PERFORMANCE EVALUATION OF THE ORMAT GENERATOR AT WABUSKA, NEVADA

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The objectives of the test program were:

1. To monitor the performance of the system as a whole and of each subsystem, i.e. production well and pump, binary machine and cooling ponds.

2. Perform energy balance calculations and to compare the results with predictions of a computer program.

3. Provide TAD's Enterprises with suggestions for improving the performance of the total system or subsystems, particularly the spray cooling pond.

4. Provide operational data that could be of value in future binary power generation installations.

APPROACH

The testing program consisted of monitoring system operation during three nominal 24 hour test periods at different ambient weather conditions; summer, fall and winter. At one hour intervals records of temperature, pressure and flow rates of geothermal water, binary fluid and cooling water were made. Also recorded were instantaneous electrical energy production and running time of pumps in order to obtain net electrical energy output. It was assumed that the parasitic load pumping energy for the well, binary fluid and cooling pond would remain relatively constant.

After the tests, energy balance calculations were made using a TI 59 calculator program developed for the tests, and plots made of electrical output, cooling water temperature, enthalpy out at the expander and turbine generator efficiency. These calculations were made in order to verify that the tests records and procedures were essentially correct.

Further analysis of the system was performed to obtain second law efficiencies using the energy analysis method proposed by DiPippo and Marcelle (Geothermal Resources Council Transactions, Vol. 8, August 1984).

SYSTEM DESCRIPTION

The production well is 350' total depth with production temperature of 223°F. Pumping level is 208 feet at approximately 825 gpm. The pump is a Centrilift Series 875 with four stages and a 100 hp motor.

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The Ormat binary unit was originally designed as a heat recovery unit operating on Freon 11. For operation on Freon 114 at the TAD's Enterprises site, the vaporizer was changed from two pass to four pass, increasing pressure drop to minimize the possibility of flashing and to increase velocity for better heat transfer. Also, the nozzle ring and turbine wheel was modified and feed pump capacity increased to provide more flow. The unit has an 800 kW generator and is rated at 600 kW nominal net for the conditions at TAD's.

The cooling system consists of two 400' x 125' spray ponds. Each pond has 22 sets of five spray nozzles (110 total) mounted three feet above the pond surface. Part of the geothermal water going to surface discharge is used for make up. Approximately 2100 gpm of cooling water is circulated.

INSTRUMENTATION AND DATA ACQUISITION

Instrumentation was set up to monitor the energy input and output of each subsystem; production well, binary unit and cooling system. On the binary unit itself electrical energy, temperature, pressure and flow rate inputs and outputs were monitored for each component; evaporator, turbine feed pump, and condenser. Weather data was monitored by an automatic weather station. Figure 1 shows the location and number of the monitored points.

During each of the three 24 hour tests, most of the parameters were manually recorded hourly. Additionally, temperatures on the Ormat unit T_2 through T_9 were recorded on a multipoint strip chart recorder. Electrical energy input to all pumps was measured at least once during each test.

SUMMER TEST

During the summer test, preliminary heat balance calculations were not consistent with measured outputs. More detailed analysis after the test confirmed errors in data and subsequent inspection of the electric output meter indicated it had been incorrectly wired. The meter was replaced prior to the fall test. During the last four hours of the test a bi-directional kWh meter was read as backup. Typical performance during the last four hours were:

- Brine inlet temperature = 221°F (saturated liquid)
- Brine flow, 870 gpm = 425, 000 lb/hr
- Cooling water inlet = 65°F
- Cooling water flow, 2130 gpm
- Gross power = 647 kW
- Parasitic loads:

– 100 hp well pump =	108.9 kW
– 60 hp feed pump =	55.0 kW
– 60 hp circ. water pump =	54.0 kW
– Other loads =	23.7 kW
– Total =	241.6 kW

- Net resource utilization efficiency, 405 kW/425,000 lb/hr = 0.95 Wh/lb
- Net heat rate, (425, 000 lb/hr x 50 Btu/lb) /405 kW = 52,470 Btu/kWh
- Net thermal efficiency, 3,413 Btu/kWh/52,470 Btu/kWh = 6.5%

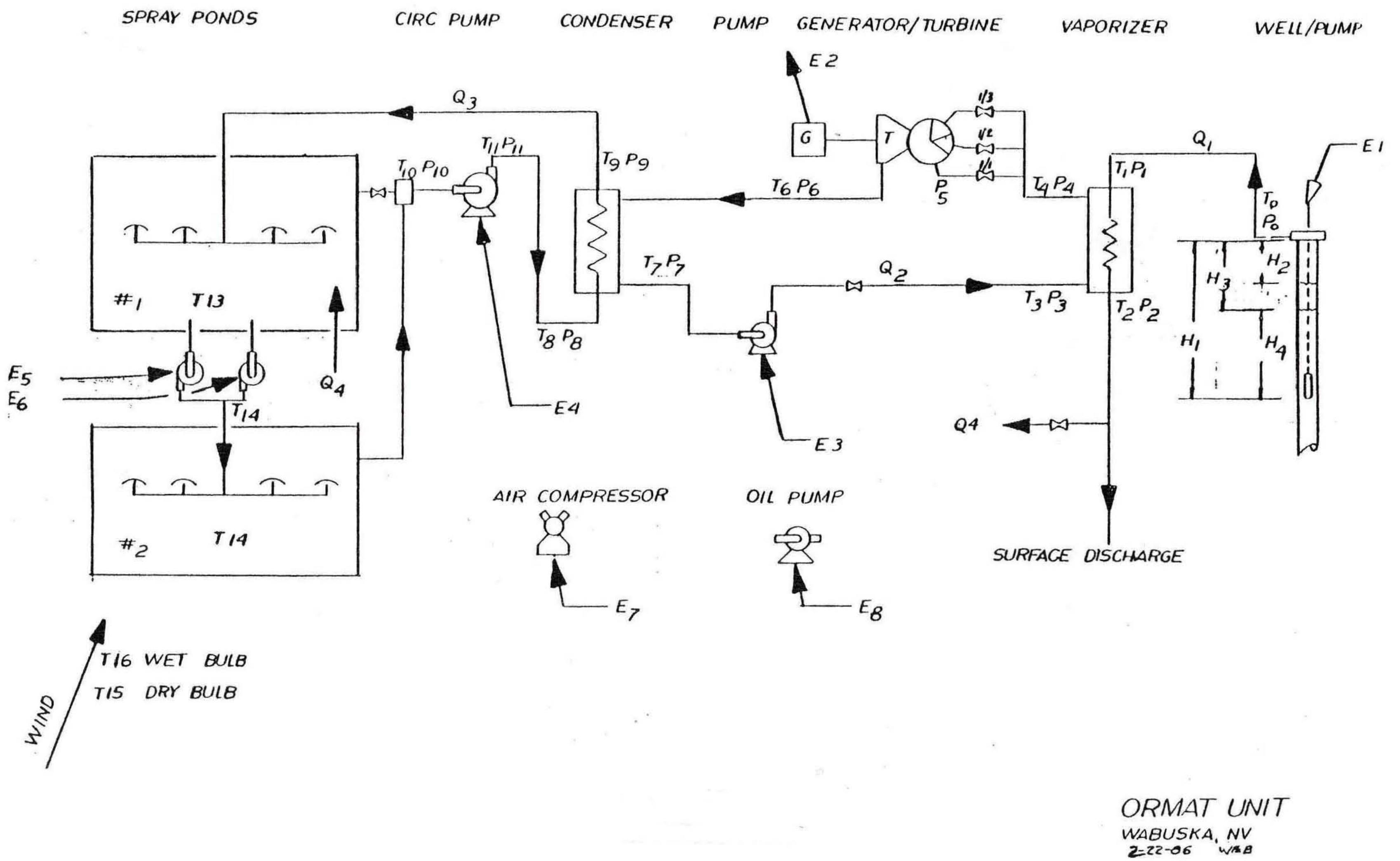

Figure 1-1
Instrumentation Points

It should be noted that ambient air temperatures reached 98°F during the test and a failure in the well pump underground cable caused a shut down for two days before the test resulting in seepage and evaporation from the cooling pond. Since large amounts of spent brine were being used as make up, cooling water temperatures were abnormally high, resulting in low efficiency.

FALL TEST

During the fall test, some unexplained variations in flow rates and large discrepancies in calculated enthalpy drops indicated there were errors in flow measurements, particularly in freon flows. This has resulted in questionable values in the second law analysis performed; however, the overall results which do not involve freon flows are considered to be fairly accurate. Conditions during the test were relatively stable and typical performance was:

- Brine inlet temperature = 221°F
- Brine flow = 774-813 gpm = 378,400 - 397,600 lb/hr
- Cooling water inlet, 55-58°F
- Cooling water flow = 2180 gpm
- Gross power = 821-852 kW
- Parasitic loads = 241.6 kW
- Net resource utilization efficiency, 1.53-1.61 Wh/lb
- Net heat rate, 36,252-38,178 Btu/kWh
- Net thermal efficiency, 8.9-9.4%

Electrical output was found to be related more to cooling water temperatures than to brine flows.

WINTER TEST

After several aborted attempts, the winter test was run March 6 and 7. Air temperatures and cooling water temperatures were higher for the “winter” test than for the “fall” test. Conditions at the Ormat unit were essentially stable during the entire test. Brine inlet and outlet temperatures did not change and cooling water inlet and outlet temperatures changed only 2.5°F. Brine and cooling water pressures did not change, although indicated flow rates varied by 3%. Electrical output high corresponded with cooling water inlet an doutlet high and vice versa. Typical performance during the winter test was:

- Brine inlet temperature = 221°F
- Brine flow = 840 gpm = 410,500 lb/hr
- Cooling water inlet, 58°F
- Cooling water flow = 2100 gpm
- Gross power = 755 kW
- Parasitic loads = 241.6 kW
- Net resource utilization efficiency, 1.25 Wh/lb
- Net heat rate, (410,500 x 58)/513 = 46,500 Btu/kWh
- Net thermal efficiency, 7.4%

RELIABILITY AND OPERATIONAL DATA

Monthly availability, power sales, capacity factor and average output per hour on line for the months of August 1985 through March 1986 are shown in Table 1-1. Capacity factor was calculated on the basis of the nominal 600 kW rating of the unit and 186.6 kW of the parasitic load. The parasitic load includes the well pump, cooling water pump and transfer pumps. The feed pump, lube oil pump and air compressor are considered part of the Ormat unit. Capacity factor = Power sales kWh per month divided by (nominal rating - parasitic loads) x total hours that month.

For example; November power factor = 304,000 divided by (600 - 186.6) x 30 x 24 = 1.02. Because the nominal rating is based on a cooling water inlet temperature of 65°F and the spray ponds are capable of providing cooler water during cold weather, the capacity factor can, and did, exceed unity during some months even though availability was less than 100%.

Ormat unit availability is based on the number of hours the unit was operated and the number of hours the system outside the unit (cooling water, geothermal water and electric grid) were available. Operating hours divided by support system available hours x 100 = % availability.

Table 1-1
PRODUCTION DATA AUGUST - MARCH

Month	Possible Hours	System Avail. Hour	System % Avail.	Ormat Unit % Avail.	Production Mwh	Capacity Factor	Avg. Site Output.Hr. On Line	Avg. Unit Output/Hr. On Line	Avg. Gen. Output/Hr. On Line
Aug	744	534.2	71.8	90.6	142	.46	265.8	452.4	507.4
Sept	720	657.4	71.3	94.9	252	.85	383.3	569.9	624.9
Oct	744	622.0	83.6	97.5	257	.84	413.2	599.8	654.8
Nov	720	671.0	93.2	96.1	304	1.02	453.1	639.7	694.7
Dec	744	644.3	86.6	86.5	311	1.01	482.7	669.3	724.3
Jan	744	702.3	94.4	98.8	314	1.02	447.1	638.7	688.7
Feb	672	428.7	63.8	99.9	245	.88	571.5	758.1	813.1
Mar	744	739.5	99.4	99.9	292	.94	394.9	581.5	636.5

Although availability data is not shown prior to August, power sales for the 12 month period of April 1985 through March 1986 amounted to 2809 MW hours. Capacity factor for that one year period was 77.5%. The low capacity was about equally due to system problems and problems in the Ormat unit.

By far the largest number of faults have been due to electric grid fluctuations and outages. If the grid was available, the unit was quickly restarted, usually within 15 minutes.

For the Ormat unit, shut down for scheduled maintenance operations has generally been less than two hours. Operations requiring shut down are items such as changing lube oil filters, taking samples of the freon for analysis, replacing feed pump packings, and electrical and control checks. Other regular maintenance procedures such as greasing feed pump and motor bearings and adding lube oil do not require shut down.

Comments by TAD's personnel indicate they feel the unit is easy to operate and maintain. If a failure occurs, the unit automatically shuts down and indicator lights show what the cause for shut down was. Once the problems is located and corrected, restart is accomplished by pushing one start button.

All rotating equipment, pumps, motors, turbine and generator are readily accessible in case of failure. For instance, the daily log shows that a shut down of four hours was required to replace the feed pump motor.

SPRAY POND PERFORMANCE

Spray pond performance averaged about 63% based on the 25 observations taken over two different 24 hour periods. Approach temperature (spray water temperature minus wet bulb temperature) averaged about 11°F.

Good spray pond performance would show an approach temperature of 4-6°F and excellent performance would be in the range of 2-4°F. The approach temperature of the spray water to the wet bulb temperature improved dramatically when the wind blew during periods of low relative humidity. On the other hand, the night time performance of the spray pond was generally poor because the ambient humidity of the air near the ponds was high and there was little air movement. The lower ambient temperatures, however, tended to compensate for this poor performance. The combination of wind and temperature experienced over the test period tended to keep the pond outlet temperature within a range of 7°F (53-60°F) while the ambient air dry bulb temperature ranged 40°F (70-30°F).

The overall efficiency of the original cooling system was probably increased 20% by adding the second pond and respraying the water to obtain additional cooling even though the cooling efficiency of this second pond is probably in the range of 35% during most periods of operation.

Although the economics computer program developed for the Oregon Department of Energy assumes an injection well and cooling towers rather than surface discharge and spray ponds, the computer prediction and actual results were fairly close. Using the resource characteristics at TAD's the program predicted a seven month net saleable power at 2065 MWh, which is 4% higher than actual sales September through March of 1975 MWh.