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Solar Total Energy Test Facility Project Test Summary Report: Rankine Cycle Energy Conversion Subsystem

Joseph P. Abbin

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SOLAR TOTAL ENERGY TEST FACILITY PROJECT TEST SUMMARY REPORT: RANKINE CYCLE ENERGY CONVERSION SUBSYSTEM

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ABSTRACT

This report describes the Rankine cycle thermal energy conversion subsystem and summarizes results of tests run on the unit from December 1975 to November 1977. The purpose of the tests was to evaluate subsystem performance and to determine its operational characteristics under input/output conditions imposed by the rest of the solar total energy system.

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Introduction

This report summarizes results of tests December 1975 to November 1977 on the Rankine cycle thermal Energy Conversion Subsystem (ECS). The ECS is part of the Department of Energy's Solar Total Energy Test Facility (STETF) at Sandia Laboratories, Albuquerque, NM.

Reference 1 describes the STETF and the function of the ECS in the STETF. Reference 2 details the overall test plan for the STETF.

Description of Energy Conversion Subsystem

The ECS operates on the Rankine cycle utilizing toluene as the working fluid. The unit is primarily a modified version of a prototype gas-fired total energy system manufactured by Sundstrand Corporation. A simplified mechanical schematic of the subsystem is shown in Figure 1. A generalized sketch of the cycle on a temperature-entropy diagram is shown in Figure 2 and on a temperature-enthalpy diagram in Figure 3.

Referring to Figure 1, the unit operates as follows. High-pressure, high-temperature toluene vapor is admitted to the turbine on demand by the band valve. After expansion through the turbine, the toluene vapor is at low pressure but is superheated (see Figure 2) when it enters the regenerator. The regenerator cools the vapor before it enters the condenser, where the vapor condenses to a liquid and collects in the hotwell. An electrically driven boost pump pumps the liquid from the hotwell to the turbine-gearbox-driven main feed pump where it is then pumped at high pressure to the regenerator. From there the liquid enters a four-stage Graham heat exchanger where it is preheated, boiled, and superheated before returning to the band valve in a continuous process. The band valve varies the number of active turbine nozzles (with a small amount of throttling between nozzle sectors) such that the generator output speed and frequency remain constant with varying electrical loads up to 32 kWe. Toluene system pressure is controlled by the flow control valve, which throttles the main feed pump outlet. The flow control valve in turn is controlled by a feed-forward signal from a band valve position transducer and a feed-back signal from a turbine inlet pressure transducer. Condenser coolant temperatures are varied depending on seasonal thermal loads. Nominally, the coolant in-and-out temperatures are as follows: winter operation, 41°/68°C (105°/155°F); spring/fall, 32°/43°C (90°/110°F); and summer, 77°/88°C (170°/190°F). Heat input to the ECS can be either from the gas-fired heater or thermal storage, both of which provide heat-transfer oil (Therminol T66 made by Monsanto) at a nominal inlet temperature of 310°C (590°F). The oil flow rate is varied such that the oil temperature out of the preheater is 246°C (475°F).

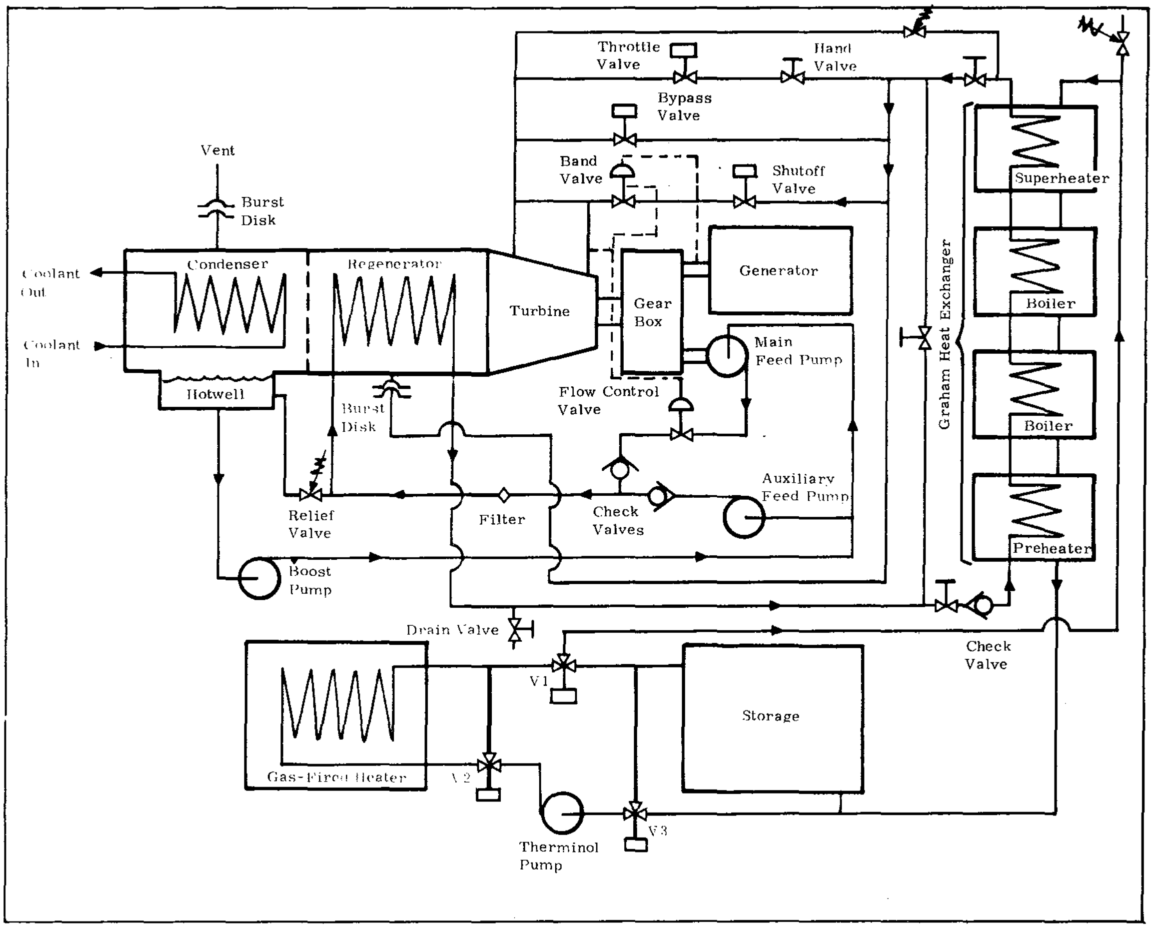

Figure 1. Simplified Schematic of the Energy Conversion Subsystem for the Solar Total Energy Test Facility (STETF)

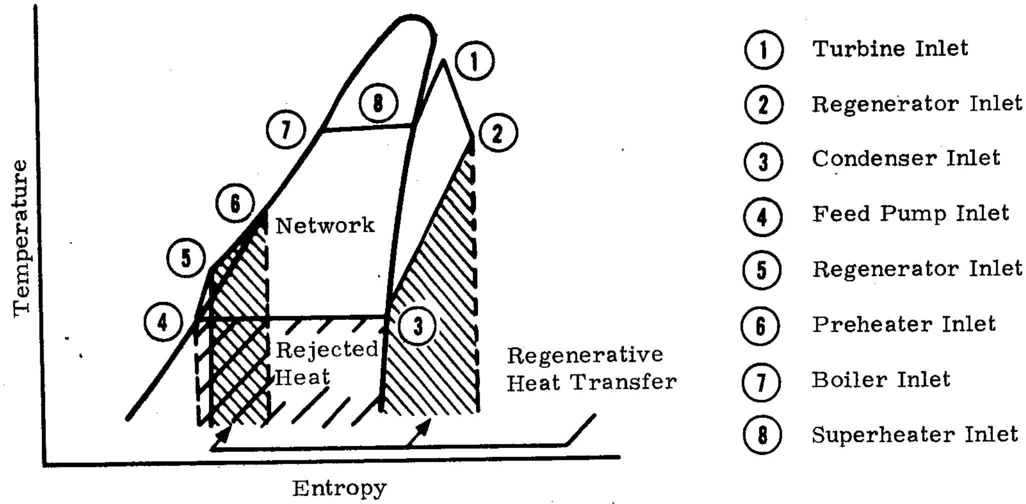

Figure 2. Temperature-Versus-Entropy Diagram for the STETF Energy Conversion Subsystem

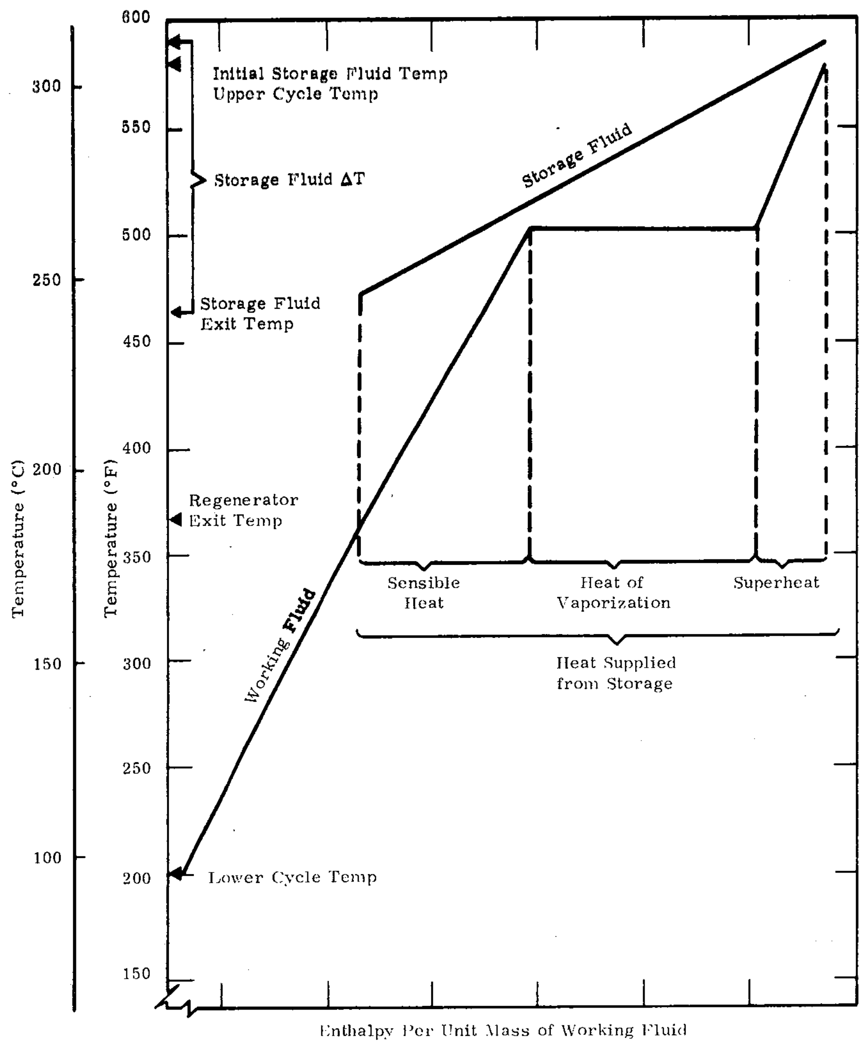

Figure 3. Storage Fluid and Working Fluid Temperature Vs Enthalpy of the Working Fluid for the STETF Energy Conversion Subsystem

Description of the Tests

The primary objective of testing has been to determine the operational characteristics and suitability of the ECS as part of a solar total energy system. Toward this objective, we measured the gross electrical generating efficiency of the unit under varying condenser coolant conditions, heat input conditions, and electrical loads. Other tests reported here include a safety-oriented test simulating loss of condenser coolant flows, and tests where the heat input was switched from the heater to storage and vice versa.

Conclusions

In general, our testing indicates that the ECS will operate satisfactorily as part of a solar total energy system. Work is still required to switch over effectively from storage to fossil-fuel-fired heater operation.

The measured gross electrical generating efficiency ranges from 11% at summer condenser coolant conditions to ~13.5% at spring and fall condenser coolant conditions. This is about two to three points lower than expected based on initial predictions by the supplier due primarily to the fact that the unit is derated from its original 100-kWe rating. A more definitive test program to measure both gross and net electrical generating efficiency will be reported in the next test summary report.

Testing at off-design turbine inlet temperatures and pressures indicates that cycle efficiency is only a weak function of these variables. However, efficiency is a strong function of condenser pressure and system electrical load.

Following addition of the turbine band valve feed-forward input signal to the flow control valve (in parallel with the existing turbine inlet pressure feed-back signal), the ECS operated stably from less than quarter load to full load.

The condenser coolant failure simulation test indicated that the ECS will fail-safe without external venting of toluene if coolant flow is interrupted.

Switchover tests from the gas-fired heater to storage heat input and vice versa indicated a problem in switching from storage to heater when the heater and associated piping are cool. Various methods for preheating the heater were tried, with one eventually successful. Switchover testing will continue as an automatic control method is evolved.

Efficiency Tests at Design Conditions

The first efficiency tests run on the ECS at Sandia were with the unit in the direct gas-fired heat-input mode. In this configuration, heat input to the unit was the same as for the original 100-kWe Sundstrand design. Toluene was heated directly with the gas-fired heater rather than using intermediate heat-transfer fluid. Tests were performed the week of December 1, 1975, primarily to shake down test cell instrumentation and to correlate with the test data obtained previously at Sundstrand. Tests were run with condenser coolant temperatures nominally controlled at 77°/88°C (170°/190°F), 57°/68°C (135°/155°F), and 32°/43°C (90°/110°F), representing design use conditions for summer, winter, and spring/fall operation, respectively. The superheater exit temperature was nominally controlled at 304°C (580°F) and the turbine inlet pressure at 1600 kPa (230 psia) for all tests representing the design conditions. Loads applied from the facility load bank corresponded to the half-load and full-load tests run at Sundstrand, where the unit carried its own parasitic loads (3 kWe on the engine frame, including 1 kWe for the combustion air blower). These loads were carried by the grid for the Sandia tests. Efficiencies measured are based on gross generator electrical power out, divided by the heat into the toluene. Test data are summarized in Figure 4 and tabulated in Appendix A.

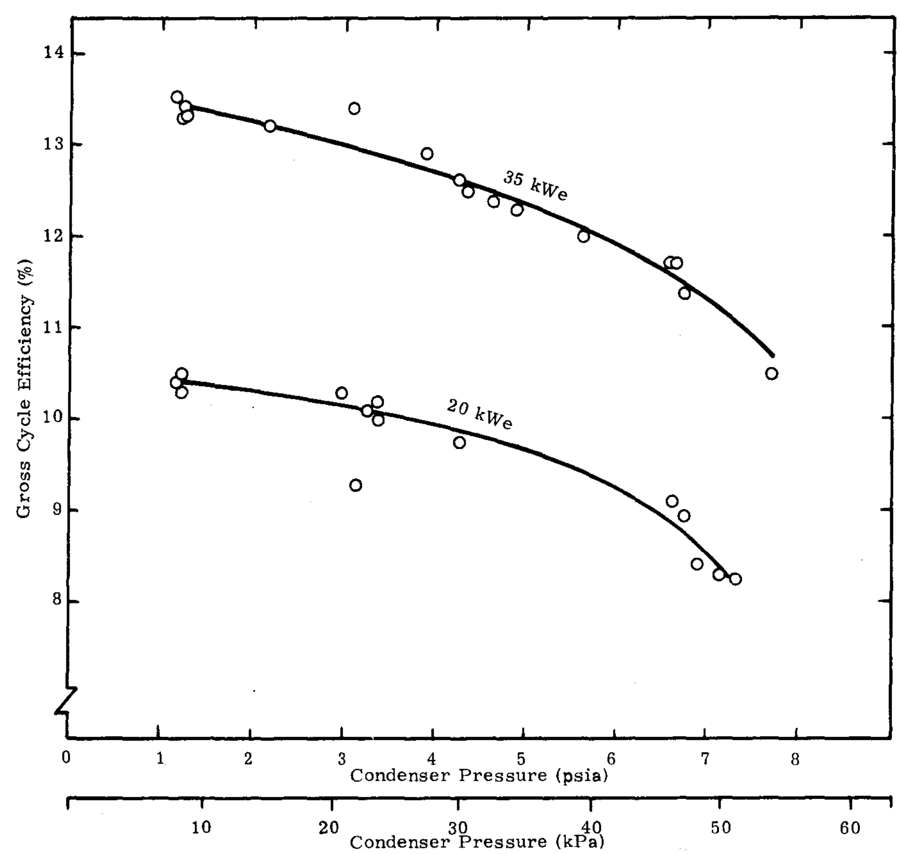

Figure 4. Gross Cycle Efficiency Vs Condenser Pressure for the STETF Energy Conversion Subsystem in the Direct Gas-Fired Mode. Tests run 12/3-5/75

After the ECS was plumbed to operate in the indirect heating mode as part of the Solar Total Energy Facility, another set of efficiency tests was run on June 23-24, 1976. In addition to the method of heat input, there were several other minor differences between the December and June tests, including a smaller fan on the generator, and slightly different electrical loads and winter condenser coolant conditions.

The June tests are summarized in Figure 5 and tabulated in Appendix B. At full load, under summer and winter operating conditions, the unit appeared to be about 0.3 to 0.5% more efficient than in the December tests. This is probably due to the smaller generator fan. Under fall/spring operating conditions, full load efficiency appeared to be about the same even with the smaller fan, primarily because the condenser pressure could not be reduced to the same level as during the December tests.

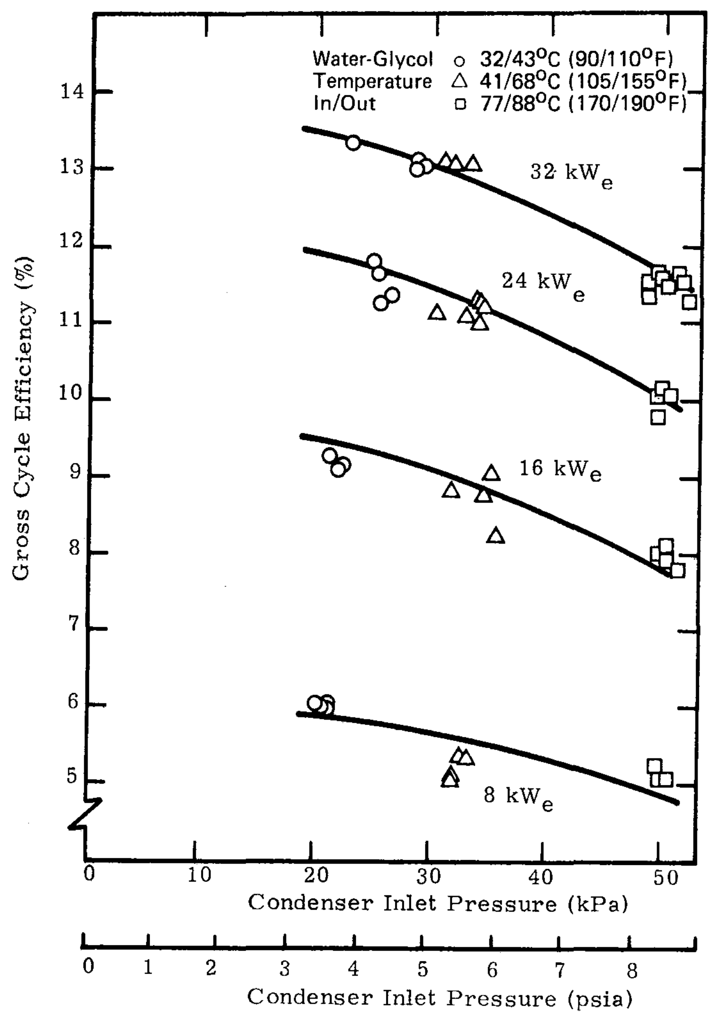

Figure 5. Gross Cycle Efficiency Vs Condenser Pressure for the STETF Energy Conversion Subsystem in the Indirect Heated Mode. Tests run 6/23-24/76

Results of efficiency testing since the June 1976 tests will be reported in the next test summary, along with measurements of the ECS parasitic power requirements.

Efficiency Tests at Off-Design Conditions

The first series of off-design parameter studies was to determine the effect of turbine inlet pressure and turbine pressure ratio on energy conversion efficiency at full load. The tests were run during October 1976. Condenser inlet/outlet coolant conditions were controlled at 77°/88°C (170°/190°F), 41°/68°C (105°/155°F), and 35°/46°C (95°/115°F) representing summer, winter, and spring/fall conditions, respectively. Varying condenser coolant temperatures varied the toluene condenser pressure, and the turbine inlet pressure was varied by adjusting the set point on the flow-control valve. Since the turbine nozzles are most efficient at design pressure ratio (230 psia/ 4.6 psia = 50), an optimum turbine inlet pressure for each condenser condition was expected to show up in the conversion efficiency. Test results, however, indicated that system efficiency was a weak function of turbine inlet pressure but a strong function of condenser pressure; i.e., changes in condenser pressure dominated changes in turbine inlet pressure. For example, Figure 6 shows the gross electrical generating efficiency versus turbine inlet pressure with the condenser operating at winter coolant conditions (which yields the nominal design value for condenser pressure). As shown in the figure, the efficiency was found to vary only 0.6% (which could easily be data scatter). Results were similar at spring/fall condenser coolant conditions, where the efficiency varied from 13.3 to 13.9%. At summer condenser coolant conditions, the unit would not run stably at lower turbine inlet pressures. Figure 7 shows the almost linear variation in cycle efficiency versus condenser pressure. As shown on the figure, condenser pressure varied considerably even when load and condenser coolant conditions were fixed. This was due primarily to a condenser air leak that caused the noncondensables removal vacuum pump to run intermittently, with resultant periodic swinging of condenser pressure. This test series emphasized the importance of maintaining a "tight" condenser and the condenser pressure as low as possible consistent with coolant conditions.

A second series of tests was run on March 16 and 28, 1977, where the Therminol 66 superheater inlet temperature (and toluene superheater output temperature) was varied. For these tests, the load was fixed at 32 kWe, and the condenser was operated at summer coolant conditions. Results shown in Figure 8 indicate that the ECS is relatively insensitive to the superheater out temperature and operated stably at temperatures down to 288°C (550°F).

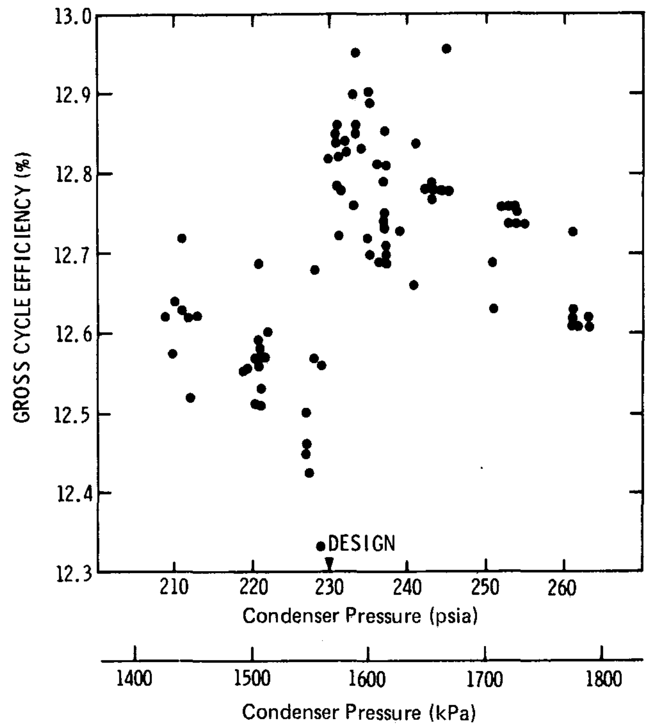

Figure 6. Gross Cycle Efficiency Vs Turbine Inlet Pressure (41°/68°C condenser coolant temperatures)

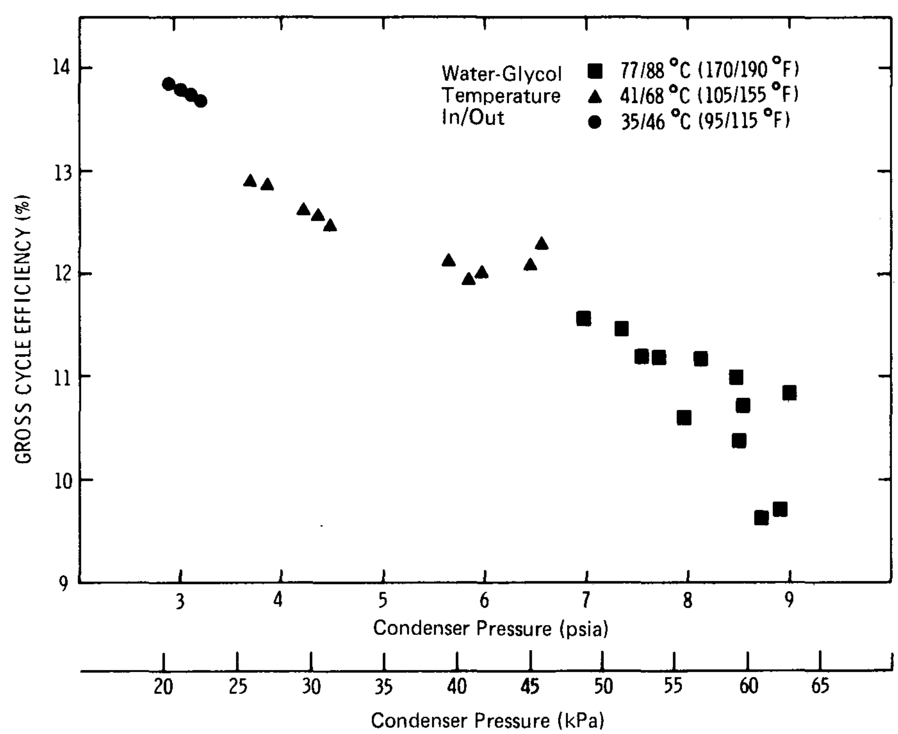

Figure 7. Gross Cycle Efficiency Vs Condenser Pressure

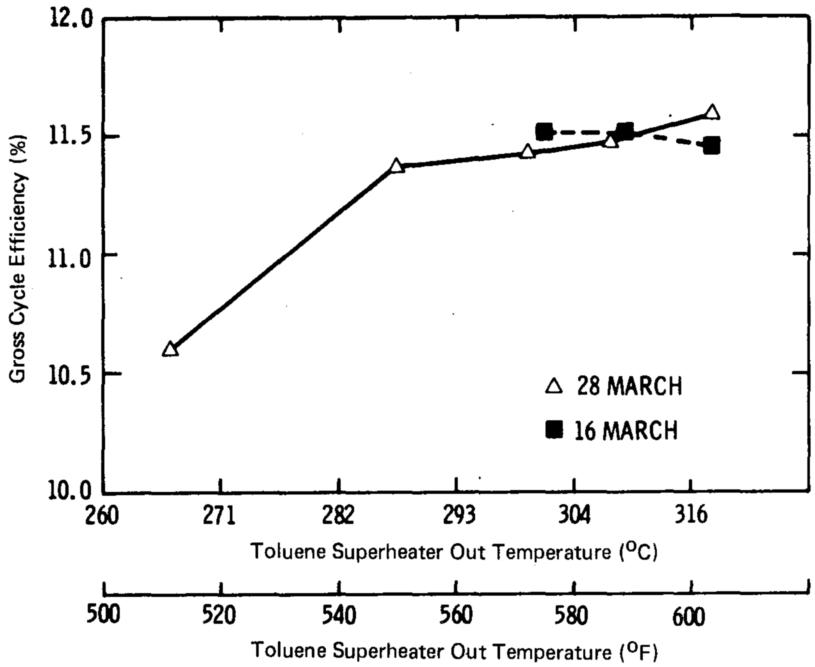

Figure 8. Gross Cycle Efficiency Vs Toluene Superheater Out Temperature (77°/88°C condenser coolant conditions)

Transient Electrical Load Response Tests

The ECS has 12 channels of pen recorders that give a real-time visual display of several system variables. These qualitative displays are used to determine when system stability is sufficient for recording efficiency or other data. Before April 1977, the system stabilized slowly after an electrical load change, often requiring 1/2 to 3/4 hr for stable operation after a load change; and the flow control valve always "hunted" or oscillated as indicated on the pen recorder. On April 28, 1977, the toluene flow-control valve was modified to accept a feed-forward signal from the turbine band valve in addition to the turbine inlet pressure feed-back signal used previously. With this change, the system operates stably except at no load (where the band valve still "hunts"), but this causes no problems. The ECS will now accept step load changes of 30 kWe, with stable operation obtained within 2 to 3 min as compared to the 1/2 to 3/4 hr experienced previously.

Loss of Condenser Cooling Tests

Preliminary safety analyses had indicated that an emergency source of cooling water would not be required to prevent overpressuring the condenser (which could blow the burst disk and vent toluene) if the condenser cooling flow was interrupted. A series of tests was run on June 30, 1976, to simulate worst-case conditions and to verify that the analyses were valid; i.e., that the various other safeties in the ECS would shut down the unit before the nominal 139-kPa (20-psig) condenser burst-disk rupture point was exceeded. Prior analyses had indicated that the condenser overpressure safety switch set point could be lowered to 3 psig (versus the 10-psig set point as received from Sundstrand) to provide additional safety margin since the ECS does not operate at as high a condenser pressure as the original Sundstrand design. The above change in set point was made before the test.

The test was conducted on the afternoon of June 30, 1977. Several safety precautions were taken because of the unknowns. If the burst-disk ruptured, toluene vapor would eject from a stack on top of Building 833. How this combustible toluene vapor would behave on its release was not known. For safety reasons, the Sandia Fire Safety Unit, Industrial Safety Unit, and Kirtland AFB Fire Department were asked to participate in the test. All contractors were removed from the immediate area and alerted to test conditions.

The ECS was run with an electrical load of 26 kW. The fossil-fuel heater was used for heat input, and Therminol temperature was reduced to increase toluene flow rate. Condenser cooling-fluid temperatures were increased to worst-case summer conditions. Condenser pressures were monitored and recorded. When desired conditions were established, the condenser pump was turned off and conditions monitored both manually and by minicomputer. Three tests were run in an attempt to rupture the burst-disk.

Initial Conditions for Test 1

1. Therminol heater output temperature of 302°C (575°F)
2. Condenser cooling-fluid temperature of 77°C (170°F) for input; 88°C (190°F) for output
3. Condenser pressure of 9 in Hg vacuum
4. Electrical load of 26 kW

The condenser coolant pump was turned off, and the pressure increased to 0 psig in ~30 s. The turbine was unable to maintain speed, and the automatic underspeed safety shut the system down. Pressure continued to rise for several minutes to 8 psig. The condenser coolant was then turned on, and the pressure dropped to 15 in Hg vacuum in 5 s.

Initial Conditions for Test 2

1. Therminol heater output temperature of 310°C (590°F)
2. Condenser cooling-fluid temperature of 75°C (167°F) for input; 89°C (192°F) for output
3. Condenser pressure of 7 in Hg vacuum
4. Electrical load of 16 kW (reduced to keep turbine running longer)

The condenser coolant pump was turned off, and the condenser pressure again increased to 0 psig in 30 s. Again the turbine was shut down by the automatic underspeed safety.

The subsequent pressure-versus-time history is given in Table I.

TABLE I

Condenser Pressure versus Time After Condenser Coolant Shutdown, Test 2

Period After Pump Shutoff (min)	Pressure (psig)
1	4
1-1/2	6
2	8-1/4
2-1/2	9
3	9
4	8-3/4
5	7-3/4

For Test 3, the electrical load was reduced to maintain turbine operation as long as possible after the coolant had been stopped.

Initial Conditons for Test 3

1. Therminol heater output temperature of 310°C (590°F)
2. Condenser coolant temperatures of 77°C (170°F) for input; 89°C (192°F) for output
3. Condenser pressure of 8 in Hg vacuum
4. Electrical load of 26 kW (reduced to keep turbine running)

The pressure-time history is given in Table II.

The tests verified that the system has adequate safety margin to prevent toluene venting if condenser coolant flow is interrupted.

TABLE II

Condenser Pressure versus Time After Condenser
Coolant Shutdown, Test 3

Period After Pump Shutoff (min)	Condenser Pressure	Electrical Load (kW)
0	8 in Hg	26
1/2	0 psig	3
1	3 psig	*
1-1/2	10 psig	-
2	13 psig	-
2-1/2	14-1/4 psig	-
3	14-7/8 psig	-
3-1/2	14-1/2 psig	-
4	13-3/4 psig	-

*Condenser over-pressure, safety sensor shutdown turbine.

Storage-to-Gas-Fired Heater Switchover Tests

Proper operation of the STETF requires the ECS to provide uninterrupted power while the source of hot fluid to the Therminol-toluene/Graham heat exchanger is switched from the storage system to the standby fossil-fuel-fired heater (or vice versa). Preliminary switchover testing on November 2, 1976, indicated that switching heat input modes would be a problem.

Part of the problem arises from the fact that the heater and associated piping, or the piping between the ECS and storage, may not have been used for several hours and may be close to outdoor ambient temperatures. Under these circumstances, cool Therminol is introduced to the Graham heat exchanger, where it absorbs energy, "quenches" the toluene, and lowers the system driving pressure.

Another problem is that the heater provides significant flow resistance, thus adding an additional load to the Therminol pump when maximum flow is already required through the Graham heat exchanger. The maximum flow of Therminol drops from ~43 gal/min to ~30 gal/min when the flow is switched through the heater. Further, operation of the turbine from storage after the system has cooled overnight is not ideal for this test because of the degradation of the storage thermocline and overall heat loss (see Reference 3), which results in a Therminol temperature much lower than the desired 310°C (590°F). For the tests discussed here, the temperature was more nearly 282°C (540°F). Because of the low temperature, the T66 pump is already near its maximum flowrate to provide sufficient thermal energy before the cold fluid from the heater is introduced. The additional cold fluid is enough to overload the system and shut down the turbine.

Several tests were conducted commencing in February 1977 to determine the extent of the problems and to arrive at a method of automating switchover. The testing in February was run by heating storage the night before each test and then allowing the piping and heater to cool overnight. The ECS was then run from storage in the morning at various power levels from full load to no load with the condenser inlet/outlet coolant at summer conditions, 77°/88°C. The heater sequence was then initiated. As soon as a heater pilot flame was indicated, the system mode switch was manually switched to circulate boiler Therminol flow from the heater rather than storage. In all cases, ECS operation could not be sustained due to low turbine inlet pressure. Shutdown occurred within ~ 2 s after switching modes at full load and within ~30 s at no load.

Manual switchover testing from the gas-fired heater to storage operation was conducted in late March. At 32-kW electrical load and summer condenser coolant conditions, the system ran ~90 s after switchover before shutting down due to low turbine inlet pressure. The ECS appeared very close to sustaining operation. This was an abnormal case, however, since the piping from storage had cooled overnight at temperatures of 4°C (40°F) or less--an unlikely combination with hot summer condenser coolant conditions. The test was rerun at winter condenser coolant conditions, and the switchover was completed successfully.

To overcome the problem of switching from the storage to the heater, some way to preheat the heater was required. Several alternatives were proposed in early April 1977. Referring to Figure 9, the proposed fixes are as follows:

(1) Fire up heater in the morning for a short period concurrent with system startup. The heater might then retain enough heat for a successful startup perhaps as long as 11 hr later.

(2) Crack heater exit bypass valve V2 slightly before using the heater to warm it.

(3) Provide a parallel bleed path (dotted line in Figure 9) from the heater entrance to the storage return line that would be opened for warmup before using the heater.

A test of the first fix was attempted May 10. The heater and piping were brought up to 310°C (590°F) to heat the storage system, and the entire system was allowed to sit 11 hr. Then the turbine was run from storage at 32 kWe with summer condenser conditions. The heater startup sequence was then initiated and the storage-to-heater mode switch actuated after the heater flame indicator lit. The turbine shut down, however, with low turbine inlet pressure ~30 s later. Therminol temperature at the heater outlet indicated 49°C (120°F) initially, although T66 temperature into the boiler did not fall below 138°C (280°F) before shutdown. Further testing revealed that the heater piping cools from 310°C (590°F) to ~149°C (~300°F) in 1 hr and falls below 93°C (200°F) in 4 hr, ruling out this preheat method.

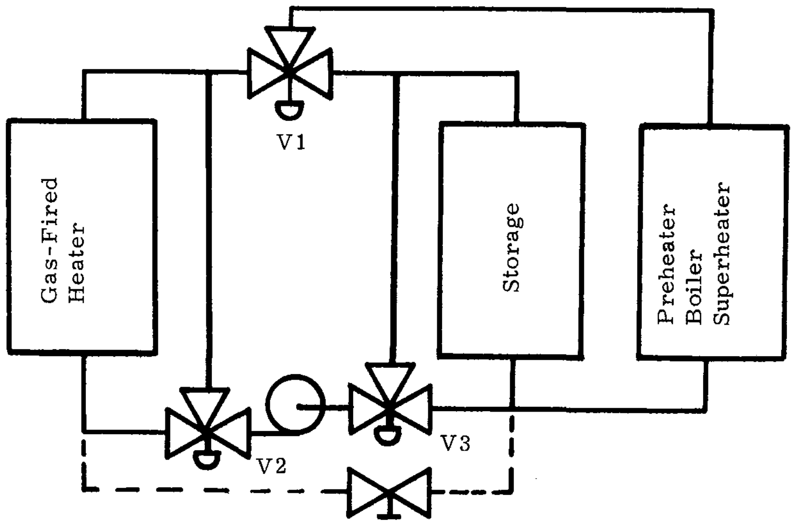

Figure 9. Heater Piping Diagram. Heater bypass shown as a dotted line.

A test of the second fix was attempted in late May. The primary problem here was to determine what the valve (V2) opening should be to allow the shortest heater warmup time (and hence minimum energy waste), and still permit sufficient flow to the boiler so that the turbine can carry full load. Breadboard control circuitry was built and this method of switchover attempted on May 27 and May 31. These attempts aborted due to a closed setting on valve V2 in one case and an unexplained lack of control of the condenser coolant flow in the second case.

On June 28-29, two more attempts were made to switch over from storage to the gas-fired heater after the heater and associated piping had cooled overnight. One test was aborted due to the insufficient hot fluid in storage. The second test appeared to be successful when a control card for the heater failed, causing the heater to shut down. In July, the turbine heater control box on the engine subsystem frame was modified by adding ventilation holes and two circulating fans to keep the printed circuit boards cooler. Three more attempts were then made to switch over from storage to gas-fired heater operation on July 2, 8, and 20 after the heater and piping had cooled overnight. The first two attempts were aborted when the storage system ran out of heat before the operation could stabilize (present storage capacity is limited to ~30 min at full load), and the third attempt failed when the heater shut down because of an overtemperature safety. As before, all attempts were initiated by opening the three-way T66 circulation valve before switchover to allow a pilot flow of T66 to circulate from storage to the heater in parallel with the flow to the boiler. One problem with this method is that the normal temperature gradient is reversed in the heater, which can cause the overtemperature situation experienced in the July 20 test.

Another series of tests were run in August, all unsuccessful. In two tests, the turbine shut down because of a toluene sniffer safety when the heater pilot light was lit. This was apparently caused by noise on the sniffer signal line, which came from the spark plug igniter on the heater. This was corrected by shielding the wiring. In another test, the turbine shut down owing to low turbine inlet pressure, as in several previous tests. Another test was somewhat successful in that the switchover was made, but the load was reduced from 26 kWe to 16 kWe to prevent underpressure, and a large amount of manual control was required to keep the heater from overheating the T66.

As a result of the above tests, we concluded that preheating the heater by cracking the three-way T66 valve (V2) would not be feasible under automatic control.

The third option for switchover consists of adding a new valve and bleed line to the heater inlet (see Figure 9) and circulating T66 from storage for preheat as in the second option, but the flow is established in the opposite direction. This allows the temperature gradient in the heater to be established in the proper direction for good control. Required modifications were completed by August 31 during a system shutdown.

Using the bypass valve and bleed line, successful changeovers from storage to heater operation were made under manual control at half load (16 kWe) and spring/fall condenser coolant conditions on November 18, 22, and 23. A successful full-load changeover was made November 30. For the tests, the hand-operated valve on the bleed line was opened two turns as soon as operation was stable from storage, allowing a pilot flow of hot T66 through the heater for preheat. The procedure varied at this point, but for the last test at full load the heater start sequence was initiated when the T66 heater inlet temperature reached ~216°C (420°F). This temperature rose to ~243°C (470°F) (i.e., the design value in normal heater operation) when the heater flame ignited. The hand-operated valve was then closed ~10 s before flame ignition. This approach gave a smooth switchover. Figure 10 summarizes data from the November 30 test. Data are tabulated in Table III.

Further testing at summer and winter condenser coolant conditions will be conducted to determine the best approach for automatic control of the sequence under all design conditions.

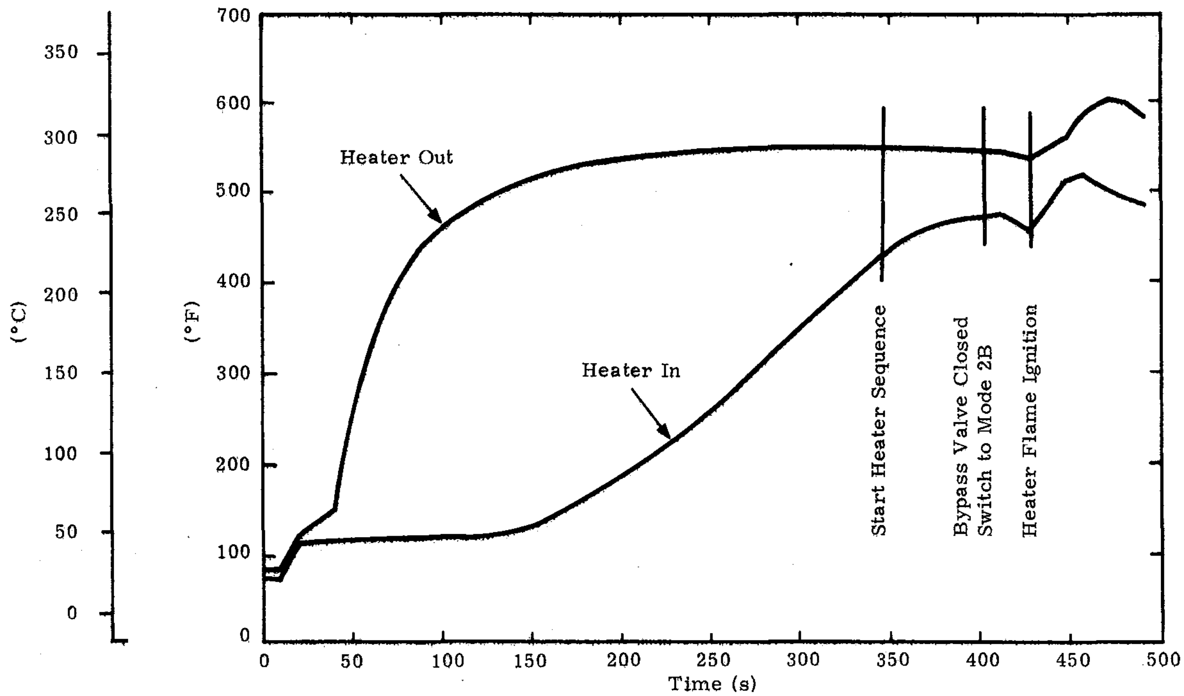

Figure 10. Heater In-and-Out Temperatures Vs Time for Storage to Heater Switchover Test, November 30, 1977

TABLE III

Turbine Switchover from Storage to Heater Using Heater Bypass Line, November 30, 1977

Solar Time	Time (s)	Heater Input (°C)	Temperature Output (°C)	Super Heater Temperature Output (°C)
10:47:80	Zero	23.2	28.9	294.6*
47:17	9	23.5	28.9	294.7
47:28	20	45.9	48.4	294.6
47:38	30	47.2	56.3	294.7
47:48	40	47.9	64.9	294.7
47:57	49	48.1	122.2	294.7
48:11	63	47.7	173.1	294.6
48:23	75	48.3	203.9	294.6
48:31	83	48.6	219.5	294.5
48:46	98	48.6	236.1	294.5
49:00	112	48.4	247.8	294.4
49:80	120	47.8	253.8	294.3
49:23	135	50.1	261.5	294.3
49:36	148	53.1	267.0	294.2
49:44	156	57.7	270.3	294.2
50:10	173	66.5	274.9	294.0
50:11	183	73.6	277.3	293.9
50:22	194	79.9	279.2	293.9
50:32	204	86.8	280.6	293.8
50:44	216	96.3	282.4	293.6
50:54	226	103.9	283.3	293.5
51:04	236	112.1	284.1	293.4
51:14	246	120.7	284.7	293.2
51:24	256	129.7	285.3	292.3
51:34	266	139.6	285.7	292.7
51:44	276	150.0	285.9	292.4
51:55	287	161.3	286.3	292.2
52:05	297	173.5	286.6	291.9
52:16	308	184.5	286.8	291.7
52:27	319	193.9	286.9	291.9
52:41	333	207.9	286.9	290.6
52:55	347	220.6	286.9	289.9†
53:06	358	228.3	286.7	289.4
53:15	367	234.6	286.6	288.9
53:25	377	238.9	286.2	288.0
53:39	391	242.8	242.8	287.6
53:51	403	244.9	285.3	287.1††
54:00	412	246.3	285.0	286.4
54:17	429	236.9	281.1	286.0
54:27	439	255.4	278.8	285.7
54:36	448	266.1	293.6	283.6
54:46	458	270.3	307.1	282.6
55:00	472	356.9	317.6	287.4
55:00	482	255.3	316.0	293.8
55:20	492	251.8	307.6	300.1
55:30	502	248.9	300.1	303.6
55:40	512	246.3	299.3	303.1
55:50	522	243.8	302.3	300.6
56:10	533	241.8	304.6	299.3
56:11	543	240.0	305.4	299.4

TABLE III (cont)

Solar Time	Time (s)	Heater Input (°C)	Temperature Output (°C)	Super Heater Temperature Output (°C)
10:56:21	553	238.6	304.9	300.1
56:29	561	237.3	303.5	300.8
56:39	571	236.2	301.4	301.1
56:33	585	234.6	299.7	300.6
57:80	600	233.4	298.8	299.3
57:18	610	232.7	299.1	298.3
57:27	619	232.3	299.3	297.7
57:37	629	231.9	299.4	297.3
57:52	644	231.8	299.2	297.2
58:30	652	231.9	298.9	297.2
58:13	665	232.3	298.7	296.9
58:30	682	233.1	298.8	296.8
58:40	692	233.7	299.1	296.7
58:49	701	234.3	299.4	296.7
58:58	710	234.8	300.1	296.8
59:13	725	235.4	300.7	297.0
59:23	735	235.7	301.3	297.3
59:33	745	235.9	301.8	297.8
59:43	755	235.9	302.3	298.2
59:53	765	235.9	302.7	298.6

*Open bypass valve two turns

†Start heater sequence

†† Bypass valve closed/switch to heater mode (mode 2B)

References

1. Solar Total Energy Test Facility Division 5712, Solar Total Energy System Facility Project Semiannual Report, SAND76-0662, Sandia Laboratories, Albuquerque, NM, April 1977.

2. K. D. McAllister and S. Thunborg, Solar Total Energy System Test Facility Operational Phase Test Plan, SAND77-0690, Sandia Laboratories, Albuquerque, NM, May 1977.

3. K. D. McAllister and T. D. Harrison, "High Temperature Thermocline Test for Storage Tank Static Stability," Letter Report, Sandia Laboratories, Albuquerque, NM, December 1976.

APPENDIX A

Test Data for the STETF Energy Conversion Subsystem in the Direct Gas-Fired Mode, 12/3-5/75

Data number	1	2	3	4	5	6	7	8
Date	12-4-75	12-5-75	12-5-75	12-4-75	12-4-75	12-5-75	12-5-75	12-4-75
Solar time	15:3:0	-	11:11:1	15:4:32	15:7:14	9:48:33	9:49:3	11:41:37
Glycol in °F	169.1	159.4	159.5	171.5	174	167.4	167.4	154.5
Glycol out °F	192.1	190.5	189.6	192.7	193.1	188.6	188.8	178.2
Glycol flow gpm	55.94	39.53	39.86	63.31	70.01	79.39	79.73	73.03
Condenser cooling Btu/hr	596554	551844	538739	622390	620203	756796	767125	803837
Regenerator liquid in °F	189	189.6	189.4	190.7	194.3	192.6	192.6	183.5
Regenerator liquid psia	283.2	288.8	286	274	286	329.2	306	327.2
Preheater in °F	359.1	365.6	366.5	358.8	366.2	357.8	354.9	343.3
Preheater psia	262.8	269.2	279.6	277.2	274.8	316.4	290.4	299.2
Superheater out °F	578.4	588.9	594.3	572	602.1	577.6	571.6	575.6
Superheater psia	233	240	251	229	241	261	257	263
Turbine in °F	554.9	570.6	574.3	550.5	570.2	561.3	554.6	552.9
Turbine psia	214	221	235	211	221	233	233	239
Regenerator vapor in °F	443.2	450.3	451.9	440.1	454.6	441.6	434.6	425.1
Regenerator vapor out °F								
Regenerator vapor psia	6.9	6.76	6.62	7.14	7.3	6.66	6.58	5.66
Condenser vapor °F	193.8	196.7	196.3	195.1	196.8	197.2	197.2	188.4
Toluene flow gpm	8.71	8.17	7.97	8.97	8.64	10.85	10.92	10.25
Energy into CP25 Btu/hr	814501	769038	755521	827835	833283	1.006×10^6	1.007×10^6	985214
Energy out T66 Btu/hr								
Gross electrical power out kW	20.12	20.2	20.2	20.15	20.15	34.5	34.5	34.57
Efficiency CP25 energy in %	8.43	8.95	9.11	9.3	8.25	11.69	11.69	11.97

Data number	9	10	11	12	13	14	15	16
Date	12-4-75	12-4-75	12-5-75	12-5-75	12-5-75	12-5-75	12-5-75	12-4-75
Solar time	12:0:43	12:4:0	13:42:26	14:3:26	14:21:23	14:23:54	14:24:32	10:5:40
Glycol in °F	166.9	171.5	136.4	129.8	134.8	135.2	135.5	117.3
Glycol out °F	188.4	195.6	151.8	152.2	156	155.9	155.7	160.8
Glycol flow gpm	75.37	77.38	79.73	55.94	52.59	53.93	54.6	23.11
Condenser cooling Btu/hr	751826	864114	553364	564225	502044	502729	496718	467154
Regenerator liquid in °F	181.1	187	164.3	163.1	163.1	163.2	163.1	157.4
psia	309.2	315.6	262.8	278.8	289.2	272	294.8	289.2
Preheater in °F	349.2	352.2	301.6	339.7	326.5	329	330	332.2
psia	318	302.4	271.6	257.2	271.6	293.2	251.6	255.6
Superheater in °F psia								
Superheater out °F	578.4	571.1	586.5	579.7	567.3	578.8	580.6	576.3
psia	263	247	250	245	235	247	247	245
Turbine in °F	561.9	555.6	560.5	559.2	542.9	552	554.2	562.3
psia	237	218	235	229	222	231	233	226
Regenerator vapor in °F	440.3	437.8	389.2	412.9	399.7	400.5	401.3	416
Regenerator vapor out °F								
Regenerator vapor psia	6.76	7.68	3.14	3.02	3.26	3.4	3.38	4.28
Condenser vapor °F	190.1	197	167.2	167.7	166.7	167.1	167.2	167.9
Toluene flow gpm	10.85	11.99	6.76	6.7	6.76	6.76	6.63	7.03
Energy into CP25 Btu/hr	1.0×10^6	1.119×10^6	741200	667261	677775	688739	676216	710171
Energy out T66 Btu/hr								
Gross electrical power out kW	34.57	34.57	20.2	20.2	20.2	20.2	20.2	20.3
Efficiency CP25 energy in %	11.37	10.54	9.29	10.3	10.1	9.98	10.17	9.75
Efficiency T66 energy out %								

Data number	17	18	19	20	21	22	23	24
Date	12-3-75	12-3-75	12-4-75	12-4-75	12-4-75	12-4-75	12-5-75	12-5-75
Solar time	11:42:18	11:22:42	11:7:50	11:5:25	11:3:30	11:1:12	15:4:36	15:5:6
Glycol in °F	125.3	111.6	129.3	131.8	136	141.4	96	96.4
Glycol out °F	162.5	151.6	154.5	156.8	160.7	164.9	111.3	112
Glycol flow gpm	38.52	38.19	62.64	63.31	64.65	65.99	71.02	69.34
Condenser cooling Btu/hr	668550	711646	735232	737006	743248	721449	490031	487836
Regenerator liquid in °F	158.7	155.8	164.2	166.9	168.1	167.2	130.1	129.7
psia	334.8	306.8	321.2	292.8	320.4	313.6	304.8	277.6
Preheater in °F	336.3	331.1	336.2	336.9	333.8	335.3	322.6	322
psia	280.9	297.2	310	307.6	296	297.2	296.2	268.4
Superheater out °F	573.6	581.7	577.7	587.9	576.9	579.5	594.7	589.5
psia	249	257	259	262	253	241	255	256
Turbine in °F	553.6	557.2	560.2	565	553	558.3	568.9	566.2
psia	229	236	240	243	231	221	237	239
Regenerator vapor in °F	413.7	409.5	420.8	422	417.6	422.3	407.2	406.3
Regenerator vapor out °F								
Regenerator vapor psia	-20.5	-20.46	4.26	4.36	4.62	4.88	1.22	1.18
Condenser vapor °F	413.7	409.5	168.2	168.9	171.1	173.3	135.7	135.4
Toluene flow gpm	9.17	8.91	9.44	9.31	9.58	9.58	6.09	6.09
Energy into CP25 Btu/hr	910943	910612	940403	943711	955986	961642	663459	657326
Energy out T66 Btu/hr								
Gross electrical power out kW	34.5	35.8	34.6	34.6	34.6	34.6	20.1	20.1
Efficiency CP25 energy in %	12.91	13.41	12.55	12.52	12.36	12.29	10.34	10.44
Efficiency T66 energy out %								

Date number	25	26	27	28	29	30
Date	12-5-75	12-3-75	12-5-75	12-5-75	12-5-75	12-5-75
Solar time	15:6:4	10:55:57	15:21:22	15:20:29	15:16:	15:16:19
Glycol in °F	97.1	91.6	90.4	90.9	92.5	92.9
Glycol out °F	113.1	111.3	110.7	110.9	112.2	112.5
Glycol flow gpm	67.33	77.72	72.02	74.03	76.71	76.71
Condenser cooling Btu/hr	485817	717764	658989	667391	681196	677745
Regenerator liquid in °F	129.7	130	127.2	127.5	128.7	129.2
psia	261.2	304.4	290.4	276.4	288	324
Preheater in °F	320.9	312.8	316.8	314.3	315.6	317.4
psia	268.4	293.8	264.8	278.8	276	278
Superheater out °F	585.5	577.8	581.2	579.4	573	575.1
psia	254	257	241	244	257	257
Turbine in °F	561.2	552.4	555.1	554.3	553.4	554.9
psia	239	237	227	226	239	238
Regenerator vapor in °F	402.4	397.9	404.5	400.1	402.7	404.6
Regenerator vapor out °F						
Regenerator vapor psia	1.22	-20.46	1.16	1.22	1.3	1.26
Condenser vapor °F	134.8	397.9	131.8	132.1	133.6	134.1
Toluene flow gpm	6.09	8.64	8.1	8.1	8.37	8.37
Energy into CP25 Btu/hr	653799	927593	873368	874098	885229	885321
Energy out T66 Btu/hr						
Gross electrical power out kW	20.1	35.8	34.4	34.4	34.5	34.4
Efficiency CP25 energy in %	10.5	13.18	13.45	13.44	13.28	13.27
Efficiency T66 energy out %						

APPENDIX B

Test Data for the STETF Energy Conversion Subsystem in the Indirect Heated Mode, 6/23-24/76

Data number	1	2	3	4	5	6	7	8
Date	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76
Solar time	9:23:49	9:25:19	9:26:50	9:28:20	9:43:21	9:44:51	9:46:21	9:54:48
Glycol in °F	91.3	91.4	91.2	91.1	90.5	91.1	91.2	91.4
Glycol out °F	108.8	109.2	108.9	108.4	109.2	108.4	108.5	109.3
Glycol flow gpm	40.7	39.02	43.6	43.21	53.43	51.25	49.74	61.1
Condenser cooling Btu/hr	324923	316878	351619	341048	455733	404499	392600	499181
Condenser hotwell liquid °F	142.2	141.8	141.5	141.4	142.2	142.7	142.9	147
Regenerator liquid in °F	155.8	155.2	155	154.9	153.3	153.6	154.2	156.5
psia	281.2	262.8	270.8	302.8	243.2	266.8	258	263.2
Preheater in °F	327.5	328.3	328.1	327	340.2	335	332.7	339.6
psia	270	270	270	270	253.2	261.2	266	251.2
Boiler #1 in °F	497.9	497.5	497.4	497.4	483.2	488.2	492.8	482.8
psia	276.4	275.6	274.8	275.6	247.2	257.2	266.4	245.2
Boiler #2 in °F	548.5	547.5	546.7	544.2	561	522.9	544.6	552.9
psia	273.2	271.6	271.6	271.6	242	252.4	262	238.8
Superheater in °F	591.9	589.8	586.6	583.3	585.5	583.6	586.7	587.8
psia	274.8	273.2	272.8	273.6	242	252	262.4	237.2
Superheater out °F	595.9	591.4	585.3	586.4	584	592.9	593.5	592.6
psia	279	278	277	277	241	255	264	237
Turbine in °F	570.7	568.6	563.3	560.7	565.3	567.5	570.6	572.7
psia	253	255	253	254	221	231	241	213
Regenerator vapor in °F	411.6	411.4	409.6	407.9	411.2	410.5	409.9	422.6
Regenerator vapor out °F	160.8	160.6	160.2	159.9	157.6	157.4	157.7	160.5
Regenerator vapor psia	3.08	3.1	3.06	3.02	3.2	3.26	3.32	3.7
Condenser vapor °F	131.3	131.6	131.9	131.9	136.5	136.5	136.4	140.3
Toluene flow gpm	4.22	4.32	4.35	4.32	5.86	5.79	5.72	6.73
T66								
Preheater out °F	468.3	468.4	469.1	468.5	469.1	469.7	469	468.8
Preheater in °F	530.3	529.4	528.9	528.3	539	535.6	532.7	534.8
Boiler #1 in °F	583.5	583.4	581.2	578.6	582.7	579.8	579	581.5
Boiler #2 in °F	596	592.7	588	586.4	586.1	587.8	592.1	591.6
Superheater in °F	588.9	587.8	586.2	587.3	585	597.5	595.5	593.8
Flow gpm	11.7	11.98	12.4	12.6	18.3	17.05	16.6	20.9
Energy into CP25 Btu/hr	445591	451469	449561	448254	592954	404499	597641	693875
Energy out T66 Btu/hr	348991	353059	358123	369776	523921	540058	521067	646742
Gross electrical power out kW	7.89	7.89	7.89	7.89	16.08	16.1	16.1	23.9
Efficiency CP25 energy in %	6.04	5.96	5.99	6.0	9.25	9.11	9.19	11.77
Efficiency T66 energy out %	7.71	7.62	7.52	7.28	10.47	10.17	10.54	12.63

Data number	9	10	11	12	13	14	15	16
Date	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76
Solar time	9:56:12	9:57:37	9:59:1	10:0:25	10:10:16	10:11:41	10:13:4	10:14:29
Glycol in °F	91.1	91.1	91	91.1	91.3	91	90.9	91.3
Glycol out °F	109	109	109.2	108.9	109.4	109.3	109.2	109.1
Glycol flow gpm	62.6	62.1	62.14	63.98	75.87	75.37	75.54	76.5
Condenser cooling Btu/hr	511494	507391	515876	519523	626438	629155	630555	621519
Condenser hotwell liquid °F	147.7	148.2	148.5	149.2	154.2	154.7	155	151.1
Regenerator liquid in °F	156.9	157.4	157.7	158.3	162.3	162.8	163.2	162.4
psia	242	246	260	265.2	269.2	290.8	291.6	238.8
Preheater in °F	340.3	341.1	338.8	338.6	340.4	340.8	341.6	339.4
psia	250	254	261.2	264.8	262.8	269.2	264.8	270
Boiler #1 in °F	483	482.8	489.8	491.9	490.3	491.1	491.1	495
psia	246	246	260.4	264.8	261.2	262	262.4	271.6
Boiler #2 in °F	552.3	551.9	544.9	539.6	527	524.9	523.5	521.7
psia	239.6	238.8	254	258.8	254	255.2	254.8	265.2
Superheater in °F	588.1	588.3	587.7	586.2	578.7	578.2	578.2	578.8
psia	237.2	237.2	252.4	258	250	250.8	251.6	262.8
Superheater out °F	593.4	592.7	591.6	592.5	584	584.4	584.9	585.1
psia	237	235	252	257	245	247	247	261
Turbine in °F	573.6	573.5	572.2	572.6	573.6	567.6	567.7	568.6
psia	213	214	228	232	219	219	221	234
Regenerator vapor in °F	422.1	423.7	418.6	417.1	424.9	425.4	426	418.4
Regenerator vapor out °F	161	161.6	162	162.8	166.3	166.8	167.2	165.8
Regenerator vapor psia	3.7	3.78	3.86	3.94	4.3	4.34	4.32	3.42
Condenser vapor °F	141	140.8	140.9	141.4	145.3	145.9	145.9	145.5
Toluene flow gpm	6.73	7.13	7.03	7.0	8.44	8.4	8.4	8.2
T66								
Preheater out °F	468.9	468.7	469	468.8	468.7	468.8	468.7	469.4
Preheater in °F	534.3	533.2	532.8	529.8	522.5	521.4	521.1	522
Boiler #1 in °F	582	582	581.5	579.6	571.1	570.5	570.2	570.8
Boiler #2 in °F	592.3	592.2	591.5	591.1	583.9	583.7	584.1	584.4
Superheater in °F	594.3	593.6	592	594.1	584.7	585.5	585.8	586.1
Flow gpm	20.6	20.5	20.97	20.28	26.77	26.6	26.7	26.6
Energy into CP25 Btu/hr	693782	732913	721573	718690	847704	843612	842763	824757
Energy out T66 Btu/hr	640155	634699	637816	629142	765589	766825	769863	765899
Gross electrical power out kW	23.9	23.95	23.9	23.9	32.3	32.25	32.25	32.25
Efficiency CP25 energy in %	11.77	11.15	11.32	11.36	12.98	13.04	13.05	13.34
Efficiency T66 energy out %	12.76	12.88	12.8	12.98	14.38	14.34	14.29	14.36

Date number	17	18	19	20	21	22	23	24
Date	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76
Solar time	10:21:30	10:22:54	10:25:32	10:26:55	10:28:20	13:10:43	13:12:10	13:14:59
Glycol in °F	91.1	91.1	91.4	91	91.1	103.7	102.4	104.4
Glycol out °F	109.1	109.1	109.4	109.9	109.5	155.6	155.9	156.2
Glycol flow gpm	77.21	77.21	76.7	78.05	80.06	15.24	15.24	15.24
Condenser cooling Btu/hr	633992	633992	629860	672833	671944	358635	369617	357931
Condenser hotwell liquid °F	147.6	147.7	148.5	148.8	148.6	162.7	163.2	164.7
Regenerator liquid in °F	156.3	156.5	157.1	157.2	157.4	171.6	172.6	174.2
psia	258.4	283.6	291.6	260.4	221.2	280.8	279.6	263.2
Preheater in °F	339.6	338.7	338.5	339.1	343.5	295.9	299.2	304.5
psia	268.4	264.8	256.4	256.4	242.8	263.6	261.6	262.8
Boiler #1 in °F	491.7	491.3	492.1	490.4	483.5	490.6	491.1	489.1
psia	262.8	261.6	263.6	258.8	246	260.4	261.2	257.2
Boiler #2 in °F	522.1	521.9	522.7	523.8	529.1	563	561.6	559.7
psia	256	254.8	256.4	250.8	237.2	256.4	257.2	252.8
Superheater in °F	577.3	577	578	578.8	579.3	587.6	588.2	584.7
psia	252.4	250.8	252.4	246	232.4	256.4	257.2	253.6
Superheater out °F	582.6	584	585.5	586.3	585.2	597.1	592.5	589.7
psia	247	247	249	239	223	259	261	257
Turbine in °F	566.8	566.9	568.4	569.5	570.2	561.2	561.1	559.2
psia	225	219	221	215	197	239	237	234
Regenerator vapor in °F	419.7	420.9	422.2	421.4	425.1	401.5	402.7	406.5
Regenerator vapor out °F	160.6	160.8	161.4	161.4	161.7	169.4	170	173
Regenerator vapor psia	3.62	3.58	3.72	3.7	3.58	4.76	4.82	4.9
Condenser vapor °F	149.8	149	148.5	148.4	149.8	162.2	162.7	163.8
Toluene flow gpm	8.34	8.34	8.37	8.37	8.64	4.75	4.75	4.72
T66								
Preheater out °F	468.5	468.4	468.9	468.7	467.4	469	468.7	468.7
Preheater in °F	520	520.8	520.9	521.5	521	545.3	542.5	538.9
Boiler #1 in °F	569.6	569	570.2	570.5	571	581.3	582.3	579.9
Boiler #2 in °F	582.6	582.9	584.1	585.1	585.1	591.5	590.9	587.1
Superheater in °F	583.5	585.1	586.7	587.4	585.3	597.9	592.2	590.9
Flow gpm	26.9	26.98	27.2	26.9	27.3	15.9	15.8	15.6
Energy into CP25 Btu/hr	839558	843699	849454	851730	871455	534434	525590	513276
Energy out T66 Btu/hr	763112	776608	791149	786700	794051	509560	481644	471319
Gross electrical power out kW	34.34	34.3	34.3	38.6	38.6	7.9	7.9	7.9
Efficiency CP25 energy in %	13.95	13.87	13.78	15.46	15.09	5.06	5.14	5.27
Efficiency T66 energy out %	15.35	15.07	14.8	16.73	16.57	5.3	5.61	5.74

Date number	25	26	27	28	29	30	31	32
Date	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76	6-23-76
Solar time	13:16:23	13:24:49	13:30:46	13:31:49	13:33:12	13:38:48	13:40:12	13:41:36
Glycol in °F	104.4	104.2	103.3	103.8	104.8	104.3	103.6	104.5
Glycol out °F	156.4	162.2	159.5	147.7	159.7	151.7	158.1	156.5
Glycol flow gpm	15.25	16.24	16.24	16.24	16.24	19.6	21.27	45.72
Condenser cooling Btu/hr	359300	426689	413625	323831	404110	421458	525329	1.08×10^6
Condenser hotwell liquid °F	165	161.8	162	161.1	162.2	160.8	162.2	165
Regenerator liquid in °F	174.7	170.5	171.1	171.7	171.4	169.7	169.8	171.6
psia	261.2	273.2	259.2	270.4	260.4	279.6	266	270
Preheater in °F	307.2	337.3	344.5	346	346.4	346.5	345.2	346.2
psia	258.8	261.2	255.2	264.8	256.4	257.2	254.8	267.6
Boiler #1 in °F	487.3	490.1	487.5	489.6	488.4	485.8	486.5	487.8
psia	254	260.4	254	260	255.2	251.6	252.4	255.6
Boiler #2 in °F	559.2	538.8	534.9	535.8	536	548	540.9	536.4
psia	250	255.6	249.2	255.2	250	245.2	246	250
Superheater in °F	584.3	584.9	583	584.6	583.5	583.8	582.5	583.4
psia	250	254.8	247.2	253.2	248.8	242.8	243.6	247.2
Superheater out °F	589.3	595.5	590.9	591.5	588.2	586.4	590.3	591.1
psia	253	254	249	257	249	241	241	246
Turbine in °F	558.9	571.4	569.1	570.9	568.8	567.7	570.3	572.1
psia	229	233	226	235	227	219	221	226
Regenerator vapor in °F	407.7	419.2	421.5	415.7	422.7	426.5	426.7	424.8
Regenerator vapor out °F	174.9	175.3	175.7	174.5	176	173.5	174.3	174.5
Regenerator vapor psia	5.0	5.34	5.18	4.74	5.24	4.92	5.06	4.54
Condenser vapor °F	164.4	171.7	171.5	172.6	172.5	175.7	176.4	176.7
Toluene flow gpm	4.72	6.49	6.26	6.23	6.13	7.43	7.4	7.33
T66								
Preheater out °F	468.5	466.4	467.9	468	468.7	470.5	469.6	468.8
Preheater in °F	538.7	528.2	524.7	524.3	524.2	532	529.2	526.1
Boiler #1 in °F	579.5	576.6	576	575.1	576	577.9	576.3	575.9
Boiler #2 in °F	586.8	591.3	587.2	591.2	587.6	587.2	588	589
Superheater in °F	590	593.5	596.4	590.2	589.4	586.8	591.5	592.7
Flow gpm	15.8	16.7	16.7	19.0	18.7	24.7	22.16	21.94
Energy into CP25 Btu/hr	510164	668243	628205	622084	608446	737344	742368	733474
Energy out T66 Btu/hr	474721	525910	531327	575595	556569	707623	667884	672447
Gross electrical power out kW	7.9	16.11	16.11	16.11	16.11	23.9	23.9	23.9
Efficiency CP25 energy in %	5.3	8.22	8.75	8.83	9.03	11.07	10.99	11.12
Efficiency T66 energy out %	5.69	10.45	10.34	9.55	9.88	11.53	12.22	12.13

Data number	33	34	35	36	37	38	39	40
Date	6-23-78	6-23-78	6-23-78	6-23-78	6-23-78	6-23-78	6-23-78	6-24-78
Solar time	13:43:0	13:44:24	13:45:48	13:50:0	13:52:48	13:54:12	14:10:17	13:10:35
Glycol in °F	104.2	103.4	104.2	105.6	105.5	105.2	112.2	170.8
Glycol out °F	154.5	155.9	155.9	152.1	156	156.2	156.9	189.9
Glycol flow gpm	21.27	22.27	22.44	24.45	25.96	26.6	27.41	47.06
Condenser cooling Btu/hr	485211	530171	526065	515974	594460	615794	557070	408213
Condenser hotwell liquid °F	163.9	165.2	167	163	162.5	163.8	160.8	190.2
Regenerator liquid in °F	172.3	172.8	174.3	171.6	170.5	170.8	168.4	198.4
psia	259.6	288.8	275.6	293.2	267.6	261.2	260.8	250
Preheater in °F	346.8	348.5	349	345.4	348.1	349.5	345	369.7
psia	269.6	252.4	264.4	265.2	266	261.2	258.8	262.8
Boiler #1 in °F	490	488.8	489.8	493.2	490.4	489.9	490.1	485.8
psia	259.6	257.2	260	266	260.4	259.2	258.8	250
Boiler #2 in °F	533.6	531.9	531.6	520.1	519.9	520.9	521.6	521.4
psia	253.2	251.6	254	259.6	253.2	251.6	250.8	245.6
Superheater in °F	584	584.4	584.2	578	578.1	579.3	577.9	578.3
psia	251.6	248.4	251.6	255.6	248.4	247.6	245.2	245.2
Superheater out °F	592.4	592.4	590.8	584	587.1	587.4	585.4	584.5
psia	249	248	247	251	243	241	239	247
Turbine in °F	572.7	573.7	573.2	567.5	569.8	570.4	569.4	566.5
psia	229	225	229	227	221	216	213	225
Regenerator vapor in °F	426.6	427.9	426.7	429.5	431	432.1	428	445
Regenerator vapor out °F	175.9	176.6	177.2	175.9	175.3	174.7	172.7	204.8
Regenerator vapor psia	5.12	5.1	5.04	4.96	4.8	4.62	4.92	7.58
Condenser vapor °F	176	177.2	176.3	178.7	176.9	175.9	177.3	199.1
Toluene flow gpm	7.26	7.33	7.3	8.5	8.5	8.5	9.04	5.69
T66								
Preheater out °F	469.3	468.3	468.5	468.5	468.7	468.7	469	467.9
Preheater in °F	525.5	523.7	523.6	520.8	518.9	518.8	520.8	509.9
Boiler #1 in °F	576	575.8	575.9	570.3	569.2	570.1	569.3	567.9
Boiler #2 in °F	590.3	590.7	590	583.8	585	586	584.3	584.5
Superheater in °F	593.9	593.2	591.7	584.6	588.6	588.4	586.4	583.9
Flow gpm	21.8	21.5	21.7	27.0	26.6	26.6	28.8	17.5
Energy into CP25 Btu/hr	726951	730755	723519	841534	840958	839044	899124	521103
Energy out T66 Btu/hr	671568	664625	662493	772992	786870	786379	835296	499665
Gross electrical power out kW	23.9	23.9	23.9	32.2	32.2	32.2	36.4	7.8
Efficiency CP25 energy in %	11.22	11.16	11.27	13.04	13.05	13.08	13.79	5.15
Efficiency T66 energy out %	12.14	12.27	12.31	14.2	13.95	13.96	14.85	5.37

Data number	41	42	43	44	45	46	47	48
Date	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76
Solar time	13:9:11	13:7:46	12:40:34	12:39:17	12:38:0	12:36:44	12:25:21	12:24:4
Glycol in °F	170.4	169.8	172.8	172.6	173	174.7	168.7	169
Glycol out °F	189.6	189.2	189.7	189.5	189.3	190.6	189.6	188.7
Glycol flow gpm	44.05	43.38	66.82	68.17	69.8	72.69	61.97	66.49
Condenser cooling Btu/hr	384067	382166	513044	523339	517214	525071	588018	594846
Condenser hotwell liquid °F	190.1	190.0	190.7	190.8	191.1	191.6	189.9	189.8
Regenerator liquid in °F	198.4	198.3	198.1	198.3	198.6	199	196.4	196.6
psia	249.2	270.8	258.4	271.6	263.2	274	294.8	317.6
Preheater in °F	367.5	366.3	366.4	367.6	369.6	369.1	360.3	361.2
psia	256.8	257.2	258	267.6	277.6	262.4	270.4	270
Boiler #1 in °F	488.9	492.7	492.3	492.8	492	492.3	499.4	498.5
psia	256.4	262.8	262.8	264	263.2	262	285.6	282.8
Boiler #2 in °F	517.5	510	500.4	508	510.5	517.5	501.4	499.9
psia	252.4	259.2	257.6	258.8	258	257.2	280	277.6
Superheater in °F	576.3	574.2	573.2	576.1	580.6	583.2	573.6	574.4
psia	253.2	260	255.6	257.2	256.4	255.6	277.6	274.8
Superheater out °F	587.7	585	581.2	579.6	582.8	591.1	586.6	584.7
psia	257	262	257	258	255	254	277	274
Turbine in °F	566.6	563.7	564.3	565.1	568.8	574.5	569.2	568.4
psia	234	241	233	235	235	233	251	249
Regenerator vapor in °F	442.9	440.4	444.8	445.8	449.9	454.5	443.3	443.4
Regenerator vapor out °F	205	204.6	204.4	204.7	204.9	204.8	202.8	203.2
Regenerator vapor psia	7.56	7.48	7.56	7.56	7.56	7.66	7.52	7.42
Condenser vapor °F	198.6	198.9	201.2	200.9	200.6	200.9	202.6	203.7
Toluene flow gpm	5.66	5.59	7.5	7.47	7.53	7.57	8.6	8.67
T66								
Preheater out °F	467.5	469.1	467.7	467.9	467.9	469.1	469.2	468.9
Preheater in °F	508.9	510.8	511.7	513.3	513.9	516	514.6	513.7
Boiler #1 in °F	564.9	564.1	564.9	567.7	571.6	572.8	562.4	564.5
Boiler #2 in °F	584.5	581.3	579.7	581.3	585.9	590.9	583.2	582.8
Superheater in °F	588.5	588.1	582.2	579.1	581.8	590.0	588.8	586.1
Flow gpm	16.6	16.2	21.2	20.8	19.8	20.3	25.7	26.3
Energy into CP25 Btu/hr	523297	514788	685290	677444	685644	702770	804646	806186
Energy out T66 Btu/hr	497018	476340	597853	568837	556744	606766	757938	760618
Gross electrical power out kW	7.8	7.87	16.0	16.0	16.0	16.0	23.9	23.9
Efficiency CP25 energy in %	5.13	5.22	7.98	8.08	7.98	7.79	10.11	10.09
Efficiency T66 energy out %	5.4	5.64	9.15	9.62	9.83	9.02	10.73	10.7

Data number	49	50	51	52	53	54	55	56
Date	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76	6-24-76
Solar time	12:22:48	12:21:31	10:38:25	10:37:0	10:32:48	10:31:24	10:30:1	10:28:37
Glycol in °F	170.2	171.2	172.4	171.8	166	165.6	165.1	165.3
Glycol out °F	188.4	189.2	189.2	188.9	187.3	187.3	187.3	187.3
Glycol flow gpm	73.19	78.89	95.3	91.79	73.86	71.85	70.85	71.18
Condenser cooling Btu/hr	605072	644962	727343	712993	714350	707920	714051	710985
Condenser hotwell liquid °F	190.3	191.3	191.3	190.7	189.4	189.6	190.2	191.1
Regenerator liquid in °F	197.1	197.7	196.4	196	195.4	195.6	196.1	196.6
psia	280.4	296.4	302	317.2	310.8	305.2	298	302.8
Preheater in °F	364.8	366.9	363	362.7	360.6	360.7	361.2	361.9
psia	269.6	267.9	265.2	270	266	270.8	270.8	270.8
Boiler #1 in °F	495.8	492.7	495.8	495.8	497.2	497.8	496.8	496.2
psia	272.8	264.8	273.2	275.6	282.4	282	282	279.6
Boiler #2 in °F	494.8	491.9	494.8	495.7	499.1	498.8	498.5	497.4
psia	266.4	258	266	267.6	275.6	275.6	274.8	271.6
Superheater in °F	574.8	575.1	570.3	570.6	569.9	569.6	569.6	569.1
psia	263.6	254.8	259.6	262	270	269.6	269.6	266
Superheater out °F	584.5	585	581.3	582.6	583.6	583.1	582.5	582.8
psia	261	249	253	253	261	263	262	258
Turbine in °F	568.4	568.5	566.4	567.5	267.9	567.4	567.	567.7
psia	235	225	221	225	237	235	231	229
Regenerator vapor in °F	446.8	452.5	444.7	444.7	443.9	443.3	443.3	443.4
Regenerator vapor out °F	203.2	203.1	201.5	201.1	200.9	201.2	201.7	201.9
Regenerator vapor psia	7.46	7.5	7.68	7.7	7.3	7.44	7.38	7.58
Condenser vapor °F	206.6	205.4	205.2	205.7	205.5	205.6	204.7	203.9
Toluene flow gpm	9.01	9.14	10.28	10.25	10.21	10.21	10.21	10.28
T66								
Preheater out °F	468.4	468	468.3	468.3	469	469.1	468.9	468.7
Preheater in °F	512.3	511.6	509.9	510.1	511.7	511.7	511.1	510.2
Boiler #1 in °F	564.7	564.8	559.2	558.9	557.6	557	557.9	556.2
Boiler #2 in °F	583	583.5	579.7	580.6	580.7	580.2	580.1	580
Superheater in °F	585.3	586	582.1	583.6	584.8	584.2	583.8	584
Flow gpm	26.23	26.0	31.5	31.1	31.28	31.62	32.0	31.98
Energy into CP25 Btu/hr	832178	843474	949308	949983	952291	950367	947842	953741
Energy out T66 Btu/hr	757857	757017	883191	883354	893114	900406	906325	908999
Gross electrical power out kW	23.9	23.9	32.18	32.14	32.19	32.19	32.19	32.19
Efficiency CP25 energy in %	9.78	9.65	11.56	11.54	11.53	11.55	11.59	11.51
Efficiency T66 energy out %	10.74	10.75	12.43	12.41	12.3	12.2	12.12	12.08

Date number	57	58
Date	6-24-76	6-24-76
Solar time	10:20:33	10:19:16
Glycol in °F	163.2	162.5
Clycol out °F	187	187.3
Glycol flow gpm	67.16	65.82
Condenser cooling Btu/hr	725551	740828
Condenser hotwell liquid °F	191	190.9
Regenerator liquid in °F	196.5	196.3
psia	292	317.6
Preheater in °F	357.2	357.2
psia	270	270
Boiler #1 in °F	498.2	498.5
psia	284.4	286
Boiler #2 in °F	499.9	500.4
psia	277.6	278.8
Superheater in °F	565.2	565.9
psia	272.4	272.4
Superheater out °F	578.8	577.3
psia	264	266
Turbine in °F	563.7	562.2
psia	237	237
Regenerator vapor in °F	439	438.3
Regenerator vapor out °F	201.5	201.4
Regenerator vapor psia	7.8	7.3
Condenser vapor °F	204.3	204.4
Toluene flow gpm	10.48	10.41
T66		
Preheater out °F	469.9	470
Preheater in °F	512.1	512.7
Boiler #1 in °F	553.6	554.4
Boiler #2 in °F	575.9	575.5
Superheater in °F	580.4	578.6
Flow gpm	33.35	33.53
Energy into CP25 Btu/hr	973078	963202
Energy out T66 Btu/hr	906959	895404
Gross electrical power out kW	32.21	32.21
Efficiency CP25 energy in %	11.29	11.41
Efficiency T66 energy out %	12.11	12.27

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