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Report on the October 1987 Hawaiian HGP-A Power Plant Overhaul and Reservoir Production Data

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ABSTRACT

The Research Corporation of the University of Hawaii (RCUH) completed the third overhaul of the HGP-A power plant during October and November 1987. The 3 MW power plant was developed jointly by the Federal government and the State of Hawaii and began operation in 1982 in order to demonstrate the electrical production ability of the geothermal resource. This paper presents the overhaul details, the investigative results and the history of the operational parameters. The increase in power output after the overhaul indicates that the HGP-A well has minimal production drawdown. However, the corrosive deterioration of the plant indicates that any new plant design must be practical, use proper materials and be easily maintainable.

INTRODUCTION

In 1976 the HGP-A well was drilled on the Kilauea East Rift Zone on the "Big Island" of Hawaii into one of the hottest geothermal reservoirs that had been identified up to that time. Short-term production tests conducted on the well showed a production capability of approximately 110,000 lbs. per hour of a mixed steam (43%) and brine (57%) fluid at a wellhead pressure of 175 psig. In order to test the long-term production characteristics of the reservoir and to demonstrate the technical feasibility of producing electrical power from this resource, a 3 MW wellhead generator facility was constructed at HGP-A and began operations in late 1981. This facility has now been in continuous operation for approximately 6 years and has maintained an availability factor of approximately 90%. During this period a substantial body of reservoir and engineering data has been generated by the operation. This paper will briefly review the changes in reservoir characteristics that have been observed and present a detailed summary of the engineering data that was gathered during the most recent November 1987 overhaul of the generator facility.

RESERVOIR CHARACTERISTICS

The production output of the well appears to have remained relatively stable during the production history of the facility. The peak output of the power plant was approximately 2.8 MW (gross) during the first several months of production from the well in 1981-1982. Although this output declined by approximately 30% during the period 1985-1987, at the conclusion of the overhaul, the power output of the facility recovered to approximately 2.45 MW (gross) indicating that much of the lost power was due to steam leaks and other losses in the surface equipment and not due to a change in the well flow. More recently, the well has also shown a further increase in production that has allowed the plant to generate approximately 2.6 MW (gross). This type of increase has been observed on at least two occasions in the past and has been tentatively attributed to clearing of a partial blockage in the wellbore. Earlier increases in productivity were followed by a gradual decline back to the pre-existing baseline production; the most recent increase has occurred so recently that the expected decline has not yet been observed.

The chemistry of the reservoir fluids produced by HGP-A has changed throughout the duration of fluid production. The most significant change has been a marked increase in total dissolved solids: sodium and chloride concentrations increased in concentration by a factor of approximately 10 during the first five years of production and achieved a maximum concentration of approximately 10,000 mg/kg (chlorides) and 5,000 mg/kg (sodium) in the brine phase. These increases were attributed to an influx of seawater into the hydrothermal reservoir that was induced by withdrawal of fluids from the well. This interpretation has been supported by changes in the concentrations of the other major ions in seawater that have shown strong similarities to the composition of fluids obtained from experimental studies of high-temperature seawater/basalt reactions. More recent observations have indicated, however, that the influx of seawater has peaked and that the total dissolved solids concentrations has begun to decline. This suggests that the instrusion aquifers are becoming obstructed by secondary mineral deposition associated with the high temperature seawater/basalt reactions. Continued production of fluids from this well is expected to show a progressive decline in seawater-derived solids as the seawater alteration proceeds.

In spite of the rather marked changes that have occurred in the dissolved ion chemistry, the concentration of silica in the fluids has remained relatively stable. The early production fluids showed a silica concentration in the range of 800 mg/kg in the brine phase. The current concentrations have remained within plus or minus 5% of this value indicating that the temperatures in the reservoir within the "equilibration radius" of the dissolved silica geothermometer, have remained stable at about 300°C throughout the production life of the well.

The concentration of noncondensible gases (.3% by wt.) in the steam phase from the well has also remained remarkably stable during the last seven years. Initial gas concentrations showed that CO_2 and H_2S, the major noncondensible gases, had concentrations of approximately 1150 mg/kg and 950 mg/kg respectively in the steam phase; the most recent analytical data available indicate a slight decline of these concentrations to approximately 950 mg/kg and 850 mg/kg respectively. These modest changes suggest that the steam reservoir has not been substantially depleted by production from the HGP-A well for a period of approximately seven years.

Because of the relatively stable rate of fluid flow from HGP-A and the relatively benign changes that have been observed in the fluid chemistry, it is expected that HGP-A could continue to supply the wellhead generator facility for several more years without substantial declines from its present level of production.

PLANT OVERHAUL

General

The plant overhaul was performed by Hawaii Electric Light Company (HELCO), who operates and maintains the plant for the RCUH. Thermal Power Company redesigned the existing steam release piping and rock muffler system and performed on-site contract supervision and liaison (Isemoto and Arakaki Construction Co.) for RCUH during the overhaul. RCUH personnel performed maintenance on the brine handling system and the Dow scrubber unit. The HELCO crew consisted of one superintendent, five mechanics/millwrights, one welder, four electricians, two combustion control mechanics and three helpers. The plant overhaul began in early November with completion six weeks later due to an extended work scope resulting from the excessively deteriorated plant condition.

The overhaul increased plant power output from 2.20 MW (gross) to 2.45 MW (gross), a 12% increase due primarily to the installation of new turbine seals, cleaning of the turbine nozzle, sealing of the diaphragm horizontal faces, cleaning of the condenser and rebuilding of the cooling tower. Figure 2 graphically represents data recorded since April 1982 through the period of several overhauls. On-line availability of the plant increased from 86% during the twelve months prior to overhaul to 97% since the overhaul, thereby reducing the operator maintenance work load and materials (primarily caustic) usage.

No steam or brine flow meter has been operational since June 1982 when the steam flow to the plant was measured at 48,000 lbs./hrs. at turbine entrance pressure/temperature of 188 psig/390°F. All informed personnel have estimated that the steam flow rate has probably decreased only marginally based on observed consistency of pressure and temperature and brine flow rate.

Steam Supply System

The condition of the single wellhead shutoff valve is unknown and therefore the well was not shut-in. After lubrication and electrical maintenance, two 10" diameter M.O.V.'s were operated to direct the fluid mass during daylight working hours to the "twin stack", a baffled expansion chamber with twin vent towers which successfully separated brine and steam. The steam billowed southwesterly away from most plant structures at an approximate noise level reading of 90 dbA. The brine overflowed into an adjacent small 1800 ft.[1] pond and due to poor percolation, thereafter overflowed across the plant entrance road into a vegetated land area. Damaged vegetation recovered within a month's time after the overhaul. The "twin stack", already in replaceable condition, was utilized only during the rock muffler rebuild, for a duration of six (6) 8-hour days, and it suffered severe stack damage. The interior was not inspected.

The original wellhead pressure and temperature instrumentation does not function due to plugging and corrosion - any measurements have been made on an interim basis with portable instruments.

The flash separator contained internal scaling up to 1/3 inch thick which was mechanically removed. The plugged relief valve was replaced with a new identical valve. The level controller was cleaned and calibrated. The separator bottom dump valve and vortex breaker which were clogged with deposited silica, were replaced. The venturi flow meter was not inspected but was assumed to be clean since the steam line interior was relatively scale and erosion free. The venturi meter differential pressure gauge has not worked since April 1982 due to corrosion of external sensing elements. The outlets were cleaned and made ready for a portable differential pressure gauge installation. The moisture separator was cleaned of scale. The turbine throttle valves were dismantled and rebuilt/adjusted to operate within allowable setting tolerances.

Steam Release System

The original 20" diameter vent piping, which was installed below-grade for noise abatement, had deteriorated badly, leaked dangerously and was replaced with an above-grade 10" diameter pipeline on supports. The M.O.V. which also leaked was replaced with a reconditioned spare valve and actuator. The water/caustic injection manifold and control valve were replaced. Mixing baffles (interior 1/2 plates) were installed downstream of the injection point. The piping system was insulated for safety and noise mitigation.

The existing rock muffler interior had collapsed and clogged. It was completely replaced with a redesign utilizing concrete supporting blocks, drill pipe grid and on-site large diameter side-drilled holes. The new 4" diameter carbon steel drain pipes were installed to the adjacent percolation pond. The original top-stack was reset in place. A hydrogen peroxide injection system was not installed as the muffler liquor immediately percolated into the ground, allowing little chance for the liquor to become acidified and release H_2S to the atmosphere.

Brine Disposal System

The two existing 4" and 3" diameter brine lines were scaled with up to 1/4" silica deposition. A new 4" diameter carbon steel pipeline and rebuilt M.O.V. was installed at the settling basin. The sparger box, which was clogged with solidified rock, was emptied (with a jackhammer) and repiped. The settling basin was cleaned of major sections of deposited silica. A new weir plate was fabricated to fit the brine outlet channel in order to measure flowrate. The settling basin provided too short a detention time therefore much of the silica deposition in the extensive pond network which had now grown to eight separate ponds - a total surface area of approximately 16,000 $ft.^2$ The pond deposition was partially removed by a clam-shelled crane for ten (10) 8-hour days resulting in only marginal improvement in the percolation rate.

Turbine

The Elliot rotor (5800 rpm, 6-stage, 26" diameter LSB, 316 stainless steel) was removed, inspected, sandblasted and partially coated with an antioxident. The rotor was found to be uniformly coated with a fine-grained, microcrystalline pyrite indicating a good mist elimination by the interstage drain system. Pitting, erosion and scaling was minimal and found to be as that reported in earlier inspection reports (worse on stationary blades than rotor blades) - some erosion on the first and second stage blades, minor pitting on the last stage blades and no evident stress corrosion cracking. The good condition of the rotor confirms the value of a rugged design which offers good distance between blade and diaphragm with a minimal number of blades. The outer blade edges were relatively clean due to particle impingement and water washing. The rotor scaling was caused by the oxygen input enhanced by temperature cycling during the many outages prior to the overhaul. This could be minimized by installing an antioxident injection capability or by nitrogen blanketing during shutdowns. The stellite shields on the last two stage outer leading edges were in good shape. The inner stage seals were, as suspected, worn down and were replaced with new stainless steel seals. The bearings were inspected, polished and reinserted.

The 29-opening nozzle block was found to be approximately 30% clogged and was scraped clean in place since a new nozzle block was not readily available. The remaining uncleaned blockage was estimated to be approximately 5%. A new nozzle block was planned to be ordered for the next plant overhaul. The clogging of the nozzle block was thought to be caused by a brine aerosol spray which passed through both the flash centrifugal separator and the corrugated plate moisture separator.

The turbine diaphragm horizontal mating faces had eroded at the inner stages and were rewelded to proper tolerance. New keys were installed. The remating of the diaphragms proved to be a tedious, precise and time-consuming task. It is not known how well the mated surfaces matched together after installation.

The gland seals were moderately clogged, and the interstage drains had some plugging from condensate carryover. The 40" diameter overhead exhaust duct was relatively clean.

The lube oil system was completely serviced; inspection showed no unusual sign of wear other than the turbine lube oil pump driver, which was found to be extensively worn and was replaced with a new one. The turbine/gear reducer coupling was found to be frozen and was repaired.

Condenser

The Graham condenser had several fitting-related air leaks which were sealed. Noncondensible gas buildup does not appear to be a problem. The condenser, located above grade and outside the turbine building showed little sign of external corrosion. The tube exteriors were very clean with no major pitting. The tube interiors were cleaned with brush plugs; approximately three gallons of iron oxide slime originating from the corroded circulation water pipelines were removed from 1200 tubes. There was minimal scaling or buildup in the water box. The vacuum breaker was serviced.

The turbine condensate drain chamber located in a vault, below grade, outside the turbine building is in an unknown internal condition. Several fitting leaks were sealed and the level control manifold and valving were replaced.

The condensate return piping system appears to be in workable condition although the orifice meter cannot be read due to plugging of the pressure outlets. A new substitute spool has been fabricated which will allow for orifice plate calibration and meter installation. Present condensate measured flow rates are not accurate. Minor sulfide control effort is made as less than 1% of H_2S remains water-bound.

Cooling System

Although the two-cell Marley cooling tower performed adequately (due to forgiveness of the design), the deteriorated physical condition warranted major repairs to prevent a future emergency shutdown and repair. The basin was emptied and substantial accumulation of deposited fibrous and iron oxide material was removed. The concrete had not deteriorated significantly. HELCO crews replaced the entire plywood water box using existing cleaned nozzles, and replaced 75% of the drift eliminators. Much of the top packing layer was replaced or repaired. The fan blades were removed, refiberglassed and balanced in place; the motors were checked and serviced. new fan safety shrouds were constructed. Approximately 1/2 of the outside corrugated fiberglass louvers were replaced. The fire alarm and spray systems were checked and made fully operational. The capacity of the cooling tower was calculated to increase by approximately 20%.

Prior to the overhaul, the 12" carbon steel water circulation pipelines were a constant area of maintenance and plant shutdown due to leakage (about one major leak per week). Sections of both the inflow and outflow pipeline were replaced with new and/or used 12" diameter pipe as available. Other less deteriorated pipe was rotated 180^o and reinstalled as the corrosion/erosion occurred on the bottom of the pipe. About 1/2" of the pipe wall thickness had been corroded along the bottom of the existing pipe. The pipe rack and supporting structure was repaired in places and painted. The circulation pumps showed extreme exterior corrosion. However, they performed adequately on an alternating basis. Sticking isolation butterfly valves were lubricated and found to be in good condition. The caustic injection sensor and controller were replaced and operational tolerances reset in order to maintain a more consistent pH range of 8-10 in the circulation water, thereby extending the service life of the bare carbon steel pipe.

Abatement System

The John Zink incinerator is designed for an H_2S rate of 33 lbs./hr. However, it receives an average flow of 44 lbs./hr. - a 33% increase. Tests show that 99% of the H_2S is abated through the system since, with lack of ammonia and boron in the steam condensate, the H_2S strongly favors the gas phase to the water phase. The system operated inconsistently due to overall corrosive deterioration. However, system repair was minimal in anticipation of replacement by a new McGill-America unit which has been engineered by Thermal Power Company.

The incinerator/scrubber system was disassembled as much as possible and inspected throughout. The propane gas system was rebuilt and new plastic solenoid-operated control valves installed. The burners were cleaned and the sight glass replaced. The refractory material was rebuilt both inside the incinerator and within the exhaust duct to the scrubber tower. The scrubber tower, which acts more as a quencher in its present configuration, was repacked and leaks were repaired. The noncondensible gas holding tank interior condition is unknown and was not maintained. The extensive exterior corrosion to the control panel throughout limits its operation to a simple on-site manual control.

The Dow Scrubber unit fixture leaks were resealed, and the corrosion-plagued pumps replaced by plastic pumps mounted within a protective enclosure. The pH-caustic controller was replaced thereby allowing for a more consistent operation and hopefully a reduction in the previously greater than 2.0 moles caustic per mole H_2S usage rate.

The sealing of leaks, rerouting of lines and improvement in subsystem capacity has lowered the ambient the air H_2S concentration near the plant by an average of approximately 20%.

The extremely corroded yet operable emergency backup scrubber column was replaced with new pipe and packing. The flow lines to the unit were also replaced. The simple automatic control system was serviced.

Chemical Supply

Both the 50% and 10% holding tanks exhibit minor exterior corrosion. The interiors were not inspected. The tank transfer and distribution pumps were replaced with plastic lined pumps. The electrical system in this area was reworked extensively replacing conduit, conductor and enclosures.

Compressed Air System

A new Joy Manufacturing Co. 140 CFM compressor was installed during the summer of 1987 with a properly sized intake filter and knockout drum. The two existing Deltech, heatless air dryers were serviced and remain in operation. The plant air system has become oil-contaminated and will take much persistent effort to clean out. The noise, generated by the air coolers (blowers) located outside the building was significantly reduced by enclosing the blowers within a temporary enclosure made from plywood and concrete blocks. The low frequency noise level had previously carried throughout the nearby neighborhoods and caused several complaints.

Generator & Electrical System

Megger tests of the Ideal Co. 3750 KVA, 510 amp (pf.8), brushless A.C. 1800 rpm generator insulation proved its good condition and the voltage regulator was satisfactory. Two (2) exciter diodes were unexpectedly found to be burnt out and were replaced; there had been no indication of this condition beforehand. The balance between phases measured at less than 1% and the currents did not exceed the design limit of 500 amps. The end bearings were removed, polished, checked and reinstalled. Quite a lot of metal oxide slime was removed from the cooler.

The main transformer load taps which had failed due to corrosion, were replaced to specification. One of the main fuses blew out earlier and was replaced with a non-identical fuse due to the difficulty in purchasing the original equipment type. The insulators were washed and silicon-coated. A new grounding resistor was installed to replace the extensively damaged original unit. The auxiliary generator remains ungrounded. The Onan 15 kw standby generator functions properly but is very limited in its function. The resistive load bank has not been used since the plant startup and remains out of service. The motor control centers, circuit breakers and relays were checked, calibrated and found to be in good working order. A thorough study of the relay response and coordination is warranted but was not performed at this time. The control and communication panels were checked and calibrated - many meters and recorders do not function well due to instrument and sensor problems. The revenue meters were calibrated.

The electrical cable tray from the turbine building to the cooling tower which was severely corroded was broken away and extensively repaired. Many on-site overhead lights were repaired or replaced with new plastic, high-intensity lights.

Building and Yard

The outside steel surfaces have corroded extensively particularly that facing the cooling tower and brine ponds. Some painting was done and the turbine building louvers were replaced with wood louvers. The interior of the building appeared in good condition; the switchgear room module interior appeared in brand new condition. The air conditioners to the switchgear and control modular rooms were recently overhauled. The dual 30-ton (total) Dankas Co. overhead bridge crane #1 brakes were repaired. However, the broken gear on the parallel crane #2 could not be repaired due to lack of available parts.

All fire extinguishers were recharged and fire alarms checked. Three new emergency shower stations were installed in place. The Gaitronics plant public address system was corroded beyond repair and remains out of service. The Hawaiian Telephone system and the automatic telemetering to HELCO's main receiving center, the Hill Street power plant, works well.

About 300 ft. of heavily corroded fence was replaced. The visitor center was in good condition and is routinely maintained.

Operations

Since operation began in April 1982, th on-line availability factor has remained at a consistent average of 96-97%. The average for 1983 was 94% due to an extensive outage for an overhaul. The lower capacity figure of 86% for 1987 prior to the overhaul was due to many short-term, intermittent shut downs for maintenance, primarily the incinerator and circulation water lines.

The cost of operation is proportioned as follows:

Operation labor & overhead	20%
Caustic	35
Guard Service	5
Operational Supplies	3
Env'l./Reservoir Monitoring	10
RCUH Administration	3
Maintenance Labor & Overhead	17
Maintenance Material	7
	100%

In 1985 the total minor overhaul cost for the year was an addition of approximately 8% of the annual operating budget and the major 1987 overhaul is an addition of 20%.

Operating costs have increased approximately 10% per year since initiation. However, revenue rates have fluctuated. Plant revenues do not cover the entire plant operational and overhaul costs.

Conclusion

The power plant was originally designed and built with intention of testing and monitoring of geothermal fluid production from the HGP-A well and proving the feasibility of electricity generation. The plant was originally designed for a short operational life span of 2 years maximum. However, changes in DOE funding led to a full ownership transfer to RCUH, who decided to continue the life of the operation. The short design life has resulted in higher operation and maintenance costs than would otherwise be expected. Hence, maintenance of the facility has been performed on an as-required basis. In spite of this, the relatively good operational condition of the major subsystems and limited drawdown of the well gives valid indication that geothermal electric power production is feasible.

This major overhaul caused the rebuilding or replacement of many systems including the cooling tower, circ. water lines, air compressor, switchyard, vent line and rock muffler, throttle valves, flash separator, incinerator/quencher, brine lines, emergency back-up facility, brine settlement basin and percolation ponds.

Upon study of the past plant operation and overhaul requirements, the following improvements are suggested:

- attempt to dispose of H_2S without using a caustic chemical process; an absorption/injection process may be economically superior and minimize the hazardous waste disposal problem;
- use proper materials, coatings and maintenance methods to minimize corrosive deterioration;
- utilize purged or air-conditioned enclosures to minimize corrosion; and allow for equipment access during rainy weather periods;
- develop an improved method to separate silica from the brine prior to percolation or directly pressure inject the silica-laden brine back in the reservoir;
- utilize additional follow-on power generation equipment to take advantage of the high pressure/temperature steam and separated brine fraction;
- continue research and developing secondary, non-electrical systems such as koa wood drying, seedling growth enhancement and many other programs (an ambitious program is presently underway by the RCUH).

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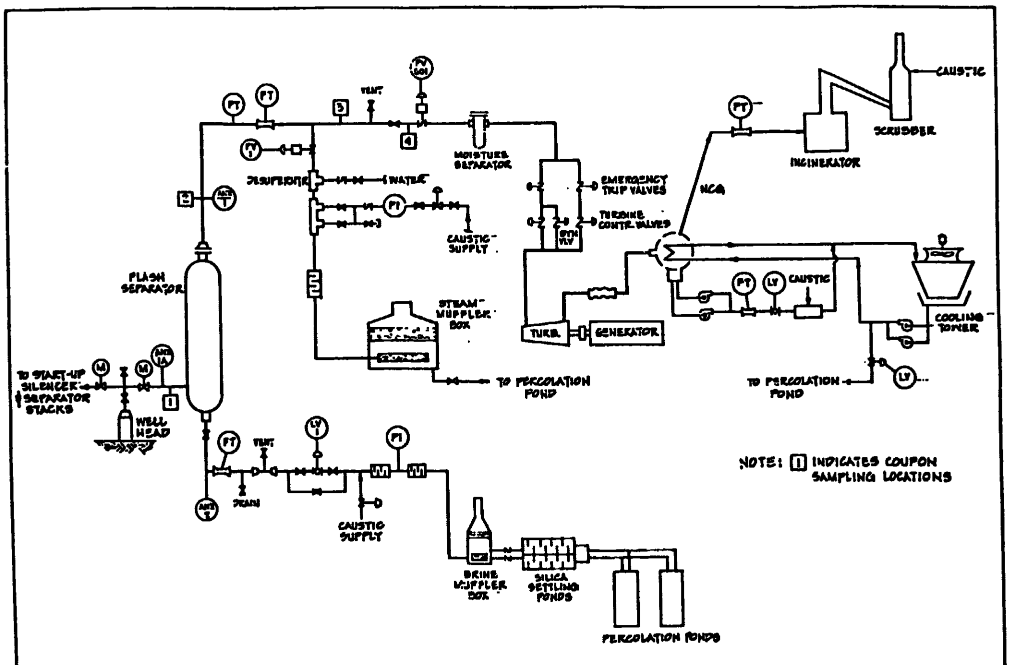

FIGURE ONE HGP-A WELLHEAD GEOTHERMAL POWER PLANT FLOW DIAGRAM

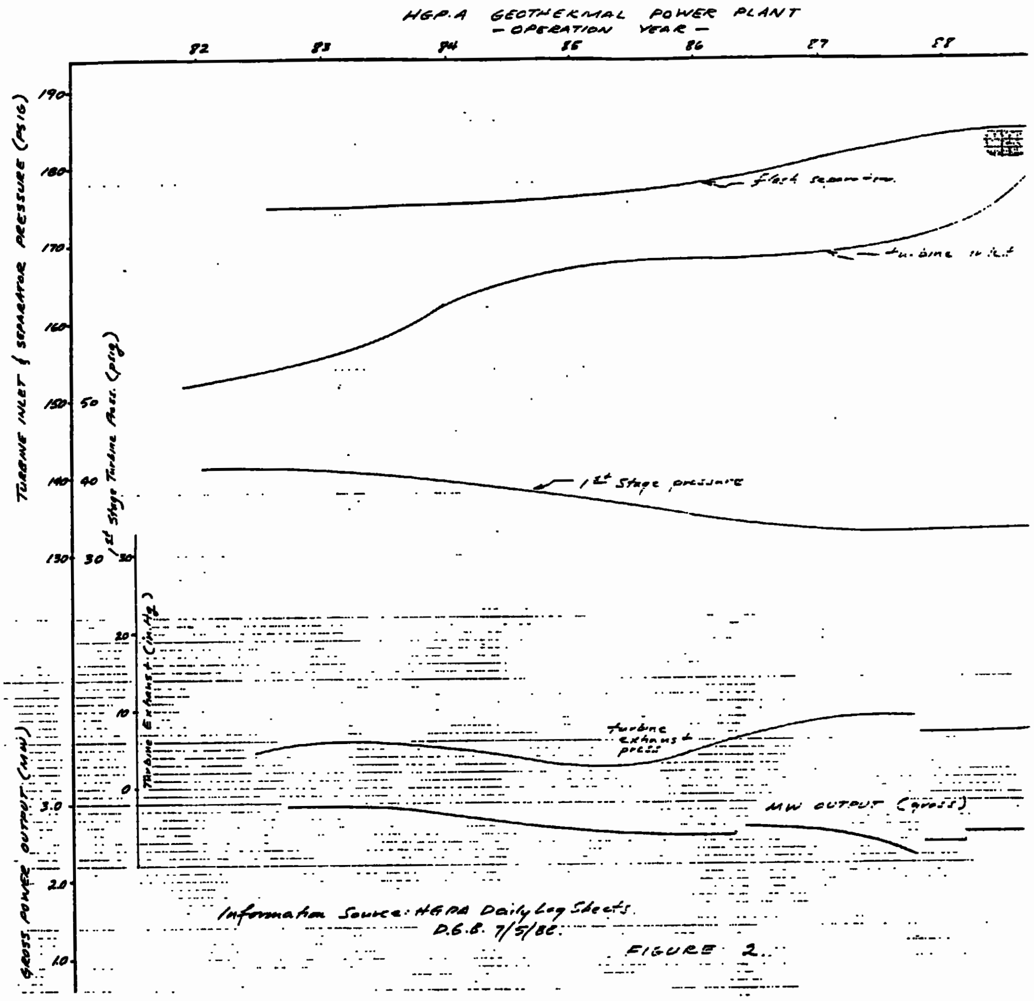
HGP-A GEOTHERMAL POWER PLANT
- OPERATION YEAR -
82
83
84
85
86
87
88
TURBINE INLET & SEPARATOR PRESSURE (PSIG)
1st Stage Turbine Press. (psig)
Turbine Exhaust (in.Hg)
GROSS POWER OUTPUT (MW)
flash separator
turbine inlet
1st Stage pressure
turbine exhaust press
MW OUTPUT (gross)
Information Source: HGPA Daily Log Sheets.
D.G.B. 7/5/88.

FIGURE 2.