THE HGP-A GENERATOR FACILITY

RESERVOIR CHARACTERISTICS AND OPERATING HISTORY

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The HGP-A Geothermal Wellhead Generator Facility, located on the Lower East Rift Zone of Kilauea Volcano, was installed as a pilot project to demonstrate the technical feasibility of producing electrical power from the geothermal reservoir discovered by the HGP-A research well in 1976. The electrical generation facility was installed in June, 1981 and, after a number of initial startup problems, began commercial operation in March 1982; it has now been in operation for nearly 40 months.
During this period a number of changes have occurred in the well fluid chemistry that have yielded insight into the character of the geothermal reservoir associated with the East Rift Zone and have identified a number of potential operating problems, for future geothermal facilities that may be installed on this reservoir.

WELL PRODUCTION AND CHEMISTRY DATE

During initial testing, the HGP-A well was found to be capable of producing approximately 50 tonnes per hour of a mixed phase fluid consisting of approximately 22 tonnes per hour of steam and 28 tonnes per hour of liquid at a pressure of approximately 1200 kPaa. Subsequent to the installation and startup of the generator facility, the well production rate, as indicated by the net output of the generator, declined by approximately 3% per year during the first thirty-six months of operation. This production decline occurred even with the reduction of the wellhead pressure from 1200 kPaa to approximately 960 kPaa. However, during the thirty-sixth month of operation the well production, and power plant output, recovered to a level slightly above the maximum production rate encountered during the first months of operation. This level of production has undergone a slight decline since this increase, but at a rate not substantially different from that occurring prior to the production increase.

The fluid chemistry encountered during the initial production tests of HGP-A showed a low to moderate dissolved solids content of approximately 2,000-3,000 mg/kg consisting predominantly of sodium chloride and dissolved silica accompanied by lesser amounts of potassium and calcium. The major dissolved gases consisted of carbon dioxide, hydrogen sulfide, nitrogen and hydrogen. Subsequent testing found an increasing trend in the major dissolved ion concentrations but a relatively stable silica concentration. These trends have continued during the operational history of the power plant and, currently, the dissolved solids concentrations are approaching 20,000 mg/kg; silica concentrations have, however, continued to maintain a relatively stable concentration in the production fluid.

In contrast to the dissolved solids, the gas concentrations in the separate steam have remained relatively constant experiencing a decline of approximately 10% during the production history of the well.

INTERPRETATION

The changes in the fluid production rate, although not inordinantly large, were cause for concern with regard to the long-term productivity of the reservoir. However, the increase in the production rate suggests that the three-year decline was not the result of reservoir depletion. Investigation of the production increase found that 1) the wellhead pressure changes associated with power increase occurred over a very short time period (on the order of minutes), 2) no geologic events (e.g. nearby earthquakes) accompanied the change in production rate, and 3) there were no detectable changes in fluid chemistry coincident with the increase. On the basis of these findings, we have concluded that the decline in production rate may have been the result of scale deposition in the well bore that, due to the high reservoir pressures, broke free and allowed flow rates to increase from the deep production aquifers in the well. This conclusion also suggests that production from the HGP-A well is casing limited and that a larger diameter well bore would permit a higher production rate from this reservoir.

The chemical data obtained for the HGP-A fluids suggest a number of important interpretations about the reservoir. The low salinities originally encountered demonstrate that the primary mode of recharge to this system is from the circulation of meteoric recharge from shallow aquifers to depth in the reservoir. The proximity of the well to the ocean (approximately 10 km) and the normally high permiability of Hawaiian basalts also indicate that structural features associated with the intrusive bodies in the rift zone control hydrothermal circulation and flow within the reservoir.

The substantial increase in salinity clearly shows, however, that seawater is now intruding into the portion of the reservoir tapped by HGP-A (Figure 1). Temperature calculations using the Na-K-Ca geothermometer (Fournier, 1981) indicate that the initial equilibrium temperatures of the brine phase approached 305°C but that the intruding seawater is reflecting a gradually declining equilibrium temperature that is currently approaching 250°C. The silica concentration in the brine phases, which can also be used to calculate reservoir temperatures, does not, however, show a decrease corresponding to the Na-K-Ca temperature decline. The apparent conflict between the two geothermometers is interpreted to be the result of differing rates of equilibration of the respective dissolved species: whereas silica equilibrates very rapidly the Na-K-Ca thermometer approaches equilibrium with reservoir temperatures much more slowly. Hence, the temperatures calculated from silica concentrations may more accurately reflect reservoir temperatures in the immediate vicinity of the well bore.

It is also of note that the changing concentrations of the alkalai ions present in the brine indicate that the seawater basalt reactions in the reservoir are occurring at a gradually increasing water rock ratio. This trend is apparent from the much more rapid relative increase in calcium and magnesium ion concentration over that for potassium in the geothermal fluids (Figure 2)

The changes occurring in the dissolved solids content of the brine phase, when compared with the stability of the gas concentrations in the steam phase, also suggest a very important conclusion: the marked contrast in the trends indicate that at least two independent production zones are supplying predominantly a steam phase and a brine phase to the well bore. Hence, the HGP-A well is deriving its production from a (presumably shallow) brine aquifer and a deeper higher temperature dry steam zone. This model is supported by geothermometer calculations, using the non-condensible gas chemistry data, that show a temperature of at least 350°C and possibly as high as 380°C in the portion of the reservoir supplying the steam phase. In addition, production tests of privately-owned wells adjacent to HGP-A have also reportedly produced dry steam. Hence, a dry steam reservoir is indicated to exist within the area around the HGP-A well and may extend over a broad area within the East Rift Zone Complex.

IMPLICATIONS

The chemical changes observed at the HGP-A facility and their interpretations have a number of important implications both for the continued operation and maintenance of the generator facility and for the future commercial utilization of this reservoir. The intrusion of seawater into the reservoir tapped by HGP-A is of major concern for the future operation of the HGP-A facility. The increased salinity of the geothermal brines has led to a substantial acceleration in the deposition rate of silica scale in the brine handling system. Even though the concentration of silica has remained relatively stable, the increased concentration of dissolved ions has led to a change in the polymerization kinetics of silica and hence the deposition rate has increased by a factor of at least five since the beginning of operations at the HGP-A facility. This increased rate of silica deposition has generated by far the most frequent and most troublesome maintenance problems occurring at the generator facility. These problems include the following (refer to Figure 3):

1. Freeze-up of the wellhead wing values;
2. Silica deposition in the flash separator vessel and plugging of the brine discharge line at the vortex breaker;
3. Plugging of sampling ports;
4. Freeze-up of separator level control values;
5. Plugging of the atmospheric brine flash tank and percolation ponds. The procedures currently undertaken to address these problems include:
    a. Frequent exercising of all values in contact with the brine phase;
    b. Frequent maintenance and clean out

of the brine flash separator;

c. Installation of a redundant brine disposal line from the exit port of the flash separator through the separator level control;

d. Monthly to bimonthly maintenance of the brine disposal lines;

e. Expansion of the brine percolation ponds from 100 m^2 to more than 1000 m^2

f. Treatment of the brine phase with a precipitating agent and semi-annual to annual cleanout of the sludge settling ponds.

Although the costs of implementing these procedures have been relatively high, whether they will be required for future geothermal facilities will depend upon the type of production zone (discussed below) encountered by future geothermal wells in the East Rift Reservoir.

Of less immediate concern to the continued operation of the facility is the apparent decline in the calculated Na-K-Ca geothermometer temperature. Although this decline implies that the intruding fluids were equilibrated with the reservoir at a lower temperature as discussed above, the relatively slow rate at which these ions achieve equilibrium with the reservoir suggests that the calculated temperatures are not necessarily representative of the water temperatures in the immediate vicinity of the well bore. An apparent decline in the silica concentrations in the brine would, however, herald an imminent decline in production temperatures and hence careful monitoring of this dissolved species is continuing.

Another aspect of the water chemistry relevant to the continued operation of the generator facility is the apparent increase in water:rock ratios. Experimental studies have shown that (Mottle, 1983 and references therein), at very low water:rock ratios, the fluid chemistry is relatively benign but at ratios approaching 50, the pH of the fluid phase can decline to levels as low as pH 2. Although the water:rock ratios represented by the fluid chemistry are currently well below 50, a significant decline in pH has occurred during the operating history of the power plant; initial pH's during the startup of the well were approximately 7.4, the most recent pH measurements made currently indicate a pH of 6.55. This change represents an increase in hydrogen ion concentration by a factor of nearly ten since the beginning of operations. Although no substantial problems have yet been encountered as a result of this pH decline, continuing acidification of the brine phase could lead to unavoidable and unacceptable corrosion of the brine handling system. The rate of pH decline is, however, currently very low and, at present, there is no evidence to suggest that corrosion rates are increasing. However, the many unknowns about the evolution of seawater basalt systems in general and the hydrothermal system on the East Rift Zone in particular suggests that careful monitoring of the fluid pH and chemistry is advisable.

The chemical composition of the non-condensible gasses present in the steam phase have also led to technical operations problems. Although some corrosion and iron sulfide scale deposition has occurred in the steam piping and turbine internals, the absence of ammonia or boron and effective steam/brine separation have led to relatively low scale deposition rates in the turbine. The major focus of deposition has been on the turbine inlet nozzels and, even here, maintenance is apparently required only on a biannual basis. Another significant maintenance problem encountered has been fouling of the steam metering system and hence well flow data is not generally reliable. The most troublesome problems, arising from the high hydrogen sulfide concentration in the steam phase have been associated with maintaining a clean air environment for plant equipment. Hydrogren sulfide promoted corrosion has generated maintenance problems for plant air compressors, electronic sensors and relays and general corrosion of steel framing and equipment that is routinely exposed to the elements. Alleviation of these problems will require the installation of a new and higher capacity air filtration system.

Although the presence of high sulfide concentrations in the steam phase have resulted in high operating costs for the hydrogen sulfide abatement system required to meet environmental and community standards, the costs are more the result of the economics of the plant size than of any inherently difficult technical problems associated with the abatement process. It is of note here as well, that the absence of ammonia or boron in the steam have proven to be a substantial advantage with regard to abatement of H_2S in the condensate steam; partitioning of the gasses in the condenser strongly favor the gas phase and less than 1% of the H_2 remains with the condensate stream that is used for recharge to the cooling tower. Hence,

there appear to be few technical barriers to cost effective removal of H_2 from the non-condensible gas stream for larger facilities that may be installed on this resource in the future.

The most favorable, and possibly most important, finding of the research undertaken at the HGP-A facility is the conclusion that a dry steam production zone may be present in the geothermal reservoir associated with the Kilauea East Rift Zone. If this production zone proves to extend to the reservoir as a whole, as has been suggested by the production of dry steam from other wells on the East Rift Zone, it may be possible to circumvent a number of the technical problems associated with the production of the brine phase at HGP-A. Exclusion of brine aquifers in future wells would entirely eliminate the silica deposition that has created both facility maintenance and brine disposal problems. The continued, near constant rate of production from the HGP-A well suggests that sustained steam production from the reservoir can occur without major deposition or reservoir plugging problems.

ONGOING RESEARCH

A number of research programs are presently underway at the HGP-A facility that are attempting to improve our state of knowledge about the reservoir and in an effort to address some of the technical problems that have occurred at the generator facility.

Monitoring of the reservoir fluid chemistry has been underway since the initial startup of the well and will be continued for the foreseeable future. Much of the current interpretation of the reservoir has relied upon the chemical data obtained to the present; future efforts will attempt to expand the interpretations to anticipated fluid recharge rates and chemical variabilities within the different horizons in the reservoir.

Efforts are also underway investigating the detailed chemical effects associated with silica polymerization and deposition, and alternative methods of removal or recovery of silica from the brine phase. Recent batch tests using metal ion addition and froth flotation on a bench scale have shown that removal of up to 80% of the dissolved silica is easily achievable. Future tests of this method on a flow-through system are planned.

Other studies are investigating the production of steam from this geothermal reservoir. Analysis of cuttings from several wells in the rift zone are underway in an effort to determine whether detectable chemical or physical characteristics can be found in the identified steam zones that will allow drilling engineers to design well completion and casing programs for future wells that will optimize steam production and minimize brine production.

PROSPECTS FOR THE FUTURE

The production characteristics of the HGP-A geothermal well suggest that an extensive and robust geothermal reservoir is associated with the Kilauea East Rift Zone. The first forty months of operation have been characterized by a number of startup or "learning" problems but, to date, no insurmountable technical barriers to the development of electrical power generation on this reservoir have been encountered. The operation of the HGP-A Generator Facility has most clearly demonstrated this conclusion by being able to maintain an availability factor approaching 95% in spite of the fact that it was the first geothermal generator constructed in Hawaii and one of the first in the world to be built in an active volcanic environment.

REFERENCES

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Mottle, 1983, Metalianalts, axial hot springs, and the structure of hydrothermal systems at mid-ocean ridges, Geol, Soc. Ad. Bull, V.94, p 161-180

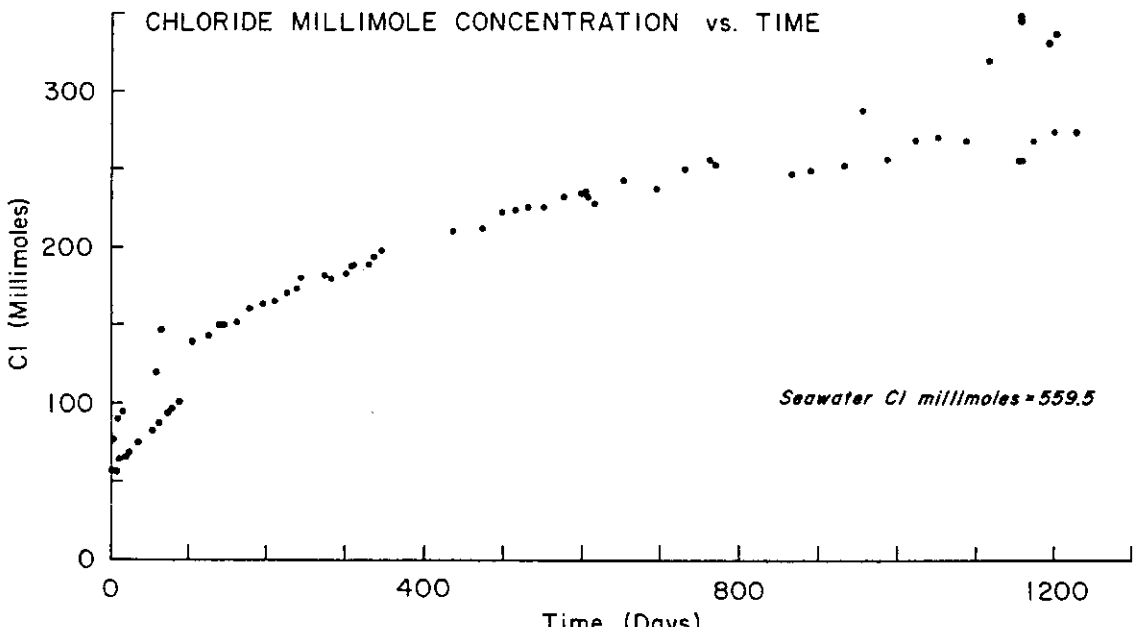
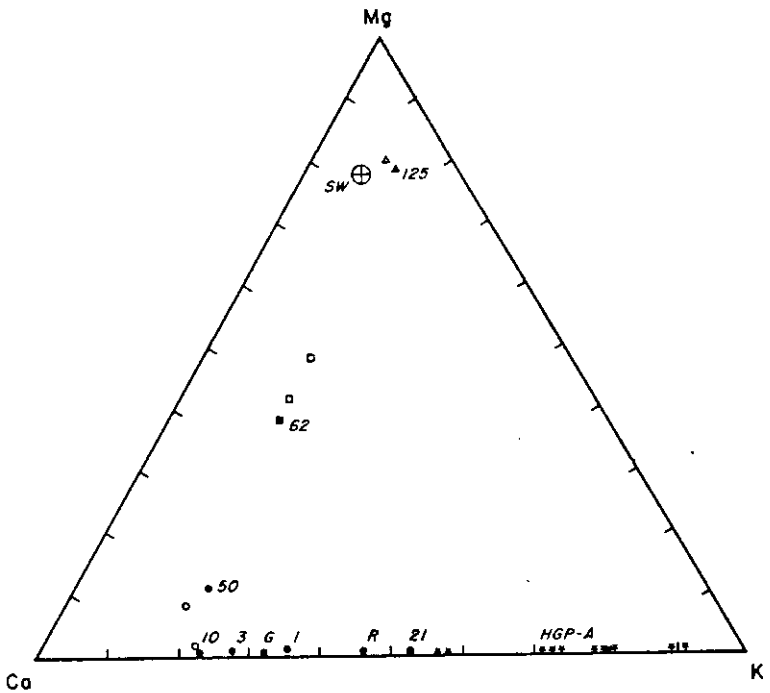


Figure 1

This figure demonstrates the five-fold increase of chloride concentration and inferred seawater intrusion into the reservoir with duration of production from HGP-A.



K-Ca-Mg Relative Concentrations
In Seawater-Basalt Systems

Figure 2

Changes in relative concentration of K, Ca, and Mg ions in the reservoir fluid.

*Corresponds to HGP-A fluid chemistry: K rich points represent early fluid compositions, later compositions trend toward higher Ca concentrations.

Label points are as follows: 21 = hydrothermal vent fluids at East Pacific Rise; R = Reykjanes Peninsula (a seawater dominated geothermal system in Iceland); G = submarine hydrothermal vent fluids at Galatagos Islands; SW = unaltered seawater compositions.

Filled numbered points (except 21) represent equilibrium ion compositions found in high temperature seawater: basalt experiments.

The number at each point correspond to the seawater: basalt ratio.

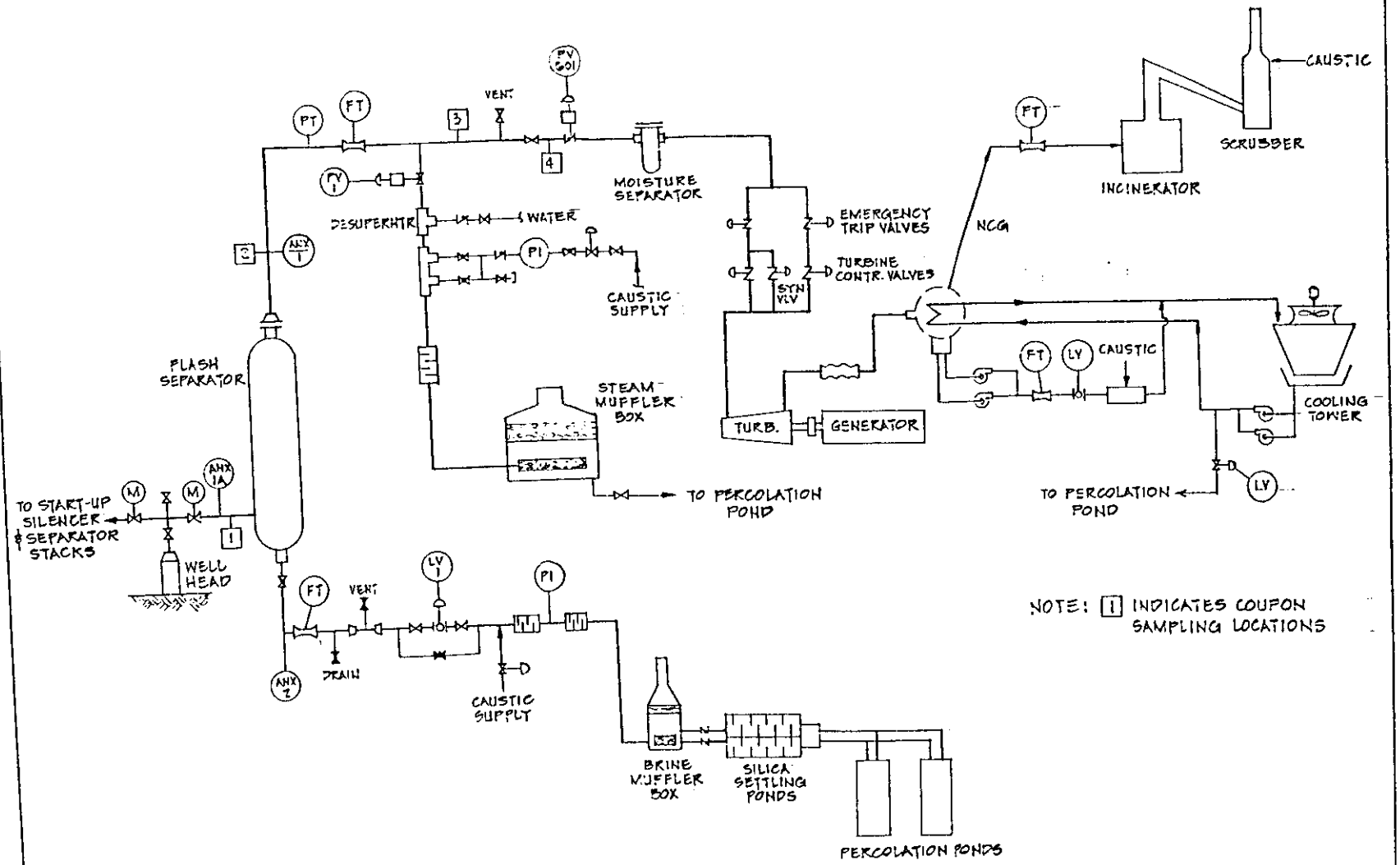


FIGURE 3 HGP-A WELLHEAD GEOTHERMAL POWER PLANT FLOW DIAGRAM