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CURRENT STATUS AND FUTURE RESEARCH OBJECTIVES FOR THE HGP-A GENERATOR FACILITY

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INTRODUCTION

The HGP-A Geothermal Generator Facility began operation in June 1981 and has been continuously producing electrical power since March 1982. Changes in the chemical composition of the fluids during the operational life of the well have not only presented a number of engineering challenges to the continued production of power but have also provided a number of very valuable insights into the dynamics of the geothermal reservoir associated with the Kilauea East Rift Zone. This paper will review the evolution of the reservoir characteristics and summarize the engineering developments that have made at the HGP-A facility during the last seven years of operation.

BACKGROUND

In 1976 the HGP-A well was drilled into the Lower East Rift Zone of Kilauea volcano to a depth of 1966 meters. Testing showed that the well had a bottom hole temperature of approximately 358°C and was capable of producing approximately 50 metric tonnes of fluid per hour with a steam quality of approximately 44%. In 1981 a 3MWe wellhead generator facility was installed at HGP-A to demonstrate the feasibility of electrical power generation from this geothermal resource. After an extended start-up and shake-down period the generator facility began continuous operation in December, 1981 and has been producing electrical power on a commercial basis since March 1982. The availability factor for the facility has been approximately 95% since the beginning of commercial operation.

RESERVOIR CHARACTERISTICS

During the initial testing of the HGP-A well, the fluids were found to have a total dissolved solids content of approximately 4000 mg/kg in the brine phase. Major dissolved constituents consisted of sodium chloride (~2200 mg/kg) and silica (~850 mg/kg) with lesser amounts of lithium, potassium, magnesium, and calcium. Non-condensable gases in the steam phase had a total concentration of less than 0.25% but had a higher hydrogen sulfide content (~900 mg/kg), relative to carbon dioxide (~1100 mg/kg), than is typically found in geothermal fluids. The balance of the NC gases consisted of nitrogen (~125 mg/kg) and hydrogen (~11 mg/kg) with traces of methane (~1 mg/kg) and inert gases.

During the seven years of operation of the well the most important chemical change observed in the production fluids has been a progressive increase in the total dissolved solids concentrations: sodium chloride concentrations are now about 15,000 mg/kg in the brine phase. This represents a seven-fold increase since the start-up of the well (Figure 1). Both the chloride and the dissolved cation concentrations (Figure 2) showed a rapid initial increase but, after approximately four years of production, they peaked and then began a slow decline. The sodium to chloride ratio of the fluids indicates that the source of the intruding fluids is seawater (Thomas, 1987) but, comparison of the other ion concentrations with seawater of equal chlorinity (Figure 3), shows that lithium and potassium have been highly enriched in the thermal fluids whereas magnesium has been nearly quantitatively removed and calcium has moved from depletion to enrichment during the production period.

The changing fluid chemistry suggests that seawater has infiltrated across the southern boundary of the Kilauea East Rift Zone and into the high-temperature reservoir (Thomas, 1987). As seawater continues to enter the geothermal system, reactions with reservoir basalts can modify the fluid compositions substantially. Other possible consequences of continued seawater intrusion into the reservoir include both a gradually falling fluid temperature and, as indicated by laboratory studies of SW/basalt reactions (Mottl and Holland, 1978), a substantial decline in fluid pH. The former result is supported by Na-K-Ca geothermometer calculated temperatures (Figure 4) that indicate an apparent decline in the source fluid temperatures. Silica concentrations have, however, remained nearly constant suggesting that reservoir temperatures within the silica equilibration path-length have declined only slightly, if at all. The

FIGURE 1

Chloride Ion Concentration versus Time
In HGP–A Geothermal Brine

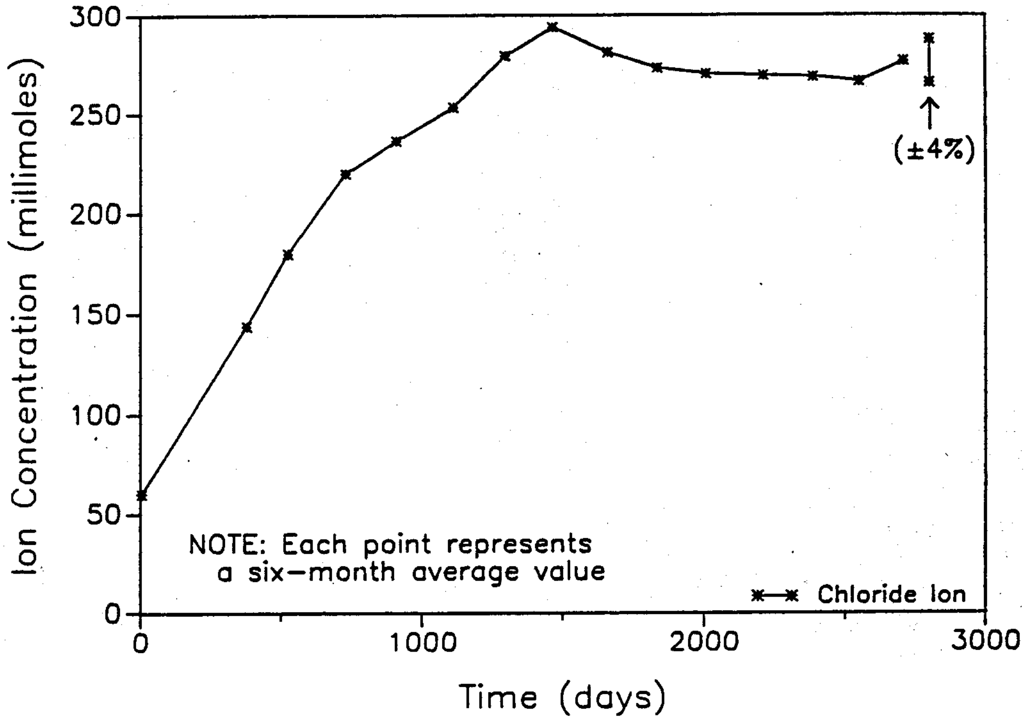


FIGURE 2

Major Cation Concentrations versus Time
In HGP–A Geothermal Brine

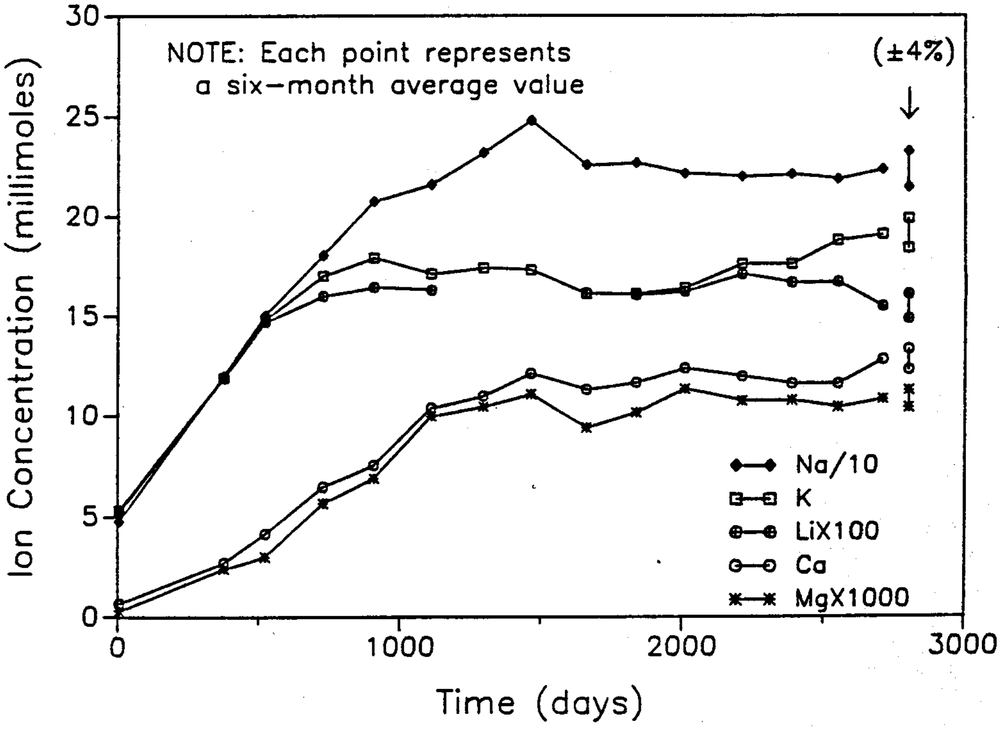


FIGURE 3

Enrichment/Depletion of Cation Concentrations

Relative to Seawater of Equal Chlorinity

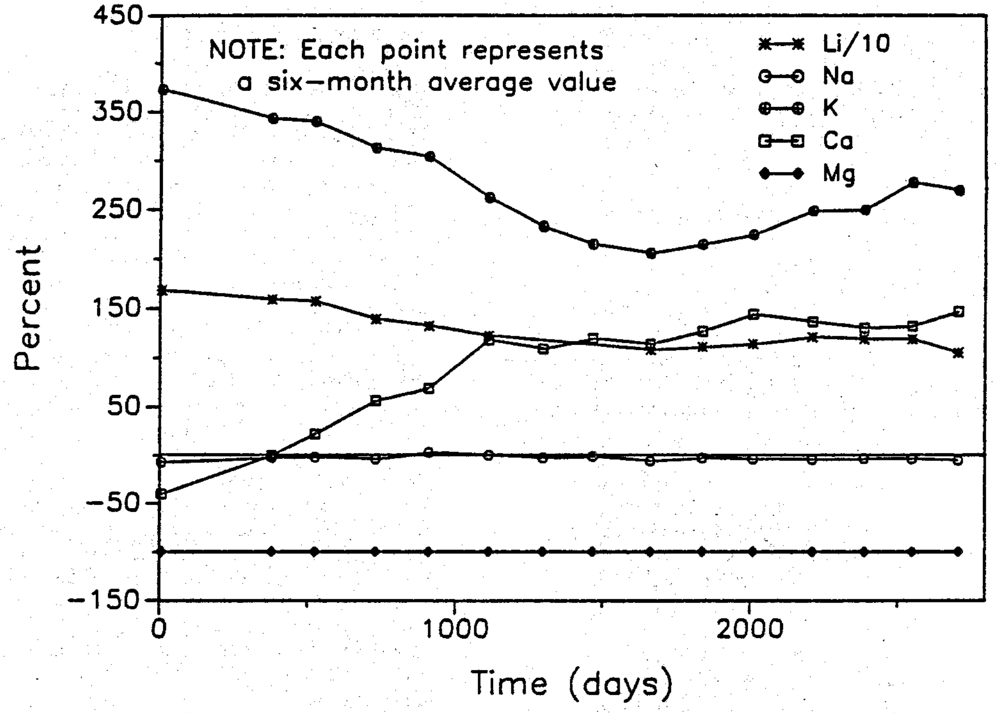
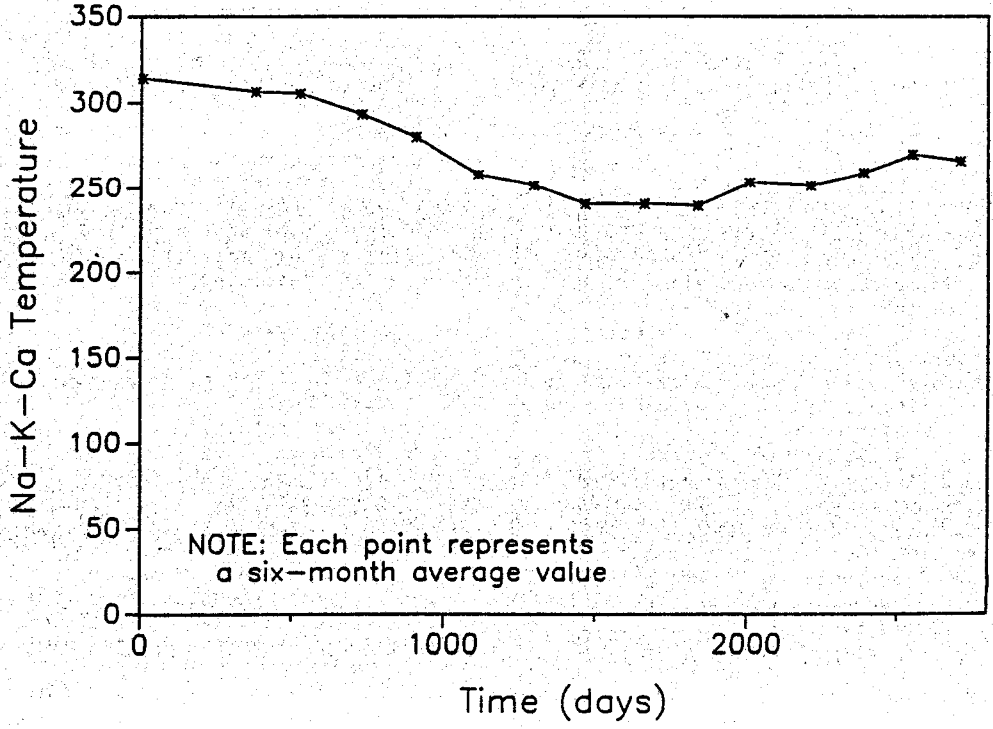


FIGURE 4

Calculated Na-K-Ca Geothermometer Temperature

For HGP-A Brine Composition



second projected outcome, a decline in fluid pH is also substantiated by measured brine pH values which have declined from a value of approximately 7.6 to about 6.5 during the operational life of the well. This change represents an increase in hydrogen ion concentration in the fluid of more than a factor of ten. Further declines in fluid pH, if continued for an extended duration, could pose corrosion problems for surface equipment as well as downhole casings.

A third possible outcome of seawater infiltration into the reservoir is a direct result of the SW/basalt reactions that modify the fluid chemistry. These reactions also modify the reservoir basalt composition by depositing secondary mineral assemblages that includes anhydrite, calcite, chlorite, and mixed-layer smectite clays. Deposition of these secondary minerals, which have been found in Kilauea East Rift drill cores, can hinder seawater infiltration and may be able to entirely seal off the intrusion zones. This process may may account for the decline in the dissolved solids concentrations that have been observed during the last three years of well production. If deposition of secondary minerals continues, further restriction of fluid intrusion may slow the rate of decline of fluid temperature and pH.

The loss of fluid entry into the reservoir is, however, cause for concern with regard to the future productivity of the well. Steam flow rates measured during the first few months of operation of the well are estimated to have been approximately 20 to 22 metric tonnes per hour (mtph), whereas those measured more recently have shown steam production rates of about 18 mtph reflecting a decline of 10% to 20% over seven years of operation. Although this decline is only an approximation because of uncertainties in the original measurements, it is consistent with changes in gross electrical output of the generator, which has fallen from about 2.9 MWe to its current value of 2.4 MWe.

It should be noted, however, that the decline in production has not been monotonic: on at least two occasions steam production from the well increased by about 10% to 15% and remained at these higher levels for periods of a few days to a few weeks before gradually returning to their original values. Although we do not have a well-substantiated explanation for this behavior, the absence of any corresponding seismic activity or any change in fluid chemistry during these episodes suggests that the increased flow rates may have resulted from the removal of an obstruction in the wellbore that was impeding flow. This in turn suggests that well productivity may be limited by the deposition of silica scale in the wellbore rather than by the productivity of the reservoir itself. (Because the well has been in continuous operation since 1981, we have been unable to test this hypothesis by inspection of the well casing or by conducting caliper logs of the well.)

POWER PLANT ENGINEERING

The wellhead generator steam system consists of a single-stage flash separator, operating at a pressure of 175 psia, followed by a moisture separator, turbine inlet manifold, a six-stage condensing turbine, and a shell and tube condenser. Steam condensate is cycled to the cooling tower as make-up water, and non-condensable gases are removed using steam ejectors and treated with an incinerator scrubber system to remove hydrogen sulfide. The brine system, downstream of the separator, consists of redundant pressurized piping and level control valves that dump the brine to an atmospheric flash system and percolation ponds.

Maintenance problems that have been encountered during the operational life of the facility can be categorized as follows: general maintenance, hydrogen sulfide abatement, surface and internal corrosion, and solids deposition. The general maintenance requirements of the facility have been much greater than might otherwise have been expected because the original design-life stipulated for the facility by the funding agency, was only two years. As a result, chemical pumps, compressors, air blowers, and control systems have required more frequent maintenance, and in some cases eventual replacement, than might have been required if the plant had been designed for a 20- to 30-year life. In most cases, the cost of manpower and lost generation time incurred during the life of the plant have substantially exceeded the cost of equipment appropriate for the conditions present.

The design of the primary hydrogen sulfide abatement system has generated similar problems as well. The short design-life dictated the choice of an incinerator and single-stage scrubber system for hydrogen sulfide abatement which had a lower capital cost. The hydrogen sulfide load (0.5 t/d) for this system resulted in operating costs for chemicals of approximately $1000/day to treat the incinerated gases. In order to reduce chemical costs, a two-stage scrubber unit was installed that reduced the caustic use rate by about 40%. Although the primary abatement system has been highly reliable, the toxicity of the raw condenser gas has required the installation of an emergency back-up column to scrub hydrogen sulfide from the condenser gases when the primary unit fails. Consisting of a packed column with a caustic feed, this system is able to alleviate both personnel hazards associated with condenser gas discharge as well as nuisance odors in the adjacent community during periods of incinerator upset.

Hydrogen sulfide abatement during periods of turbine standby (atmospheric steam release) is accomplished by injection of sodium hydroxide into the steam phase up-stream of a rock muffler. Although a number of abatement problems were encountered during the initial start-up phase of generator operation, abatement efficiencies of about 95% were found using a caustic to sulfide mole ratio of approximately three to one. Earlier tests of this system using both caustic and peroxide injection showed that the addition of the latter reagent gave only minimal improvement in abatement efficiency; in light of this fact and the increased personnel hazards associated with peroxide transport and on-site storage, the plant design did not use peroxide injection.

Corrosion in the steam and brine systems has not been a major problem at the power plant. Substantial rates of surface corrosion have, however, been observed on mild steel as well as in the interior of the cooling water system. Several factors that are somewhat unique to the HGP-A power plant and to the local environment are responsible for this corrosion: high rainfall rates (>100 in/yr), high ambient levels of sulfur dioxide (produced by an active volcanic vent uprift of HGP-A and by leakage of gases from the hydrogen sulfide abatement system), and high ambient concentrations of saline aerosols from atmospheric discharge of the separated brine phase. All of these factors contribute to the corrosion at the site that has been controlled to only a modest degree by normal maintenance procedures.

The ambient levels of sulfur dioxide and salt aerosols may also contribute to the extreme corrosion observed in the mild steel cooling water piping system. Degradation of the circulation lines is, however, believed to have been caused by the loss of automated pH control of the cooling water system. Even though an effort was made to control fluid pH manually after the original control system failed, periodic treatments of the cooling water with caustic resulted in wide pH swings that produced both acid corrosion of the mild steel and caustic attack of the interior wood framing of the cooling tower. Restoration of automatic control during the last several months has largely alleviated these problems.

Deposition of silica from the flashed geothermal fluids has been one of the most difficult engineering problems encountered during operation of the generator facility. The brine handling system has required frequent maintenance to remove accumulations of amorphous-silica scale deposits from the interior of the flash vessel, the pipelines, and the brine level control valves. Silica deposition in the latter equipment has been especially troublesome because changes in the temperature and pH associated with boiling substantially accelerate silica deposition rates. Even greater problems have been encountered downstream of the brine release system: after the brine flashes to atmospheric pressure the temperature and fluid volume losses increase the concentration of silica in the brine to a factor of about five times its equilibrium solubility. Although silica polymerization and deposition is an inevitable result of this supersaturation, the chemistry and kinetics of these processes result in the formation, over a period of several hours, of a gelatinous precipitate composed of about 5% silica and 95% water. As a result, disposal of the geothermal brines by percolation has required frequent cleaning of the disposal ponds as well as their progressive expansion during the life of the plant.

We do not currently have a satisfactory solution to the scale deposition problems at the HGP-A facility. In order to maintain system reliability, a redundant brine handling systems has been installed that allows continuous operation during system maintenance. In order to minimize the formation of scale on valve seats and stems, the plant operator is required to exercise the level control valves on a frequent basis. The fluid disposal ponds, as noted above, have been expanded from approximately 75 m^2 as originally constructed (and which functioned adequately for the first several months of operation) to 8500 m^2 currently in use for approximately the same volume of brine discharge. Removal of silica has not only become very time consuming and expensive, the material generated has become a solid waste disposal problem. Although this system has allowed us to continue operating the HGP-A facility, improvements in the brine handling system are required for any future commercial-scale geothermal generation stations. The land use and solid waste problems associated with brine disposal on a commercial scale suggest that future generation facilities will have to institute a brine reinjection process which may also require brine pretreatment to reduce silica supersaturation prior to reinjection.

FUTURE RESEARCH OBJECTIVES

During the coming year of operation our research efforts will be focussed on developing solutions for the current operational problems faced by the HGP-A facility. The two most significant issues will be improvements in the hydrogen sulfide abatement technology and development of a process for brine disposal. Although two separate projects are currently underway to improve these processes, it is hoped that the ultimate solution will be able to combine the disposal of the non-condensable gases and the brine phase. The first set of investigations, conducted by Ormat Energy Systems, is evaluating the engineering conditions under which non-condensable gases from the condenser system can be combined with either the excess cooling water/condensate or with the waste brine stream and reinjected into a disposal well. The objectives of this study are to determine the optimal conditions for recombining the waste streams while still minimizing corrosion and scaling in the disposal system.

A separate study is also underway on the chemistry of silica polymerization and precipitation in the geothermal fluids produced by the HGP-A. This investigation will determine the polymerization rate of silica in the geothermal fluids under natural conditions and as well as the effects of varying solution pH and dissolved ion concentrations on the rate of polymerization and precipitation. As data becomes available on different types of reagents that might accelerate the precipitation rate of silica, a pilot system for continuously treating a side-stream of brine will be designed. The results of the latter study will be applied to the preparation of a preliminary design of a full-scale brine treatment system capable of reducing silica supersaturation in the geothermal waste fluids. If reagents are identified that retard silica precipitation, then the pilot system will be used to determine whether the retardation times are sufficient to allow commercial volumes of brine to be reinjected on a long-term basis.

The pilot system will also be used to determine whether recombination of the non-condensable gases with the brine phase will affect the polymerization rate of dissolved silica in the brine or whether the gases have a significant effect on the action of other reagents used in the silica removal process.

SUMMARY AND CONCLUSIONS

The seven years of operation of the HGP-A geothermal generator has successfully demonstrated that production of electrical power from Hawaii's geothermal resources is technically feasible. This period of study has also enabled us to characterize the chemistry and reservoir dynamics of a high-temperature hydrothermal system on the Kilauea East Rift Zone and its response to exploitation for power generation.

Operation of this facility has enabled us to test and refine engineering designs appropriate to the reservoir conditions found in Hawaii and to identify economically viable and environmentally acceptable means of producing geothermal power on the island of Hawaii. If the currently planned studies of hydrogen sulfide and silica control are successful, then two of the most important environmental and economic impediments to the development of Hawaii's geothermal resources will have been resolved.

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