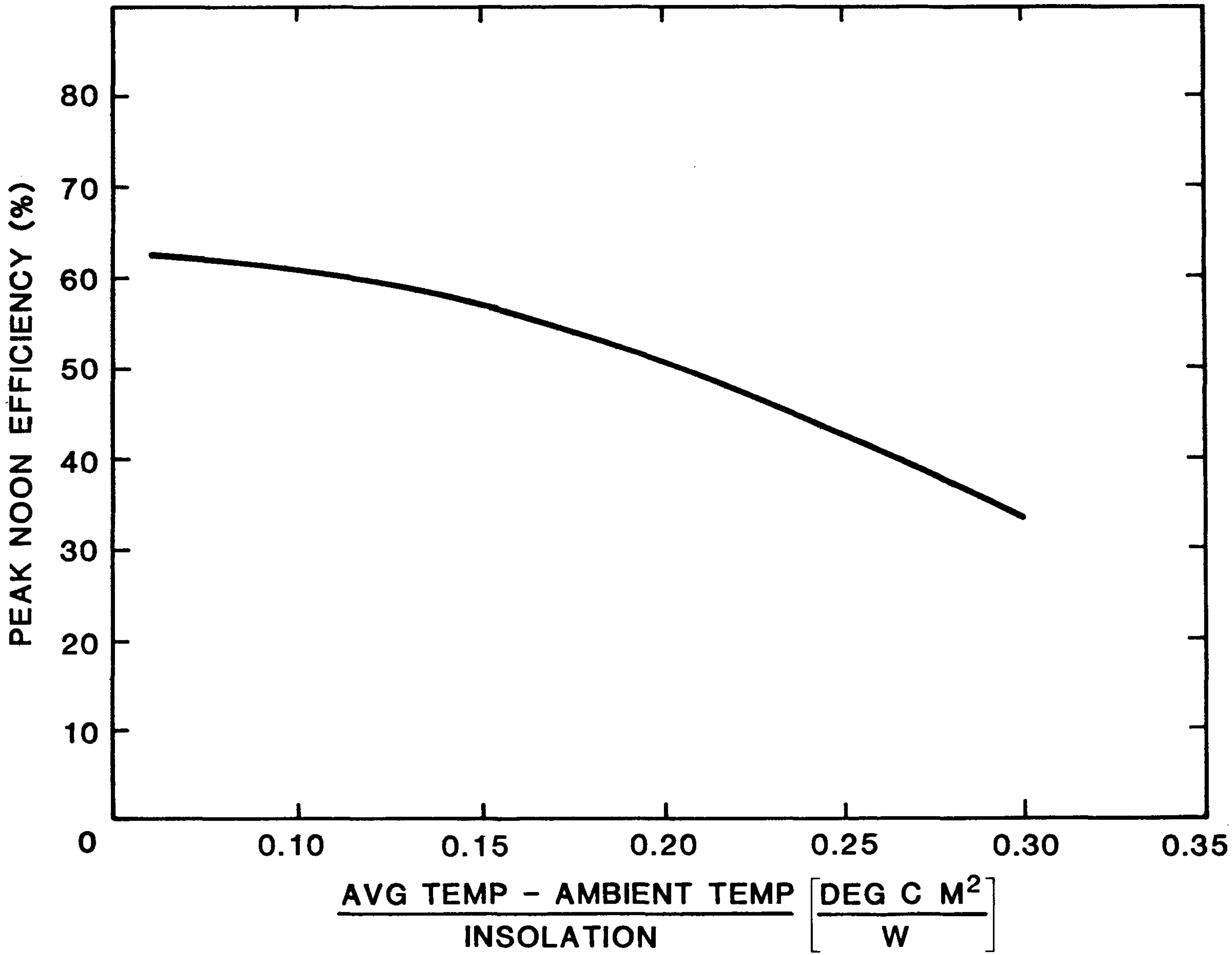

Figure 4-3. Generalized Module Performance of the Jacobs/Del Parabolic Trough Concentrator

Data Acquisition System -- The data acquisition system (DAS) is a data logger with a microprocessor for data reduction. Peripherals include a visual display and a printer, floppy disc storage, an A/D converter module, a temperature sensor multiplexer, and a voltage-multiplexer.

FY82 Progress

The fiscal year began with most of the construction activities of Phase II complete. However, design changes in the tracking drive system and subsequent retrofitting along with repair of various leaks delayed the acceptance test until April 12, 1982, with final acceptance not coming until August 31, 1982.

Preliminary pressure testing in February demonstrated that leaks in flexhoses were large enough to require their replacement. Two retrofit designs were evaluated and all 116 hoses were retrofitted before the acceptance test. Additional minor leaks were corrected in a storage tank gasket, a receiver tube, and a vent valve on the compression tank.

Start-up of the collector array was begun concurrently with pressure testing. Row to row alignment and tracker alignment was performed after adjusting the alignment of each of the 15 drive strings.

The sensitivity of the tracking system was such that no combination of settings of the Delavan control unit was adequate for all insolation conditions. The system would either require excessive operator control during periods of high insolation or have inadequate tracker sensitivity during hazy conditions. The problem was resolved by increasing the time delay in the drive motor circuit so that there was a longer delay between motor operations.

Following the acceptance test the system was operated to produce steam, the system was checked-out and minor repairs were made. During this time, component compatibility problems with the data acquisition system were resolved and data reduction software was developed. Most of the system performance data for the year was not recorded because of these problems. Final acceptance of the system was made August 31, 1982.

In early August, the Home Laundry experienced the failure of their domestic hot water heat exchanger. At the request of Home Laundry, solar operations were dedicated to the production of domestic hot water from that time since the solar system was their only source of hot water.

The fiscal year, which opened with the Home Laundry system in the final phase of construction, closed with the system operational and delivering hot water and steam to the facility. The system was available for operation most of August and 100% available for the month of September.

Data Presentation and Analysis

Only one month of the fiscal year was officially spent in the operational phase. Due to DAS problems, operational data were not recorded during this period. Typical data produced on the second day of the acceptance test and the performance averages for the month of May are shown below:

	Insolation	Energy Produced	Array Efficiency
April (one day)	650 W/m^2 (206 $Btu/h\text{-}ft^2$)	--	50%
May (monthly average)	757 W/m^2 (240 $Btu/h\text{-}ft^2$)	408 kg/h (900 lbs/h) of steam	--

Predicted clear-day efficiency was estimated to be 54.1% based on solar energy incident in the plane of the collector. The efficiency for the April day was 50%.

The original design prediction for rate of steam production was 405 kg/h (900 lbs/h). This was the actual steam production rate on average during the May operational period.

Although much time and effort was spent on this system during the construction phase, once it became operational, it has proven to be a reliable system performing close to expectations.

Future Plans

Phase II construction of the IPH system was completed in August 1982. Since that time the system has been operating routinely. It will be operated through September 30, 1983. Subsequently, the system will be retained by Jacobs Engineering who has contracted with Home Laundry for a period of 5 years. The contract, however, provides that either party may terminate it upon 30 days notice. In fact, the laundry plans to move shortly after September 30. Disposition of the system under these circumstances has not been determined.

5. LONE STAR BREWERY

SAN ANTONIO, TEXAS

The solar energy system at Lone Star Brewery is designed to produce process steam for all processes involved in brewing beer. These include bottle washing, canning, pasteurizing, and cleaning activities. By locating the interface between the solar energy system and the plant steam system close to the steam header in the canning plant, thermal loss and piping costs are kept to a minimum. An aerial view of this system is shown in Figure 5-1.

The brewing industry as a whole is a large energy user, with estimated annual energy costs of $235 million. The Lone Star Brewery uses natural gas at a rate of approximately 3.6×10^5 m^3 (12.7 MMcf) per month. There is interest, therefore, in the brewing industry in general and at the Lone Star Brewery in particular in reducing energy use and exploring alternative energy sources.

Southwest Research Institute (SWRI) was responsible for design, construction, and operation of the Lone Star project. The design phase began in 1978 and was completed a year later. SWRI began construction in 1979 and completed the project in December 1981. The acceptance test occurred in January 1982. The Lone Star Brewery system produced 10 months of performance data in the FY82 period. At the close of the fiscal year the system was operational and producing data, however two of the fifteen collector rows were in stow pending retrofit of receivers to correct oil leakage problems.

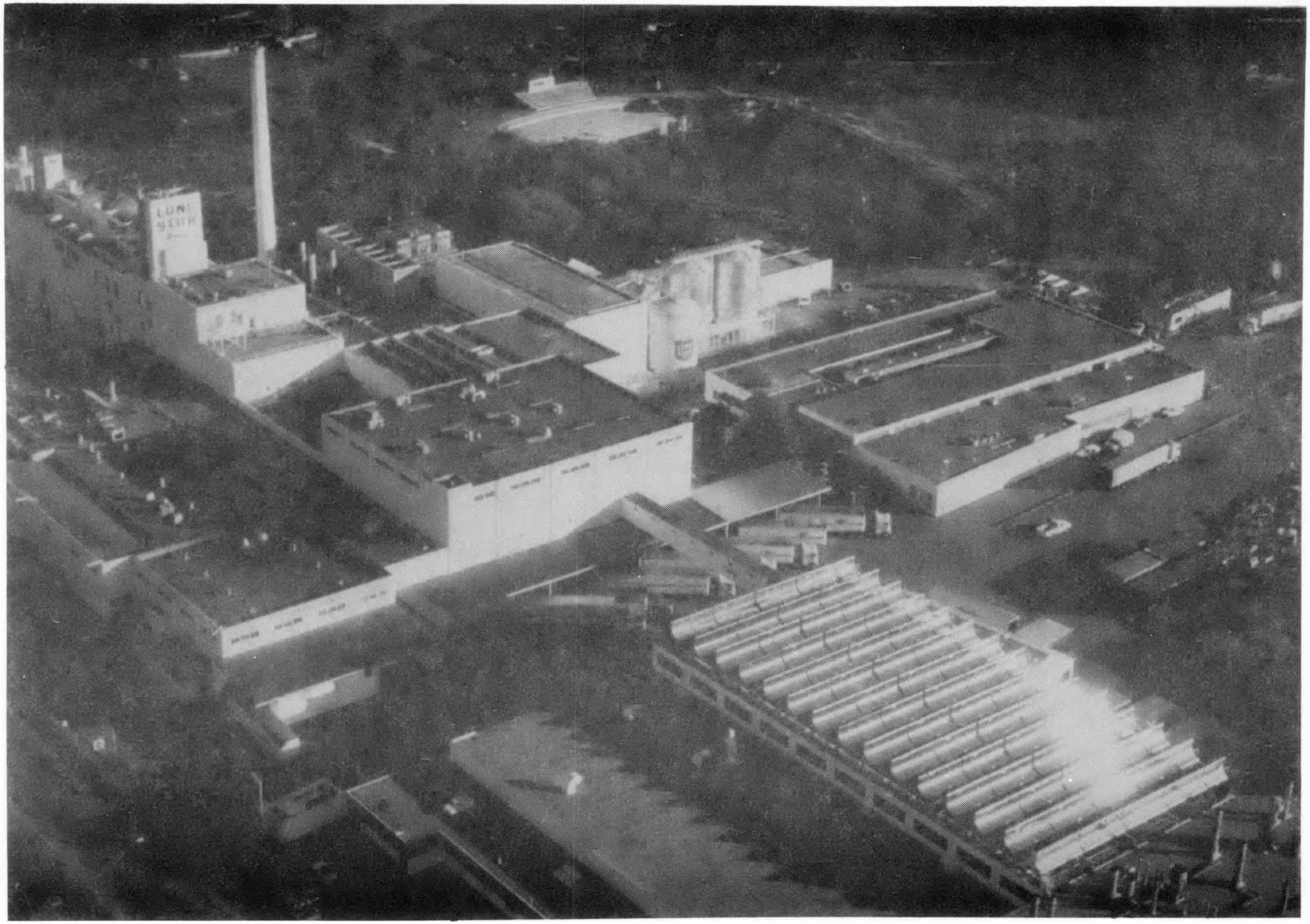

Figure 5-1. Solar Collector Array at Lone Star Brewery, San Antonio, Texas

Description

Plant Description

Lone Star Brewery has a steam requirement of 862 kPa (125 psig) and 178°C (353°F) at approximately 22,700 kg/h (50,000 lb/h). The steam is produced by two 13,600-kg/h (30,000-lb/h) shell-and-tube Keystone boilers. The boilers are fired by natural gas with diesel fuel burners installed for supplemental use in the event of natural gas curtailment. In addition to the Keystone boilers, Lone Star also has a 22,700-kg/h (50,000-lb/h) Erie City boiler which is fired by natural gas, but can also be operated on oil.

The plant operates 24 hours per day. The maximum load of 27,200 kg/h (60,000 lb/h) occurs in the daytime and the minimum load of 18,100 kg/h (40,000 lb/h) occurs at night. The weekend load is 2720 kg/h (6000 lb/h).

Solar Energy System

The solar energy system consists of 878 m^2 (9450 ft^2) of Solar Kinetics, Inc. (SKI) T-700 collectors arranged in fifteen 27.4 m (90 ft) long rows. The collectors are mounted on a roof top with their tracking axis oriented in the north-south direction. The collector rows are spaced approximately 4.6 m (15 ft) giving a packing fraction of 0.46.

Each row consists of four-2.13 m (7 ft) by 6.1 m (20 ft) modules and one 2.13 m (7 ft) by 3.05 m (10 ft) module, all positioned by a hydraulic drive mechanism receiving signals from a shadow band sun sensor. The receiver tubes of each row are connected in parallel, making the inlet and outlet temperature the same for each row.

The heat transfer fluid, Therminol T-55, is pumped to the collector field at a constant flow rate of 4.73×10^{-3} m^3/s (75 gpm) with a pump head of 345 KPa (50 psig). Pump suction head is maintained by an expansion tank. After leaving the collector field, the hot fluid passes through a heat transfer tube in the solar steam boiler. Under maximum insolation conditions, the temperature of the Therminol leaving the field will be 246°C (475°F) when the inlet temperature is 185°C (365°F).

There is no provision for thermal energy storage in this system. Table 5-1 summarizes the characteristics of this system. The solar energy system is shown schematically in Figure 5-2.

Interface -- At the Lone Star plant, steam is generated by three fossil fuel boilers. The boilers deliver steam to a common header that feeds the various steam loads. The solar energy system interfaces with the brewery by injecting the solar-produced steam into the main steam header that passes through the canning warehouse just below the roof on which the collector field is mounted. This minimizes the piping runs between the collector field and boiler and between the boiler and steam header.

The piping that carries the solar generated steam is connected to the plant steam header through a check valve. This valve serves to prevent plant-produced steam from flowing upstream into the solar line while solar steam is not being produced but will admit solar-produced steam to the plant header when it is available at plant pressure. This scheme reduces fossil fuel use by the plant boilers because their controls automatically limit their firing to produce a constant pressure at the steam header. Feedwater is returned to the solar boiler at 93°C (200°F), after being heated by a deaerating feedwater heater.

Process Utilization -- The steam demand schedule for the Lone Star Brewery is shown in Figure 5-3. The maximum load of 27,200 kg/h (60,000 lb/hr) occurs during weekdays. The steam requirement for the processes downstream from where the solar-produced steam is injected is 2720 kg/h (6000 lb/h), 7 days per week. Under ideal conditions, the maximum output from the solar collection system is 544 kg/h (1200 lb/h), which is 20% of the steam load downstream from where this steam is injected.

Table 5-1

Lone Star Brewery Solar Energy System Characteristics

General	
Site:	San Antonio, Texas
Demand:	Steam at 862 kPa (gage)/178°C (125 psig/353°F); 544 kg/hr (1200 lb/hr) max
Collector	
Type:	Solar Kinetics T-700 parabolic trough
Area:	878 m^2 (9450 ft^2)
Mounting:	Roof-mounted; N-S orientation arrayed in 15 rows
Mirror Module:	Aluminized acrylic film (3M-FEK 244) on aluminum face sheet
Receiver Tube:	41.3-mm (1-5/8-in) o.d. carbon steel tube plated with black chrome and covered with a 63 mm (2-1/2 in) Pyrex glass tube
Solar Tracking:	Shadow band sun tracker; hydraulic actuator moves collectors
Working Fluid	
Type:	Therminol 55 (Monsanto)
Control:	Constant flow rate
Flowrate:	4.73×10^{-3} m^3/s (75 gpm)
Outlet Temperature:	246°C (475°F) (maximum)
System	
Interface:	Hot Therminol boils water to steam in a tube and shell steam boiler
Process Schedule:	Beer brewing and bottling processes; 24 hours per day, 7 days per week
Auxiliary Fuel:	Natural gas
Thermal Storage:	None
Design Energy Delivery:	498 kW (1.7×10^6 Btu/hr) max; 3376 GJ/y (3.2×10^9 Btu/yr) or 3% of total plant load (SOLIPH model estimate: 1367 GJ/yr (1.29×10^9 Btu/yr)

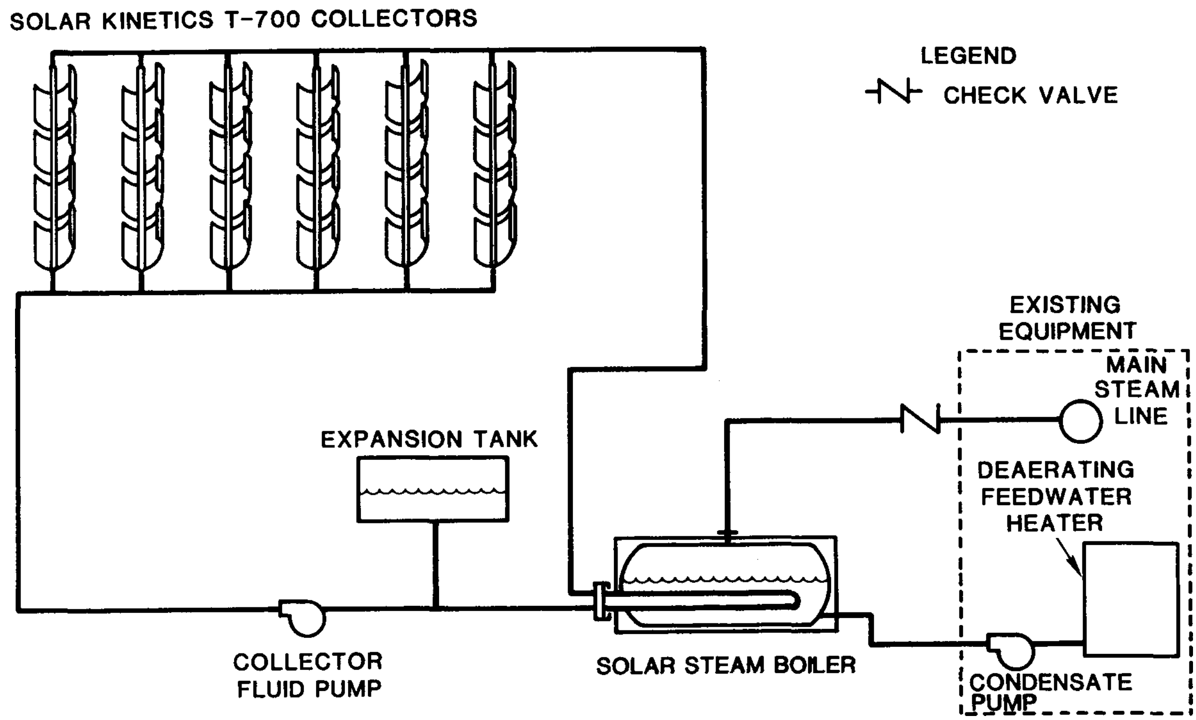

Figure 5-2. Schematic of the Solar Energy Steam System at Lone Star Brewery, San Antonio, Texas

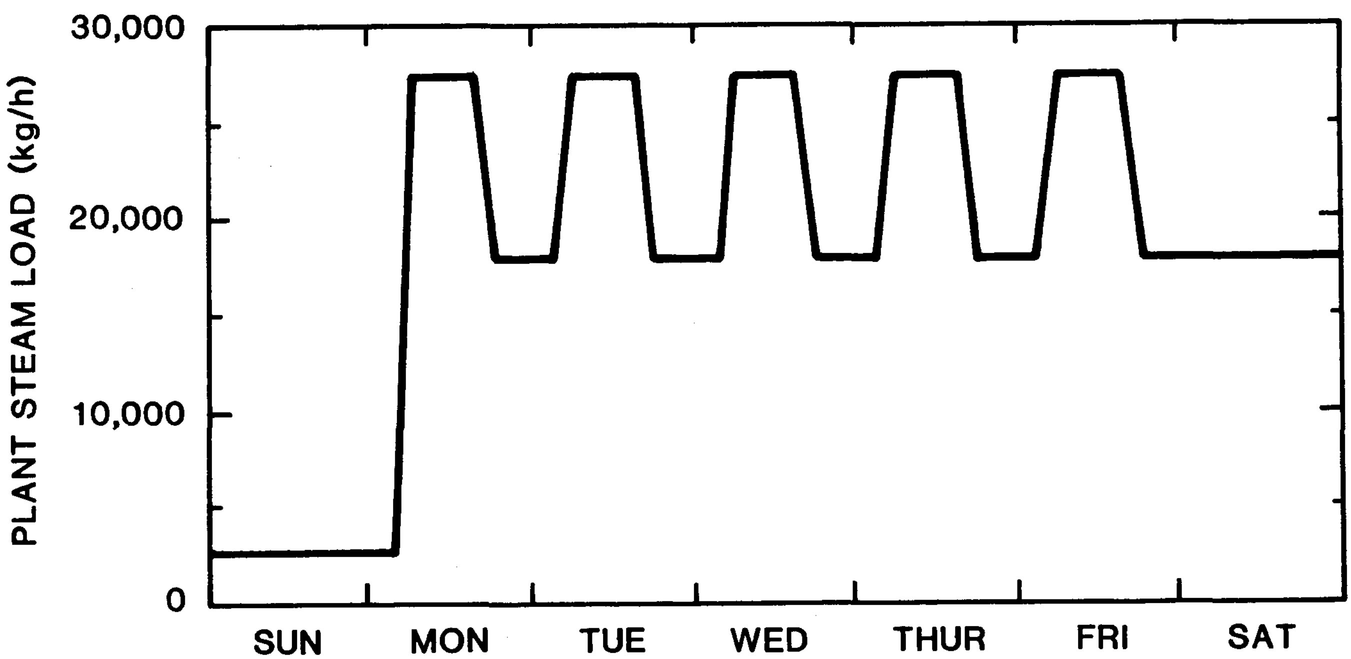

Figure 5-3. Lone Star Brewery Process Load Time History

Collectors -- The physical and performance characteristics of the SKI T-700 are described in Appendix A. Both 6.1 m (20 ft) long collector modules and 3.05 m (10 ft) long collector modules are used in this system.

Steam System -- The collector fluid pump used in this system is a positive displacement rotary pump manufactured by the Viking Pump Division of Hondaille Industries, Inc. The pump is rated at 4.73 x 10^{-3} m^3/s (75 gpm) for a 345 kPa (50 psig) head.

The solar steam boiler is a Patterson-Kelly Series 380 shell and tube heat exchanger. The tube side contains hot working fluid from the solar field and the shell side contains water and steam.

The piping used for this system is Schedule 40, seamless carbon steel pipe, assembled by fitting and then welding. Prevention of Therminol leakage was important to the system because of its interface with food processing equipment and the potential fire hazard of a roof-top installation.

Controls -- The collector control system is a microprocessor based unit. It operates the collector fluid pump and controls each collector row tracker system. Tracking is accomplished by a signal from a shadow band sensor on each row of collectors. A signal is sent to the control system which activates a hydraulic power pack with a nitrogen pressurized accumulator. The collectors in the drive string are then positioned by a hydraulic actuator operated by this power pack.

The control system provides for unattended operation of the solar energy system. It is programmed to bring the solar energy system into operation when conditions are appropriate. It checks for hazardous environmental and flow loop conditions which might damage the solar energy system, both before and during operation. If a hazardous condition does exist, the solar energy system is designed to be deactivated, and to stow all collectors until the hazardous condition is cleared.

Data Acquisition System -- The data acquisition system (DAS) consists of an Acurex Autodata Ten/10 Datalogger to collect and process data, a Tectran Datacassette magnetic tape unit for data storage, various signal conditioners and sensors to monitor system performance, and a paper printer. The entire solar facility has been instrumented to monitor the system's performance and environmental conditions. The datalogger receives the sensor input signals, processes the signals, and stores the data on magnetic tape. The stored data show the energy collected, energy delivered, piping losses, parasitic losses, flow rates, and operating temperatures and pressures, as well as solar radiation, ambient temperature, and wind data. The DAS operates automatically.

FY82 Progress

The Inspection and Acceptance Test of the Lone Star Brewery installation was originally scheduled for December. However, because of system operational problems and cloudy weather, the inspection and testing was postponed. As a result, the solar energy system was granted a test waiver, and the operation and evaluation phase was initiated on December 15, 1981. The Inspection and Acceptance Test was successfully concluded on January 16, 1982.

The solar energy system operated continuously from 15 December 1981 to the end of FY82 and was scheduled to complete the operation and evaluation phase on 30 November 1982. During the period of operation, the solar energy system experienced several problems resulting in the entire system being down 35 days and, for the last few months in the fiscal year 2 of 15 rows were inoperative. Recurring problems experienced by the Lone Star Brewery solar system included the following:

- Failure of individual collector rows to properly track the sun
- Failure of the hydraulic drive system
- Therminol leaks

- Glass receiver tube breakage
- DAS and DAS-related failures

During the first 8-1/2 months of operation, there were 37 instances reported where one or more collector rows failed to track the sun correctly. Because maintenance personnel do not visit the site every day, more undocumented row misalignments may have occurred. Ten of these failures were caused by problems with the electrical system, such as bad switches, cut wires, or bad relays. These problems were remedied by repair or replacement of the malfunctioning electrical item.

A more persistent problem was the failure of collector rows to track the sun due to partly cloudy conditions. There were 15 such incidents reported, affecting from 1 to 10 rows at a time. This problem was not resolved at the close of FY82.

During the first few months of operation, 23 days of data were lost due to DAS-related failures. DAS problems included software errors, power supply problems, and failure of the microprocessor. The power supply problems were solved when a 1-kVA uninterruptible power supply was installed and the DAS and associated air conditioner were put on two different breaker circuits. The display monitor was repaired on 15 March. There have been no DAS-related failures since this time.

Significant nitrogen leaks in the collector drive hydraulic system were detected as early as the first month of operation and continued to be a problem at the end of FY82. In March 1982, SKI replaced seven hydraulic accumulators. By June 1982, 4 rows had lost pressure again. Leaks also occurred in pipe fittings of the hydraulic system and in the expansion tank on the inlet side of the fluid pump.

Therminol leaks were first observed at the flex hose fittings of 3 rows in January 1982. At that time, the fittings were tightened in an attempt to stop the leaks. One month later, Therminol leakage was again observed in 2 rows. By May 1982, the leakage was severe enough to cause a fire hazard and could not be remedied by tightening the fittings. As a result, the two rows were valved off and placed in the stow position.

In June 1982, a maintenance crew put the collectors in automatic mode after washing the mirrors, causing the two rows that had been shut down to track the sun. During this time, there was no operator on duty. The resulting thermal expansion of the Therminol caused a pressure increase great enough to rupture one flex hose on each row. In addition, three receiver tubes warped and glass tubes broke on one row. Since this incident, the 2 rows have been kept in the stow position, reducing the effective collector area by 13%, or from its original 877.9 m^2 (9450 ft^2) to 760.8 m^2 (8190 ft^2).

The collector field receiver tube glass breakage was mapped in June. Minor chips or cracks were observed at 15 locations while 10 sections of glass needed to be replaced. This showed the glass breakage problem had increased since April when the breakage was first mapped. At that time, there were nine locations with minor chips or cracks and six tubes that needed to be replaced. In less than 2 months, the percentage of glass requiring replacement increased from 4.4% to 7.4%.

The collector-pylon interference problem observed at Caterpillar Tractor Co. was encountered at Lone Star Brewery. Three collectors were found to be hitting the support pylons while tracking the sun. Upon inspection of the entire collector field, two more locations were found where the collectors had hit the support pylons. At many more locations, the pylons were no longer properly centered between the reflectors. The off-center pylons were pried back into position. After realignment, most of the pylons remained aligned after the pry bar was removed. The collector field is being monitored to determine whether further misalignment of pylons will occur.

Data Presentation and Analysis

Monthly and Annual Performance

The solar energy system at the Lone Star Brewery operated for 9-1/2 months between December 15, 1981 and September 30, 1982 and continued to operate at the close of FY82. Because of DAS and DAS-related malfunctions, data was collected only 232 days of the 290-day period the system was in operation and insolation data in the collector plane was collected only 191 days. Also, during the last 3 months of operation, only 13 of 15 rows or 87% of the collector field were functioning.

The total energy delivered by the Lone Star solar energy system during the 232 days in which data was collected was approximately 94,814 kWh (3.24×10^8 Btu). An extrapolation of this figure for an entire year of operation yields a yearly energy output of 1.4×10^5 kWh (4.78×10^8 Btu). This is only 15% of the 9.4×10^5 kWh/yr (3.2×10^9 Btu/yr) the system was designed to deliver. Factors that account in part for this low value include the number of days the solar energy system or several of its rows were down, climatic conditions, and piping thermal loses.

The average thermal efficiency of the solar energy system, determined by using the available insolation in the collector plane, was 19.5%. This value was calculated for the 191 days that insolation data was available. Daily thermal efficiencies ranged from a high value of 42.6% to 0%. May had the best monthly average efficiency of 36.4%. The efficiency of the system dropped to 16.6% in June, probably due to the large number of partly cloudy days which affects the control system. The thermal efficiencies improved for July and August to 23.0% and 28.3%, respectively.

During the 290-day period of operation, the solar energy system was down 25 days. The down time could be substantually reduced if the solar energy system is monitored on a daily basis. There was one incident where the solar energy system was down for 10 days by a minor malfunction and a similar incident where the system was down for 9 days. For these two cases alone, 17 days of down time could have been averted if the malfunctions had been observed on the days they first occurred.

Performance data are presented in Figures 5-4 through 5-13 and in Table 5-2.

Clear Day Performance

Clear-day performance is described below.

Typical performance for the system was reported for May 8, 1982 (Figure 5-14). Energy delivered was approximately 80% of energy collected. The clear-day system efficiency was 37.5%.

On May 8, the effect of varying condensate flow into the boiler used to measure energy delivery is shown. Since this flow is used in calculating the energy delivered by the system, the data often shows greater energy delivered than collected for some hourly readings. Because condensate flow is controlled by a float valve in the boiler the calculated energy delivered appears to be greater than it actually is if the condensate flow turns on several times during a 1-hour averaging period. Also, if the condensate flow turns on only a few times during the 1-hour averaging period, the calculated energy delivered will be less than it should be. The long term (daily) average will still be correct.

On July 25, 1982, the energy delivered averaged 72 percent of the energy collected, once steam production began. This 28% loss of energy resulted from piping losses, boiler losses, and a small steam leak in a bucket trap. System efficiency for the day based on insolation in the collector plane was 30.2% and the time required to achieve steam production was 1 hour 40 minutes. On July 25, 1982, 2 rows of collectors were down; thus, only 87% of the total array area was available. Performance for July 25, 1982 is shown in Figure 5-15.

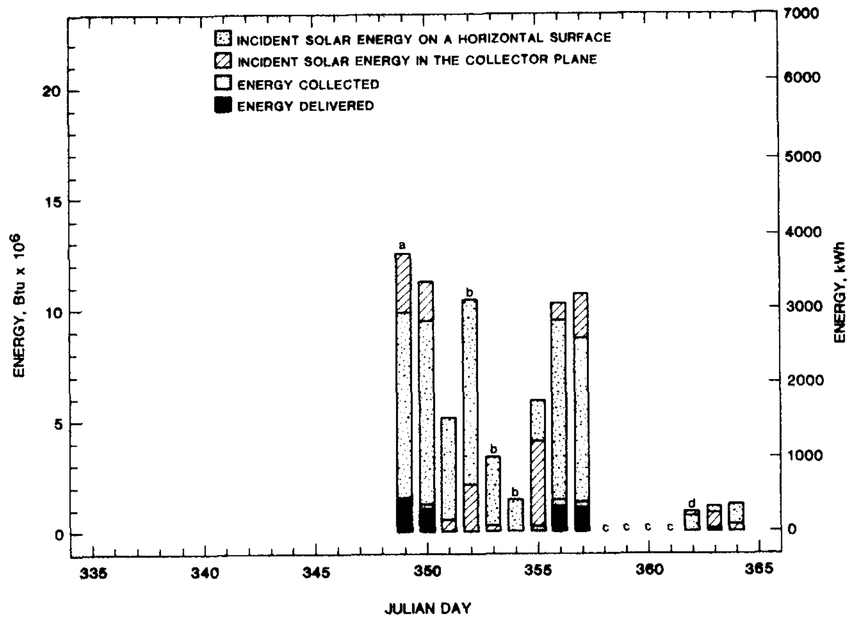

Figure 5-4. Performance Data for December 1981

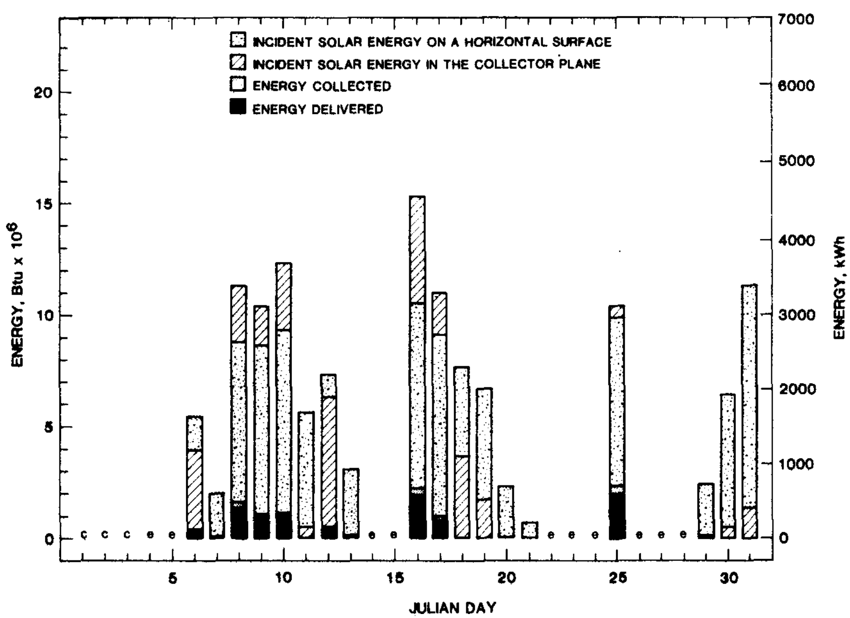

Figure 5-5. Performance Data for January 1982

a - First day of operation
b - Central controller failure; microprocessor malfunction
c - Plant down, solar energy system idled
d - Computer system down till afternoon
e - Solar system and plant both operational but
DAS down resulting in loss of data

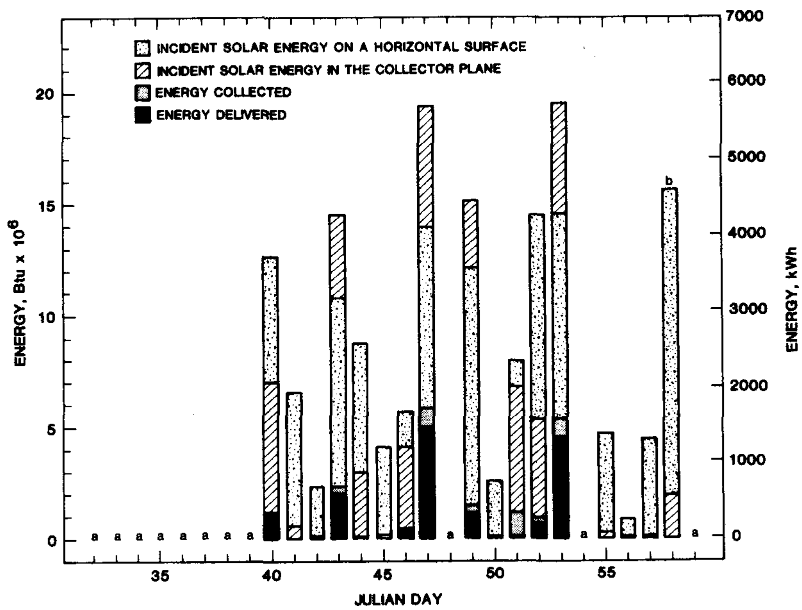

Figure 5-6. Performance Data for February 1982

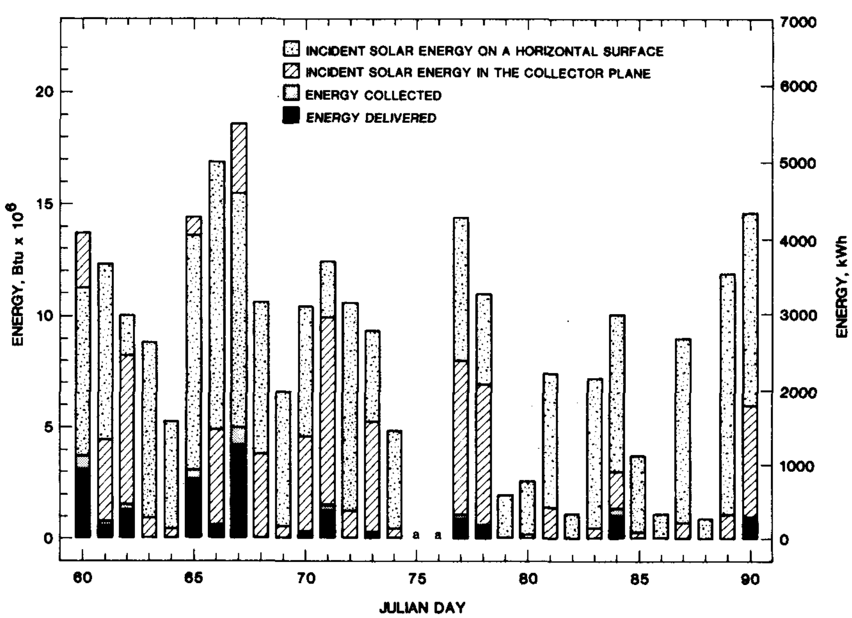

Figure 5-7. Performance Data for March 1982

a - Solar system and plant both operational but DAS down resulting in loss of data

b - Solar energy system not turned on

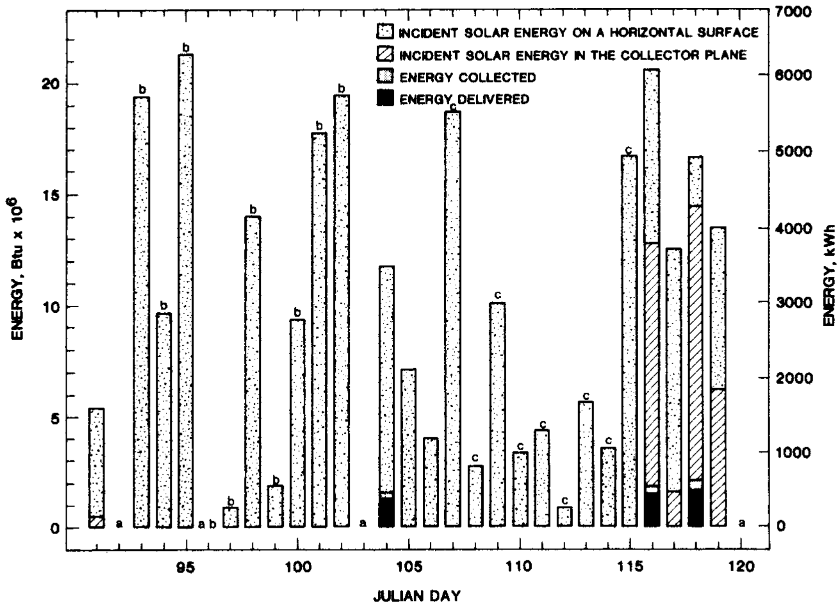

Figure 5-8. Performance Data for April 1982

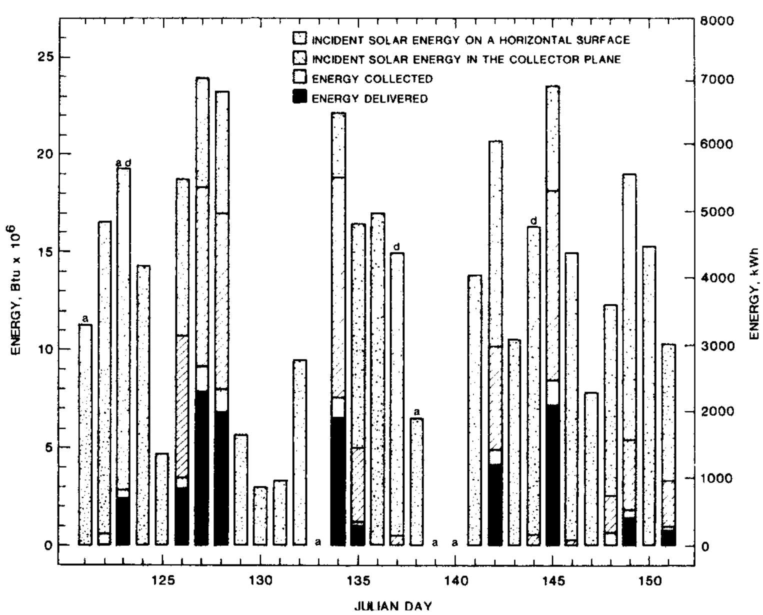

Figure 5-9. Performance Data for May 1982

a - Solar energy system and plant operational, but DAS down, resulting in loss of data

b - Solar energy system down due to bad fuse in collector central controller; undetected until 4/12

c - Solar energy system down due to malfunction of flow switch in hazard loop; undetected until 4/26

d - Row 15 out of focus; instrumentation used to obtain radiation in the collector plane is mounted on row 15

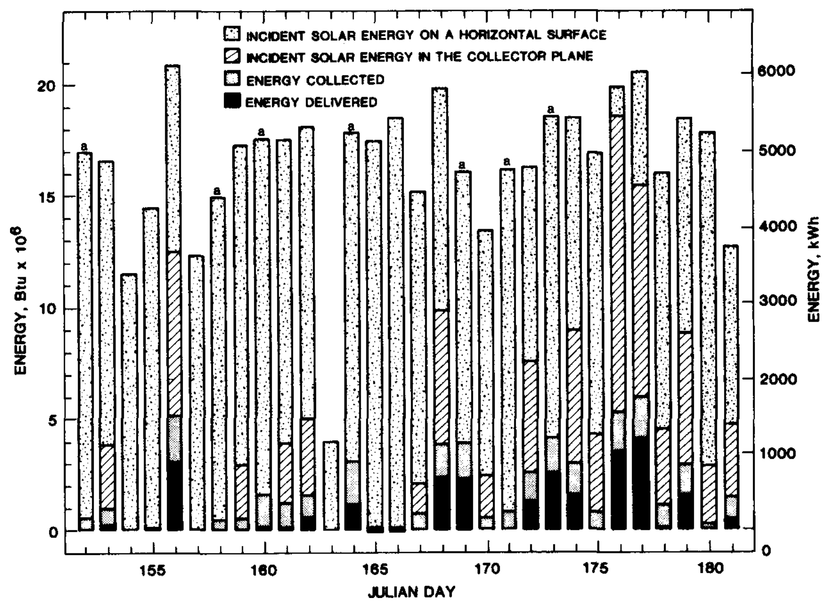

Figure 5-10. Performance Data for June 1982

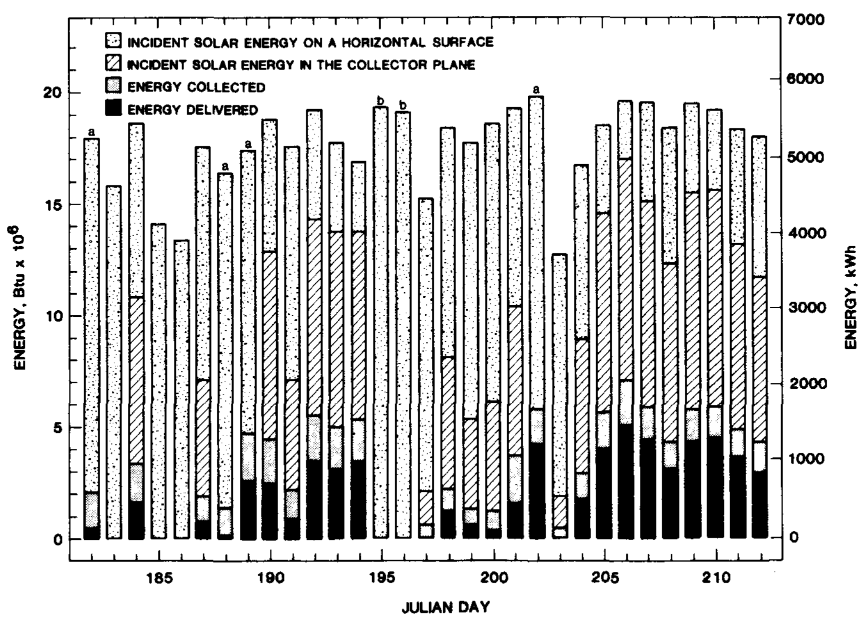

Figure 5-11. Performance Data for July 1982

a - Row 15 out of focus; instrumentation used to obtain radiation in the collector plane is mounted on row 15

b - Solar energy system down for maintenance

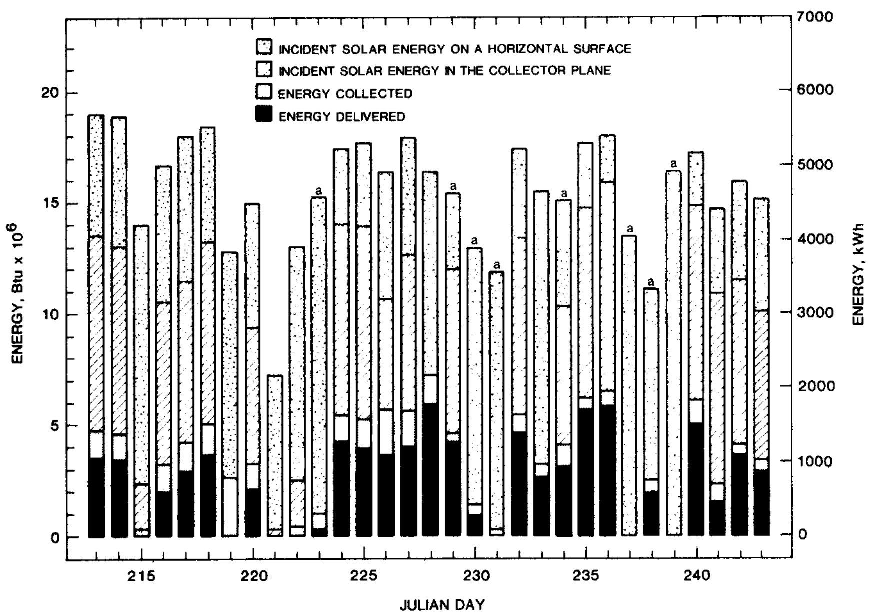

Figure 5-12. Performance Data for August 1982

a - Row 15 out of focus; instrumentation used to obtain radiation in the collector plane is mounted on row 15

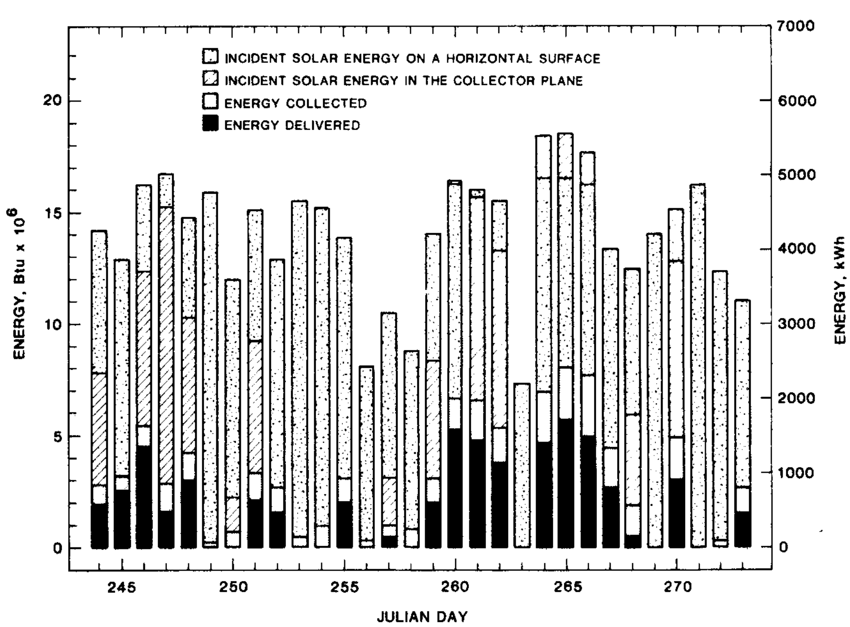

Figure 5-13. Performance Data for September 1982

Table 5-2

Lone Star Brewery Monthly Performance

Date (Month/ Year)	Number of Days Data Recorded	Number of Days Solar System Operated[a]	Available Insolation in the Collector Plane kWh	(Btu x 10^6)	Energy Delivered kWh	(Btu x 10^6)	Parasitic Energy Used kWh	(Btu x 10^6)	System Thermal Efficiency[b] %	Fossil Fuel Displaced[c] -- BBL's oil	(ft^3 x 10^3 gas)	Comments
12/81	12	9	15,798	(53.904)	1,381	(4.711)	N/A		8.7	1.160	(6.41)	Operation began 12/15/81
1/82	18	27	25,972	(88.620)	2,589	(8.835)	N/A		10.0	2.176	(12.02)	Data lost on 10 of 28 days: DAS down
2/82	17	26	28,891	(98.581)	4,425	(15.099)	N/A		15.3	3.719	(20.54)	Data lost on 11 of 28 days: DAS down
3/82	29	31	35,378	(120.716)	5,266	(17.970)	51.9	(0.177)	14.7	4.383	(24.21)	Data lost on 2 of 31 days: DAS down
4/82	8	11	10,393	(35.464)[d]	1,382	(4.715)	16.7	(0.057)	9.3[d]	1.147	(6.34)	Solar system down 19 days, DAS down 3 days
5/82	28	31	32,919	(112.323)[e]	12,139	(41.419)	55.4	(0.189)	34.6[e]	10.155	(56.10)	DAS down 3 days
6/82	30	30	34,833	(118.854)[f]	7,773	(26.522)	80.6	(0.275)	16.6[f]	6.465	(35.71)	87% of collector field functioning
7/82	29	29	69,870	(238.405)[g]	18,519	(63.191)	119.3	(0.407)	23.0[g]	15.464	(85.42)	87% of collector field functioning
8/82	31	31	71,669	(244.545)[f]	24,024	(81.973)	381.3	(1.301)	28.3[f]	19.870	(109.76)	87% of collector field functioning
9/82	30	30	54,216	(184.985)	17,314	(59.075)	379.1	(1.300)	31.2	14.230	(78.61)	87% of collector field functioning
Total	232	255	379,939	(1,296.397)[h]	94,812	(323.510)	1,084.3	(3.706)		78.769	(435.12)	
Average									19.17[h]			

a - Does not include days solar system idled

b - Calculated using the formula: $\frac{\text{Energy Delivered - Parasitic Energy}}{\text{Insolation in the Collector Plane}} \times 100\%$

c - Calculated using the formula: $\frac{\text{Energy Delivered - Parasitic Energy}}{\text{Combustion Efficiency Factor of 70\%}} \times \text{Conversion Factor}$

The conversion factors used are: 1 ft^3 gas = 1050 Btu
1 BBL oil = 5.8 x 10^6 Btu

d - Reflects only 5 days of data
e - Reflects only 24 days of data
f - Reflects only 23 days of data
g - Reflects only 25 days of data
h - Reflects only 191 days of data

Insolation data in the collector plane missing on days when collector row 15 was out of focus because the instrumentation used to collect this data is mounted on row 15

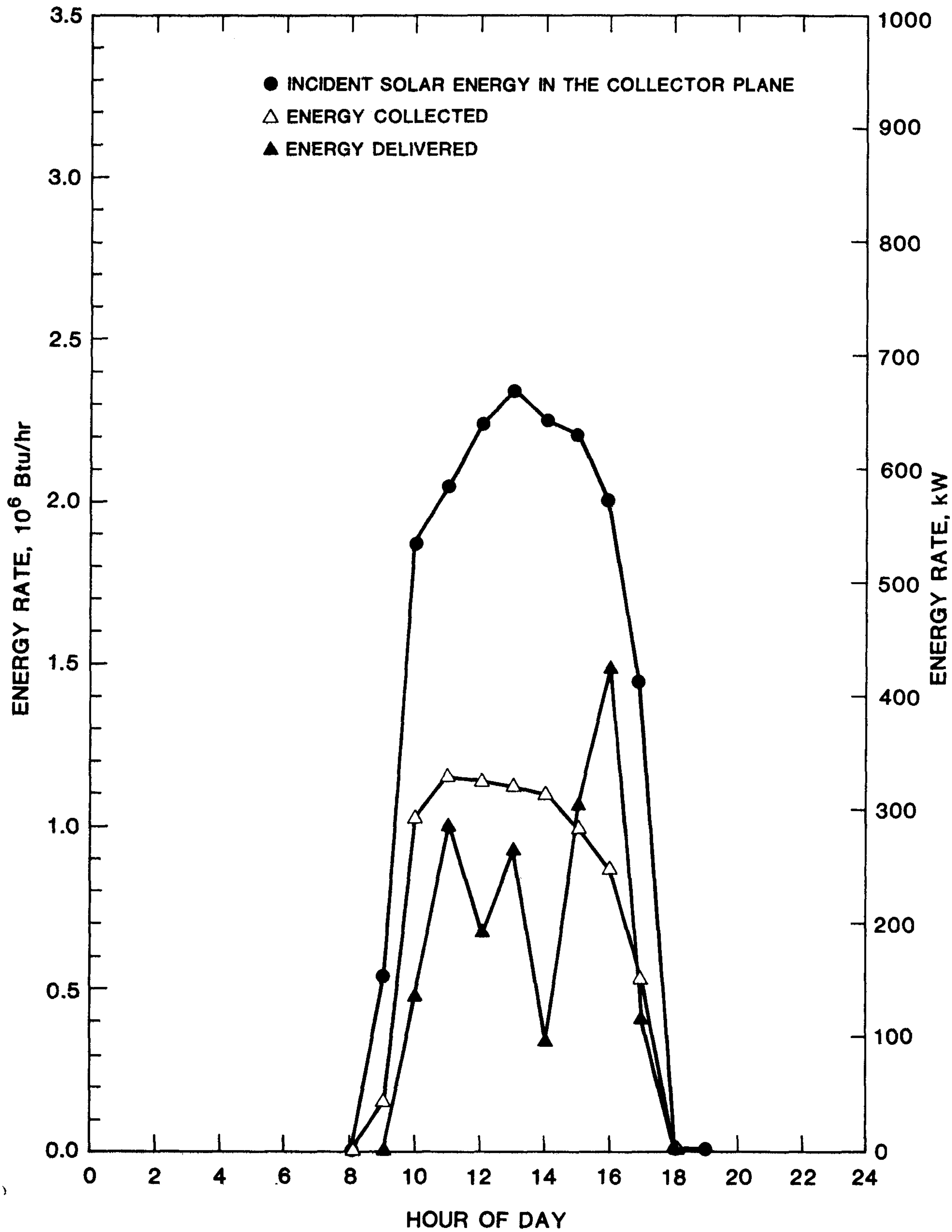

Figure 5-14. Clear Day Performance for May 8, 1982

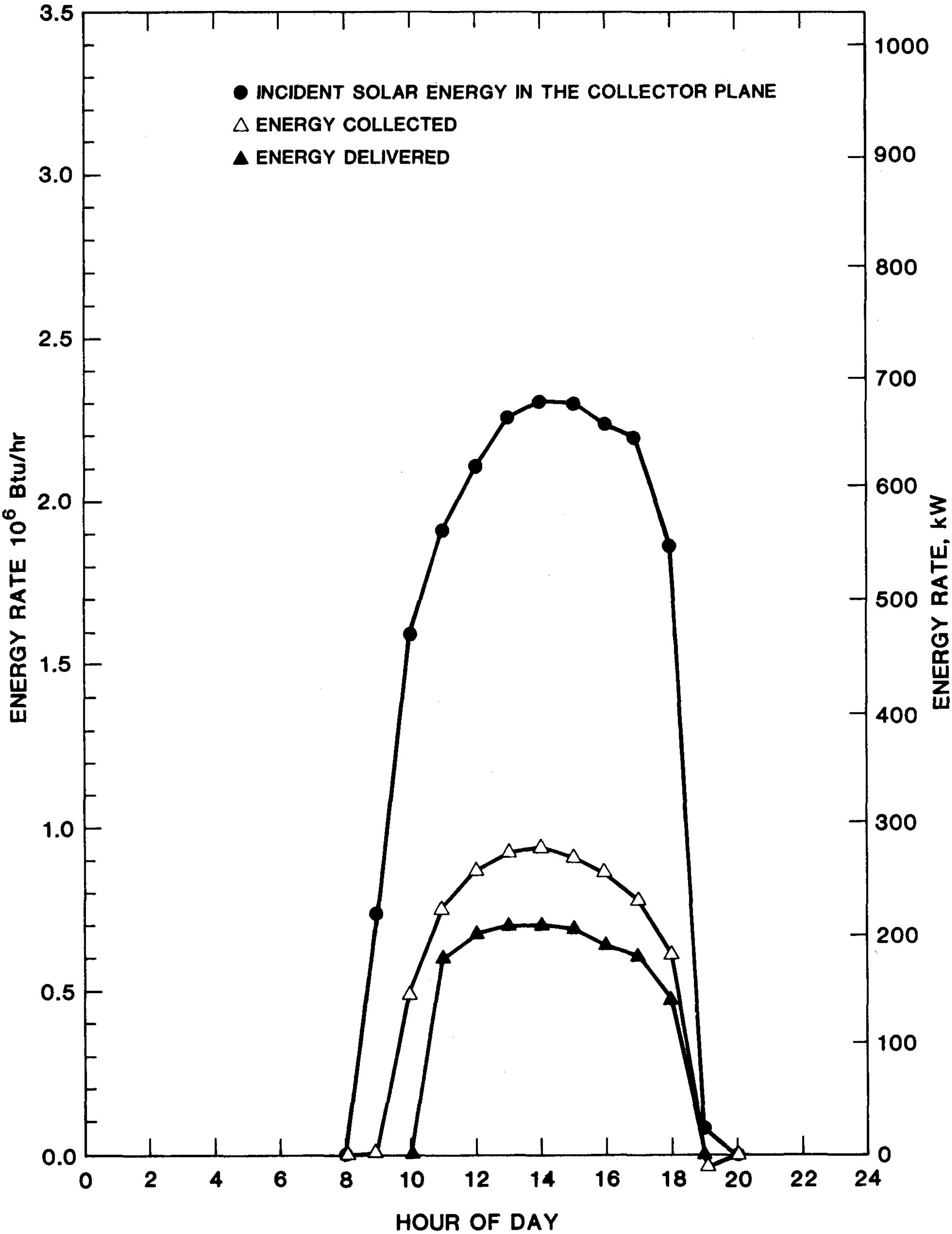

Figure 5-15. Clear Day Performance for 25 July 1982

The average thermal efficiency for the 8 other clear days reported (1 day per month of the first 8 months of operation) is only approximately 18%, and the average percentage of energy delivered compared to energy collected is approximately 58%.

System Performance Prediction

The SOLIPH system performance computer model developed by the Solar Energy Research Institute (SERI) has been configured to predict the performance of the Lone Star Brewery solar energy system. System performance in this instance means the amount of thermal energy delivered to the process for a certain amount of solar input. The model utilizes hourly insolation data for a typical meteorlogical year (TMY) at San Antonio and collector performance characteristics obtained from module test data modified for average dust build-up. Both the rate of heat loss and the thermal capacity of the pipes, supports, fittings, valves and flex hoses are modeled. System control functions are modeled on an hour-by-hour basis. The task of tailoring the model to the Lone Star system is continuing.

Predictions of the amount of energy delivered by the system on a July clear day (the 22nd) from the TMY data set are shown in Figure 5-16. Also shown for comparison is the measured amount of energy delivered to the Lone Star main steam line on July 25, 1982. This also was a clear day and the data have been adjusted for time and a slight difference in the total amount of insolation between the two days. It has also been increased by 15% to account for the two collector rows which were stowed.

The amount of energy predicted by the SOLIPH model is 40% greater than that actually delivered. It is assumed that the differences lie either in inaccuracies in the SOLIPH model or less than optimum collector or system performance. Work is continuing to identify these problems and when completed, the model will provide a valuable tool for monitoring system performance and for future system designs.

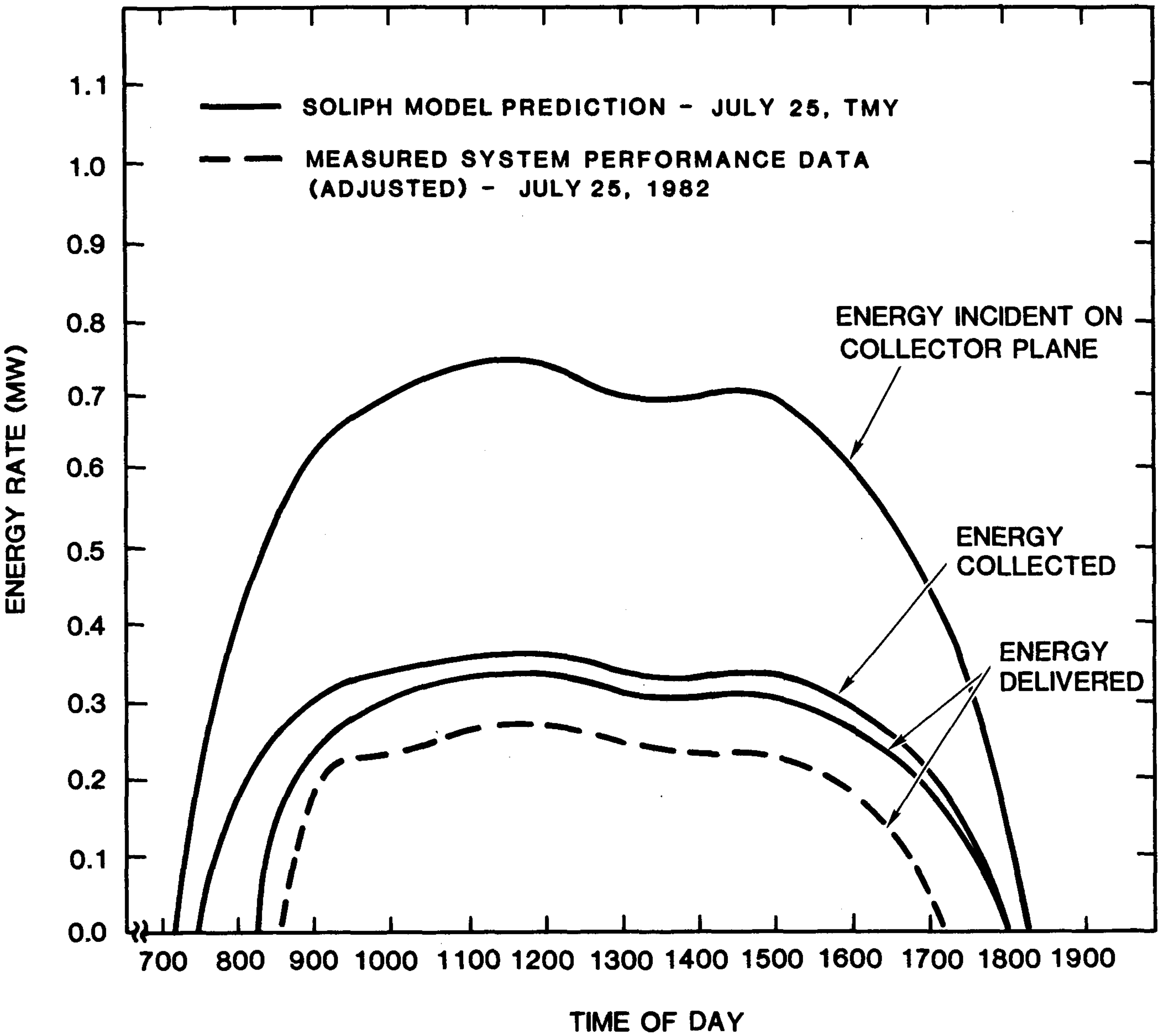

Figure 5-16. SOLIPH model performance predictions compared with actual system performance for the Lone Star Brewery

Operation and Maintenance

The Lone Star Brewery solar energy system contractor, SWRI, has developed a record on the operation and maintenance activities and costs for the period between January 1982 through September 1982. Activities are listed as either Routine/Scheduled or as Unscheduled; the list contains washing and cleaning activities, greasing, servicing of the water softener, and boiler blowdown. The items listed as Unscheduled Incidents not only reflect the major costs, but also serve as a history of some of the major problems experienced by the Lone Star project. Much of the activity can be considered as shakedown, dealing with adjustments and fine tuning that are normal to the beginning of any operation. The data for the year have been presented in two ways to show (1) the overall O&M by month and (2) shakedown-related and real problems in terms of frequency. The numbers on the "Unscheduled Incidents" show that these costs are four times as great per month, on the average, as those of routine, scheduled maintenance. Real costs would be even greater if those incurred by the collector manufacturer were considered. Table 5-3 shows the O&M activities from January through September 1982, and Table 5-4 shows a chronological history of problems by category.

Future Plans

Contract modifications have authorized replacement of the receivers with new Solar Kinetics, Inc. modular receivers to correct oil leakage and glass breakage. The work is awaiting scheduling by Solar Kinetics. Another contract modification is in process to authorize modification of the hydraulic drives and the control system, changing the system from high-temperature oil to low temperature water, and extension of the operating period through April 1984. The change from high temperature to low temperature will improve performance by 40% and will reduce the risk of fire, important for a roof-top installation.

Table 5-3

O&M Activities, January - September 1982

Date (Month/ Year)	O&M Activities: No. of Routine/ Scheduled	O&M Activities: No. of Incidents/ Unscheduled	System-Downtime Days*: R/S	System-Downtime Days*: I/U	Cost: Labor**: Man Hours: R/S	Cost: Labor**: Man Hours: I/U	Cost: Labor**: $: R/S	Cost: Labor**: $: I/U	Cost: Materials: $: R/S	Cost: Materials: $: I/U	Cost: Subtotal: $: R/S	Cost: Subtotal: $: I/U	Total
1/82	2	15			8	16	120.00	240.00	0	723.87	120.00	963.87	1,083.87
2/82	2	6			3	5	45.00	75.00	32.40	13.21	77.40	88.21	165.61
3/82	2	11			1	6	15.00	90.00	155.21	1,800.50	170.21	1,890.50	2,060.71
4/82	1	16		1/2	8	17	120.00	255.00	78.03	229.17	198.03	484.17	682.20
5/82	1	8			0	5	0	75.00	140.08	451.25	140.08	526.25	666.33
6/82	4	4			12	4	180.00	60.00	15.46	595.70	195.46	655.70	851.16
7/82	1	12			0	21	0	315.00	21.60	394.26	21.60	709.26	730.86
8/82	2	16			8	23	120.00	345.00	4.60	293.55	124.60	638.55	763.15
9/82	2	8			8	5	120.00	75.00	38.65	1,076.75	158.65	1,151.75	1,310.40
Totals	17	96		0.5	48	102	$720.00	$1,530.00	$486.03	$5,578.26	$1,206.03	$7,108.26	$8,314.29
Average	1.8						$80.00	$170.00	$54.11	$619.81	$134.00	$789.81	$923.81

*Due to O&M activities only

**Originally reported at $25/hr; subsequently reduced to $15/hr.

R/S - Routine, Scheduled

I/U - Incident, Unscheduled

Table 5-4

Chronological History of O&M Activities

TRACKER

1/82	Relocated tracker heads over receiver tubes to eliminate afternoon shading.
1/82	Blinder on central light switch adjusted.
1/82	Tracker head refocused.
1/82	Removed varistors on new tracker boards.
3/82	Rows 13 and 15 tracker systems repaired.
3/82	Row 9 - Tracker board relay replaced.
3/82	Refocus tracker head.
4/82	Row 4 op amp replaced. Dead band adjusted.
4/82	Row 5 malfunction traced to loose tracker head wire.
4/82	Row 5 - replaced op amp that was loose.
4/82	Row 14 - Removed control board for repairs.
5/82	Aligned row 5 tracker head.
5/82	Repair row 15 tracker system.
5/82	Repaired row 10 tracker system.
6/82	Repair row 1 tracking system.
7/82	Tracker head adjusted.
7/82	Row 4 tracker board repaired and pressure switch wires rerouted.
7/82	Trouble shoot and repair row 10 tracking system.

TRACKER (Continued)

8/82	Realign row 7 tracker head.
8/82	Trouble shoot row 9 tracking system.
9/82	Adjusted light switch sensitivity on 5 rows.

CENTRAL CONTROL & MICROPROCESSOR

3/82	Central controller microprocessor failure. Restarted.
3/82	Spare microprocessor for central controller.
4/82	Tracked cause of system malfunction to burned out fuse in central control panel.
9/82	Made modifications to microprocessor program.

SITE VISIT MAN DAYS

12/81	Visited site 13 days during December.
1/82	Visited site 16 days during January.
2/82	Visited site 12 days during February.
3/82	Visited site 17 days during March.
4/82	Visited site 14 days during April.

SITE VISIT MAN DAYS (Continued)

5/82	Visited site 13 days during May.
6/82	Visited site 14 days during June.
7/82	Visited site 16 days during July.
8/82	Visited site 13 days during August.
9/82	Visited site 12 days during September.

MISC. & ONE-TIME PROBLEMS

12/81	Injected more therminol into flow loop from storage tank.
12/81	Water softener
12/81	Boiler blow down.
12/81	Storage cabinet
1/82	Miscellaneous
2/82	Miscellaneous
3/82	Miscellaneous
4/82	Miscellaneous
5/82	Miscellaneous
7/82	Therminol
7/82	Touch up painting.
7/82	Cleaned therminol off of reflectors.
7/82	Replaced missing screws in drive pylon cover.
8/82	Balanced flow through collectors.

Table 5-4 (Continued)

Chronological History of O&M Activities

HAZARD LOOP

(Hazard loop wiring was installed as Routine/Scheduled Maintenance)

1/82	Hazard loop open--row 14 temperature swithc open.
1/82	Hazard loop rewired.
1/82	Replacement hazard loop temperature sensors installed in rows 6 & 14.
4/82	Hazard loop open. Traced to expansion tank level switch.
4/82	Hazard loop temperature switches.
4/82	Differential pressure switch taken out of hazard loop since pressure switch was installed.

PRESSURE SWITCHES/VALVES

12/81	Pressure switch
12/81	Pressure relief valve
12/81	Replaced leaky steam pressure relief valve.
3/82	Differential pressure sensor for Venturi.
4/82	Row 14 - repaired pressure switch wires.
4/82	Row 15 - needle valve clogged. Cleaned out valve.
4/82	Row 13 - repaired pressure switch wires that were cut.
9/82	Pressure switches

HYDRAULIC

12/81	Charged hydraulic accumulator in row 8
1/82	Added hydraulic fluid to collector hydraulic drivers.
1/82	Charged hydraulic accumulators on 4 rows.
3/82	SKI replaced 7 hydraulic accumulators.
5/82	Individual collector rows focused on 3 days.
6/82	Individual rows focused on 3 days.
7/82	Row 2 hydraulic accumulator charged with nitrogen.
7/82	Row 3 hydraulic leak fixed.
7/82	Charged hydraulic cylinders on slow tracking rows.
8/82	Nitrogen bottle
8/82	Fixed row 14 hydraulic leak.
8/82	Trouble shoot row 12 drive system.
8/82	Installed nitrogen over pressure cylinder.
8/82	Fix row 4 hydraulic leak.
9/82	Repaired row 4 hydraulic leak.
9/82	Cleaned up hydraulic leak on row 14.
9/82	Hydraulic fluid.

FOCUSING

10/81	Individual collector rows manually focused on 3 days
1/82	Individual collector rows manually focused on 3 days.
2/82	Individual collector rows manually focused on 3 days.
3/82	Single collector rows manually focused on 3 days.
7/82	Manually focused individual collector rows on 6 days.
8/82	Manually focused single collector rows on 6 days.
9/82	Manually focused single collector rows on 7 days.

FLEXHOSE

1/82	Tightened flexhose fittings on rows 5 and 13.
8/82	Removed ruptured flex hoses (rows 5 and 13) and cap off rows.

RECEIVER TUBE

1/82	Row 9 receiver tube
5/82	Tightened receiver tube standoffs on row 14 and receiver tube hose clamps on rows
7/82	Row 3 receiver tube

Table 5-4 (Continued)

Chronological History of O&M Activities

MISC. & ONE-TIME PROBLEMS (Continued)

8/82 Replaced steam bucket trap gasket to repair steam leak.

8/82 Pryed off center support pylons back into their proper position.

INSTRUMENTATION/SENSORS/RELAYS

Switches & Sensors

1/82 Thermometers

1/82 Row 13 temperature switch repaired.

2/82 Repaired row 14 temperature switch.

3/82 Row temperature switches.

3/82 Installed new temperature swtiches in rows 13 and 14.

8/82 Traced cause of solar system stowing under clear skies. Row 15 over temperature.

8/82 Thermowells

INSTRUMENTATION/SENSORS/RELAYS

Relays

4/82 Row 7 - replaced rotary switch.

4/82 Replaced row 7 control relay.

8/82 Replacement relays

INSTRUMENTATION/SENSORS/RELAYS

Flow Valves/Switches

2/82 Repaired mercoid flow switch.

2/82 Row 15 bypass valve repaired.

4/82 Flow switch and Venturi installed.

4/82 Steam flow meter (Venturi)

5/82 Flow switch

6/82 Condensate flow totalizer.

6. ORE-IDA FOODS
ONTARIO, OREGON

The Ore-Ida Foods plant in Ontario, Oregon is a large producer of frozen potato products. Located in an arid region along the Oregon, Idaho border, the plant uses steam to heat cooking oil for blanching, washing, and frying potatoes. A project to use solar energy for producing steam to supplement the company's fossil fuel steam plant was begun in July 1979. The project consisted of designing, constructing, and operating a solar collector field and steam system at the Ore-Ida plant. Ore-Ida foods was the industrial participant. The prime contractor was TRW who had the primary responsibility for the solar energy system design. In addition Hexcel-Suntec Systems, the collector manufacturer, and CH2M-Hill, architects and engineers, played major roles in the design and integration of this system. An aerial view of the system is shown in Figure 6-1.

The design of the system was completed in July 1980. Construction (Phase II) was completed in June 1981 when the acceptance test was performed. Phase III operations were initiated in August 1981 and, because of early operational delays, was extended from the original completion date of July 1982 to January 1983. At the end of FY82, the system was inoperative because of failure of the main circulating pump.

Description

Plant Description

The Ore-Ida Foods plant has two dual-fueled boilers (gas or oil), each producing 2070-kPa (300-psia) steam at the rate of 22,500 kg/h

Figure 6-1. Solar Collector Array at Ore-Ida Foods, Ontario, Oregon

(49,600 lb/h). Forty-five percent of this steam is used at 214°C (417°F) for the potato frying operations. The remainder is used for other processes in the plant at lower temperatures.

Solar Energy System

The solar energy system consists of 14 rows of Suntec/Hexcel parabolic trough concentrators. Their tracking axis is oriented 11 degrees counterclockwise from the North-South direction. The system was designed as a roof-top collector installation, but was changed after the Phase I study to locate the collector field on the ground adjacent to the plant. The total collector aperture area is 929 m^2 (10,000 ft^2). The collector rows are spaced 15 feet apart resulting in a collector packing factor of 0.59.

There are 56 collector modules used in the field. Four modules are connected together and driven by a single electric drive motor connected through a gearbox and chain drive. The tracking system for each of these drive strings receives input from a Honeywell flux line tracker which senses the position of the concentrated flux at the receiver tube. The receiver tubes of each 24.4 m (80 ft) long drive string are connected in parallel to header piping resulting in the full temperature rise taking place across this length.

Boiler quality water is circulated at a constant flow rate through the collectors at a pressure of up to 4140 kPa (600 psia) to prevent boiling. The pressure is then dropped to 2070 kPa (300 psia) to generate steam. Treated, potable water is used in the system to avoid contaminating food products. Flash steam from this water is used to heat the cooking oil.

The system is protected from freezing by a recirculation drain-down feature. Flash tank water is recirculated. An electric heater is used if necessary to heat the flash tank water. Under extreme cold conditions and for long term, the system is drained.

The major components of the system are the collector field, a flash tank, a main circulating feed pump, and several flow-regulating valves. During operation, water returned from the bottom of the flash tank is mixed with treated makeup water and fed to the suction side of the main circulating pump. The pump delivers water to the collector field at a constant flow rate of 3.15 kg/s (25,000 lb/hr). Collector field pressure is maintained at 4140 kPa (600 psia) by a back pressure regulator located at the field exit. As the water flows through the regulator, its pressure is reduced to flash tank pressure which is held by the steam pressure regulator at 2070 kPa (300 psia), and is partially flashed to steam. System water inventory is maintained by a flash tank water level controller that controls the flow into the circulating pump. There are no provisions for thermal storage in the system. However, the water in the flash tank constitutes a small amount of stored energy. A summary of the solar energy system characteristics is presented in Table 6-1. Figure 6-2 is a schematic of the solar energy system.

Interface -- The solar energy system produces steam, which is added into the existing main steam line feeding a heat exchanger that is used to heat potato frying oils. The steam is generated in a 1.6-m^3 (425-gallon) flash tank maintained at 2070 kPa (300 psia) by an electronically controlled back pressure regulator valve. The tank is 91 cm (36 in) in diameter by 267 cm (105 in) high with a 7.6-cm (3-in) fiberglass insulating jacket. It is American Society of Mechanical Engineers (ASME) certified for a 2280-kPa (330-psi) (gage) maximum allowable working pressure at 343°C (650°F). Two ASME-rated relief valves protect the tank and operating personnel. In normal operation, the process controller maintains about 1.14 m^3 (300 gal) of water in the tank, adding makeup as steam is drawn off. At the maximum output case, with 3.15 kg/s (25,000 lb/h) of water circulating through the collectors, 875 kg/h (1930 lb/h) of steam is generated in the tank.

Process Utilization -- The potato fryers operate 24 hours a day, 6 days per week from August to December. From January to July, the operating week is reduced to 5 days. The frying operations are

Table 6-1

Ore-Ida Foods Solar Energy System Characteristics

General	
Site:	Ontario, Oregon
Demand:	Steam at 2069 kPa/214°C (300 psia/ 417°F); 869 kg/h (1930 lb/h) max
Collector	
Type:	Suntec/Hexcel SH1655 parabolic trough with high pressure receiver tube
Area:	929 m^2 (10,000 ft^2)
Mounting:	Ground level oriented 11° ccw from N-S axis, arrayed in 14 rows
Mirror Module:	Aluminized acrylic film (3M FEK244) on face sheet of aluminum honeycomb core panels
Receiver Tube:	Nickel oxide-coated, 3.18-cm (1-1/4-in), schedule 80 steel pipe
Solar Tracking:	Honeywell Flux-line suntracker; geared electric drive motors with chain drive
Working Fluid	
Type:	Pressurized water 4137 kPa (600 psia)
Control:	Constant flow rate
Flow Rate:	3.79×10^{-3} m^3/s (60 gpm)
Outlet Temperature:	247°C (477°F) (maximum)
System	
Interface:	Flash tank steam generator supplies steam to plant steam lines
Process Schedule:	Potato fryer heating; 3-8h shift/day, 6d/wk, August to December; 3-8h shift/day, 5d/wk, January to July
Auxiliary Fuel:	Natural gas
Design Energy Delivery:	566 kW (1.93×10^6 Btu/hr) max; 2745 GJ/yr (2.6×10^9 Btu/yr) net; 1% of annual process demand (SOLIPH Model estimate: 1149 GJ/yr (1.1×10^9 Btu/yr)

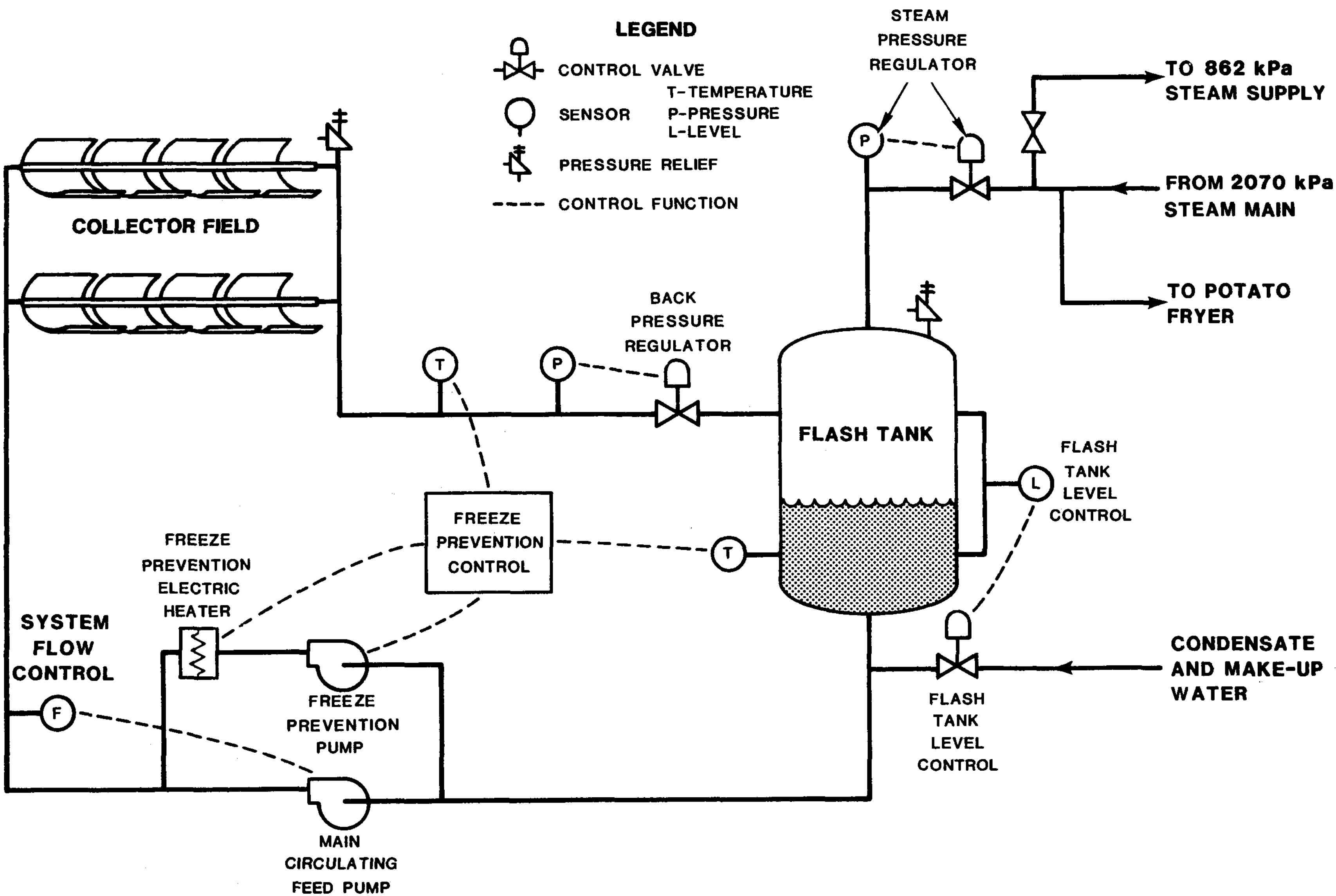

Figure 6-2. Schematic of Ore-Ida Foods Solar Energy System, Ontario, Oregon

accomplished with three separate and independent frying lines. The solar steam system supplies one line. Frying is performed in stages with a separate heat exchanger supplying heated oil for each stage.

The solar energy system, is capable of collecting 2 GJ/h (1.9 x 10^6 Btu/h) during hours of maximum insolation. Since the total load for all processes exceeds this heat production rate, all solar produced steam can be used.

The annual fryer line steam requirements and projected solar produced steam are listed below:

- annual steam required for all frying operations -- 26,398 GJ (2.5 x 10^{11} Btu)
- annual steam required for the line being supplied with solar steam -- 50,683 GJ (4.8 x 10^{10} Btu)
- projected annual supply of solar-produced steam -- 2,745 GJ (2.6 x 10^9 Btu)
- parasitic electrical energy consumed -- 179 GJ (1.7 x 10^8 Btu)
- net solar energy supplied -- 2,534 GJ (2.4 x 10^9 Btu)
- natural gas displaced -- 8.5 x 10^4 m^3 (3.0 x 10^6 ft^3)

Collectors -- The physical and performance characteristics of the Suntec/Hexcel collectors used in this system are described in Appendix A. The basic collector configuration was modified for this system by using a high pressure receiver tube.

Steam System -- The collector field uses reverse return for even flow among the 14 parallel connected rows. Pressurized water is circulated through the collector field by a 3500-rpm turbine pump, manufactured by Roth Pump Company. The connecting plumbing runs about 128 meters (420 feet) from the field to the flash tank. Each collector has shutoff, vent, drain, and overpressure protection valves. Upon leaving the collector field, heated pressurized water arrives at the flash tank, where the pressure is reduced to tank pressure by an electronically controlled back pressure valve.

Controls -- The central process controller is an Eagle Signal Corporation Eptak minicomputer complete with signal conditioning equipment. The tracking control of the collectors is provided by a Honeywell Flux-Line Suntracker and an Eagle Signal Eptak process controller. Weather data is fed into the controller to determine the need for activation or stowing, and insolation measuring devices provide both command and performance measurement information. The process controller uses an independent set of field sensors and therefore operates independently of the DAS.

Data Acquisition System -- The Data Acquisition System (DAS) used on the Ore-Ida project is built around a WeatherMeasure M733B microcomputer. This unit, interfaces with signal conditioning and field sensor devices and peripheral equipment. It monitors system functions, converts data to engineering units, performs calculations, records data on tape, and prints reports.

FY82 Progress

During October 1981, the main circulating pump, which had previously been returned to the manufacturer for repair, was received and reinstalled. The system was then filled and checked out. Upon completion of checkout, the system was operated for several days under automatic control. During this period, Ore-Ida personnel were trained in the operation of the system. Later in the month, the pump failed again, and it was returned again to the manufacturer for repair. The pump was repaired by mid-January, however poor weather conditions delayed the start-up until late in February.

The main circulating pump continued to be a problem throughout the fiscal year. Following its replacement in mid-January, the pump appeared to be using excessive amounts of lubricant and was leaking water. In the last part of April, one of the flex hoses connecting the pump to the rigid piping failed, filling the area with steam. The flex hose had been installed following a change order, and the new part had a lower burst strength than specified. The repair of this failure was completed by mid-June. In mid-August, the pump failed again leaving the system in a non-operational status at the end of the fiscal year.

During initial data collection in February, large energy losses which prevented a net positive energy production were recorded. The losses were attributed, in part, to breakage of a number of receiver tube glass housings, to long piping runs, and to thermal losses through the pipe supports. Glass breakage was caused by interference between the receiver and the collector support stanchions, which in turn was caused by failure of a spring wire to activate mechanical limit switches designed to limit travel of the collectors. A design modification corrected this problem, and the broken glass was replaced. The excessive heat loss continued following glass replacement. A heat loss analysis was made by an outside engineering firm, who computed the thermal loss in terms of steam equivalent to be 0.02 kg/s (180 lb/hr) and the time to bring the system up to temperature to be approximately 3 hours.

During initial start-up, the liquid level sensor in the flash tank did not provide adequate control. A float gage was added to correct the problem. This sensor failed to operate satisfactorily. The problem was traced to misassembly of the gage at the factory.

The system was operated sporadically throughout the year because of the problems noted above and because of periods of bad weather. Problems with the Data Acquisition System (DAS) prevented measuring system performance when the system was operating.

Data collected prior to mid-April was lost because of DAS problems. In addition, problems with the printer and the recording tape deck caused additional loss of operating data. The computer program which calculates integrated energy delivered by the system was corrected in June. Prior to this time however, instantaneous data was recorded.

Data Presentation and Analysis

Clear Day Performance

System performance data collected on a representative clear day (August 5, 1982) are presented in Figure 6-3 and in Table 6-2. The system was started before 8:00 am and operated for approximately 12 hours. Steam was delivered to the potato fryer by 12:00 noon. The collector field outlet temperature averaged about 190°C (375°F) with the collector field efficiency peaking at 34 percent. The average system efficiency was 16 percent.

Performance

The solar energy system at Ore-Ida operated only sporadically during FY82 because of a series of problems and failures combined with periods of cloudy weather.

The system was not operational until February when there were four days of operation, mostly for problem identification. The system was up during all of March and operated 21 days. Energy was supplied to the plant seven of these days. In April the system operated for seven days until the circulating pump flex hose failed on April 23. The system was reactivated on June 16 with a few days of operation for that month. In July there were 7 days of operation and in August, 9 days of operation when the pump failed again on August 19. The system remained non-operational for the remainder of FY82.

During August, a sequence of daily performance data were recorded between August 5 and August 11 and are shown in Table 6-3. These data represent system performance for days with various degrees of cloudiness. For two days, only a small amount of energy was collected because the plant was not operating and there was no demand for steam.

System Performance Prediction

The SOLIPH system performance computer model developed by the Solar Energy Research Institute (SERI) was used to predict performance

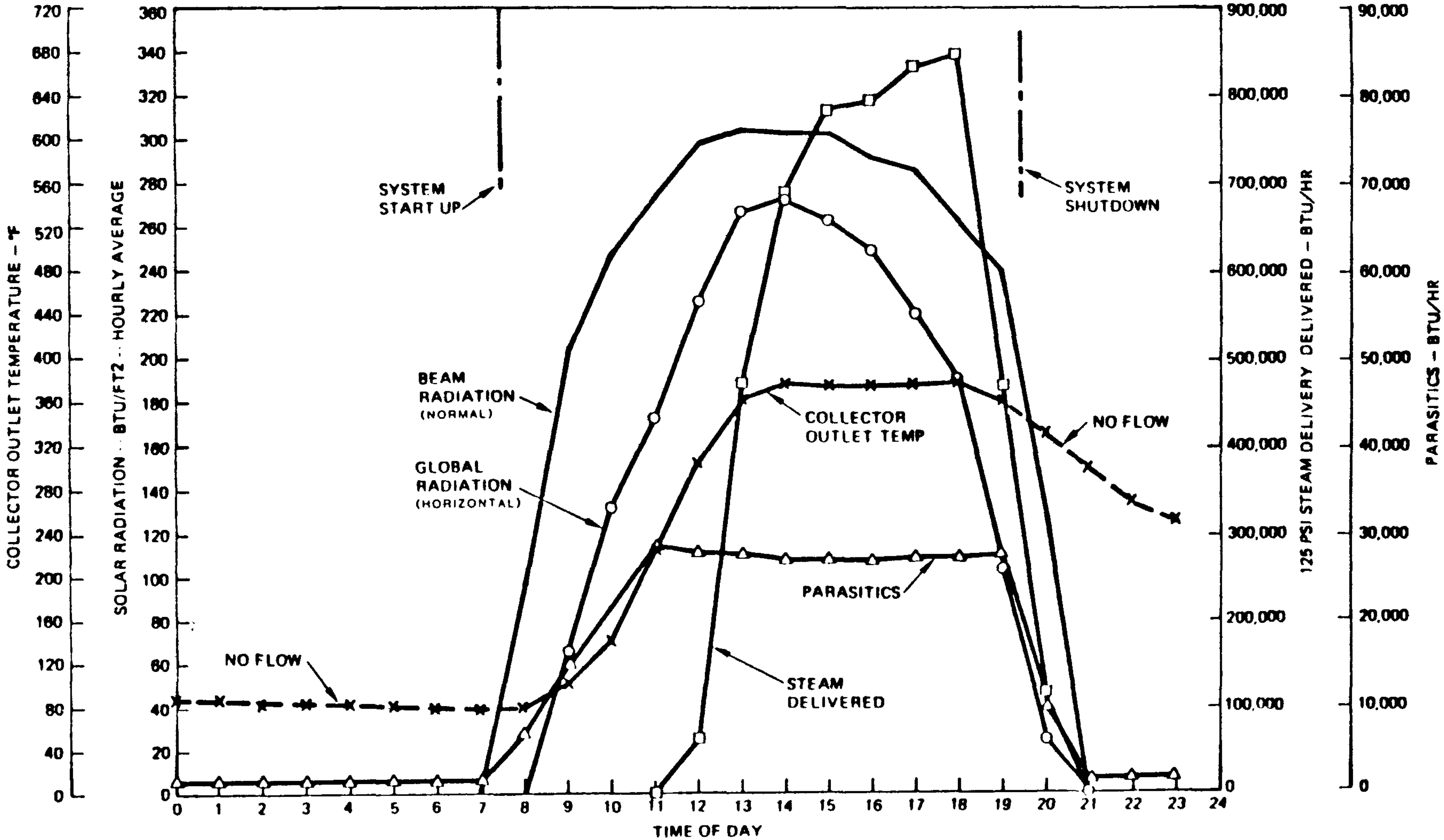

Figure 6-3. Clear Day Performance - August 5, 1982

Table 6-2

Clear Day Performance - August 5, 1982

Hour	Wind MPH	Air Temp F	Beam Radiation Btu/Ft^2	Global Radiation Btu/Ft^2	Collector Outlet Temp F	Temp Rise F	Energy Collected Btu	Collector Efficiency %	Energy Delivered Btu	Parasitic Energy Btu	Net Energy to Process Btu	System Efficiency %
0	0	79	0	0	87	-2	0	0	0	1561	0	0
1	0	75	0	0	86	-2	0	0	0	1562	0	0
2	0	75	0	0	85	-1	0	0	0	1563	0	0
3	0	72	0	0	84	-1	0	0	0	1557	0	0
4	0	71	0	0	83	-1	0	0	0	1557	0	0
5	0	69	0	0	82	-1	0	0	0	1555	0	0
6	0	68	0	0	81	-1	0	0	0	1551	0	0
7	1	66	0	0	80	-1	0	0	0	1555	0	0
8	0	67	97	0	80	-3	-32973	-4.7	0	6952	0	0
9	1	71	204	66	102	4.8	56017	3.8	0	14871	0	0
10	1	76	248	133	142	11.3	333707	18.6	0	28501	0	0
11	2	80	275	174	225	18.1	511673	23.6	0	28761	0	0
12	1	85	298	226	317	21.1	601775	23.6	60914	27984	60914	1.2
13	2	88	304	267	363	24.7	690410	26.6	474259	27494	473118	15.9
14	2	92	303	273	378	26.1	747608	28.8	690533	27155	690533	23.7
15	3	96	303	264	375	26.2	735613	28.4	783901	27197	783901	27.1
16	3	97	292	250	377	26.4	741665	29.7	792484	27219	792484	28.5
17	3	100	287	221	378	27.5	774715	31.6	832305	27523	832305	30.5
18	2	101	263	171	379	27.3	760815	33.8	846438	27474	846438	33.7
19	3	101	240	104	362	16.4	444751	21.7	468067	27708	468067	19.9
20	2	98	128	24	329	-2	9096	0.8	115763	10164	115763	8.9
21	0	95	0	0	291	-15	0	0	0	1895	0	0
22	0	90	0	0	271	-15	0	0	0	1915	0	0
23	0	83	0	0	253	-15	0	0	0	1914	0	0
Daily Average and Totals	1	83	3242	2173			6.37×10^6	21.3	5.06×10^6	327555	5.05×10^6	15.8

Table 6-3

TRW/Ore-Ida Foods Monthly Performance Summary
August 1982

Date		Beam Rad	Global Rad	Air Temp	Outlet Temp	Energy Collected	Collect Eff	Energy Delivered	Parasitics	Net Energy Delivered	System Efficiency	
		Btu/Ft^2	Btu/Ft^2	°F	°F	Btu	%	Btu	Btu	Btu	%	
8-1	s	1795	1*	1*	99	0	0	0	37234			3*
8-2		1923	1*	1*	82	0	0	0	37147			3*
8-3		2291	1*	1*	81	0	0	0	37286			3*
8-4		2116	1*	1*	81	0	0	0	37363			3*
8-5		3242	1*	1*	227	6.37×10^6	21.3	5.06×10^6	327655	5.05×10^6	15.8	2*
8-6		3189	1*	1*	242	4.37×10^6	14.9	3.21×10^6	243638	3.21×10^6	10.1	
8-7	s	2181	1*	1*	188	0.28×10^6	1.4	0.07×10^6	104165	S	S	
8-8	s	1262	1*	1*	154	0.31×10^6	2.7	0.07×10^6	90076	S	S	
8-9		2344	1*	1*	218	3.38×10^6	15.6	1.65×10^6	252275	1.65×10^6	6.5	
8-10		2632	1*	1*	244	2.85×10^6	11.8	1.63×10^6	286207	1.63×10^6	5.5	
8-11		957	1*	1*	121	0.45×10^6	5.2	0.07×10^6	154779			
8-12		603	1*	1*	1*	0	0	0	323602			
8-13		308	1*	1*	1*	0	0	0	321492			
8-14	s	562	1*	1*	1*	0	0	0	315907			
8-15	s	339	1*	1*	1*	0	0	0	71465			
8-16		536	1*	1*	1*	0	0	0	35956			
8-17		309	1*	1*	1*	0	0	0	39756			
8-18		1*	1*	1*	1*	0	0	0	12217			4*
8-19		842	1696	1*	1*	0	0	0	35801			5*
8-20		626	1562	1*	1*	0	0	0	36683			
8-21	s	314	1580	1*	1*	0	0	0	35583			
8-22	s	750	1775	1*	1*	0	0	0	35769			
8-23		510	1551	1*	1*	0	0	0	35645			
8-24		320	1467	1*	1*	0	0	0	35536			
8-25		482	1581	1*	1*	0	0	0	35501			
8-26		656	1742	1*	1*	0	0	0	35560			
8-27		1007	1726	1*	1*	0	0	0	35571			
8-28	s	438	1571	1*	1*	0	0	0	35508			
8-29	s	1*	836	1*	1*	0	0	0	35361			
8-30		1*	1784	1*	1*	0	0	0	35414			
8-31		452	1493	1*	1*	0	0	0	35326			

*1 Poor data

*2 System set for 125 PSI

*3 System shut-down

*4 Replaced CMOS chips in DAS
Replaced repaired Kennedy tape recorder
System would not start-up
Cleaned collector rows 7 to 14

*5 System shut-down and main circulation pump removed for repair

S Plant shut down

of the Ore-Ida Foods solar energy system. System performance in this instance means the amount of thermal energy delivered to the process for a certain amount of solar input. The model utilizes hourly insolation data for a typical meteorlogical year (TMY) at Boise, Idaho, and collector performance characteristics obtained from module test data modified for average dust build-up. Both the rate of heat loss and the thermal capacity of the pipes, supports, fittings, valves and flex hoses are modeled. System control functions are modeled on an hour-by-hour basis.

Predictions of the amount of energy delivered by the system on an August clear day (the 3rd) from the TMY data set are shown in Figure 6-4. Also shown for comparison is the measured amount of energy delivered to the Ore-Ida main steam line on August 5, 1982. This also was a clear day and the data have been adjusted for time and a slight difference in the total amount of insolation between the two days.

The amount of energy predicted by the SOLIPH model is 51% greater than that actually delivered. It is assumed that the differences lie either in inaccuracies in the SOLIPH model or an early degradation of collector or system performance. Work is continuing to identify these problems and when completed, the model will provide a valuable tool for monitoring system performance and for future system designs.

Future Plans

During the first half of FY83 the system was inoperative; first because of failure of the main circulating pump and, during the winter months, because with north-south orientation of the collectors energy production does not exceed thermal losses in the system. An upgrade of the system was considered in January 1983 but was turned down by DOE when Ore-Ida officials indicated they probably would not continue to operate the system after the DOE experiment was complete.

After the Phase III contract expired, limited financial and technical support were offered to Ore-Ida for reporting performance

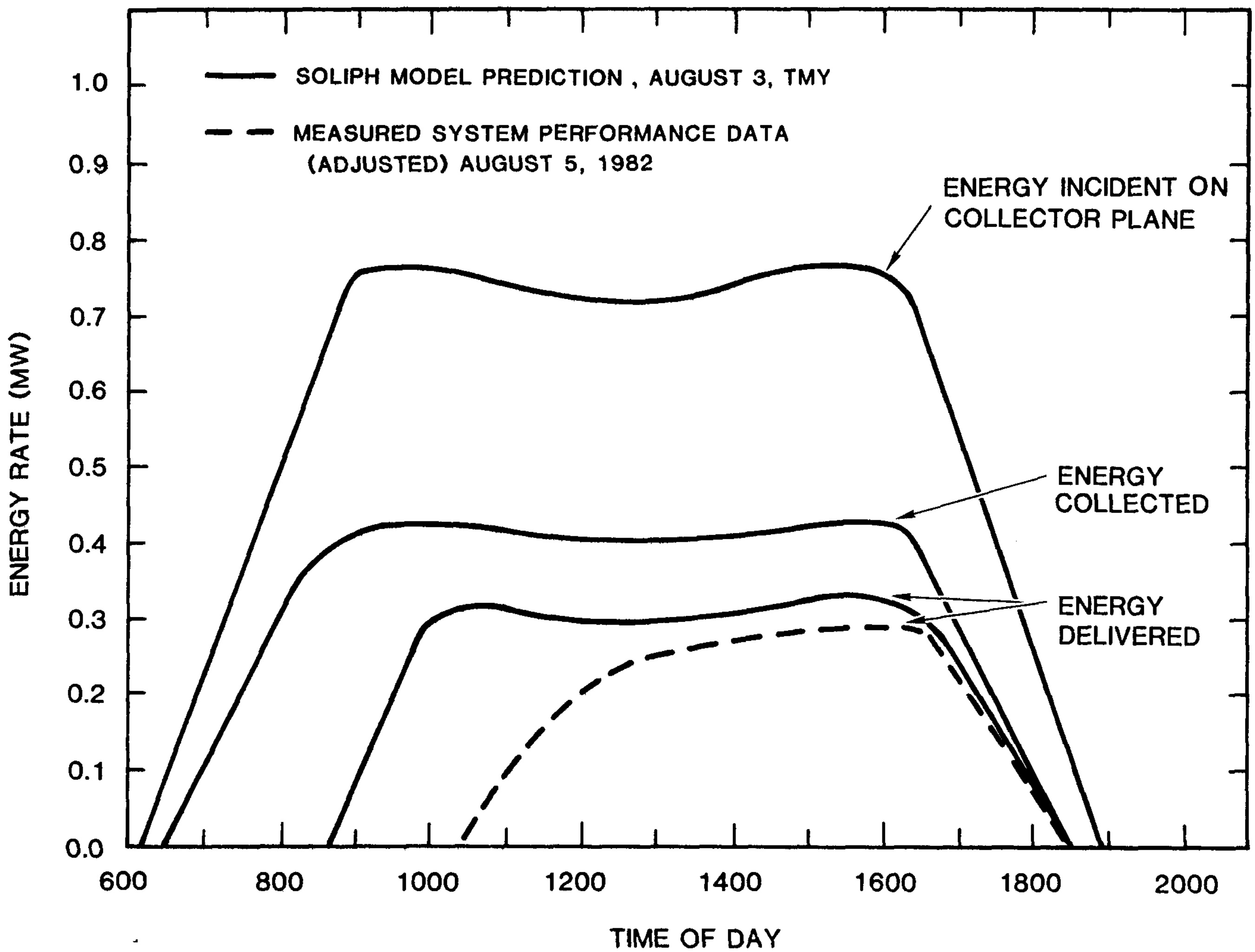

Figure 6-4. SOLIPH Model Performance Predictions Compared With Actual System Performance for Ore-Ida Foods

data on the assumptions that the system was operational and would be operated by Ore-Ida. Ore-Ida Officials reported, however, that the system was not operational and decided against undertaking the work necessary to make it operational. Based on the history of the project, they considered the potential gross energy production with an estimated value of $6,000 per year to be insufficient to justify further investment in the system. As a result, the contract with TRW was allowed to expire. Ore-Ida indicated that they would retain the system for some months but that they would not attempt to operate it.

7. SOUTHERN UNION REFINING COMPANY LOVINGTON, NEW MEXICO

The Southern Union Refining Company Famariss Energy Refinery project began in September 1978 with the design Phase I contract with Monument Solar Corporation, which later became Texas Energetics Corporation. Working with the Monument Solar Corporation were Bridgers and Paxton Consulting Engineers and the New Mexico Solar Energy Institute (NMSEI). The system is designed to produce steam for general refinery operations. The solar energy system is shown in Figure 7-1.

The Phase I period ended in September 1979, and Phase II, the construction of the project, began. The beginning of FY82 was devoted to final construction and inspection. In January 1982, acceptance testing had been completed, and the Phase III operational period began.

The Famariss Energy Refinery of Southern Union Refining Company near Hobbs, New Mexico, was one of the two industrial process heat (IPH) projects that produced significant amounts of both energy for the industrial user and data for the DOE during FY82. The project operated for 7 months in this fiscal year. While the system experienced a number of problems, it did, nevertheless, provide operational and performance data. At the end of FY82, the system was producing steam for the industrial user on a regular basis.

Description

Plant Description

The Southern Union Refining Company's Famariss Energy Refinery at Lovington, New Mexico is a major refinery in the petrochemical industry.

Figure 7-1. Solar Collector Array at Southern Union Refining Company, Lovington, New Mexico

It has a winter energy demand of 42 GJ/h (40 MBtu/h) and a demand of 32 GJ/h (30 MBtu/h) in the other three seasons. This energy is normally supplied by boilers fired either by natural gas or No. 5 fuel oil.

The refinery uses steam at 1207 kPa (175 psig), 192°C (378°F) to provide heat for refining processes, tank heating, and energy to run power turbines. The solar energy system is connected to the main plant steam system and provides a portion of this demand.

Solar Energy System

The solar collector field uses Solar Kinetics Inc. (SKI) T-700 parabolic trough concentrators. There are 12 rows of collectors installed at ground level with their tracking axes aligned in the east-west direction. The total collector aperture area is 936.5 m^2 (10,080 ft^2) and the rows are spaced 4.88 m (16 ft) apart giving a packing factor of 0.43.

The field consists of 72 collector modules each having an aperture width of 2.13 m (7 ft.) and length of 6.1 m (20 ft). Six modules are connected together to form a 36.6 m (120 ft) drive string. There are 12 drive strings, each positioned for tracking by a hydraulic drive system commanded by a signal from the shadow band detector located on the string.

The receiver tubes of the drive strings are connected in parallel. This makes the six-module units delta-T strings also since the full temperature rise occurs across each row.

The working fluid used in this system in Texatherm, an oil based high temperature heat transfer fluid. It is pumped at a constant flow rate of 6.18 x 10^{-3} m^3/s (98 gpm) during operation and 2.02 x 10^{-3} m^3/s (32 gpm) during start-up reaching a maximum temperature of 228°C (442°F) during peak operating conditions when the field inlet temperature is 195°C (383°F).

Heated Texatherm goes to the solar steam generator where it transfers heat to feedwater converting it to steam. The steam generator is bypassed during initial start-up. A heat exchanger is included in the feedwater loop to recapture some of the energy lost during blow-down. There is no thermal energy storage included in the system. A schematic of the solar energy system is shown on Figure 7-2 and its design characteristics are summarized in Table 7-1.

Interface -- Steam at 1207 kPa (gage)/191°C (175 psig/375°F) is fed from the solar steam generator directly into the plant's main steam line which is supplied by existing fossil fuel boilers. The maximum design steam flow rate is 816 kg/h (1800 lb/hr). Condensate return from the plant and make-up water are deaerated and fed to both the solar steam generator and the fossil fuel boilers. The feedwater enters the solar steam generator at 104°C (220°F).

Process Utilization -- Steam is used for five refinery steam demands; process, atomizing, power turbines, miscellaneous heating, and tank heating with a year-round demand of from 13,608 kg/h (30,000 lb/h) to 18,144 kg/h (40,000 lb/h). Since the demand in the refinery industry remains high all year, and runs 24 hours per day, all week long, all solar energy produced can be used. The solar energy system will produce the equivalent of 107.6×10^3 m^3 (3.8×10^6 ft^3) of natural gas or 90 m^3 (23,789 gallons) of fuel oil and reduce plant use of fossil fuels by that amount.

Collectors -- The solar collectors used in this project are Solar Kinetics model T-700 concentrators. Their characteristics and performance are described in Appendix A.

Main Circulating Pumps -- The main collector circulating pumps used are Viking heavy-duty positive displacement pumps, one for normal running and a second, higher-pressure pump for start-up. The two pumps are 7-1/2 horsepower each. Both have high-temperature mechanical seals to prevent oil leakage, and built-in adjustable high-pressure relief valves.

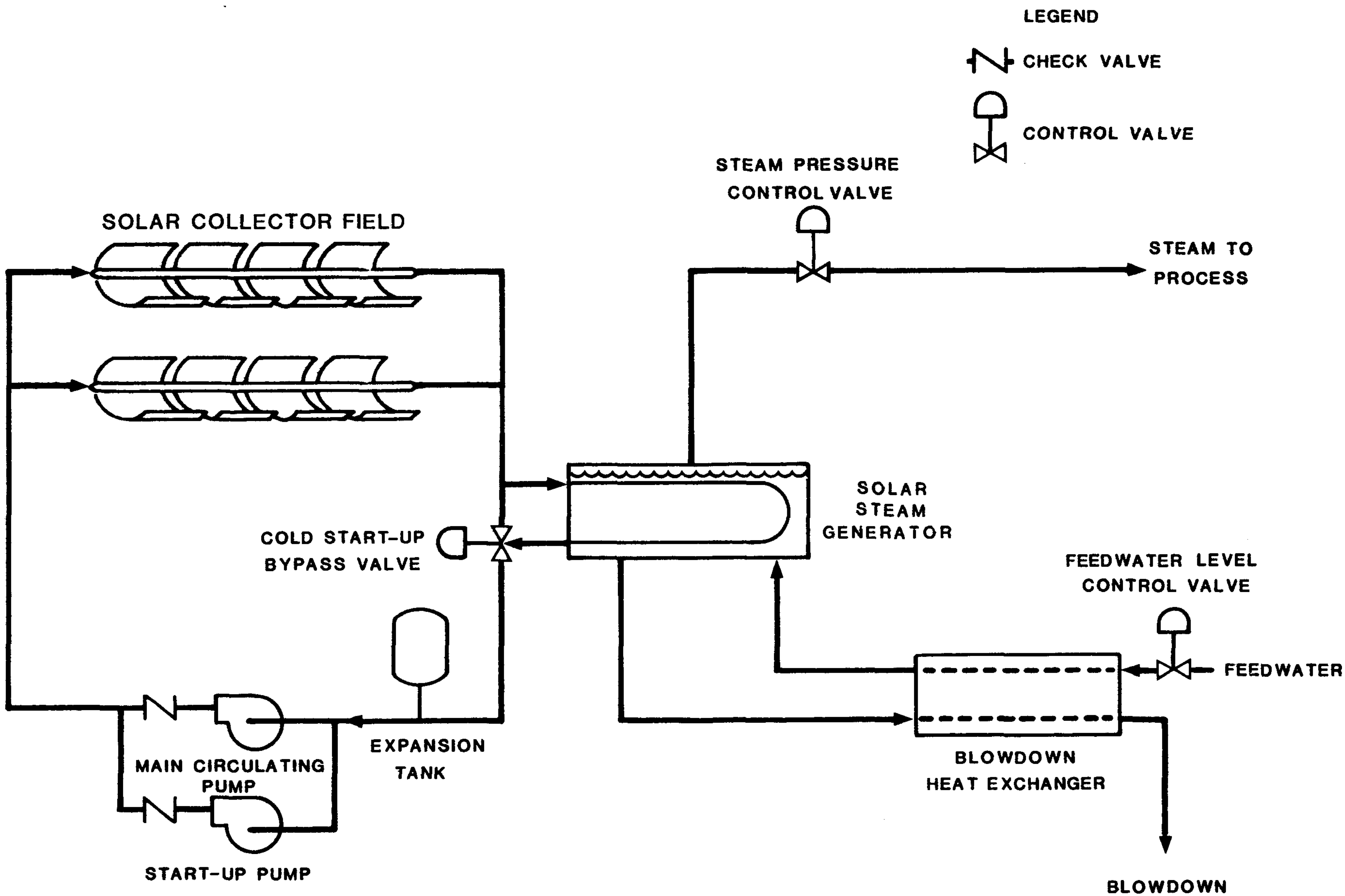

Figure 7-2. Flow Diagram for the Southern Union Refining Company, Lovington, New Mexico

Table 7-1

Southern Union Refining Co.
Solar Energy System Characteristics

General	
Site:	Lovington, New Mexico
Demand:	Steam at 1207 kPa (gage)/192°C (175 psig/378°F); 816 kg/h (1800 lb/h) max
Collector	
Type:	Solar Kinetics T-700 parabolic trough
Area:	936.5 m^2 (10,080 ft^2)
Mounting:	Ground-mounted, E-W orientation arrayed in 12 rows
Mirror Module:	Aluminized acrylic film (3M FEK 244) on aluminum face sheet
Receiver Tube:	41.3 mm (1-5/8 in) OD carbon steel tube plated with black chrome; covered by 63 mm (2-1/2 in.) Pyrex glass tube
Solar Tracking:	Shadow band sensor, hydraulic tracking drive
Working Fluid	
Type:	Texatherm; (Texaco)
Control:	Constant flow rate
Flow Rate:	6.18×10^{-3} m^3/s (98 gpm)
Outlet Temperature:	228°C (442°F) (maximum)
System	
Interface:	Hot Texatherm boils water in steam generator to steam for main plant steam line.
Process Schedule:	General refinery operations; 24-hr operation, 7 days/wk, 50 wk/yr
Auxiliary Fuel:	Natural gas
Thermal Storage:	None
Design Energy Delivery:	528 kW (1.8×10^6 Btu/hr) max; 3466 GJ/yr (3.28×10^9 Btu/yr) or 10% of refinery minimum energy requirement/yr SOLIPH model estimate: 2019 GJ/yr (1.91×10^9) Btu/yr)

Controls -- The control system consists of light detectors, pressure and temperature sensors, water level sensors, weather warning, flow sensors that activate the hydraulic tracking devices, one- to three-way temperature control valves, a steam flow meter and recorder, and blowdown and relief valves. The electric line power is backed up by a battery system, which is kept charged automatically.

Steam is controlled by the steam pressure control valve which varies the flow through the steam generator while keeping oil flowing constant through the solar collectors. The temperature in the generator is controlled at a minimum of 191°C (375°F) to maintain steam generation. When the solar collector working fluid drops below this level, the working fluid bypasses the steam generator until the collectors again achieve the minimum temperature. In addition to this bypass, the steam generator is bypassed for the start-up of the system to reduce differential pressure and start-up parasitic energy use.

The collectors are operated by a hydraulic drive system controlled by a shadow band tracker. The system contains several three-way electrical solenoid valves and a servo amplifier. Limit switches are mounted on the collectors to protect the system. A stow relay operates to position the collectors when the system shuts down.

A dc electrical system is used as backup for emergency stow. Fluid overtemperature is prevented by controls that automatically stow when this condition occurs.

Data Acquisition System -- The data acquisition system consists of a data logger, a cassette tape recorder to store raw data, and, onsite, an Acurex Autodata 10 minicomputer for data reduction and communication with the offsite computer system. Signals that are received by the data logger include those from sensors for temperature, insolation, wind speed, flow, pressure, and electric power.

The instrumentation system works with the controls to provide information for proper operation. Visually available data include main steam pressure and flow, steam generator oil flow, oil inlet and outlet temperatures for the collector and the steam generator, and steam generator feedwater and steam outlet temperatures.

The DAS has the capability to reduce and to display data onsite and interfaces with a computer at Energetics. In addition to values required for system performance evaluation, the DAS was planned to measure heat exchanger performance, efficiencies of the array (before and after cleaning) and long-term performance characteristics, such as pointing and system thermal degradation.

FY82 Progress

Final construction and inspection was in process at the beginning of FY82. The acceptance test was completed on January 22, 1982, and Phase III (operation) began.

Early February was devoted to completing the interface between the onsite minicomputer and the Energetics computer, which was used to reduce data from the tapes generated at the site. Also during February a number of receiver tubes were leaking oil. The field was mapped to identify the leaks. Some operation took place in February, but no data were produced. Personnel training for Southern Union was also begun.

Between March 1 and September 30, Southern Union's project operated and produced 7 months of performance data. However, because of equipment problems the system operated only 126 days out of a possible 237. Southern Union experienced many of the same operational problems encountered at other IPH projects that used the SKI T-700 collector.

Primary system problems included the following:

- Tracking and focusing
- Hydraulic drives
- Oil leakage

- Glass receiver tube breakage
- DAS

The primary problems identified for the project began almost with the opening of Phase III. In February, leakage of oil and receiver tube glass breakage were identified as significant problems.

In March, data averaging problems with the DAS were corrected, the pyrheliometer sensor was moved, a mechanical seal in the main Viking pump was replaced, an overtemperature and smoke detector device connected to an alarm in the main plant was installed, debugging of sensors and software was completed, and glass was replaced throughout the system.

The DAS averaging problem was resolved in April by a modification to the computer program. Efficiencies during this early period were 30% to 40% from a collector system predicted to perform at better than 50%. In response to this information, SKI personnel checked the system to determine possible causes.

Maintenance down time reduced available days of operation during April and May. In addition, in May, the drive module on the row of collectors to which the pyranometer was attached failed. More glass breakage was discovered in May. SKI was notified that the amount of glass breakage was significant, and they agreed to send representatives to the site.

June was a month of poor weather and limited operation. SKI personnel onsite repaired the defective drive modules and replaced broken glass on the receiver tubes. SKI personnel returned in July. By that month, erratic behavior of the hydraulic drive modules had increased; four units were inoperative, and two operated sporadically. There was more glass breakage also.

Few data were generated in August because of hydraulic drive problems. The fiscal year closed with unresolved reliability and DAS problems but with the system up and producing steam.

Data Presentation and Analysis

Monthly Performance

The solar energy system at the Southern Union Famariss Refinery was in Phase III for 8 months during FY82, from January 22 to September 30. Operational status was achieved in February, but no data were recorded. The first documented performance took place in March 1982. Six additional months reported measurable performance, for a total of 7 months of data. Figures 7-3 through 7-9 present graphically the data during these 7 months.

A summary of the monthly performance data and total performance for the fiscal year are presented in Table 7-2. The energy delivered over the entire 7-month period totaled 156 GJ (148 MBtu). The predicted yearly annual delivery was 3466 GJ/yr (3285 MBtu).

Clear Day Performance

Clear day performance of the Southern Union project provides a meaningful measure of the potential of the system. There was a complete clear day report for each of the data recording months.

Clear day performance for March and September (Figures 7-10 and 7-11) are typical. Peak collector thermal output was predicted to be 0.352 MW (1.2 MBtu/h). For April it was 0.404 GJ/h (1.38 MBtu/hr). The average collector field efficiency was 37.5%, and the average system efficiency was 30.8%. The noontime rate of energy delivered ranges from 0.196 MW (0.67 MBtu/hr) in August to a high of 0.44 MW (1.4 MBtu/hr) in April. Total daily insolation in the plane of the collector for a day ranged from as low as 13.4 GJ (12.7 MBtu) on the clear day for May to 19.6 GJ (18.6 MBtu) for the clear day in April.

System Performance Prediction

The SOLIPH system performance computer model developed by the Solar Energy Research Institute (SERI) was used to predict the performance of the Southern Union Refining Co. solar energy system. System

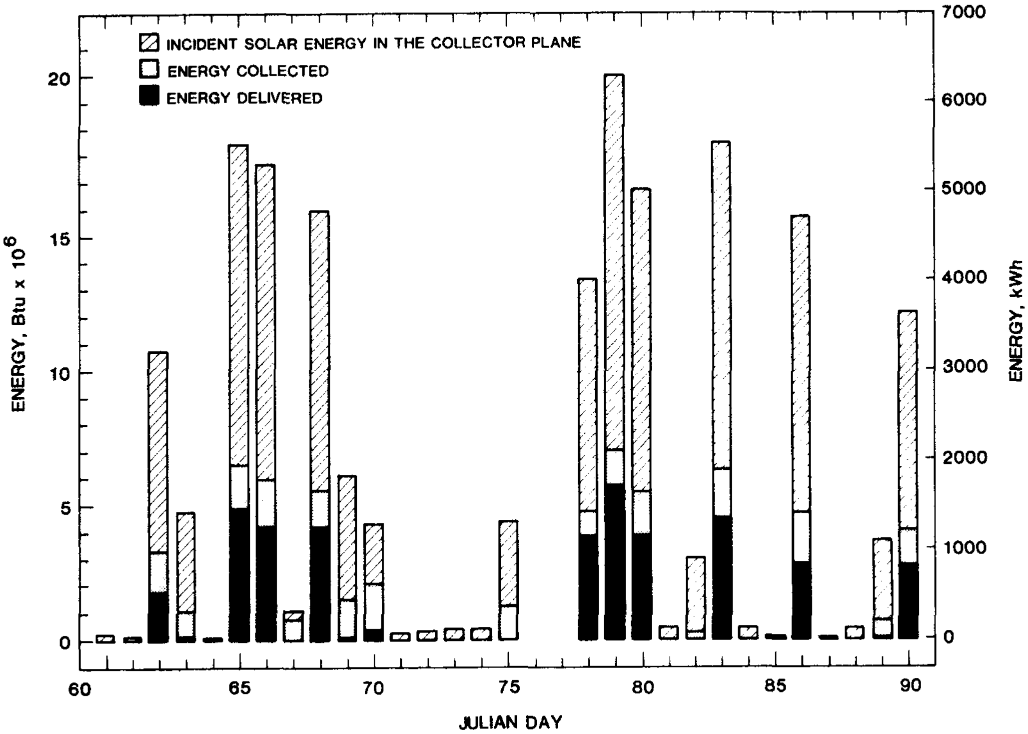

Figure 7-3. Performance for March 1982

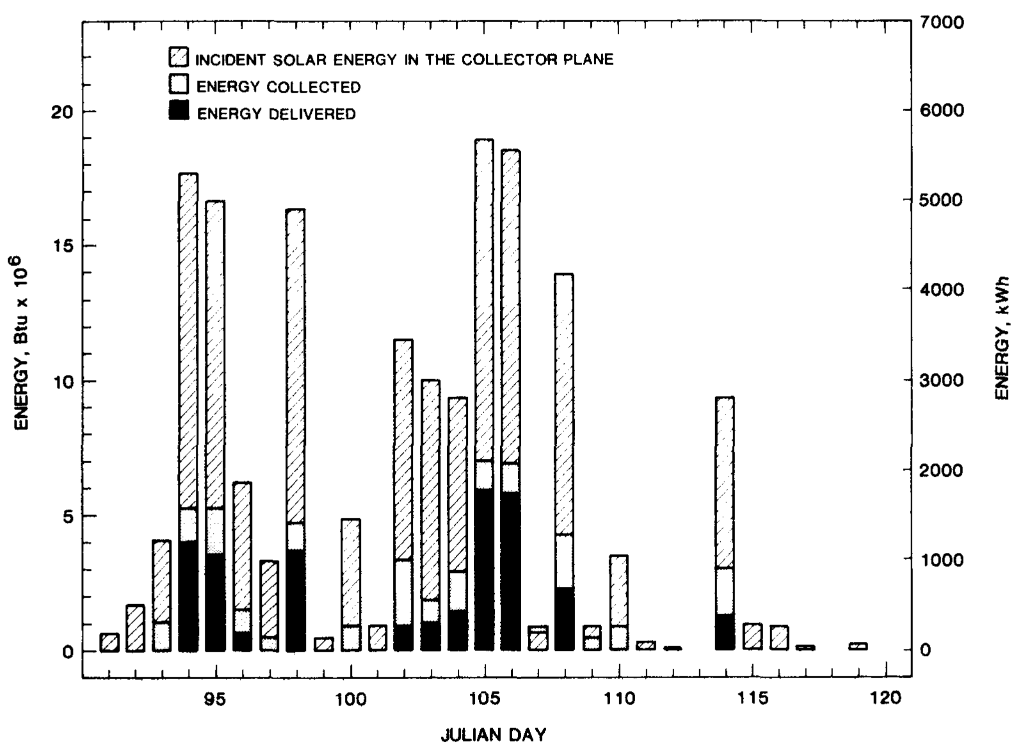

Figure 7-4. Performance for April 1982

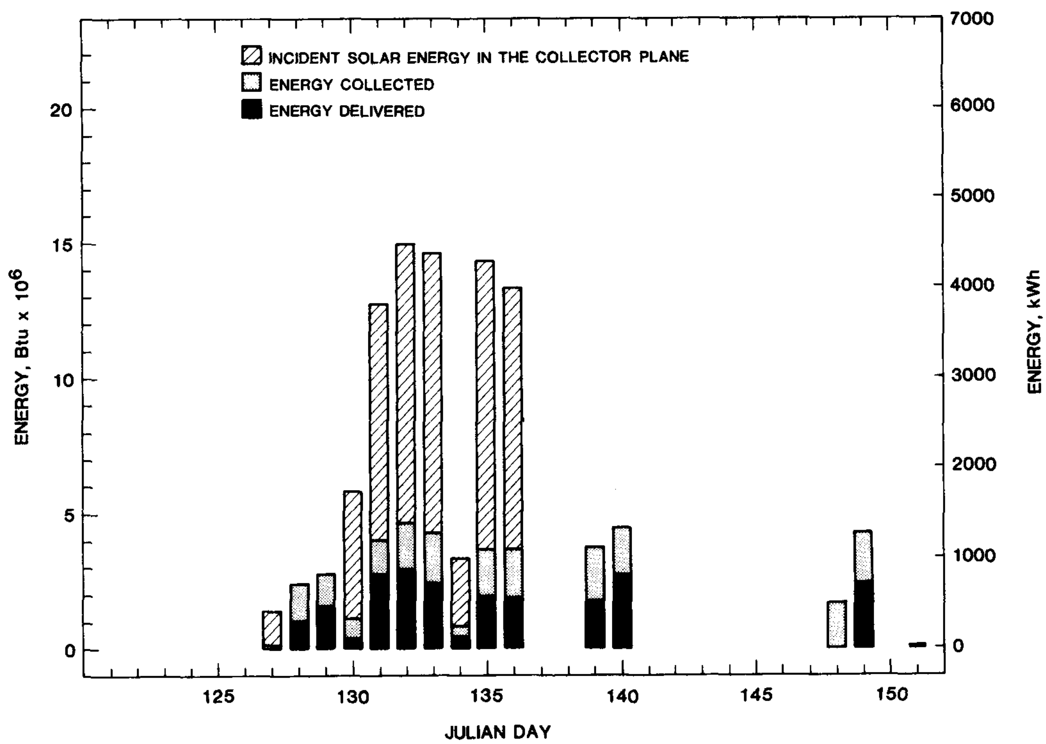

Figure 7-5. Performance for May 1982

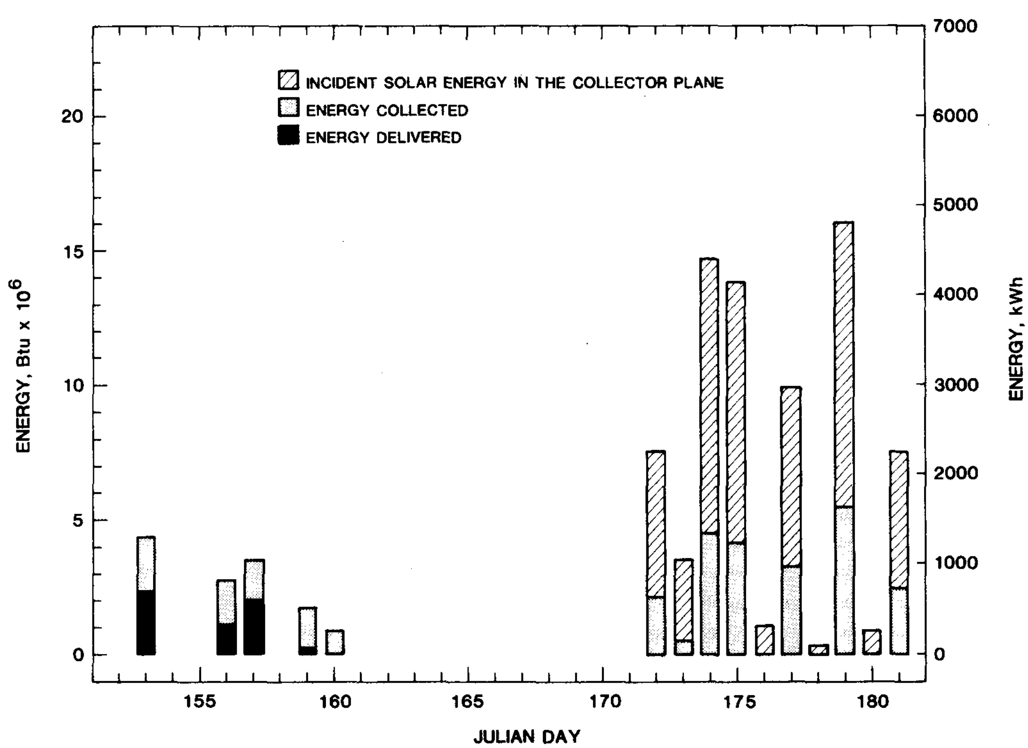

Figure 7-6. Performance for June 1982

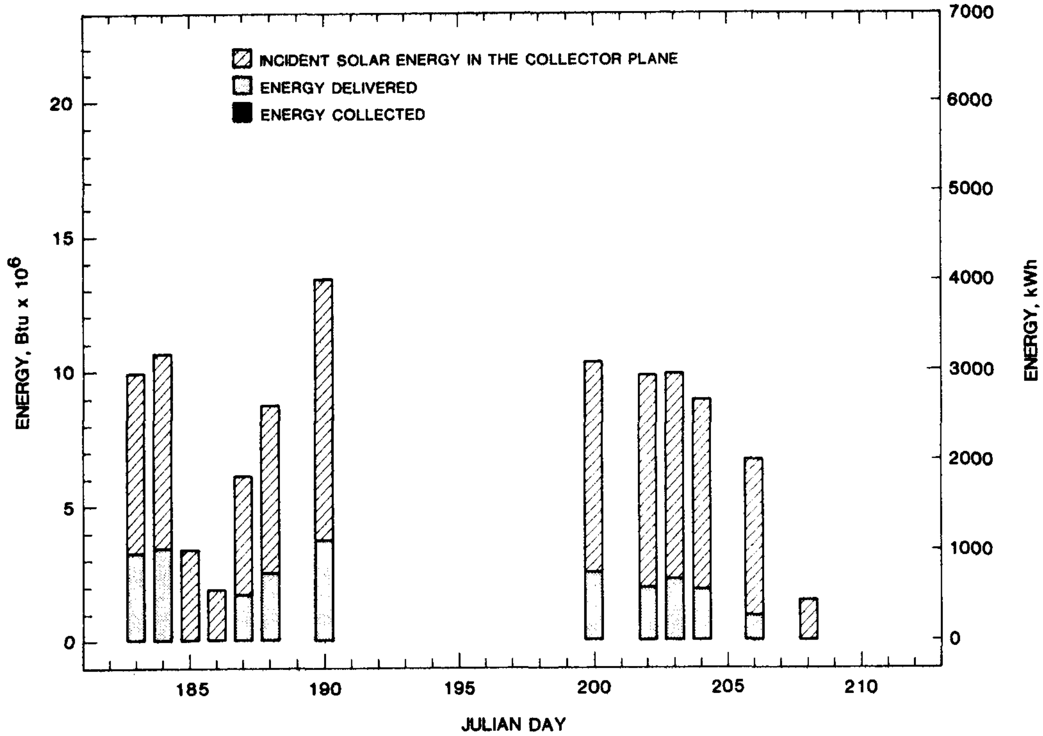

Figure 7-7. Performance for July 1982

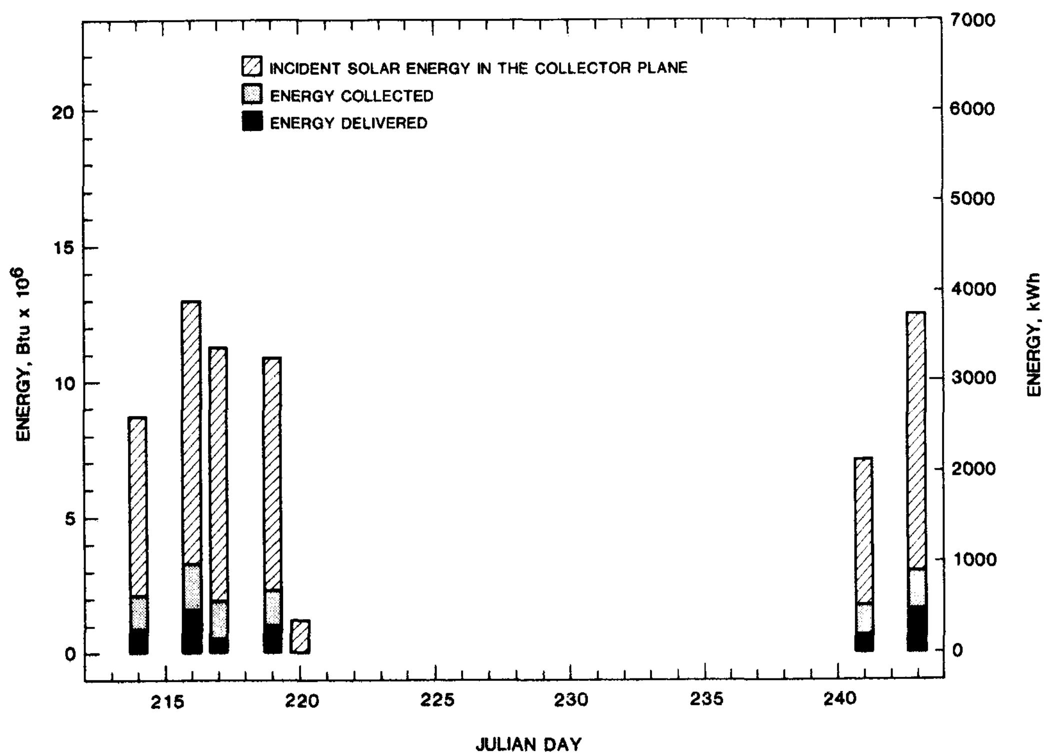

Figure 7-8. Performance for August 1982

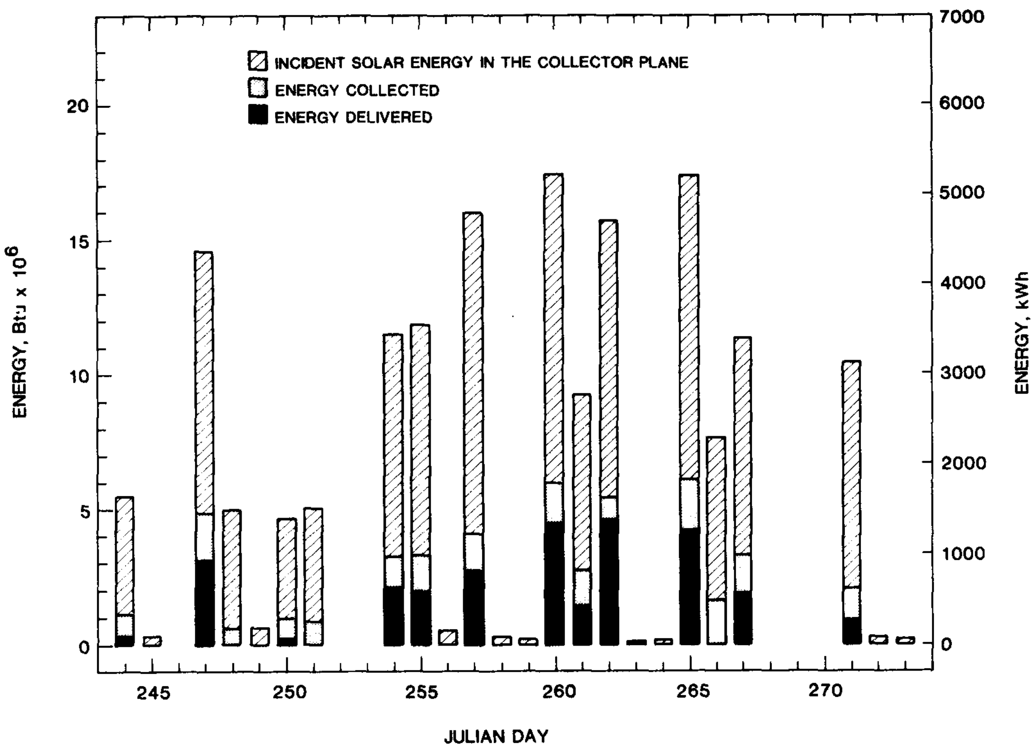

Figure 7-9. Performance for September 1982

performance in this instance means the amount of thermal energy delivered to the process for a certain amount of solar input. The model utilizes hourly insolation data for a typical meteorological year (TMY) as monitored at Roswell, New Mexico, and collector performance characteristics obtained from module test data modified for average dust build-up. Both the rate of heat loss and the thermal capacity of pipes, supports, fittings, valves and flex hoses are modeled. System control functions are modeled on an hour-by-hour basis.

Predictions of the amount of energy delivered by the system on a March clear day (the 29th) from the TMY data set are shown in Figure 7-12. The measured amount of energy delivered to the Southern Union main steam line on March 20, 1982 is shown for comparison. The data have been adjusted for time and a slight difference in the total amount of insolation between the two days.

Table 7-2

Southern Union Refining Co. Monthly Performance

Date (Month/ Year)	Number of Days Data Recorded	Number of Days Solar System Operated[a]	Available Insolation in the Collector Plane kWh	(Btu x 10^6)	Energy Delivered kWh	(Btu x 10^6)	Parasitic Energy Used kWh	(Btu x 10^6)	System Thermal Efficiency[b] (%)	Fossil Fuel Displaced[c] -- BBL's oil	(ft^3 x 10^3 gas)	Comments
1/82												Acceptance Test completed 1/22/82
2/82												Initial operation; no data recorded, problems with feedwater valve and DAS
3/82	26	17	55,776	(190.309)	11,594	(39.560)	1,609	(5.49)	20.8	10.69	(55.37)	Five days data lost due to no operator and DAS failure
4/82	23	11	50,599	(172.645)	8,905	(30.382)	2,342	(7.99)	17.6	7.48	(38.74)	Feedwater and steam line check valves malfunction
5/82	15	13	23,200	(79.158)	6,528	(22.197)	1,565	(5.34)	15.2[d]	5.62	(29.09)	Microprocessor failed 5/22; collector control and drive problems; collector sprayed with oil
6/82	18	9	13,497	(76.051)	1,680	(5.733)	1,249	(4.26)	d	e	(e)	Hydraulic drive unit problems, Row 6W down
7/82	18	11	29,699	(100.99)	4,751	(16.21)	1,093	(3.73)	e	e	(e)	Problems with drive units persist, awaiting repairs
8/82	e	7	18,989	(64.79)	1,840	(6.277)	756	(2.58)	9.7	1.37	(7.09)	Drive unit problems continue, SKI repairs units, system down 8/8-28
9/82	26	13	49,170	(167.767)	8,197	(27.967)	1,627	(5.55)	16.7	7.23	(37.48)	Collector operation problems; weather poor
Total	126	81	240,930	851.71	43,495	148.326	10,241	34.94		32.39	167.77	
Average									17.0			

a - Does not include days solar system idled

b - Calculated using the formula: $\frac{\text{Energy Delivered}}{\text{Insolation in the Collector Plane}}$

c - Calculated using the formula: $\frac{\text{Energy Delivered - Parasitic Energy}}{\text{Combustion Efficiency Factor of 70\%}}$ x Conversion Factor

d - Efficiency data not available or incorrect due to row 6W inoperability

e - Data not available

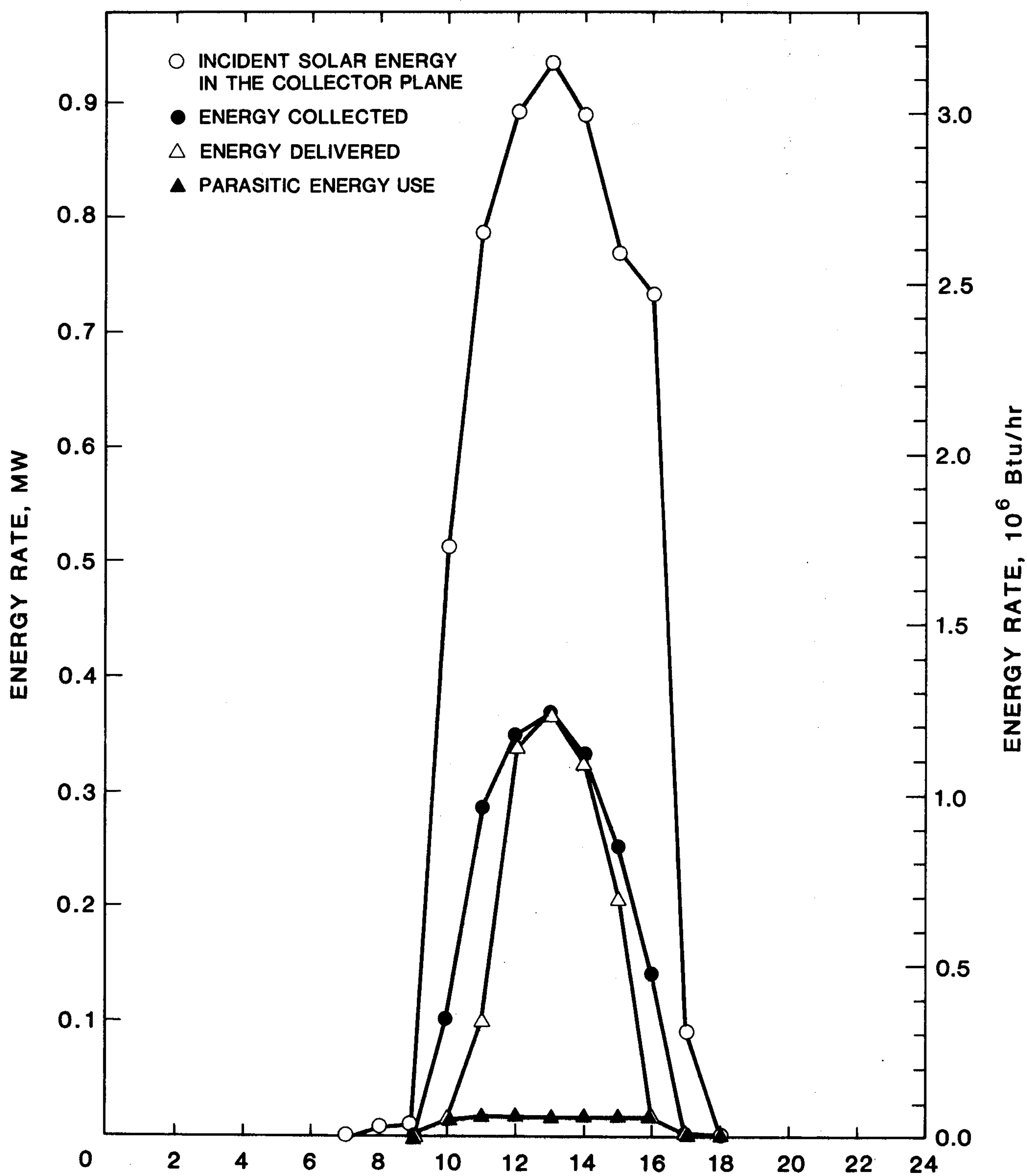

Figure 7-10. Clear Day Performance - March 20, 1982

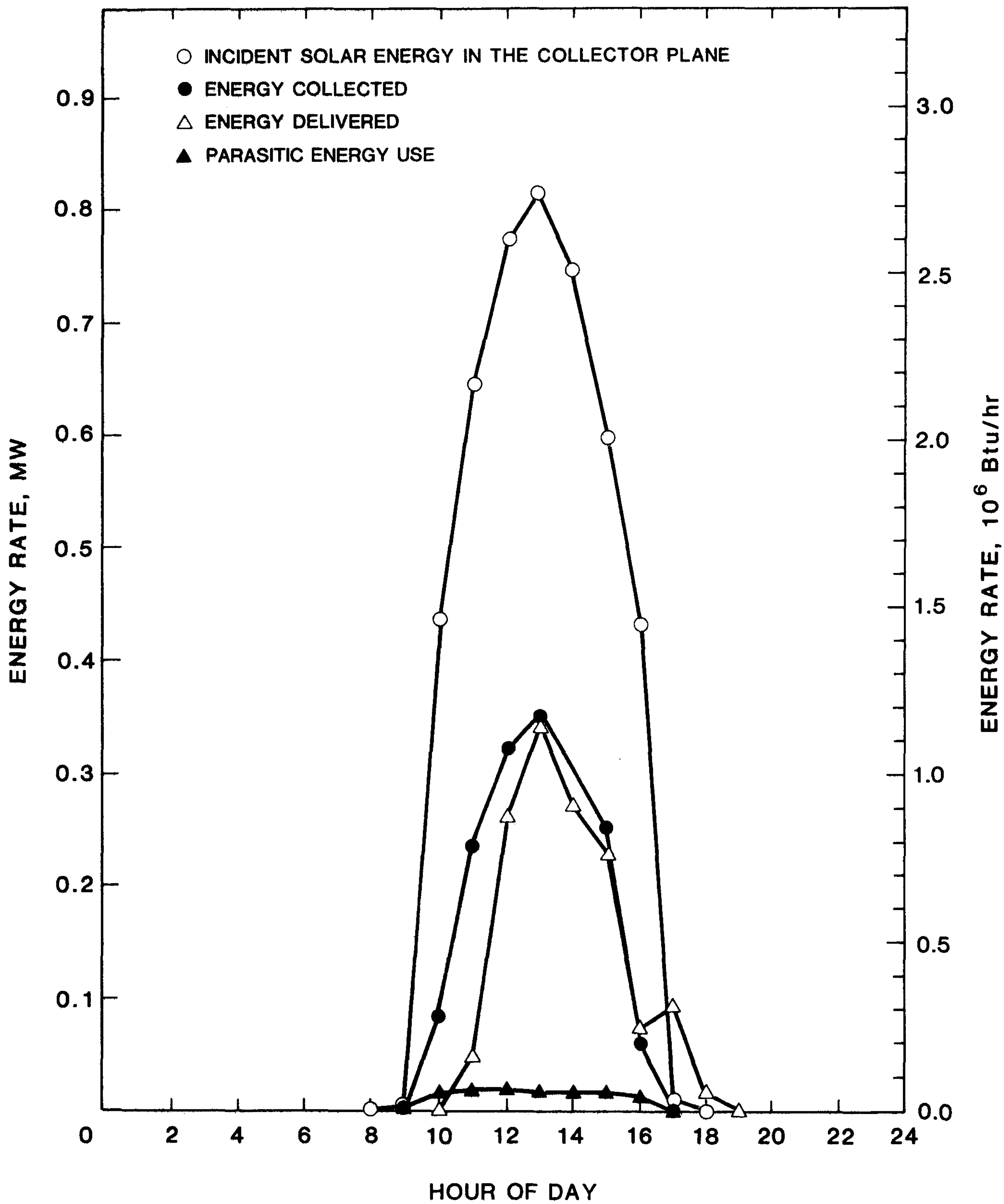

Figure 7-11. Clear Day Performance - September 18, 1982

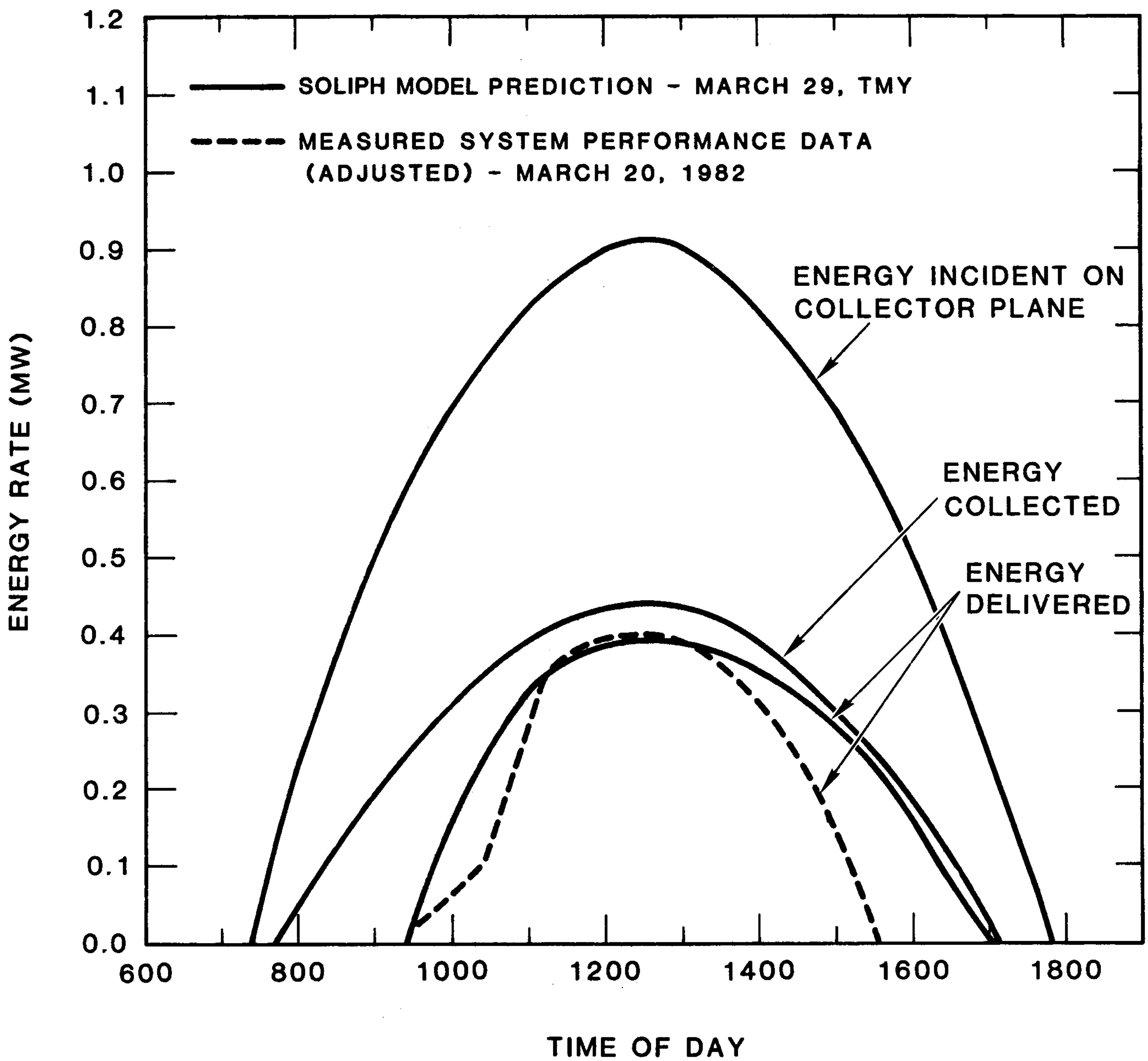

Figure 7-12. SOLIPH Model Performance Predictions Compared With Actual Performance--Southern Union Refining Co.

The amount of energy predicted by the SOLIPH model is 35% greater than that actually delivered. It is assumed that the differences lie either in inaccuracies in the SOLIPH model or an early degradation of the collector or system performance. Work is continuing to identify these problems. When completed, the model will provide a valuable tool for monitoring system performance and for future system designs.

Operations and Maintenance

Operations and maintenance costs were much higher than expected because of early equipment problems. Maintenance activities from June through September required 23 man days and cost $2800 (Table 7-3).

Future Plans

Construction of the system was completed in January 1982. It is in the operational phase with the current contract scheduled for completion in April 1984. The contract has been revised to upgrade the system by modifying the hydraulic drives, modifying receiver supports to correct glass breakage problems, replacing flex hoses to prevent oil leaks, and changing piping to reduce thermal losses, and to provide spare parts.

Table 7-3

Operation and Maintenance Data

Activity	Man Days	Estimated Cost
June, 1982		
(1) Washed Collectors	2	$ 160
July, 1982		
(1) Cleaned float on feed water control valve	1/2	80
(2) Cleaned exterior surface of glass receiver	2	160
(3) Reinstalled vortex shedding flow meter	1	80
August, 1982		
(1) Repairs begun on 3 collector drive units	1	80
(2) Troubleshooting by SKI (3 men x 3.5 days)	10.5	1680
September, 1982		
(1) Electric steam valve repair	2	240
(2) Repair collector drive unit	3	240
(3) Cleaning of collectors and receiver tubes	1	80
Total	23	$2800

8. U.S.S. CHEMICAL COMPANY

HAVERHILL, OHIO

The Industrial Process Heat project at the United States Steel Chemical Company Plant at Haverhill, Ohio provides steam for processes in the production of phenol. The project was funded under joint agreement among the Columbia Gas Service System Corporation, the U.S. Department of Energy and the U.S.S. Chemicals Division of United States Steel Corporation. Figure 8-1 shows the solar collector array at U.S.S. Chemical Co.

The Design Phase began in September, 1979, and construction was completed in January, 1982. The solar energy system has operated in a shakedown mode by Columbia Gas and U.S.S. Chemical Co. during the period February through April 1982. The acceptance test was conducted in May 1982, and the system became operational in June 1982.

Description

Plant Description

The U.S.S. Chemical, Haverhill facility is a major producer of hydrocarbon derived chemicals and uses steam at 3000, 1034 and 345 kPa (450, 150 and 50 psig) to provide reaction energy for many different processes. Steam produced by the solar energy system is currently utilized in the facility's phenol plants. Most of the process steam at the Haverhill facility is generated by steam boilers primarily fired with natural gas although portions of the plant's total steam requirements can be produced with oil and coal.

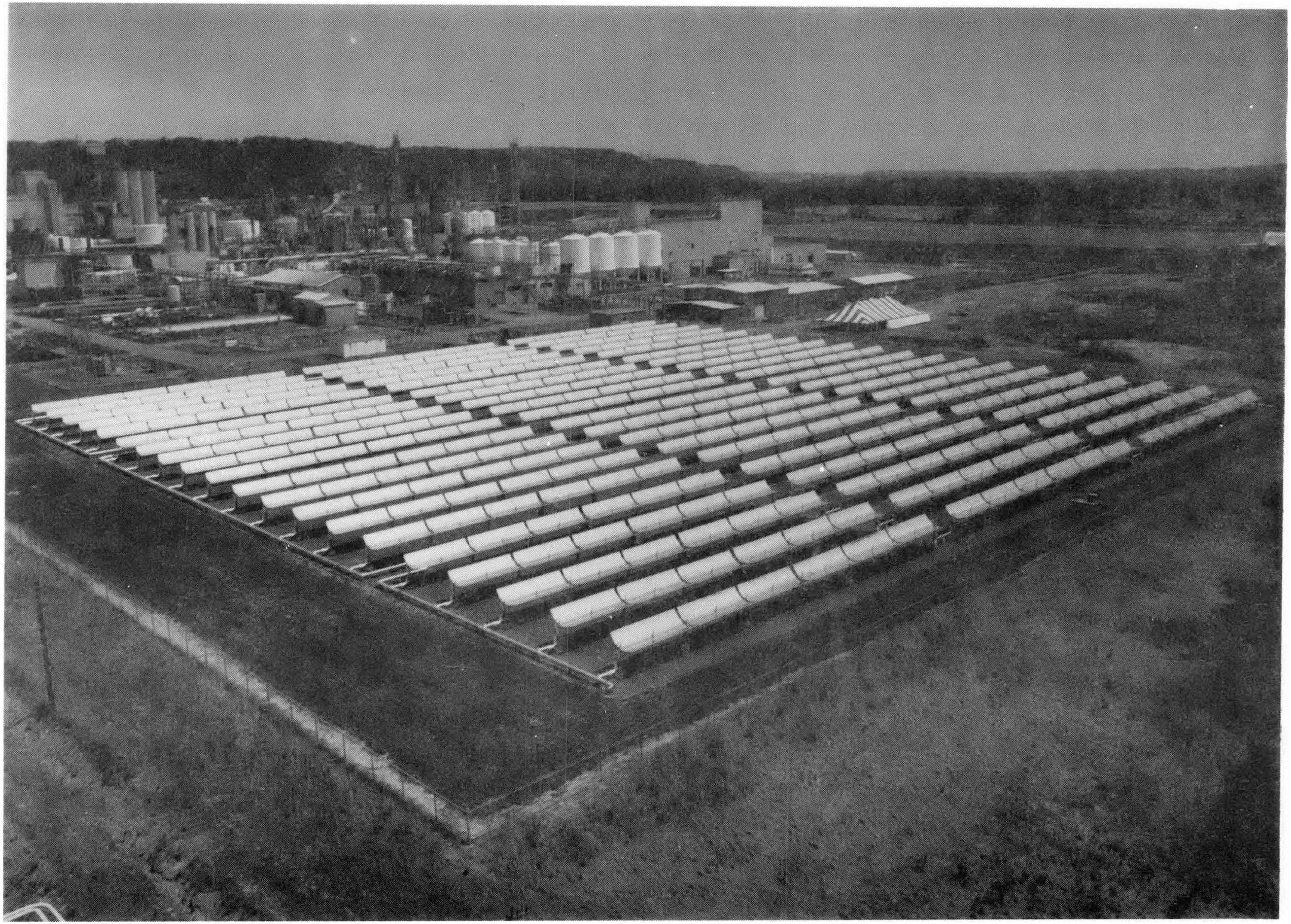

Figure 8-1. Solar Collector Array at U.S.S. Chemical Company, Haverhill, Ohio

Solar Energy System

The collector field at Haverhill consists of 60 rows of Solar Kinetics T-700 parabolic trough concentrators having a total field aperture area of 4682.3 m^2 (50,400 ft^2). The collectors are arranged in 3 banks of 20 rows each. The tracking axes of the collectors are oriented along a line running 25 degrees west of north. They are mounted at ground level on a field sloping toward the south at a 1 percent grade. The rows are spaced 6.1 m (20 ft) apart and the three banks are separated by 3.0 m (10 ft) resulting in a packing factor of 0.33.

There are 360 2.13 m (7 ft) by 6.1 m (20 ft) collector modules in the field. Six modules are connected together to form a drive string. A drive string is positioned by a single hydraulic actuator receiving tracking signals from a photo-detector sensor which measures the position of the concentrated beam on the receiver tube. The receiver tubes of three 36.6 m (120 ft) long drive strings are connected in series for each delta-T string. The receiver tubes of 20 delta-T strings are connected in parallel between the field exit header and the field return header.

The heat transfer fluid is Therminol 60. It flows through the solar collector field at a constant rate of 20.2 x 10^{-3} m^3/s (320 gpm) and can reach a maximum temperature of 232°C (450°F).

The solar energy system, shown schematically in Figure 8-2, consists of the collector field and a steam generator. Heat transfer fluid is pumped to the collector field by the main circulating pumps. During start-up a bypass valve diverts the flow of heat transfer fluid around the steam generator until the fluid reaches 121°C (250°F). Because the plant demand is large enough to use all solar generated steam, there is no thermal energy storage included in this system. The characteristics of this system are summarized on Table 8-1.

o Interface -- Steam at 379 kPa (55 psig) and 150°C (303°F) is fed directly into the plant's steam header from the solar energy system.

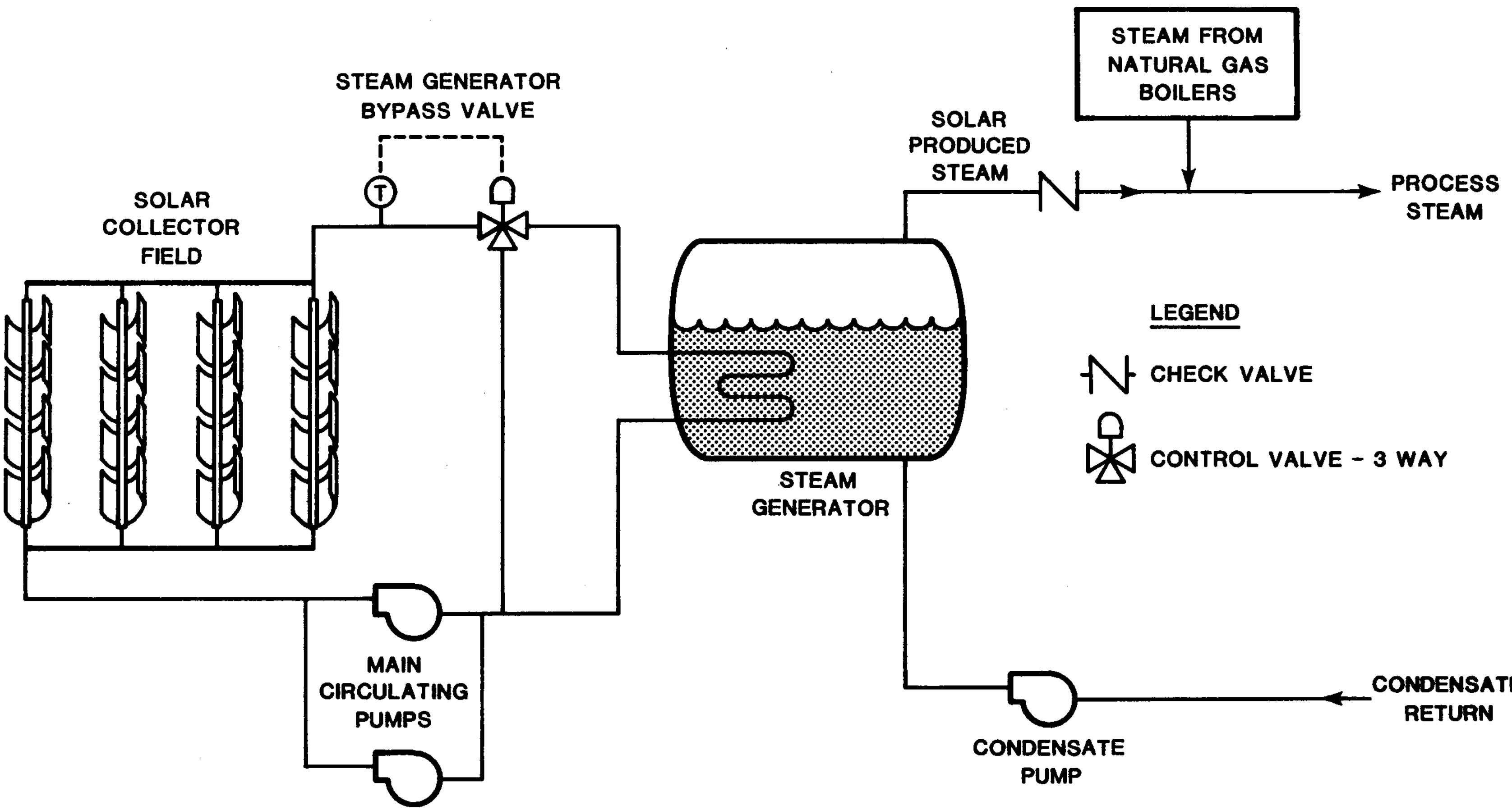

Figure 8-2. Schematic of the Solar Energy System - U.S.S. Chemical Company

Table 8-1

U.S.S. Chemical Co.
Solar Energy System Characteristics

General	
Site:	Haverhill, Ohio
Demand:	Process steam at 380 kPa/150°C (55 psig/303°F); 1.26 kg/s (10,000 lb/hr) max
Collector	
Type:	Solar Kinetics T-700 Parabolic Trough
Area:	4682.3 m^2 (50,400 ft^2)
Mounting:	Ground level; 25° west of North, 1/2° slope to south arrayed in 3 banks of 20 rows each
Mirror Module:	Aluminized acrylic film (3M FEK 244) on aluminum face sheet
Receiver Tube:	41.3 mm (1-5/8 in.) O.D. carbon steel tube plated with black chrome covered by a 63.5 mm (2-1/2 in.) diameter Pyrex tube
Solar Tracking:	Honeywell concentrated flux sensor, hydraulic actuator system positioner
Working Fluid	
Type:	Therminol 60 (Monsanto)
Control:	Constant flow rate
Flow Rate:	20.2×10^{-3} m^3/s (320 gpm)
Outlet Temperature:	232°C (450°F) (maximum)
System	
Interface:	Hot Therminol boils water in steam generator providing steam to plant steam header
Process Schedule:	Phenol plant operations; 24 h/day, year round
Auxiliary Fuel:	Natural gas
Thermal Storage:	None
Design Energy Delivery:	2931 kW (10^7 Btu/hr) max; 8400 GJ/yr (8×10^9 Btu/yr); SOLIPH model estimate: 4330 GJ/yr (4.1×10^9 Btu/yr) or 0.3% of annual plant demand

A check valve prevents backflow when the solar system is not producing steam. Condensate returns from the plant and provides feedwater for the steam generator. The maximum design steam flow rate from the solar boiler is 1.26 kg/s (10,000 lb/hr). Although currently configured to produce 379 kPa/150°C (55 psig/300°F) steam, the system is capable of producing steam up to 1034 kPa/185.5°C (150 psig/366°F).

Process Utilization -- Steam for the phenol trains (phenol processing units) and other chemical trains at U.S.S. Chemical Co. is produced by five natural gas fired boilers rated at 72,576 kg/h (160,000 lb/h) each. The phenol trains operate 24 hours per day, 7 days a week and for 51 weeks per year. Therefore, the additional steam provided by the solar energy system can be used whenever it is available. It is predicted that the solar energy system will provide 8400 GJ/y (8×10^9 Btu/y) or 0.3% of the annual plant demand.

Collectors -- The physical and performance characteristics of the SKI T-700 parabolic trough solar concentrator are described in Appendix A.

Main Circulating Pumps -- There are two 10 hp Dean Brothers main circulating pumps in the system, both capable of producing 18.9×10^{-3} m^3/s (300 gpm) flow. Although capable of simultaneous operation under conditions of high insolation, each pump is normally used individually on alternating months.

Controls -- An automatic control system governs the operation of the solar energy system. A threshold of 299.5 W/m^2 (95 $Btu/hr/ft^2$), sensed by three photo transistors starts the operation. After a 15 minute time delay, the pump is turned on and the collectors are brought out of the stow position and control is passed to a Honeywell Flux Line tracking system. When insolation goes below the threshold value, the system is shut down after a 15 minute time delay. Safety functions stow the collectors during high wind, loss of flow, overpressure, and over-temperature conditions. In case of electrical power loss, each drive string has a hydraulic accumulator to provide emergency stow capability.

Data Acquisition System -- The data acquisition system (DAS) consists of a Hewlett Packard 3052A Automatic Data Acquisition System linked to a HP 9835A programmable desktop computer. Data output and storage is provided by a cartridge tape unit and a printer. Direct normal insolation data are measured by an Eppley pyrheliometer.

FY82 Progress

The beginning of the fiscal year was devoted to the completion of construction. By January 1982, the demand for 1034 kPa (150 psig) steam, planned in the design of the system, no longer existed. New steam loads were studied and it was decided that the solar energy system should be fed into the 345 kPa (50 psig) steam load of the phenol units.

Three months of check-out operation began in February. The solar energy system was operated manually during February. Automatic operation commenced in March. There were few problems during this period. The oil temperatures reached levels above design at 246°C (475°F) and producing 0.55 to 0.62 MPa (80-90 psi) steam. At these temperatures and pressures, no oil leakage was observed. There was leakage from two of the system pumps, and seal replacements did not completely correct the problem. Minor leaks in thermocouple wells were also occurring and installation of the pipe insulation had to be delayed until the problem could be resolved. Some problems in the tracking system were under study during February, with Honeywell personnel at the site assisting in fine tuning the system.

The condensate lines were rerouted in March, shut off valves were installed, and two solar energy system pumps were eliminated by using the main plant high pressure condensate pump. Automatic operational check-out continued in March with steam being produced and vented to the atmosphere.

Pump leakage was corrected during March, but leakage in the thermocouple wells continued. Tightening the fittings stopped this leakage. Tracking problems persisted and Honeywell agreed to return to the site to assist in adjustments and corrections.

In April all of the field operated, except one collector row with minor drive system problems. The final acceptance test took place on May 10, 1982, conducted by Energy Technology Engineering Center. The system performed well in normal, emergency and protective modes. A punch list of items to be corrected was prepared and submitted to Columbia Gas and DOE approved the beginning of Phase III, to follow correction of the punch list items.

Speckling of the receiver tube black chrome surfaces was noted after a few cycles of the solar energy system. In addition, as time passed, more heat transfer fluid leaks occurred. The field was mapped for both conditions in June to assess the size of the problems. The speckling problem was disregarded after tests showed that black chrome optical properties were within specification. Other activities in June included correction of punch list items and sensor recalibration. Some improvements were also made in the DAS software.

Annual plant maintenance occurred in July. Hydraulic drive modules on 2 of the 60 rows began to malfunction during the month. A new steam orifice plate was installed to improve accuracy of the steam flow measurements.

Rudimentary data collection began in August. The system operated 28 days, while work continued on the DAS software and hardware. SKI had repaired or scheduled repair of all the drive module units. Work on the punch list continued throughout August.

During August, 23 receiver tube joints were leaking heat transfer fluid. A problem of collectors striking the support pylons was corrected by lubricating the collector bearing and using magnetic indicators to show critical clearances. Once the critical clearances were determined, pylon positions were adjusted to prevent further occurrence of the problem.

During September the project produced 103,706 kg (228,628 lb) of steam, and the system operated 29 days.

Eight rows were down early in September, but six had been repaired by the end of the month. SKI personnel replaced approximately 120 silicone rubber receiver tube seals and repaired hydraulic drives in November. Silicone rubber O-rings were installed as a temporary measure until a long-life seal material could be qualified.

Data Presentation and Analysis

Although the solar energy system operated throughout the last six months of the fiscal year, problems with the data acquisition system resulted in incomplete data for FY82.

Future Plans

The U.S.S. Chemical solar energy system is scheduled to operate through July 1984 under a cooperative agreement with Columbia Gas.

Since the system began operation there have been problems with oil leaks at the receiver tube joints, with unsatisfactory seals between the receiver tubes and their Pyrex jackets, with the hydraulic drives, with interference between the collectors and their pylons, and with speckling of the black chrome. The receiver tube seal problems and the interference problem were corrected by Solar Kinetics, Inc., the collector manufacturer. Minor hydraulic drive malfunctions will be repaired as necessary. It is anticipated that there may be more major problems with the hydraulic drives and with flex hoses. Therefore, corrective action for both problems may be required. Also, spare parts will be procured to minimize down time during maintenance and repair activities.

APPENDIX A

COLLECTOR CHARACTERISTICS

There are four types of concentrating solar collectors in use in the eight solar IPH projects described in this report. Detailed descriptions of the Solar Kinetics, Inc. T-700 and the Suntec-Hexcel Model SH-1655, which are used in multiple projects, follow. The Power Kinetics and Del-Jacobs collectors, which are used in one project each, are described in Sections 1 and 4, respectively. Table A-1 summarizes the collector usage.

Table A-1

Collectors Used in the IPH Project - FY82

Type	Project Use	Total Aperture Area
Solar Kinetics T-700 Parabolic trough	Caterpiller Tractor	4682 m^2
	Lone Star Brewery	878 m^2
	Southern Union Refining	936 m^2
	U.S.S. Chemical Co.	4682 m^2
Suntec-Hexcel SH-1655 Parabolic trough	Dow Chemical	923 m^2
	Ore-Ida Foods	891 m^2
Jacobs/Del Parabolic trough	Home Laundry	604 m^2
Power Kinetics Point focus Fresnel concentrator	Capitol Concrete	80 m^2

Collector Characteristics

Solar Kinetics, Inc. Model T-700

Description -- The Solar Kinetics model T-700 concentrator is manufactured by Solar Kinetics Incorporated (SKI) of Dallas, Texas. These are single axis tracking parabolic trough concentrators. Each module has an aperture length of 6.1 m (20 ft) and width of 2.13 m (7 ft) and a total effective aperture area of 12.80 m^2 (138 ft^2). A 3.05 m (10 ft) long "half-module" is also available to provide flexibility in field sizing.

The modules are monocoque structures using full width aluminum castings as bulkheads and 4 mm (0.157 in) thick tempered aluminum sheets as the front and back surfaces. The reflective surface is covered with 3M FEK 244, an aluminized, second-surface acrylic sandwich bonded to the face sheet of the module.

The collector has a focal length of 0.56 m (1.83 ft) giving it an f/d ratio of 0.262 and a rim angle of 90 degrees.

The receiver tube is made of carbon steel and plated with black chrome over nickle plating. It is 41.3 mm (1-5/8 in) in diameter. The internal flow passage is smooth and comprises the full inside area. It is covered by a 63.5 mm (2-1/2 in) diameter Pyrex glass tube.

Performance -- The SKI T-700 collector module was tested at Sandia National Laboratories, Albuquerque. The results of these tests are reported in SAND81-0984 (November, 1982). Figure A-1 presenting generalized, noon-time performance for this collector has been taken from that report. The abscissa of this figure is the difference between the average fluid temperature in the receiver tube and ambient temperature, divided by the direct normal insolation.

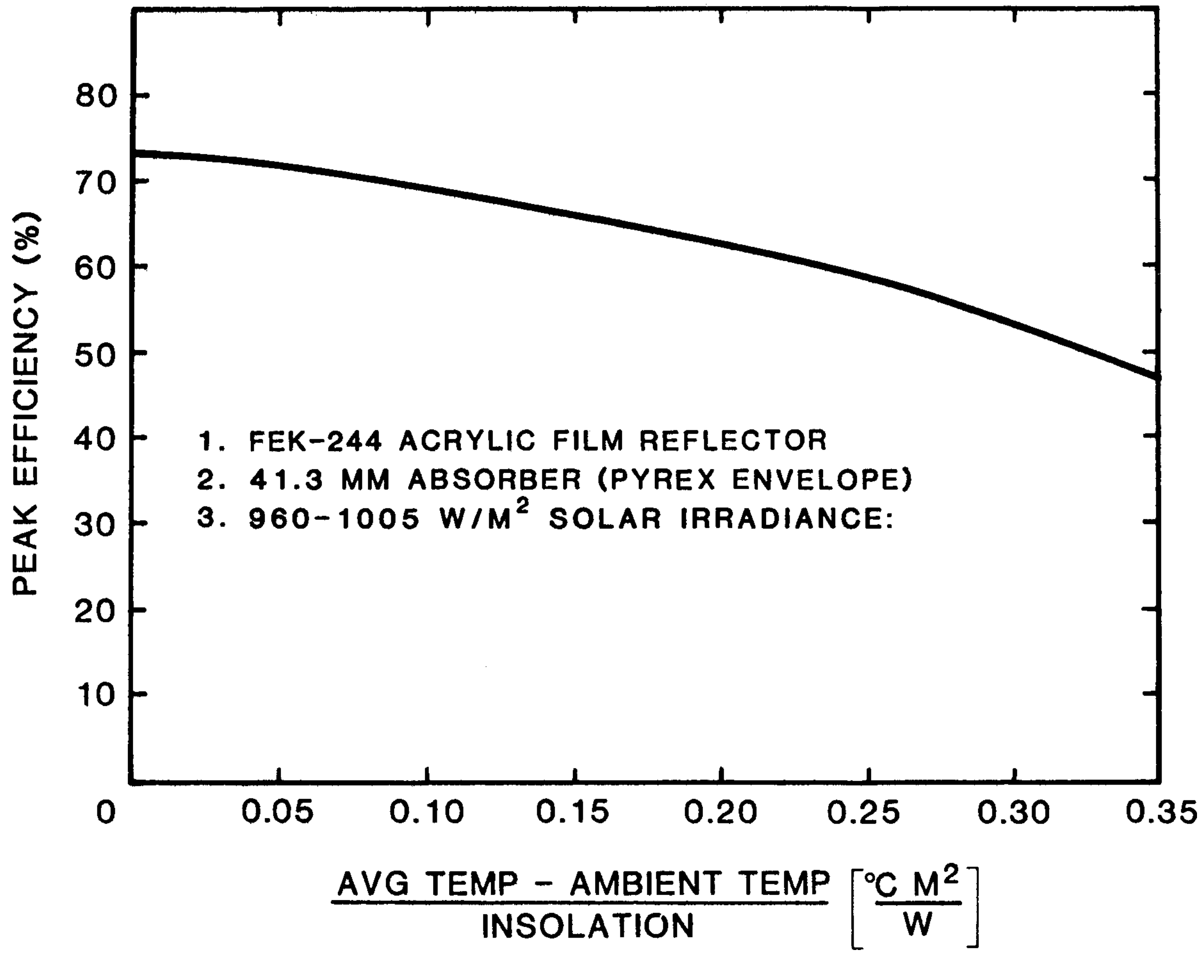

Figure A-1. Generalized Performance of the SKI T-700 Parabolic Trough Concentrator

<u>Suntec-Hexcel Model SH-1655</u>

<u>Description</u> -- The Suntec-Hexcel Model SH-1655 is a single axis tracking parabolic trough concentrator. The aperture of each module is 5.92 m (19.42 ft) long by 2.69 (8.82 ft) wide having an area of 15.91 m^2 (171 ft^2).

The reflective elements of the collector module consist of four panels of aluminum honeycomb having 0.5 mm (.02 in) thick front and back sheets bonded onto 25 mm (1 in) thick honeycomb core and formed into the shape of one-half of a parabola. The panel assemblies are attached to a 6.1 m (20 ft) long torque tube. Each panel is 2.95 m (9.67 ft) long and 1.47 m(4.83 ft) wide. The panels are covered with an aluminized acrylic reflective surface (3M FEK 244) having a spectral reflectance of 82%.

The receiver tube has an annular flow passage, created by centering a plug tube with closed ends, inside of the outer tube. The outer tube is made of 38.1 mm (1.5 in) Schedule 40 carbon steel pipe, rated at 4054 kPa at 271°C (40 atm at 520°F). The annular plug has an outside diameter of 30.1 mm (1.187 in). The receiver tube is coated with black chrome to maximize solar radiation absorption and minimize radiated thermal losses.

The parabolic reflector has a rim angle of 72 degrees and the receiver tube is placed 0.914 m (36 in) from the apex of the parabola. This results in a collector with an f/d ratio of 0.34. The receiver tube is supported along the focal line every 3.05 m (10 ft) by riser weldments.

The receiver tube is enclosed in a housing which insulates and provides structural support for the absorber. Half-cylinder curved glass panels cover the bottom half of the receiver tube facing the parabola. The upper housing forming the other half of the cylinder is made of aluminum and is insulated with fiberglass with polished aluminum on the inside to rereflect radiation back onto the receiver tube.

The receiver tube for the Ore-Ida system is a special modification of the above configuration. The annular flow tube configuration described above is replaced by a single Schedule 80 steel pipe. This pipe has an outside diameter of 31.7 mm (1-1/4 in) and is dark nickel coated.

Performance -- The Suntec-Hexcel Model SH-1655 parabolic trough solar collector was tested at Sandia National Laboratories (SNLA) for peak noon efficiencies. The results of these tests are reported in part, in SAND78-0381 (March 1978). A generalized performance curve for this collector is shown in Figure A-2. T_{avg} is the mean temperature of the fluid in the receiver tube, T_{amb} the ambient temperature and I the direct normal insolation.

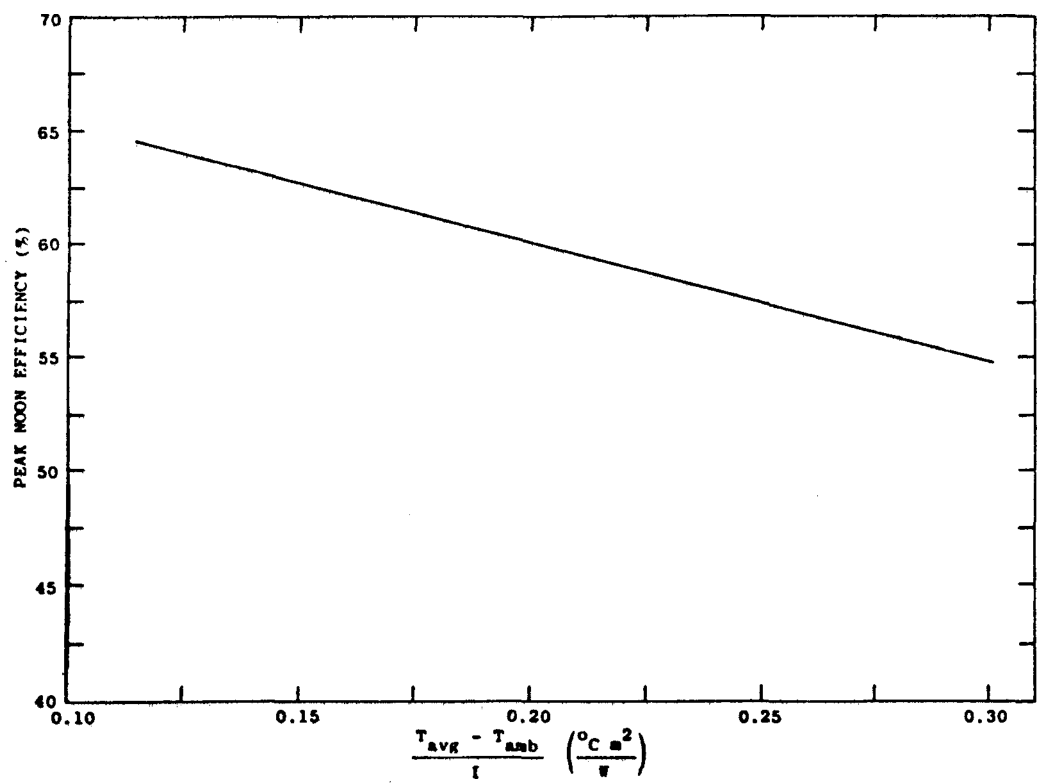

Figure A-2. Generalized Performance of the Suntec-Hexcel SH-1655 Collector