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SOLARIZED TEXTILE DRYING AT WESTPOINT PEPPERELL. PHASE III

Final Report, Covering System Operation December 1978 to June 1979

March 1981

Work Performed Under Contract No. AC05-76CS35124

Honeywell Inc.
Technology Strategy Center
St. Paul, Minnesota

U.S. Department of Energy

Solar Energy

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PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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By

Honeywell Inc.
Technology Strategy Center
1700 West Highway 36
St. Paul, Minnesota 55113

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ABSTRACT

This DOE program has resulted in the installation of a solar energy collection system for providing process heat to a textile drying process. The solar collection subsystem uses 700 square meters (7500 square feet) of parabolic trough, single-axis tracking, concentrating collectors to heat water in a high temperature water (HTW) loop. The solar collectors nominally generate 193°C (380°F) water with the HTW loop at 1.9×10^6 Pa (275 psi). A steam generator is fueled with the HTW and produces 450 kg/hour (1000 pounds per hour) of process steam at the nominal design point conditions. The solar-generated process steam is at 0.5×10^6 Pa (75 psi) and 160°C (321°F). It is predicted that the solar energy system will provide 1.2×10^6 MJ/year (1.1×10^9 Btu/year) to the process. This is 46 percent of the direct insolation available to the collector field during the operational hours (300 days per year) of the Fairfax mill.

The process being solarized is textile drying using can dryers. The can dryers are part of a "slashing" operation in a WestPoint Pepperell mill in Faixfax, Alabama. Over 50 percent of all woven goods are processed through slashers and dried on can dryers.

The collectors were fabricated by Honeywell at a pilot production facility in Minneapolis, Minnesota, under a 3000-square-meter (32,000-square-foot) production run. The collectors and other system components were installed at the site by the Bahnson Service Company and their subcontractors, acting as the project general contractor. System checkout and start-up was conducted. Preliminary system performance was determined from data collected during start-up.

Operation of the system over the first six months after start-up demonstrated improving reliability as the system was initially operated under manual supervision (for three months), then generated low pressure steam under automatic operation. Poor performance of the shadow bar suntrackers limited the range of efficient system operation.

Early in June 1979 gearbox problems were detected and eventually one gearbox failed. The system was shut down to avoid additional gearbox damage. The system currently remains shut down awaiting repair of the collectors and replacement of the shadow bar trackers with a flux line tracker.

ACKNOWLEDGEMENTS

This document reports the activity of Honeywell Inc. and WestPoint Pepperell during Phases I, II, and III of the subject program. The overall program was under the direction of P. D. Mitchell of Honeywell. WestPoint Pepperell support was provided by R. I. Uhl and C. Summers.

Support provided to this program by the Agricultural and Industrial Process Heat Branch, Division of Solar Energy, U. S. Department of Energy and the help provided by William W. Auer, Technical Project Officer, and the Program Consultants, A. Clark, W. C. Dickenson, G. Greyerbiehl, J. Mills, D. E. Randall, and G. W. Treadwell, is acknowledged with sincere thanks.

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SECTION I

INTRODUCTION

1.1 PROGRAM OBJECTIVE

The overall objective of the Application of Solar Energy to Industrial Drying or Dehydration Processes program, under which this Textile Drying project is funded, is to stimulate and give impetus to the growth of industry in areas capable of supplying significant amounts of industrial process heat through the use of solar energy.

The specific objectives of the Textile Drying project were to design, build, install, and evaluate the application of solar energy to textile drying and to provide an analysis of the economic benefits to be gained by such application.

1.2 PHASES OF THE PROGRAM

This document is the Final Report for Phase III of the Textile Drying Project.

Phase I included the process definition, detailed design of the solar energy system, development of specifications and installation blue-prints for the system, and an economic analysis of the solar application.

Phase II included the procurement and assembly of the system components and subsystems, the installation of the system at the MARTEX* towel mill of WestPoint Pepperell at Faixfax, Alabama the system start-up and checkout, and the development of a plan for tests to be conducted in Phase III.

* brand name

Phase III included operation, maintenance and test of the system, repair of the system following leaks and/or failure, collection of system operating data, and evaluation of system performance based on the data collected.

1.3 REFERENCES

The Phase I Final Report, "Textile Drying Using Solarized Cylindrical Can Dryers", documented the detailed design of the solar process steam system at the conclusion of Phase I. Improvements of that design were realized, both prior to and during construction. The Phase II Final Report "Textile Drying Using Solarized Can Dryers to Demonstrate the Applicability of Solar Energy to Industrial Drying or Dehydration Processes", described the detailed design "as built".

1.4 DESIGN SUMMARY

The solar system designed to provide process steam for textile drying consists of five major subsystems:

- The collector field
- The high temperature water (HTW) pipe loop
- The steam generator
- The steam pipe loop
- The process

Figure 1-1 is an illustration of this system combining a simplified system schematic and photographs of the subsystems.

The collector field consists of 24 concentrating trough collectors arranged on the weave room roof to provide 7500 square feet of collector aperture. The collector field is aligned along the building coordinates, and spacing between collector axes is 10 feet 8 inches, which eliminates shadowing from adjacent collectors unless the sun is below 22° elevation.

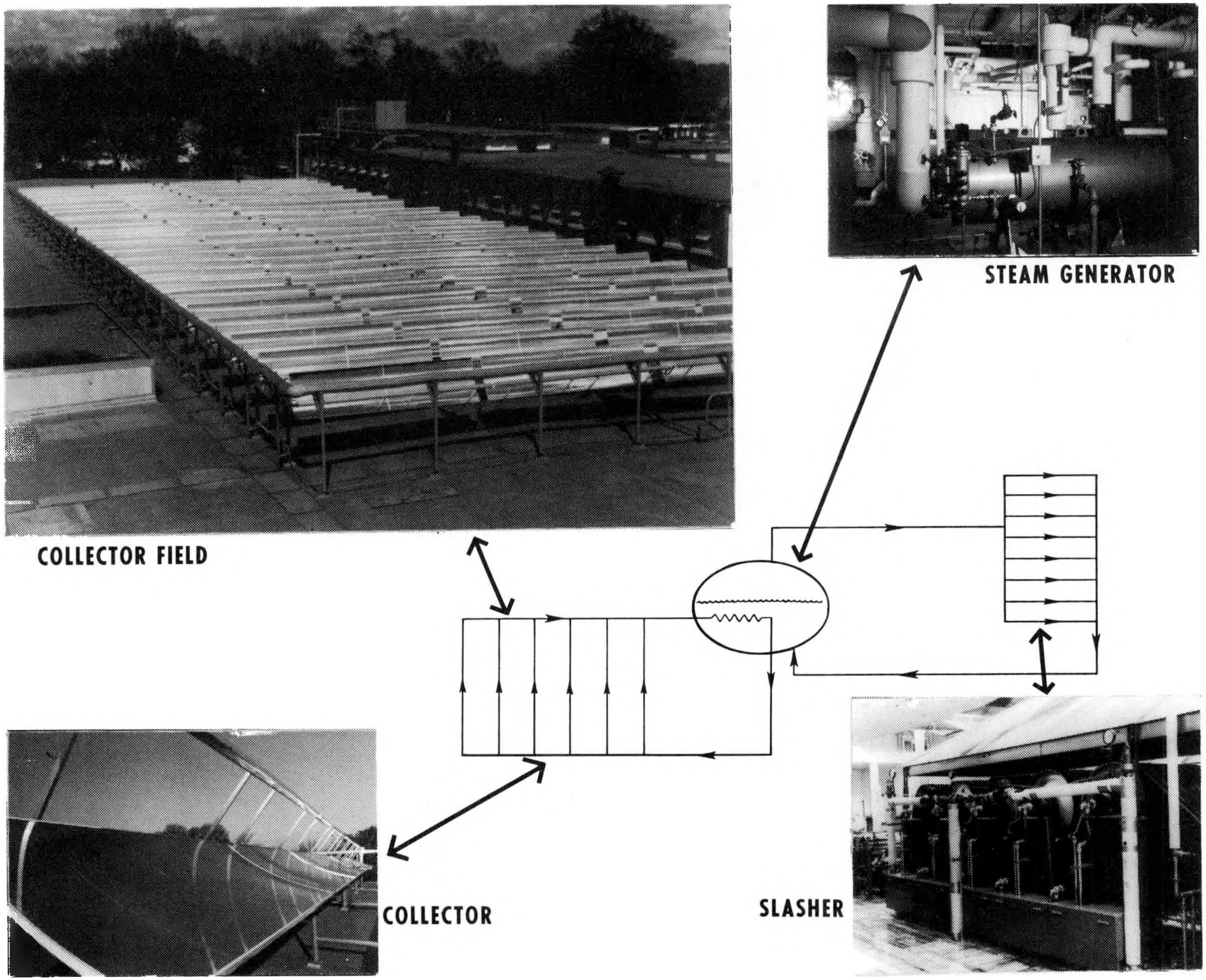

Figure 1-1. System Schematic Illustrated

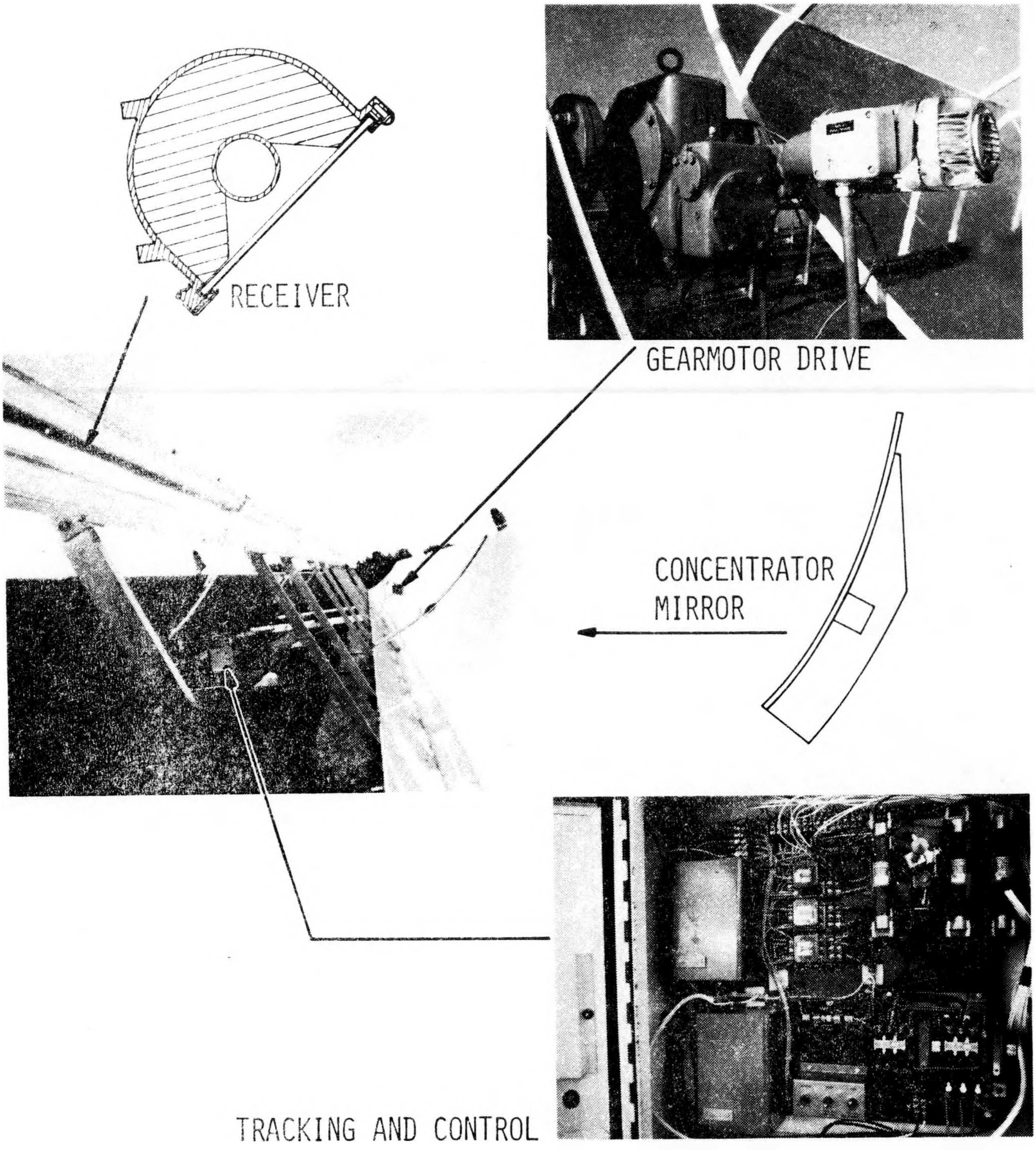

Figure 1-2. Concentrating Collector Components

The collector, illustrated in Figure 1-2, uses a half-parabola mirror concentrator to focus solar energy on an insulated tube receiver. The mirror is constructed of aluminum honeycomb with a reflective surface applied. Four 20-foot by 4.3-foot mirrors per collector result in 313 square feet of active mirror aperture per collector unit. The collector rotates through 270° to allow stowing. A motor/gearbox drives the mirror assembly via a torque tube under control of a sun tracker. The pivot axis is at the middle of the mirror chord to minimize wind loads on the drive system. The receiver/absorber is attached to the mirror drive and rotates with the unit. The receiver uses calcium silicate insulation and an etched soda glass window to reduce thermal losses.

The collector field is under control of the system controller and individual collector controllers. System start-up is initiated by a preset minimum insolation level and maximum wind level. At start-up each collector acquires the sun (points at the sun) and initiates tracking. The collectors track individually throughout the day using a shadow bar tracker. High wind or low light level will cause the system controller to command the collectors to stow. In the stowed position the mirrors look downward to protect the surface from the weather and reduce wind loads on the collector support structure.

The high temperature water (HTW) loop transports the thermal energy to a steam generator and includes the solar receivers. The loop is a closed system pressurized to 275 psi to allow for HTW transport without the formation of vapor (boiling). A supply header feeds the collectors from one edge of the field to form a "C" loop flow pattern. Valves at the collectors are used to balance the flows in the collectors and for isolation the HTW loop is sloped to enhance elimination of air bubbles and contains manual air vents, an air trap, and an air eliminator. A 5-hp pump provides the 48-gpm field flow against a 22-psi head. An expansion tank allows for daily expansion and contraction of the HTW fluid. A water-to-steam package boiler (steam generator) is fueled by the HTW and provides the process steam.

The steam generator is the interface between the HTW loop and the process steam loop. It is a commercially available package boiler that generates 76 psi steam when fueled with 380°F water. Feedwater for the steam generator is taken from a steam condensate tank. The steam generator is located on the weave room roof near the collector field.

The steam loop transports the solar steam from the steam generator into the building and to the process. Steam flow is controlled by a check valve that allows displacement of fossil-fuel-generated steam when solar-generated steam is available. When solar steam is not generated, the existing steam system supplies the process steam. Completing the steam loop is the feedwater line from a condensate receiver.

The slasher steam manifold is maintained at 70 psi by a pressure regulator off the main high pressure steam line. The drying cans are set at some pressure (less than 60 psi) to maintain a proper drying rate. The slashers operate 24 hours a day, 6 days a week, except for stoppage to unload and load.

SECTION II

PHASE II SUMMARY

2.1 INTRODUCTION

Phase II was initiated on 18 July 1977. Based on the bids received during Phase I, the Bahnson Service Company, a Division of Envirotech, Winston-Salem, North Carolina, was selected as the general contractor for installation of the system at the site.

Collector parts procurement was conducted by Honeywell. System parts procurement was conducted by Bahnson. System installation was scheduled in two parts: 1) collector support installation; 2) completion of system installation, to allow WestPoint Pepperell to reroof the weave room roof (at their cost) after the supports were installed and before winter weather.

2.2 COLLECTOR FABRICATION

Honeywell initiated parts procurement for the 24 concentrating collectors in August 1977. This procurement was done in concert with procurement of parts for collectors for other projects. In all, parts for 3000 square meters (32,000 square feet) of collector were procured (77 collector rows of various lengths).

In October 1977, the pilot production line for the concentrating collectors was set up in Minneapolis. This line produced collectors through the months of November and December 1977, and January and February 1978. Once established, the facility produced collectors at the rate of 900 square meters per month (10,000 square feet per month). The collectors were shipped to the site in several truckloads during February and early March 1978.

2.3 INSTALLATION

Collector Supports -- The collector supports were delivered to the site in October 1977. The center post is fabricated from 5-inch schedule 40 pipe to support the motor/gearbox unit and withstand the torque moments imposed by wind loads. The outer posts (four per collector) are fabricated from 3-1/2 inch schedule 40 pipe to support the collector bearings. The posts were fabricated oversized (in length) so that they could be sized and leveled in the field to adjust for uneveness in the wood beam roof.

Installation of the collector supports was completed in November, allowing WestPoint Pepperell to reroof (at their cost) during December.

Collector Installation -- Installation of the collectors on the support posts was initiated in April 1978, and the mechanical installation was completed in May. Bahnson elected to assemble the collectors on the posts first, then build the high temperature water loop around them to allow easy access to the collector field during this critical installation.

Mirror assemblies were lifted from the shipping crates to the roof with a crane, and hand-carried to the supports for assembly. Support arms and receivers were installed using a template for proper spacing.

Collector leveling, mirror alignment, receiver alignment and tracker alignment were conducted in June, July and August as weather and other site activities permitted.

Installation of the electrical components of the collector began in May 1978 and continued until September 1978.

High Temperature Water (HTW) Piping---The HTW piping was built around the collector field at the conclusion of the collector installation. It consists of two 2-½-inch headers, a collector supply and a collector return. Pipe brackets were fabricated and hangers were installed as part of the HTW piping installation. The pipe is anchored at two locations--the penthouse and the center of the field. Pipe expansion under heating is accomodated by "Z" ball joints at the penthouse end of the field and by the freedom to expand outward at the far end of the field.

Penthouse---The penthouse is a three-sided, prefabricated metal building that is set against a brick wall of the textile mill to form the fourth wall. It contains the vast majority of the process steam equipment, including HTW loop accessories, steam loop accessories, electrical equipment, and data collection equipment.

Electrical---Electrical installation at the site was conducted in June, July, August and September 1978. Late delivery of electrical panels and other components delayed this construction. The electrical service panels tie into a plant 600-volt, three-phase line and include a watthour meter for monitoring solar steam system electrical power requirements. Pump motors are supplied with 600 volt power for consistency with plant standards. The solar collector motors use 440 volt power. Electrical service outlets at 110 volts are provided alongside the collector field.

SECTION III

PHASE III

3.1 INTRODUCTION

The data collection period for Phase III began 5 December 1978. On that date, a construction review meeting was held at the site to formally conclude Phase II and initiate Phase III.

This report covers the first six months of operation (December through June 11) and describes the transition from intermittent manual operation to continuous operation. Initially, the system was operated in a manual mode (collectors automatic), and data was collected only when personnel were on the site. As reliability and confidence in the system operation and system protection components were gained, the system operated for extended periods without continual monitoring, and data was collected continuously.

The following sections describe the OPERATION of the system over the six month period, the MAINTENANCE required during this period, and the DATA that was collected during the operation.

3.2 OPERATION

The operation period was initiated by a construction review meeting on 5 December 1978. On that day DOE consultants from Idaho National Labs visited the site to observe operation of the system. Operation continued until mid-June when a gear-box failure forced operations to halt. Operation over the first three months (Dec., Jan., Feb.) was conducted by manual wake-up of the system, automatic tracking by the collectors, and manual shut-down at night. Personnel from Honeywell or WPP were generally in the area during operation. Operation after this first quarter shake-down was automatic. When Honeywell personnel were not at the site, WPP personnel monitored system operation on a regular schedule, filling out preprinted forms and making operational adjustments as necessary.

Table 2-1 summarizes operational data for the first two quarters of operation. In general, a significant number of bad weather days (62%) occurred during the operating period. Operational improvements occurred during the second quarter in each category. However, the combination of minimal good sunny weather and poor tracker performance restricted operation to an undesirable low level.

Table 2-1. Operations Summary

	First Quarter	Second Quarter	% of Improvement
Number of days in quarter	90	92	-
Number of days of data	64	70	9%
Number of sunny days	24	45	88%
Number of bad days	66	47	29%
Number of days system operational	60	79	32%
Number of days system down	30	13	57%
Number of days system collected energy	9	35	290%
Number of days system reached 140°F	8	32	300%
Number of days system reached 165°F	6	25	300%
Number of days system reached 225°F	3	17	400%
Number of days system reached 330°F	1	2	100%
Number of days steam generated	3	11	270%

Tables 2-2 and 2-3, and the following discussion, provides a more detailed review of the operation of the solar process steam system over the 6-month period. Summarized in the tables are environmental data, system sataus, maintenance data, and operational data.

3.2.1 December

During the month of December 1978, operation was limited by system leaks and weather conditions. System leaks kept the system down for 22 of the 31 days in the month. Of the remaining 9 days, there were four days of sunshine. The system was in operation each of the nine days, but steam was generated only one day out of the four sunshine days.

The first four days in December were spent working on system operation and working with a data logger that was unreliable. Weather was bad, and operational conditions were simulated to checkout controls response. Mechanical work was done on the collectors, supports, piping, and the penthouse.

December 5 was cold and clear, allowing a demonstration of system warmup for the Construction Review Meeting. With the ambient temperature in the 40's, the system warmed up at the rate of about 100^{o}F per hour. Several times during warmup, solar generated steam was manually vented off into the atmosphere to control system conditions. When the system reached operating conditions, a threaded pipe fitting on the return header began to leak. The leak was caused by failure of the pipe threads, which stripped when the pipe pushed against a support brace (caused by header expansion). The system was shut down, and the steam stored in the steam generator was dumped.

Table 2-2 Summary of First Quarter Data

DATE	DAY	WEATHER	MAINTENANCE	TIMES OF DAY	DNI_{max} (w/m^2)	T_{max} (°F)	$Flow_{max}$ (LBS/HR)	REMARKS
DEC 1	F*			MIDNIGHT-13:36	-	-	-	
2*	S			08:09-MIDNIGHT	24	80	0	
3*	S			24 HOURS	86	69	0	DATA LOGGER BAD
4*	M			24 HOURS	28	63	0	DATA LOGGER BAD
5*	T			MIDNIGHT-NOON	1000	330	640	DEMO FOR INL
DEC 6 TO DEC 14			SYSTEM DOWN DUE TO LEAK					
15*	F			MIDNIGHT-EVENING	790	69	0	NEW DATA LOGGER
16*	S			09:30-MIDNIGHT	1020	59	0	
17	S			24 HOURS	730	86	0	PUMP STOPPED &
18*	M			MIDNIGHT-16:00	-	-	-	FREEZING OCCURRED
DEC 19 TO JAN 3			SYSTEM DOWN DUE TO LEAK					
4	TH	CLOUDY	EXP JT REPAIR	24 HOURS	41	45	0	
5*	F	CLOUDY	EXP JT REPAIR	24 HOURS	51	55	0	
6*	S	RAIN	EXP JT REPAIR	TO 22:00	0	59	0	SHUTDOWN
7	S	RAIN		-	-	-	-	OFF
8*	M	CLOUDY/SUN	START-UP	10:30-MIDNIGHT	970	180	0	
9*	T	SUN	START-UP	24 HOURS	1010	255	640	NOISY
10	W		YES	24 HOURS	950	77	0	
11	TH			24 HOURS	920	73	0	
12	F			24 HOURS	9	77	0	
13	S			24 HOURS	2	58	0	
14	S		YES	24 HOURS	780	60	0	
15	M			24 HOURS	960	68	0	
16	T		VALVE A	24 HOURS	280	67	0	
17*	W		ELECTRICAL	24 HOURS	770	145	0	NEW TEMP SENSORS
18*	TH	CLOUDY	ELECTRICAL	MIDNIGHT-15:00	930	140	0	
19*	F	CLOUDY	ELECTRICAL	NOON-MIDNIGHT	0	-	0	
20*	S	RAIN		24 HOURS	2	-	0	
21	S	SNOW		MIDNIGHT-07:40	0	60	0	
22*	M	RAIN	ELECTRICAL	08:40-MIDNIGHT	490	70	0	
23*	T	SUN/CLOUDY	YES	24 HOURS	890	228	295	
24*	W	CLOUDY	YES	24 HOURS	3	81	0	
25*	TH	CLOUDY	YES	24 HOURS	730	170	0	
26	F			24 HOURS	270	48	0	
27	S			24 HOURS	0	52	0	
28	S			24 HOURS	750	57	0	
29	M			24 HOURS	870	64	0	
30	T			24 HOURS	870	59	0	
31	W			24 HOURS	810	55	0	
FEB 1	TH			24 HOURS	650	53	0	
2	F			24 HOURS	750	69	0	
3	S		ADD N_2	24 HOURS	0	48	0	
4	S			24 HOURS	9	62	0	
5	M			24 HOURS	2	50	0	
6	T			24 HOURS	2	45	0	
7	W			MIDNIGHT-08:00	1	39	0	
8	TH			24 HOURS	0	45	0	
9	F			24 HOURS	9	69	0	
10	S			24 HOURS	8	55	0	
11	S			24 HOURS	11	66	0	
12	M		ADD N_2	24 HOURS	11	74	0	
13	T			MIDNIGHT-03:00	8	64	0	
14	W			14:20-MIDNIGHT	5	76	0	
15	TH			24 HOURS	930	72	0	
16	F			24 HOURS	650	70	0	
17	S			MIDNIGHT-18:00	8	83	0	
18	S	SLEET		09:00-17:00	0	64	0	
19	M			02:00-MIDNIGHT	0	54	0	
20	T			24 HOURS	2	53	0	
21	W		ADD N_2	24 HOURS	2	57	0	
22	TH		DEMAG WORK	24 HOURS	1	61	0	
23	F			24 HOURS	0	64	0	
24	S			24 HOURS	0	63	0	
25	S			24 HOURS	0	45	0	
26*	M	CLOUDY	YES	24 HOURS	0	44	0	
27*	T	CLEAR	YES	24 HOURS	930	93	0	
28*	W	CLEAR	YES+DEMAG	24 HOURS	920	176	0	

*HONEYWELL AT SITE

DATE	DAY	WEATHER	NO. UP	KWHR	MAINTENANCE	TIMES OF DAY	DIN MAX (MV)	T MAX (MV)	F MAX (MV)	REMARKS
Mar 1*	Th	CLEAR			YES	MID-07:00, 14:00-MID	5.073	- 0.01	- 0.01	
2*	F	CLEAR	17		YES	24 HOURS	6.587	44.43	15.28	
3	S		0		YES	24 HOURS	-0.009	35.59	15.16	
4	S		0			24 HOURS	2.939	32.51	15.06	
5	M		0			24 HOURS	7.905	30.42	15.13	
6*	T	CLEAR	17		ADD N_2	24 HOURS	8.336	67.15	34.33	
7*	W	HAZY	18	?		MID-05:00, 15:00-MID	6.169	46.85	15.20	DEMO FOR DOE & SANDIA
8	TH	CLOUDY	0	13605	ADD N_2	24 HOURS	6.698	45.67	15.23	
9	F	FAIR	17	13839		24 HOURS	8.103	69.75	45.94	
10	S		0			24 HOURS	2.554	31.95	15.16	
11	S		17	14050		24 HOURS	8.474	66.89	33.65	
12	M	FAIR	15	14218	DEMAG	24 HOURS	8.439	67.52	34.56	
13	T					24 HOURS	7.845	62.78	15.33	TOOK PHOTOS
14	W	CLOUDY	0		DEMAG	6:00-MID	8.247	36.94	15.27	
15	TH	FAIR	13	14594	DEMAG	24 HOURS	8.441	66.13	21.93	
16	F	CLOUDY	0	14710		24 HOURS	6.153	37.89	15.08	
17	S	CLOUDY	0	14837		24 HOURS	4.431	31.78	15.03	
18	S	FAIR	0	14924	ADJUSTED PYRH. ADD N_2, VALVE A	24 HOURS	5.664	39.53	15.31	HIGH VOLTAGE
19	M		0		ADD N_2	24 HOURS	1.808	36.21	15.11	PYRH OFF
20	T	FAIR	0	15173	REPAIR PYRH	24 HOURS	6.733	52.44	15.27	
21	W	CLOUDY	12	15270		MID-16:00	7.303	41.02	15.32	
22	TH	CLOUDY	0	15382	REPRESSURIZED SYS	8:00-MID	3.701	32.92	15.16	TURN OVER PAPER
23	F	HAZY	11	15488		24 HOURS	7.442	52.20	15.30	
24	S	CLOUDY	DOWN		24TH-SYSTEM DOWN	BUT GET 24 HRS DATA	6.351	29.94	15.30	SYSTEM DOWN
25	S	FAIR	12			TIME MIXUP				PROBLEMS: PUMP, ROWS
26	M	FAIR	1	15186		7:00-MID	7.991	56.05	15.15	
27	T				SYSTEM DOWN					SYSTEM DOWN
28	W	FAIR	0	15915		24 HOURS	7.534	65.93	23.78	
29	TH	HAZY	14	16129		MID-17:30	6.455	47.51	15.29	SUN TRACKER SLIGHTLY OFF TRACK
30	F	HAZY	14	16132		NO DATA FOR 30TH				
31	S	CLOUDY	0	16238	ADJUSTED PRESSURE	13:00-21:00	0.012	33.35	15.24	
APR 1	S				SYSTEM DOWN DUE TO HIGH VOLTAGE					
2	M	CLOUDY	0	16364		7:00-MID	6.891	33.28	15.12	
3	T					24 HOURS	1.549	31.60	15.16	
4	W					MID-15:00	UNREADABLE DATA			
5	TH		23	16559		8:30-18:20	8.373	88.85	32.13	
6	F	FAIR	21	16668	LOOSE CONNECTIONS REPAIRED	MID-16:43(2)	GAPS IN DATA			
7	S		SYSTEM DOWN			8:10(2)-MID	GAPS IN DATA			
8	S	CLOUDY	SYSTEM DOWN			24 HOURS	GAPS IN DATA			
9	M		SYSTEM DOWN			?-MID	GAPS IN DATA			
10	T	FAIR	21	17147	VENTING N_2	7:10-MID	7.658	90.67	55.74	
11	W	HAZY	0	17252		24 HOURS	4.215	35.28	15.19	HIGH PRESSURE SUSPECTED
12	TH	CLOUDY	0	17379		24 HOURS	5.193	37.96	15.41	
13	F	CLOUDY	0	17410	FILLED PUMP	24 HOURS	0.003	33.38	15.19	
14	S	FAIR	0	17442		24 HOURS	8.457	31.29	15.19	
15	S				NO DATA AVAILABLE -	SYSTEM MAY BE DOWN				
16	M				NO DATA AVAILABLE -	SYSTEM MAY BE DOWN				
17	T	FAIR	12	17599		24 HOURS	7.027	65.83	21.26	
18	W	HAZY	1	17671		MID-19:40	6.251	54.03	15.34	
19	TH	HAZY	0	17730	RESET SCREENS	7:40-MID	2.449	55.17	15.30	
20	F	HAZY	17	17786		24 HOURS	6.687	67.08	15.56	TRACKERS BLIND IN EYE
21	S	FAIR-HAZY	19			24 HOURS	6.960	68.41	32.45	
22	S	CLOUDY				24 HOURS	2.962	46.82	15.12	
23	M	HAZY	0	17897		24 HOURS	3.775	35.28	15.19	
24	T	CLOUDY	0	17923		24 HOURS	0.002	30.96	15.13	
25	W	RAIN	0	17959		24 HOURS	-0.005	30.10	15.21	
26	TH	HAZY	0	17974		24	6.121	30.61	15.29	
27	F	FAIR	0	17006		MID-22:15	7.474	29.90	15.22	
28	S	FAIR	0	17050						
29	S	HAZY	0	18123		DATA UNAVAILABLE				
30	M	HAZY	20	18243	WORKED ON SCREENS	6:40-MID	5.349	45.90	15.54	PROBLEMS WITH A FEW TRACKERS
MAY 1	T	FAIR	18	18353		24 HOURS	7.214	66.04	15.37	
2	W	HAZY	18	18303		24 HOURS	6.661	65.38	15.34	SCREENS NOT WORKING
3	TH	CLOUDY	0	18409		24 HOURS	3.561	35.98	15.24	
4	F	CLOUDY	0	18537		MID-11:40	0.125	33.58	15.35	
5	S					SYSTEM DOWN				COULD NOT WORK PANELS
6	S	NO SHEET				24 HOURS	6.922	32.39	15.11	
7	M	HAZY	18	18641	PUMP FILLED	24 HOURS	4.547	36.23	15.44	
8	T	CLOUDY	0	18667		24 HOURS	1.998	33.65	15.32	
9	W	HAZY	0	18692	BRAKES BEING POLISHED	24 HOURS	6.560	35.25	15.41	
10	TH	HAZY	17	18735		24 HOURS	6.838	65.45	15.59	
11	F	HAZY	18	15783	SCREENS WASHED	24 HOURS	5.578	41.67	15.54	
12	S	HAZY	17	18828		MID-12:15	6.250	52.41	15.57	
13	S	NO SHEET								
14	M		14	18981						
15	T	FAIR	11	18188		GAP IN DATA				
16	W	FAIR	0	19177	PUMP FILLED					TRACK MOTORS 2 & 13 BURNED UP
17	TH	HAZY	12	19102						
18	F	HAZY	4	19311						
19	S	NO SHEETS				7:45-MID	7.148	55.17	15.23	3 MOTORS BURNED UP
20	S	-				24 HOURS	6.687	67.08	15.56	
21	M	HAZY	11	19493		24 HOURS	6.960	68.41	32.45	SYSTEM NOT TRACKING CORRECTLY
22	T	HAZY	12	19542		24 HOURS	2.962	46.82	15.12	
23	W	CLOUDY	0	19586		24 HOURS	3.775	35.28	15.19	NOT TRACKING CORRECTLY
24	TH	HAZY	12	19627		24 HOURS	0.002	31.96	15.13	
25	F	HAZY	12	19731		24 HOURS	-0.005	30.10	15.21	
26	S	FAIR	12	19701		24 HOURS	6.121	30.61	15.29	NO. 8 MOTOR BURNED, WATER LEAK
27	S	NO SHEET				MID-22:15	7.474	29.90	15.22	
28	M	HAZY	10	19927		-				
29	T	CLOUDY	0	19967		GAP IN DATA				
30	W	HAZY	16	20017		-				
31	TH	CLOUDY	0	20052	REPLACED DOOR ON NO. 22 SCREEN	6:40-MID	5.349	49.06	15.54	
						24 HOURS	-0.004	40.42	15.41	

Table 2-3 Summary of Second Quarter Data

Because of the cold weather conditions being experienced at the site, the HTW loop was drained to prevent freezing. The freeze protection system could not function properly with the leak in the return header.

Repair of the leak, and several other pipes which posed similar clearance conditions, began the following Monday (12/11/78). In addition to the leak repair, a new data logger was installed at the site, which proved to be much more reliable and easier to operate than the original one. During that week, the leaks were repaired, the HTW loop was refilled and pressure tested, and a system checkout was completed.

Unfortunately, over the next weekend, a series of events occurred that initiated a set of HTW loop leaks that again shut the system down. On the night of Saturday, December 16, the cold ambient temperature caused the HTW loop recirculation pump to be operating. When the mill shut down at about midnight Saturday, the service voltage rose to a level such that the pump motor protection circuit (circuit breaker) tripped, shutting the motor off. With the motor off, the freeze protection system could not function properly, and on early Monday morning, some freezing occurred in the HTW loop.

This freezing was confined to the smallest pipes in the field, the collector absorbers. Expansion of the freezing water was taken up in the (thermal) expansion flex hoses at the collector centers. Some hoses were deformed, and six had leaks. It was decided that all of the collector flex hose expansion joints had suffered stress and all should be replaced. The system was, therefore, drained and left inoperative until early January when the hoses were replaced.

3.2.2 January

During the month of January, 1979, operational conditions improved. After the expansion joints were repaired, there were

19 days of complete data (24 hours) and 5 days of incomplete data. Of these 24 days, 14 had sunshine. The system operated (manual wake-up) six of these days and produced steam on two days.

Operation after repair of the flex hoses began on 8 January. On that day (of partial sunshine), a system temperature of 82°C (180°F) was reached. January 9 was a sunny day, and the system operated at temperatures up to 122°C (250°F) and dumped steam to the atmosphere.

During this operation, controls problems were detected. Noise in the temperature sensor signals were causing undertemperature (freeze) signals to occur when the system was in nominal operation. These extraneous control signals prohibited automatic operation of the system.

On 17 January, new temperature sensors and wiring were installed at the site to eliminate the noisy-signal problem. Over the next nine days, the system was operated with a manual wake-up. Four of the nine days contained some sunny weather, and energy was collected during those periods. On 23 January, low pressure steam was generated and dumped to the atmosphere.

3.2.3 February

Weather at the site consisted of only six sunny days during February. Bad weather included heavy rains and sleet. Operation was hampered by a N_2 leak in the HTW loop and collector motors that would stick. Solar energy was collected on two days during the month (27 and 28 February), and system temperature reached 80°C (176°F) under intermittent operation (during maintenance).

3.2.4 March

The month of March had 11 days of FAIR to CLEAR weather. Steam was produced on 6 of these days. The remaining days were either HAZY or CLOUDY. The system then operated on full automatic, including the "wake-up" and "stow" operations. This automatic operation was hampered by the following problems:

- variable weather conditions
- suntracker problems
- motor brakes sticking
- N_2 leak

A demonstration of the system was performed for D.O.E. and Sandia Labs on March 7. Late in March the feedwater pump/ motor failed resulting in the system being shut down for four days (March 24-27). The unit was replaced with a larger pump/ motor and operation since that time has been satisfactory.

3.2.5 April

Weather conditions continued to hamper operation with only 8 days being recorded Clear or Fair. System temperature exceeded 220^{o}F on five days and steam was generated on four of these days.

The system was down eight days of the month, due to weekend problems. High line voltage that occurs about midnight on Saturday (due to plant shut down) affects the HTW loop recirculation pump and shuts the system down until reset.

Operation problems which persisted include;

- motor brakes sticking
- shadow bar tracker problems

The N_2 leak was found and repaired eliminating an occasional system shut down that would occur when the system pressure/ temperature ratio would go out of range.

3.2.6 May

Poor weather prohibited any continuous day-after-day operation of the solar energy system. Only four Fair days were recorded. System temperature exceeded 235^{O}F on five days operating primarily in hazy conditions. Steam was generated on one day.

Operational problems with the shadow bar trackers continued. In addition several drive motors burned out.

3.2.7 June

The first half of June was all cloudy or hazy and system temperature exceeded 200^{O}F only once. Operation was hampered by an apparent binding in the collector drive on several collectors. One gearbox failed in mid-June. Inspection of that gearbox and others resulted in the decision to stow the collector field to avoid further damage to the gearboxes.

3.2.8 Thereafter

After failure of the gearbox the collector field was stowed and turned off to avoid damage to other gearboxes. In addition to the unit that broke, several other gearboxes appeared to exhibit binding. The broken gearbox was first inspected in the field. The low speed worm had failed. A binding gearbox was also inspected in the field. The medium speed gear was misaligned with the worm due to a sheared pin. The key allowed the gear to continue to operate in spite of the sheared pin.

The broken gearbox was removed and shipped to the manufacturer for inspection. Their assessment was that the gearbox failed due to overloaded operation.

The HTW loop recirculation pump was returned to the manufacturer for warranty work. This pump/motor had been specified for 600 V and delivered with a 550 V plate on the motor. However, persistent operational problems were exhibited by the motor during weekend operation (higher voltage on line). It was determined that the motor was in fact a 440 V motor. The manufacturer replaced this motor with a 550 V unit at no charge. The pump was also reconditioned at that time.

3.3 MAINTENANCE

During the operation of the system, maintenance and repair occurred frequently and was conducted by Honeywell personnel, WestPoint Pepperell personnel, Bahnson (general contractor) personnel, and some outside contractors. Tables 2-2 and 2-3 include comments indicating maintenance actions.

3.3.1 Data Logger Maintenance

Early in the period, the data logger caused considerable problems by losing its program, printing poorly, and/or printing bad data. Maintenance and adjustment of the unit was conducted. A new data logger was installed and checked on 15 December. Maintenance since that date has consisted of replacing printer paper and printer ribbon.

3.3.2 Temperature Sensor/Transmitter Maintenance

During the first month and a half of operation, noisy data from the temperature sensors caused control abnormalities. Considerable effort was expended testing and modifying the sensor circuits. On 17 January 1979, new temperature sensors were installed and rewired. The noise and associated control problems were eliminated.

3.3.3 Tracking Pyrheliometer Maintenance

This instrument requires frequent maintenance to 1) adjust the declination setting and 2) unwind the sensor wires. Considerable difficulty was experienced in keeping the instrument properly positioned to track the sun. During periods of extended cloudiness, in attention to maintenance allowed the sensor wires to become tangled and broken. During March, April, May, and June, operation of the pyrheliometer became more reliable as periodic maintenance was more regular.

3.3.4 Sun Tracker Maintenance

The shadow bar tracker on the collectors exhibited a varient of characteristics requiring maintenance. Early in the operating period component failures occurred regularly and required replacement (with better components). In general, tracker performance was disappointing. Adequate tracking accuracy could be maintained only over very limited weather (sky) conditions. The shadowbar control circuitry was modified to improve operating characteristics. These electronic modifications resulted in better tracker operation, however, operation unattended in the automatic mode allows tracker anomalies that include, collectors that do not track (stationary while sun moves on), and collectors that develop severe oscillations due to erroneous tracking commands.

Adjustment and maintenance of the shadow bar trackers was a continuous (almost daily) occurance. In spite of this attention to the trackers, neither its reliability or capability ever reached a satisfactory level. Furthermore, the tracker instability and collector oscillation eventually led to the gearbox damage and failure that has shut the system down.

3.3.5 Collector Motor Maintenance

The collector motors use a brake mechanism to eliminate motor coast (overrun) and improve tracking acccuracy. On numerous occasions this brake has stuck, prohibiting operation of the motor. Maintenance is required to free the brake and allow the motor to operate normally.

During this operating period, the motor manufacturer performed a modification on the unit to eliminate this problem. Otherwise WPP or Honeywell personnel at the site perform the necessary maintenance. This problem continued to exist in wet weather but appeared to be decreasing in frequency as the motors were used.

Late in the operating period a significant number of motors burned out requiring maintenance and repair. These occurances were consistant with unattended operation and were probably due to collector oscillations, gearbox binding or both.

3.3.6 Feedwater Control Valve Maintenance

Two separate problems caused a feedwater control valve to require maintenance. Early in the period, leakage was detected. Later in the period, the valve operation sequence was found to be incorrect; electrical fixes were made.

3.3.7 Mirror Maintenance

Soon after installation at the site, mirror "tunnels" or wrinkles appeared in the acrylic mirror surface, mostly at corners. After extensive investigation, the manufacturer stated that these wrinkles were due to the expansion of the acrylic material in the high humidity conditions. Although these imperfections looked bad, they are in fact "cosmetic" because they represent a very small percentage of the total mirror area. However, the manufacturer proceeded to "patch" the mirrors and demonstrated a very successful mirror repairing technique.

3.3.8 System Controller Maintenance

During the first quarter of operation, several control components failed and were repaired and/or replaced. These components included relays, diodes, resistors, and capacitors. In addition, the controller was modified to include more control functions and more displays.

3.3.9 High Temperature Water Loop Maintenance

Maintenance of the HTW loop consisted of checking insulation and pipe hangers, exercising manual vents to check for vapor bubbles, and adding N_2 to maintain loop pressure.

3.3.10 Washing

Washing of the mirrors was performed by turning the system on in a rain and commanding the synthetic authorize signal. This resulted in a brief satisfactory wash.

3.3.11 Painting

Various collector components made of steel were touched up with paint in areas where rusting began.

3.3.12 Repair

In addition to the maintenance conducted, five significant repairs were made. These repairs are discussed in Section 3.2 Operation and are listed below:

- Return header repair (leaks)
- Collector expansion joint repair (leaks)
- Feedwater pump failure and replacement
- N_2 charging system repair (leak)
- HTW loop recirculation pump repairs

3.4 DATA

During this operation, data from 14 sensors was recorded on data logger paper tape at preset time intervals (30 seconds to 30 minutes). Tables 2-1, 2-2, and 2-3 summarize the extent of data collection for each day in the period.

Data for five days from this period has been extracted from the data logger tapes, converted to physical units, graphed, and analyzed. the following paragraphs describe the operation of the system on those five days.

3.4.1 Tuesday, 5 December 1978

The solar process steam system was operated on this date by manually switching on the system at 7:30 CST. The wakeup of the collector field was performed manually at this time. thereafter, all collectors and the system operated automatically, and data was taken at two-minute intervals. Because the temperature sensors were sending noisy data, and the data logger occassionally printed erratic data, the data documented below consists of selected data in which obviously bad data points have been excluded.

System wake-up begins with startup of the HTW loop recirculation pump. When flow has been verified, collector wake-up is initiated, and the collectors move from the stowed position into a tracking position.

Figure 3-1 shows the insolation (direct normal), ambient temperature, and system temperature from 7:00 until 12:00, when the system was shut down due to a leak. The weather was cold ($46^{o}F$) the insolation level was high (to 317 $Btu/hr/ft^2$), and the system warmed up at a rate of $100^{o}F$ per hour.

System performance during the warmup period was estimated to be approximately 13% using the warm up rate and thermal capacitance assumptions. This efficiency is representative of the system operating while the insulation is incomplete, and includes the cosine losses that occur in the A.M.

3.4.2 Tuesday, 9 January 1979

This day dawned clear and cool. When engineers arrived at the site, the temperature was $18^{o}F$, and the freeze protection system was operating. The system was turned on manually, warmup began, and data was collected at two-minute intervals.

Of the 24 collectors, 16 tracked properly, 4 tracked poorly and 4 were out of commission due to electronics problems.

Figure 3-2 shows the insolation (direct normal), ambient temperature, and system temperature from 6:30 until 12:00 when the collectors were stowed. At noon the ambient temperature had risen only to $38^{o}F$, and the insolation level was 317 $Btu/hr/ft^2$.

The pressure in the steam generator rose to about 10 psig, whereupon, the steam valve was opened, and low pressure steam was dumped into the atmosphere. Steam flow continued for 12 minutes at 5 psig and 600 pounds per hour of steam (0.6×10^6 Btu/hr).

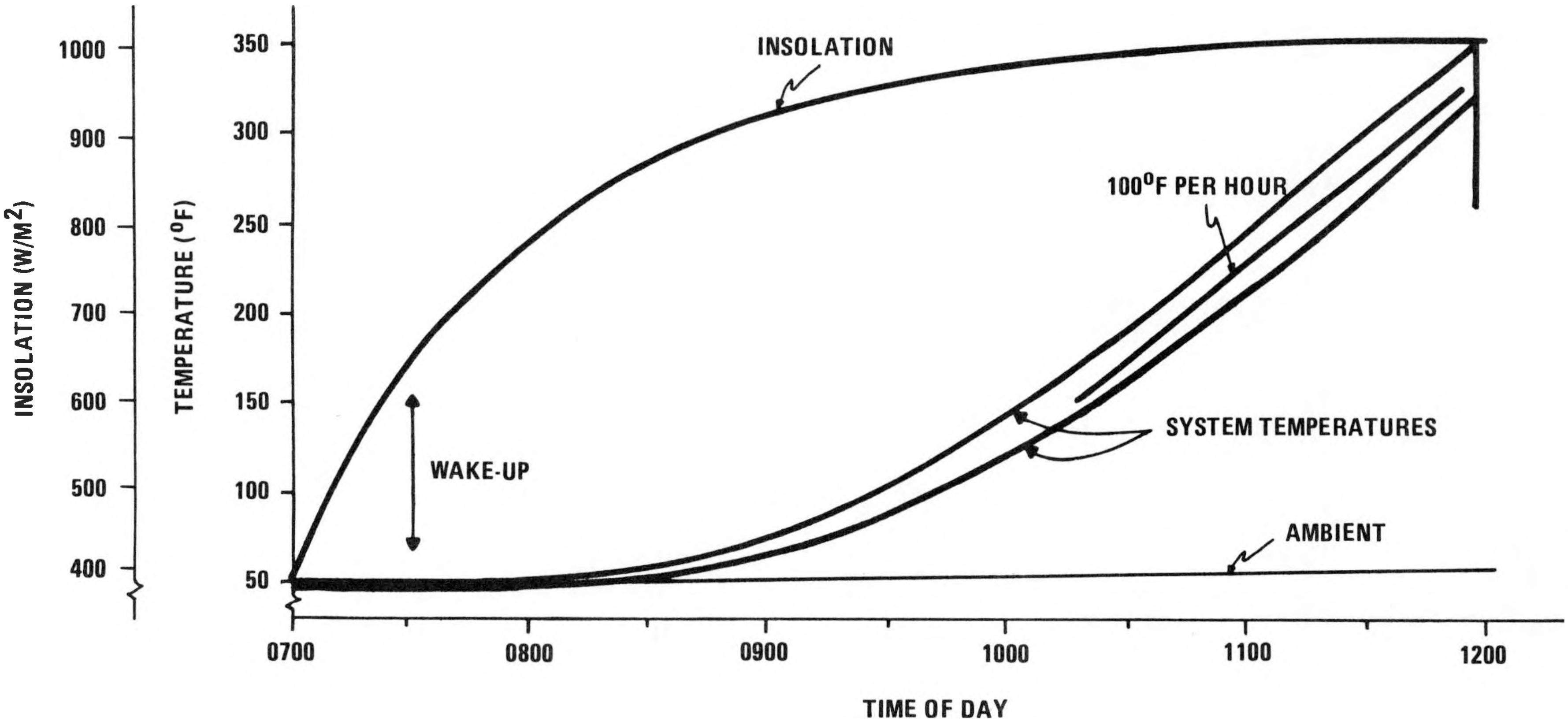

FIGURE 3-1. SYSTEM WARM-UP ON 5 DECEMBER 1978

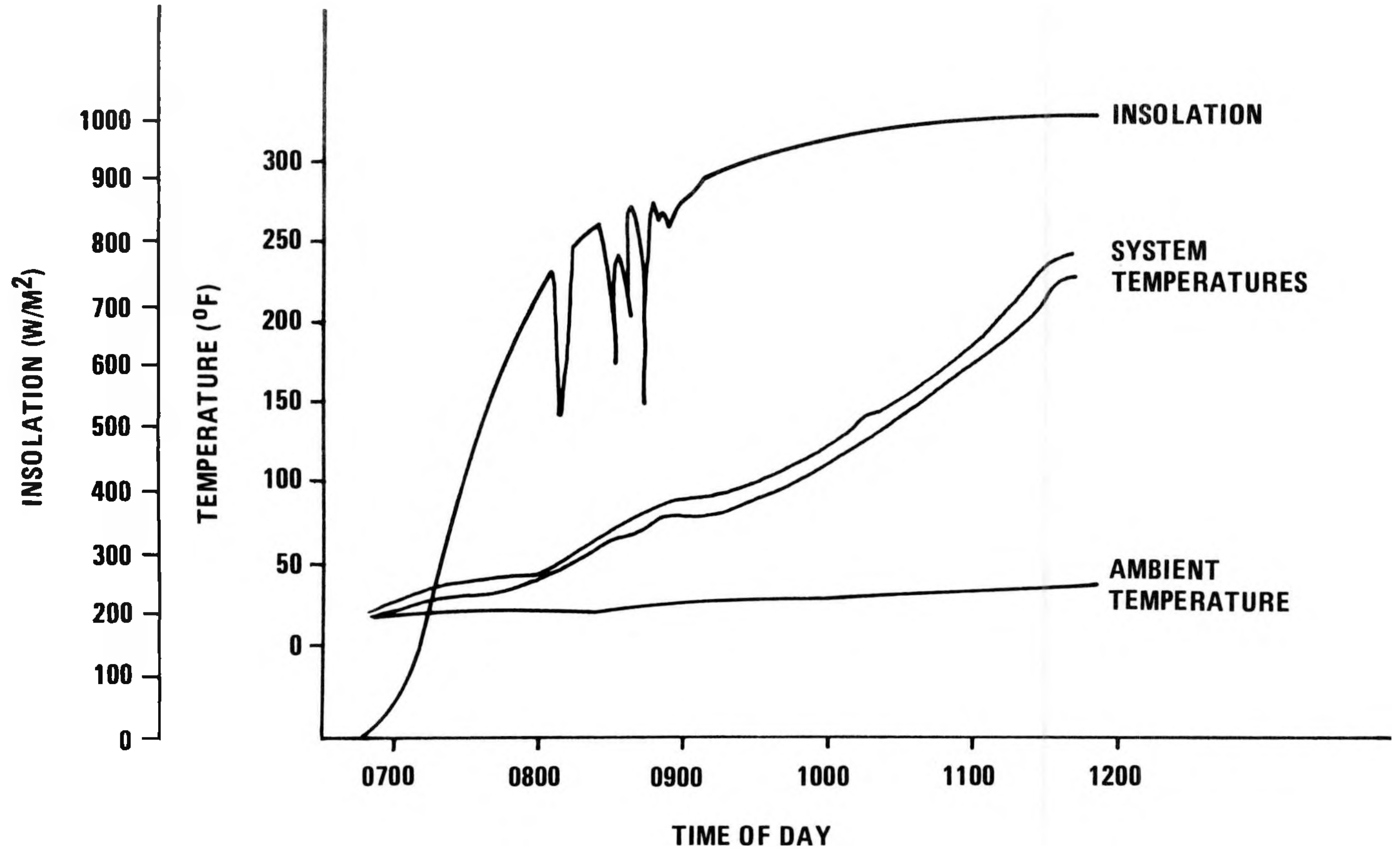

FIGURE 3-2. SYSTEM WARM-UP ON 9 JANUARY 1979

During the one-hour period of 10:30 to 11:30, the system warmed up at a rate of about 100°F/hr. Insolation was about 300 Btu/ hr/ft^2, and 18 collectors were tracking. From this warmup rate and thermal capacitance assumption system efficiency was approximately 19%. This efficiency is representative of the system operating while the insulation is incomplete and the alignment is incomplete, and includes the cosine losses that occur in the A.M.

3.4.3 Tuesday, 23 January 1979

This day was cold and clear in the morning. The temperature at dawn was 18°F. A south wind was blowing steam from vents across the front of the collector field. Initially, this steam affected the tracking of some rows of collectors. By 10:00 A.M., 21 collectors were tracking reliably. The system warmed up to 288°F, and steam was vented to the atmosphere.

Clouds began appearing before noon, and at 12:50 the controller stowed the field due to the absense of direct normal radiation.

This morning represented the first clear sky, 200°F operation of the system since the installation of new temperature sensors. Temperature signals were steady (not noisy), and the controller did not chatter as it had earlier under noisy temperature signals.

Figure 3-3 shows the insolation (direct normal), ambient temperature, and system temperature from 7:00 to 23:30. The collecotrs stowed at 12:51, and thereafter, the data shows system cool down. Steam flow of up to 300 lbs per hour occurred when the vent was opened at 12:40.

3.4.4 Friday, 9 March 1979

Aside from a cloud which obscured the sun from 7:00 a.m. to 8:00 a.m., this day was cool and clear. Figure 3-4 graphically

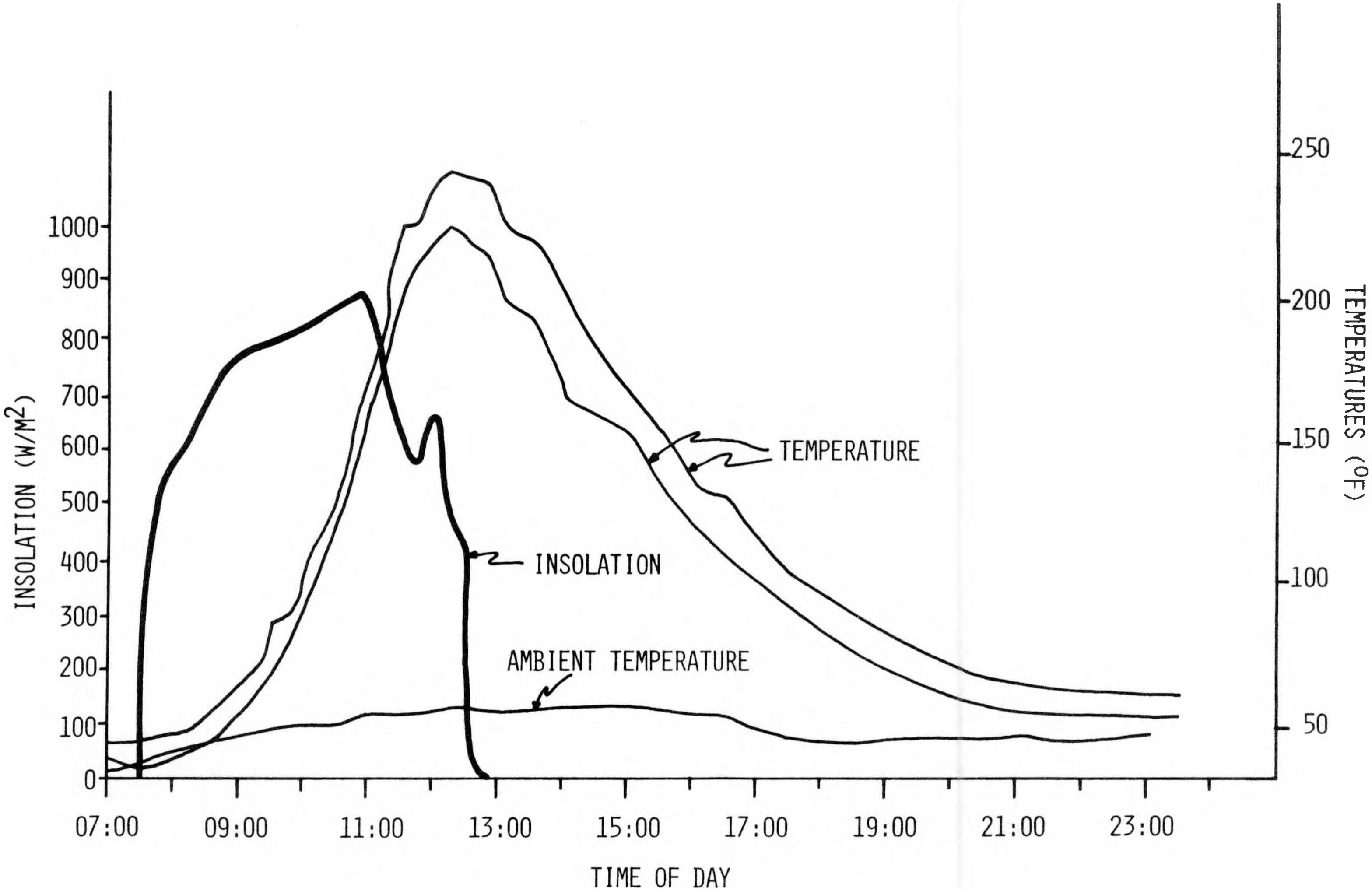

FIGURE 3-3. SYSTEM OPERATIONAL CHARACTERISTICS ON 23 JANUARY SHOWING COOL-DOWN

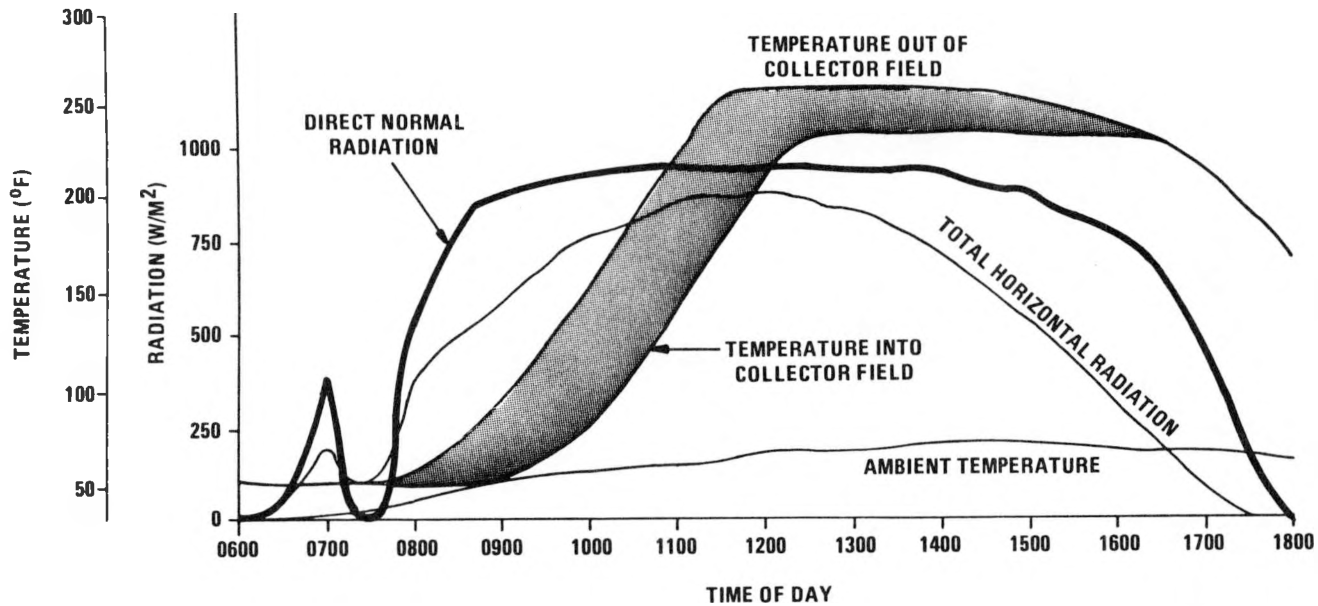

FIGURE 3-4. SYSTEM OPERATING CHARACTERISTICS ON 9 MARCH 1979

illustrates the Total Horizontal Radiation and Direct Normal Insolation over the day (showing the morning dip due to the clouds), the ambient temperature rising from 40°F to 70°F, and the system temperature rising to 260°F. While producing low pressure steam the system operated at a delta T of about 25°F. Steam production occurred over a 5 hour period from 11:00 a.m. to 4:00 P.M.

Figure 3-5 illustrates the steam flow with respect to the system temperature and the insolation.

Considering only 71% of the field area was collecting energy (17 of 24 collectors), the collector field efficiency was 32%, and 29% of the available energy was delivered as steam (total system efficiency).

3.4.5 Thursday, 5 April 1979

This day was clear all day. Twenty-two (22) of the 24 collectors were tracking properly and steam was delivered to the process in the afternoon. Figure 3-6 shows the radiation levels and ambient temperature versus time of day. The total horizontal radiation sensor measured values slightly over 1,000 w/m^2, the tracking pyroheliometer measured DNI values just under 1,000 w/m^2.

Figure 3-7 illustrates the system temperature versus time with respect to the DNI level and ambient temperature. The system warmed up at a rate of about 100°F per hour with a system delta T of about 25°F. Operation between 1400 and 1500 (2 to 3 o'clock) realized a stabilized condition with the collector inlet (steam generator outlet) at 329°F, the collector outlet (steam generator inlet) at 356°F and a system delta T of 27°F. Considering that 22 collectors were tracking the sun (6875 ft^2 of aperture), the collector field operated at an efficiency of approximately 33% of the hour 2 to 3 o'clock, from delivering steam to the process.

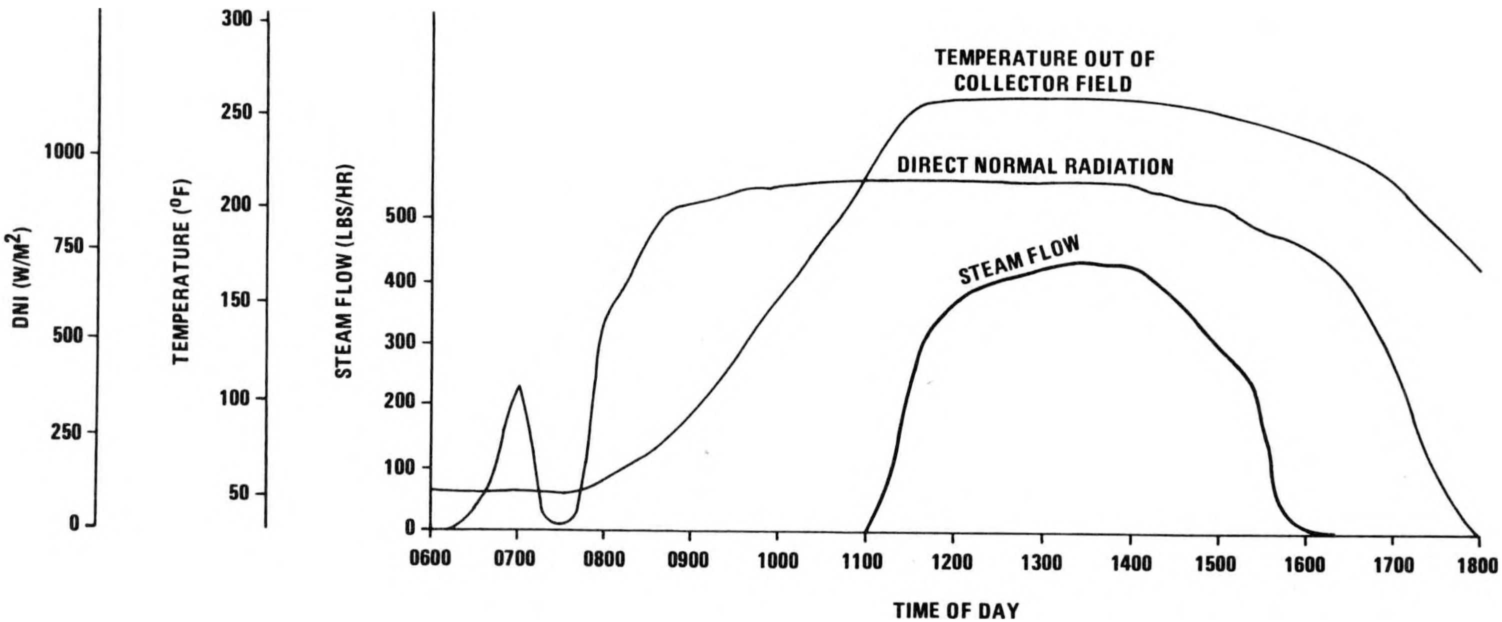

Figure 3-5 Solar Steam Flow on 9 March 1979

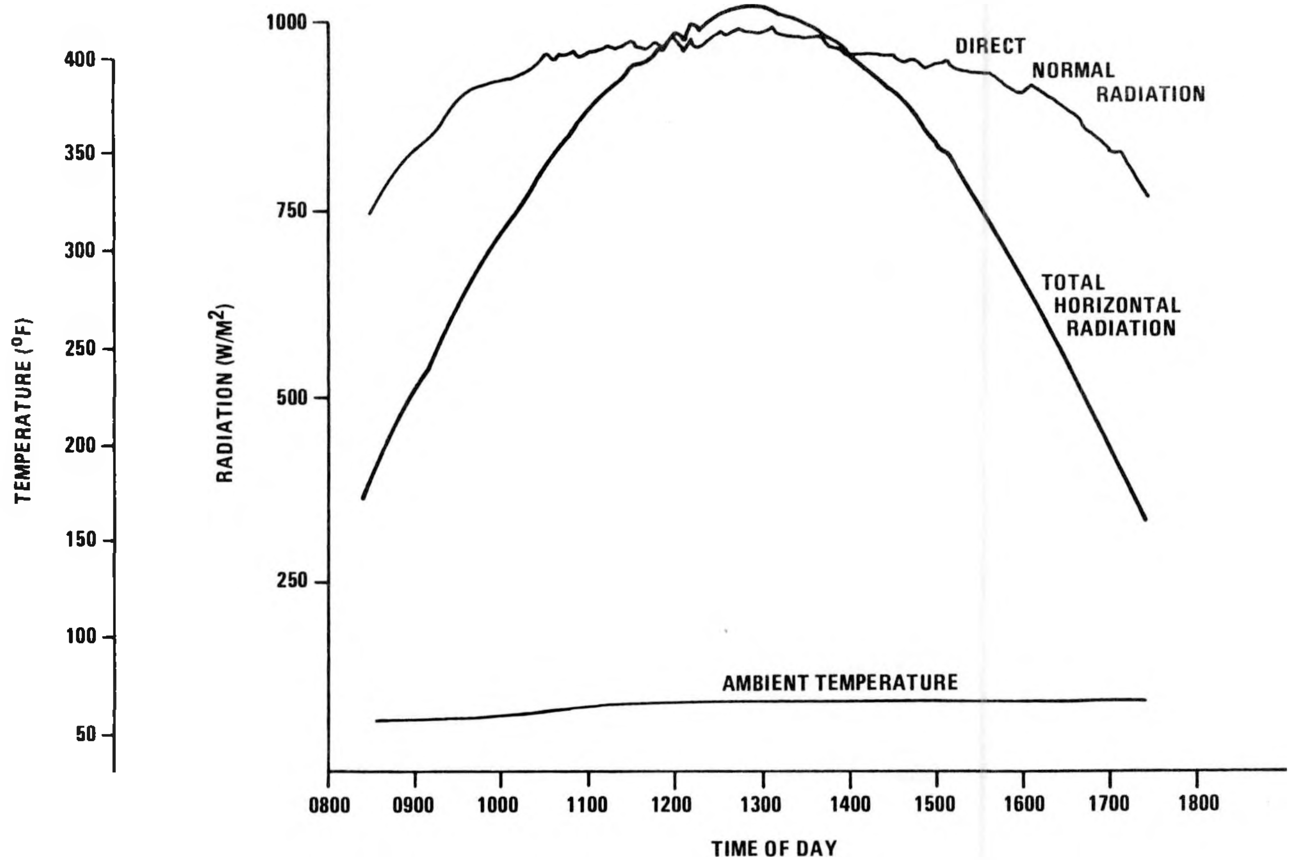

FIGURE 3-6. RADIATION AND AMBIENT TEMPERATURE ON 5 APRIL 1979

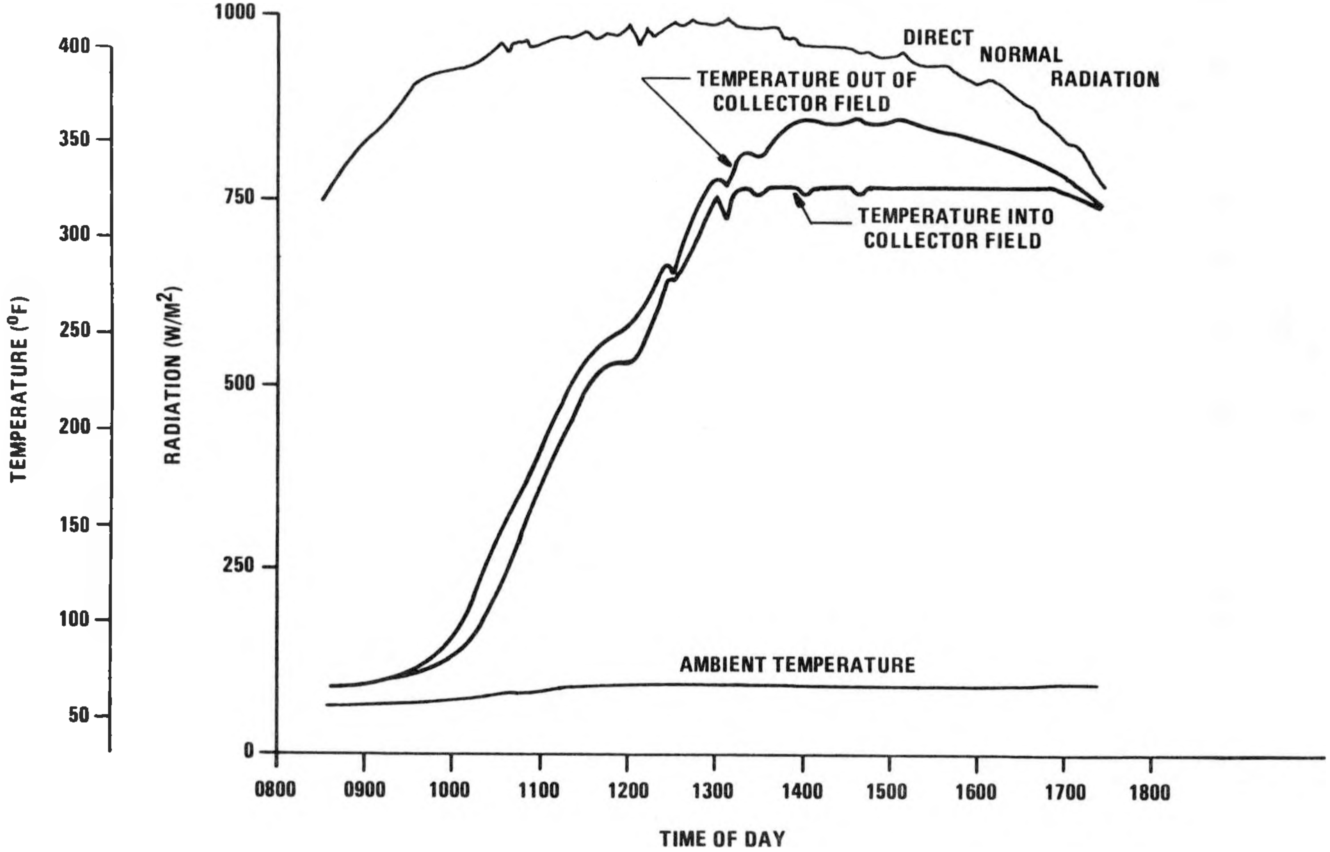

Figure 3-7 System Temperature on 5 April 1979

The steam flow, shown in Figure 3-8, occurred at noon, and between 1400 and 1600 (2 to 4 o'clock). The noon steam flow was at low pressure as steam was vented to the atmosphere. Later the system reached nominal operating conditions and steam was delivered to the process.

Steam flow during these conditions was highly irregular. Approximating a 250 lbs per hour flow, the system efficiency in delivering steam to the process was 12%.

3.5 ASSESSMENT

Operation over the six month period of December 1978 to June 1979 provided extensive experience in local weather conditions, tracking collector operation and maintenance, and data collection and analysis. Key issues that impacted system operation are:

- weather at the site was worse than expected. Rainy and cloudy weather were more prevalent than the norm. High thin haze was more detrimental to system operation than expected.
- the shadow bar tracker was shown to be incapable of successful operation over the range of weather (sunshine) conditions experienced at the site. Furthermore, tracker instabilities caused collector oscillations that resulted in damage to the collectors.
- system operation and system control were successfully achieved with a high level of automation and self-protection. Automatic operation including morning wake-up, evening shutdown, and response to clouds was demonstrated.
- day-to-day operation (weather permitting) at low pressure conditions was demonstrated.
- operation at nominal conditions was demonstrated and steam was delivered to the process.

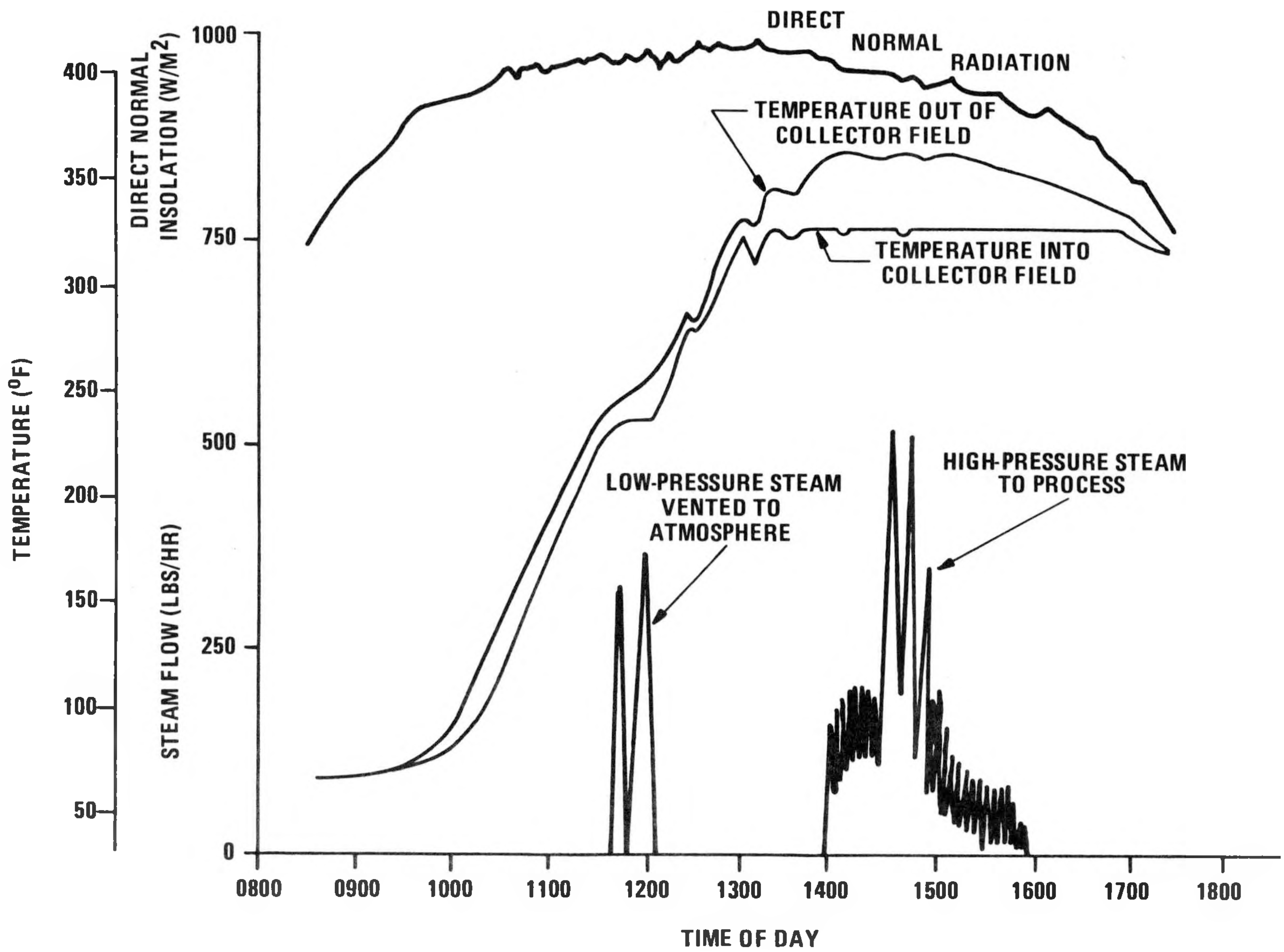

Figure 3-8 Steam Flow on 5 April 1979

- the HTW lines, carrying 360^{o}F water at 275 psi were unpopular with the site personnel because of safety concerns. A combination of occasional leaks, and obvious daily expansion and contraction of the system piping made WPP recommend use of a lower pressure collector loop using a heat transfer fluid with a high boiling point.
- system efficiency, as estimated from data samples, was promising, considering only a fraction of the collectors were tracking regularly.
- understanding system dynamics requires more data at nominal operating conditions and detailed analysis of that data. System warm-up appears to be slower than anticipated, however, data sample timing may influence this affect. Feedwater supply rate may also affect dynamics. The steam flow to the process appears erratic and the steam flow check valve has been heard to rattle (open and closed) during operation. Additional attention to steam flow control may be required.

SECTION IV

UPGRADE PROPOSALS

4.1 REPAIR

Based on assessments of the problems encountered at the WPP project and following DOE's recommendations, an upgrading of the entire system by repair was proposed in August of 1979.

The repair tasks proposed included:

- o Replace the shadow bar solar trackers with flux-line trackers.
- o Repair gearboxes.
- o Replace water in primary loop with a high temperature oil that will permit low operating pressure of 30 to 40 P.S.I.
- o Replace the flexible hoses at the greatest stress areas with a more flexible hose.
- o Repair and improve the collectors in the following way:
  - add counterweights to mass balance collector
  - pin flanges
  - replace receiver insulation
  - repair and strengthen receiver and supports
  - seal mirror honeycomb
  - alignment and adjustment

DOE/IPH response to this proposal was positive with the following reservations. Since the collectors at WestPoint Pepperell do not represent a current collector manufacturer's product, DOE/IPH was reluctant to expend funds for repair. Rather, DOE/IPH recommended that a collector substitution be proposed. Utilizing a production collector from a recognized collector manufacturer would facilitate DOE/IPH objectives and provide additional data to the manufacturer in terms of potential product improvement.

4.2 COLLECTOR SUBSTITUTION

In response to the DOE/IPH recommendations, the potential for substituting existing collectors at the site was investigated. Collector physical sizes with respect to the existing supports and piping were analyzed. Bids for collectors were solicited from manufacturers. A proposal for collector substitution was generated and submitted to DOE/IPH in December 1979. This proposal addressed specifically:

- Design of modifications necessary to allow for the collector substitution (mechanical, electrical).
- Procurement and Installation of new collectors.
- Operation over a 12 month period (with data acquisition and analysis).

The program activities described in the proposed Statement of Work are summarized below.

Design -- To accomodate the new collectors, design activities will address modifications to the collector support structure, the collector piping interface with the headers, the electrical power wiring, and the collector control interface. This design will include consideration of a heat transfer fluid substitution and the associated pump and other accessory changes. These tasks will result in specifications and drawings for procurement of materials and services. Installation costs will be obtained via firm bids from these procurement packages.

Installation -- Procurement of equipment, removal of the old collectors, installation, and checkout & start-up are included in the installation activities.

The collectors specified are line concentrating parabolic troughs manufactured by Suntec Systems, Inc. These collectors can be purchased with acrylic film mirrors or second surface glass mirror parabolas. The acrylic film represents the current state-of-the-art in mirror surfaces.

The glass mirrors represent the latest development in concentrators and are expected to provide both higher performance and longer life than the other common reflective surfaces. Higher performance will result from both higher reflectivity of the surface and greater ease in cleaning, which will reduce reflection losses due to dirt accumulation.

The collectors will be controlled by the Honeywell Flux Line Tracker to provide accurate and reliable collector operation. Other significant procurements that have been identified include heat transfer fluid (oil) for the primary loop, a new primary loop pump, and a stationary "wake-up sensor" to eliminate the need for a control signal from the pyrheliometer.

Installation labor will be required to remove the old collectors and install the new collectors. The installation activities will be concluded with checkout of the electrical and mechanical aspects of the system by Honeywell engineers and technicians, alignment of the collectors, and start-up and initial operation of the upgraded system.

Operation -- The final activity consists of operation of the system over a 12 month period, collection of data during that period, analysis of that data, and evaluation of the system. Initially, operation will be under the direction of an on-site Honeywell engineer. This engineer will train WPP personnel to operate the system to allow WPP operation and maintenance of the system for the majority of the test period. Data will be analyzed by Honeywell.

This proposal was presented to DOE/IPH in December, 1979. Action on the system upgrade and collector substitution has been delayed due to transfer of IPH project responsibility to DOE/SAN.

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