

WATER AND GAS CHEMISTRY FROM HGP-A GEOTHERMAL WELL: JANUARY 1980 FLOW TEST

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ABSTRACT

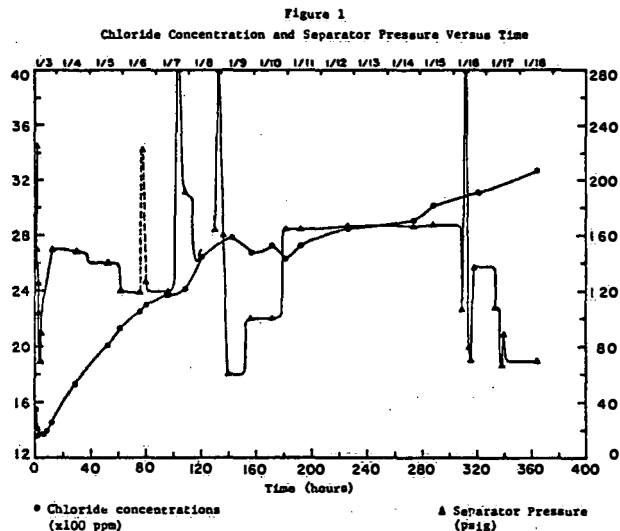
During January 1980, a two-week production test was conducted on the geothermal well HGP-A. Brine chemistry indicates that approximately six percent of the well fluids are presently derived from seawater and that this fraction will probably increase during continued production. Reservoir production is indicated to be from two chemically distinct aquifers: one having relatively high salinity and low production and the other having lower salinity and producing the bulk of the discharge.

INTRODUCTION

During January 1980, a two-week production test was conducted on the geothermal well HGP-A. This well is located on the east rift zone of Kilauea volcano, on the island of Hawaii, and was completed in 1976. This effort was the final flow test of HGP-A preliminary to the installation of a 3.5 MWE well head generator and, as such, was conducted in order to obtain data on steam quality, production rate, non-condensable gas concentration and composition, and brine chemistry. The present report is concerned with the results obtained to date from water and gas chemistry analyses conducted during and immediately following the test. Further chemical and isotopic analyses are currently underway in an effort to confirm some of the preliminary conclusions drawn from the presently available data.

Water Chemistry

Figure 1 presents a plot of chloride concentration in the weirbox water (and well head pressure) versus time through the duration of the well test. The trend of increasing chloride is apparent and shows no significant break point at which the chloride concentrations level off. Previous flow tests of HGP-A have also produced similarly increasing chloride concentrations with time, although the most recent results indicate a somewhat more rapid rise to slightly higher chloride values than were previously observed (Kroopnick et al., 1978). The data presently available strongly suggest that the source of the chloride ion, as well as most of the other major ions, is derived from seawater intrusion into the geothermal reservoir. Although the rate of chloride increase during the test was quite high, tritium



data (see below) on the discharge water suggests that the natural rate of increase under continuous production will be substantially less rapid.

The short term variations observed in the chloride chemistry can be correlated with changes in well head pressure as plotted in Figure 1. Although both the chloride and pressure curves have been considerably smoothed it is apparent that a decrease in flow rate, and consequent increase in well head pressure, results in a decrease in the chloride concentrations observed. All the chloride values plotted are from the weirbox samples, and thus were obtained at the same temperature and pressure. When these chloride data are calculated back to constant temperature and pressure flash in the well head separator the chloride concentrations in the effluent water are somewhat lower at the high discharge pressure than can be accounted for simply by changes in the percentage of flash from a constant chloride reservoir fluid. It is possible that the small differences observed are the result of changing production rates from different aquifers at the higher and lower pressures. However, at present, more precise pressure-temperature and chloride concentration data are necessary before any definite conclusions can be drawn.

The remainder of the brine chemistry is summarized in Table 1 and Figure 2. If one

Table 1. Separator Brine Chemistry (mg/Kg brine)

Date	"Pretreatment"	Press Psig	Cl	Na	K	Ca	Mg	SO ₄	SiO ₂
01/10/80	Untreated	88	2390	1430	200	16.3	<10	50	865
01/11/80	Untreated	154	2450	1463	211	33.2	<10	60	792
01/12/80	Untreated	155	2350	1405	204	25.9	<10	62	
01/14/80	Untreated	156	2450	1440	205	30.5	<10	60	796
01/16/80	Untreated	130	2600	1530	216	33.2	<10	67	832
01/17/80	Untreated	52	2920	1713	247	17.9	<10	59	875
01/18/80	Untreated	55	2930	1700	248	17.9	<10	73.6	873
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Seawater			19,500	9600	398	450	1290	2200	4
15% Seawater			2925	1440	60	68	194	330	0.6

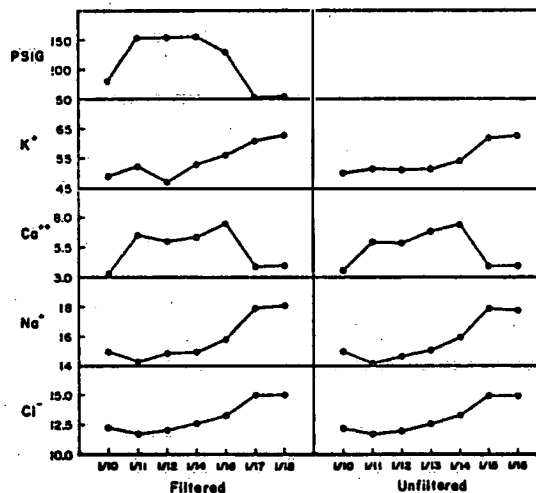
assumes that the chloride ion concentration is representative of the seawater mixing it is apparent that there has been a slight enrichment in the sodium ion concentrations and a much greater enrichment in potassium whereas calcium and sulfate have been heavily depleted and magnesium removed almost completely. These trends are virtually identical to those observed in earlier production tests of HGP-A and present no significant deviations from its earlier behavior.

One question of importance to the future productivity of the well is the mechanism for the depletion of some of the seawater ions. It is generally understood that magnesium is removed through the formation of the hydrothermal alteration mineral chlorite which is abundant in cores from the deeper parts of HGP-A (Stone, 1977). The removal of calcium ion can be effected in two ways: by the formation of calcite and by precipitation of anhydrite. Both of these minerals have been identified in small amounts in cores and cuttings from near the bottom of HGP-A and in grab samples of material scraped from the inside of the well bore. Anhydrite has a retrograde solubility product and it is not known at present whether the increased concentrations of calcium and sulfate brought about by flashing of the reservoir fluid exceeds the higher solubility product of anhydrite in the adiabatically cooled brine. We are presently attempting to acquire the data necessary for the solubility calculations in the original reservoir fluids and in the flashed brine.

Figure 2 presents plots of the chloride, sodium, calcium, and potassium concentrations in the separator brine as well as the separator pressure at the time of collection. It is apparent that all the ions plotted respond to changes in separator pressure as would be expected for different flashing fractions of the well fluid, however, the calcium ion concentration responds in the opposite manner to the other ions plotted. This behavior suggests that the calcium carbonate-dissolved CO₂ equilibrium is controlling the calcium concentration in the liquid phase. At higher separator pressures the dissolved CO₂ concentration in the brine can maintain a CaCO₃

concentration of approximately 0.85 millimolar at approximately 0.45 millimolar. We are presently in the process of acquiring additional data in an effort to determine whether calcite solubility is controlling the dissolved calcium concentrations at the higher separator pressures. If the calcium concentrations in the brine are at the calcite: carbon dioxide equilibrium concentrations then it must be assumed that calcite is being deposited either in the aquifer or in the well bore.

Figure 2
Major Ion Concentrations
Normalized to Percent Seawater



Calculation of the reservoir temperature through application of the silica and sodium-potassium-calcium geothermometer was attempted. In every case the calculated temperature was at least 50°C below the observed reservoir temperature confirming the inapplicability of these geothermometers in the Hawaiian environment.

Non-Condensable Gas Composition

Table 2 presents a selected set of the most reliable analytical results obtained for the non-condensable gas compositions during the January test. Comparisons between earlier data on HGP-A

non-condensable gases (Kroopnick et al., 1978) and those obtained during the January test strongly suggest that the total non-condensable gas content may have decreased substantially. It should be noted, however, that the earlier samples were taken using considerably less elaborate equipment and the analytical techniques used on those samples were not as accurate as those applied in the recent test.

Table 2. Non-condensable Gas Analyses
(expressed in mg/kg of steam)

Date Sampled	H ₂ S	CO ₂	N ₂	H ₂	Separator Pressure
01/10/80†	704	825			88
01/11/80†	782	864			154
01/13/80†	766				156
01/14/80†	837	930			156
01/15/80*	825	900	195	10.9	155
01/16/80†	760	1010	169	11.0	155
01/17/80*	750	1000	168	11.0	96
01/18/80*	690	783	117	8.9	56
01/18/80*	900	760	108	6.4	56

† field analysis * laboratory analysis

Although there are several potential explanations for the apparent decrease in non-condensable gas content, the one which is most consistent with the data is that gases are being preferentially mined from the reservoir during production. Whether the source of the non-condensable gases being withdrawn are in the form of dissolved carbonate and sulfide or whether they are from the remobilization of carbonate and sulfide minerals cannot be determined at present. Although New Zealand geothermal reservoirs have shown a similar trend of decreasing non-condensable gas concentrations (Ellis, 1962; Mahon, 1962), the proposed mechanism does not appear to be applicable in the Hawaiian geologic environment. Whether the trend of decreasing non-condensable gas content will continue in the future cannot be determined with the presently available data. Although there are also apparent changes in the relative ratios of the non-condensable gases, we have found that the differences observed are artifacts of the earlier analytical techniques and that the more recent analyses are more representative of the non-condensable gas compositions present.

It is apparent from the data presented in Table 3 that there is a substantial variation in the gas compositions and concentrations through the duration of the test. This can, in large part, be attributed to changes in steam quality at the different separator pressures; as the separator pressure is increased the steam fraction is decreased substantially whereas there is relatively little change in the total amount of gas discharged. The net result is that at higher separator pressures (and lower steam fractions) the relative amount of non-condensable gas in the steam phase increases. Although it is theoretically possible to use the gas compositions at different separator pressures to determine the fluid enthalpy as well as several other down-hole geochemical and production parameters, we will not be able to perform this type of

analysis until further analytical data have been obtained.

In addition to the major components of the non-condensable gas fraction, minor amounts of several other gases were also found to be present. The trace gases detected in the steam discharge included helium, argon, carbon monoxide, and possibly methane. None were present in concentrations greater than 2-3 ppm of the steam phase. Although ammonia and mercury were analyzed for, neither were present at the detection limits for the technique applied. Further analyses are being pursued for these species.

Isotope Chemistry

Table 2 presents tritium analyses performed on selected samples of the well discharge water through the duration of the test as well as a few samples taken prior to the extended well discharge.

Tritium analyses done on discharge water from earlier production tests of HGP-A have yielded values of approximately 0.2 TU or less thus indicating that the reservoir water for HGP-A is older than approximately thirty years (pre-bomb). It can be concluded then that the tritium present in the recent discharge water is derived entirely from water pumped into HGP-A prior to the well test; the activity of the quench water was approximately 7.93 TU (Fire Hydrant Sample). Several hypotheses are suggested by the tritium data:

1. Discharge samples collected from the silencer overflow immediately after the well rework had an activity of 4.0 TU, however, samples collected after a long period of shut-in had a substantially higher activity. This suggests that two aquifers were being produced during the 10/17 discharge: a "high tritium" aquifer which received the bulk of the quench water and a "low tritium" aquifer. The increase in tritium following the three-week shut-in can probably be attributed to circulation within the well bore between the two aquifers. Downhole water chemistry samples taken subsequent to the January 18 shut-in also suggest that this type of circulation pattern is continuing and that the "high tritium" reservoir

Table 3. Isotope Analyses of HGP-Discharge

Sample Source	Date Collected	Tritium Act. (T.U.)
Well head	11/09/79	6.48 ± 0.91
Fire Hydrant	11/09/79	7.93 ± 0.97
Weirbox	10/17/79	4.00 ± 0.56
Weirbox	12/28/79	2.31 ± 0.40
Weirbox	01/03/80	2.08 ± 0.37
ANX-2	01/12/80	1.32 ± 0.42
ANX-2	01/18/80	0.50 ± 0.38
Sample Source	Date Collected	¹⁴ C Age
Well head	05/08/77	12,800 ± 200 years
Well head	05/08/77	13,600 ± 200 years
ANX-1	01/18/77	12,203 ± 142 years

is of a lower salinity than the "low tritium" reservoir. If this is the case, it can be concluded that the majority of the HGP-A production is from a low salinity aquifer and that a somewhat lower pressure/less permeable saline aquifer is producing at a shallower level.

2. Samples taken during the January discharge have a substantial amount of tritium still present. This would suggest that circulation within the reservoir is relatively slow relative to the fluid withdrawal rate during production from the HGP-A reservoir.

3. The correlation between decreasing concentrations of high tritium-low salinity quench water and the increasing chloride concentration in the discharge fluids strongly suggests that the rate at which the chloride ion was increasing during the initial part of the production test was somewhat higher than its natural rate would have been had there been no quench water present. It is highly probable that the rate at which the chloride ion concentration was increasing would have abated had the test been continued.

Carbon dioxide samples were also obtained for ^{14}C analysis of the gases being discharged from HGP-A. The results of these analyses are puzzling at best. Carbon-14 is present at a level equivalent to 20% of modern activity which corresponds to a maximum average carbon age of approximately 12,000 years. This age assumes no contribution from magmatic carbon dioxide; if one assumes magmatic carbon is present then the actual age of the non-magmatic component would be younger by the assumed proportion of magmatic carbon. The apparent ages of the carbon dioxide samples taken during the January 1980 test are virtually identical to an earlier ^{14}C analysis of HGP-A gases done in June of 1977. Although there are several possible sources of carbon in the well, there are only two which could reasonably supply the biogenic carbon in the well: organic material pumped into the well during drilling operations or calcite which has been deposited from groundwater circulated through the rift zone. Whether either of these sources could provide the seemingly constant proportion of ^{14}C to the well fluids is questionable. Continued monitoring of the ^{14}C in the fluids during production will be required before a more definite source for the carbon in the well discharge can be identified.

CONCLUSIONS

The conclusions which can be drawn from the presently available results of this production test of HGP-A are as follows: 1) The chloride and total dissolved solids concentration in the HGP-A fluids will continue to increase during production from the HGP-A reservoir although it is highly probable that a plateau will be reached as production stabilizes. 2) The non-condensable gas fraction in the HGP-A discharge has decreased substantially from earlier production concentrations. 3) Carbonate scaling within the piping network during production is unlikely to occur if the well production pressure is maintained above 150 psi. 4) the rate of circulation through the

reservoir is on the order of at least years but is probably no more than a few thousand years.

5) Production from the HGP-A reservoir is withdrawn from at least two reservoirs; one is more saline than the other and, under shut in conditions, the less saline aquifer circulates water into the well bore and thus must be at a higher pressure.

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