PRECOMMISSIONING SAMPLING TO ESTABLISH A BASELINE FOR GEOCHEMICAL MONITORING AT BROADLANDS-OHAAKI GEOTHERMAL SYSTEM, NEW ZEALAND

Chemistry Division, DSIR, Wairakei
Private Bag, Taupo, New Zealand

ABSTRACT
Discharge and/or downhole sampling of production, injection and monitor wells has been conducted at Broadlands-Ohaaki to establish a precommissioning baseline; this will allow changes related to future production to be assessed. Changes related to long term discharge testing have been essentially due to two processes, (1) steam gain or loss from the formation and (2) dilution by shallow and marginal steam-heated waters. These changes are predicted to continue once full scale production is started, but the interpretation may be complicated by returns of high chloride reinjection waters.

There appears to be similar concentrations of CO₂ in the production liquid and the steam-heated waters; however, the H₂S is greatly depleted in the steam-heated waters, causing a strong increase in CO₂/H₂S ratios when dilution occurs. This signature may help to predict the incursion of dilution waters, and also to distinguish these fluids from trends related to reinjection returns. The planned assessment of monitoring results of production wells will greatly assist in the reservoir management of the system.

INTRODUCTION
The Broadlands-Ohaaki geothermal system is located 25 km northeast of the Wairakei geothermal system in the Taupo Volcanic Zone of New Zealand. A 110 MW power station will be commissioned in early 1989; first exploratory drilling began in 1965. After final separation of steam at 4.8 b.g., all waste water will be reinjected along the southwest to southeast margins of the system. Several changes in the production reservoir may occur subsequent to commissioning, including (1) an increase in discharge enthalpy due to depressurisation within the reservoir, (2) an eventual decline in discharge enthalpy due to the extraction of heat from the reservoir, (3) dilution of reservoir fluids by marginal, steam-heated waters and (4) return of reinjected fluids.

In order to predict and monitor these changes to the production reservoir, a programme of regular sampling and analysis of discharging wells, separation plants and reinjection lines has been established. This report describes the results of the sampling programme conducted in late 1987 and early 1988 to provide a present day baseline of chemistry against which to assess production-related changes.

This monitoring programme and the continual assessment of results will be essential to reservoir management. Some chemical indicators may help to predict changes before they occur, the data will also be useful in testing the results of reservoir modelling and related predictions.

Background
Figure 1 shows the locations of production, injection and monitor wells at Broadlands-Ohaaki. The steady state (pre-drilling) geochemical structure of the system was deduced by Hedenquist and Stewart (1985) from initial discharge chemical and stable isotope patterns. These data are summarised in an enthalpy-chloride diagram (Figure 2); the enthalpy was determined from quartz geothermometry and the chloride concentration has been corrected to reservoir conditions.

Hedenquist and Stewart (1985) identified a steam-heated water as being the principal natural diluent of both East and West Bank deep chloride fluids. This steam-heated water is CO₂-rich due to the high gas content of the deep chloride fluids and, subsequently, the steam which forms during boiling.

The steam-heated waters are present at shallow (200 to 400 m) depths over the deep upflow, and drape downwards along the margins of the system, like a discontinuous umbrella. They are often associated with both shallow and (on the margins) deep thermal inversions of 150 to 175°C. Hedenquist and Stewart (1985) determined that the shallow CO₂-rich, steam-heated waters were the cause of casing and casing corrosion; also, these cool, dilute fluids were drawn down into the production reservoir during long term discharge testing. The present state of the reservoir fluids,
somewhat modified from the initial, natural conditions, is discussed here. This present state will be used as a baseline in the future monitoring programme.

RESULTS OF THE BASELINE SAMPLING OF WEST BANK PRODUCTION WELLS

Enthalpy-Chloride Relations

The West Bank production wells were discharged in turn from late February to early May, 1988; weirbox and Webre water and Webre gas samples were collected, and discharge enthalpies measured. East Bank wells have yet to be sampled in the present programme, as these wells are part of the second stage of commissioning.

The results have been compiled along with previous sample data for West Bank producers (initial sample conditions denoted by a tick mark). Three diagrams are used to present the data and look at trends; total discharge enthalpy versus chloride (Figure 3), enthalpy of the quartz geothermometer versus reservoir liquid chloride (Figure 4), and total discharge CO\textsubscript{2} versus CO\textsubscript{2}/H\textsubscript{2}S ratio (Figure 5).

Two principal trends are observed in the enthalpy-chloride variation. One is due to steam gain or loss from the formation and the other is dilution; in the case of the dilution trend, extrapolation to nil chloride indicates an endmember enthalpy of 600 to 700 kJ/kg (145 to 165°C), i.e. the same steam-heated fluid identified from initial conditions in Figure 2 (Hedenquist and Stewart, 1985).

There is much variation in total enthalpy (Figure 3), though this is largely due to steam gain or loss from the reservoir (due to production testing). However, when only the liquid phase in the reservoir is considered (Figure 4), a strong component of dilution is evident. In many wells, the 1988 sample is more dilute than the initial discharge (shown by tick mark); once dilution begins, it seldom reverses, even when the well is not discharged for long periods.

Trends in Gas Chemistry

The trends in gas chemistry of the total discharge are shown in Figure 5. A model curve has been calculated for changes in dissolved gas in a liquid boiling from 290 to 270°C (based on an initial gas content determined from some high temperature liquid-feed wells); a portion of the corresponding vapour composition curve is also shown.

Wells with liquid feeds should show compositional variations approximately along the liquid trend, while those showing excess enthalpy (i.e. a two phase feed) will have more gas in the discharge, and will plot between the two curves. Most data, particularly for initial discharges, do fall between these curves, with trends parallel to the curves (except where a well undergoes a large variation in discharge enthalpy).

However, several wells deviate from these trends for recent, and particularly 1988, samples. There is a large increase in the CO\textsubscript{2}/H\textsubscript{2}S ratio without the necessary increase in total CO\textsubscript{2} required by gas fractionation from a single fluid. These trends indicate the presence of a component of fluid distinct from the production fluid; this component has a similar CO\textsubscript{2} concentration to the production fluid, but is depleted in H\textsubscript{2}S (i.e. has a much higher CO\textsubscript{2}/H\textsubscript{2}S ratio).

The greatly increased CO\textsubscript{2}/H\textsubscript{2}S ratios in some wells are most likely due to the presence of a component of steam-heated waters (i.e. reflecting dilution). These steam-heated waters can have CO\textsubscript{2} concentrations similar to those of the deep chloride liquid (Hedenquist and Stewart, 1985); however, their CO\textsubscript{2}/H\textsubscript{2}S ratios can range from 300 to 1000, as evidenced from downhole gas samples.
Figure 4: Enthalpy of quartz geothermometer versus the reservoir liquid chloride for all available West Bank production well samples since initial discharge (initial designated by tick marks).

This relative depletion in H$^+$ in the steam-heated waters may be caused by one or more of at least three processes: (1) H$^+$ is more soluble in the liquid being boiled such that CO$_2$ is enriched in the initial steam, and therefore will be enriched in the condensate; (2) H$^+$ is partly oxidised upon condensing into the steam-heated waters (elevated sulphates are noted, but not to the extent of producing acid conditions); (3) some of the H$^+$ is fixed as pyrite (iron sulphide is a common alteration mineral associated with the CO$_2$-rich steam-heated waters).

A 10 to 20% dilution of the production liquid by a steam-heated water with a X$^{\infty}$/H-S ratio of 300 and a CO$_2$ content similar to the production liquid would easily explain the trends in Figure 5. This would also conform to the dilution trends (well and magnitude) noted from enthalpy-chloride trends (Figure 3).

Steam Fraction Estimates from Gas Chemistry

Total discharge gas data have been used to calculate the log K of the reaction

$$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_4 + \text{H}_2\text{O},$$

and this compared with the log K for equilibration at the reservoir temperature (reservoir temperature estimated by quartz and Na-K-Ca geothermometers). These data are plotted on the Giggenbach of Figure 6. Where the apparent equilibrium is different from the reservoir temperature (reservoir temperature estimated by quartz and Na-K-Ca geothermometers), this departure from equilibrium is caused by the differential fractionation of gases into steam, which disturbs their relative proportions (as well as total amounts) in the total discharge (Giggenbach, 1980).

Data lying below the equilibration curve indicate steam and gas loss from the formation, whereas data above indicate steam plus gas gain. The former is due to boiling, whereas the latter is due to steam gain, resulting in excess enthalpy of discharge.

The two wells with the largest log K are also noted to have the greatest degree of excess enthalpy. All other wells are close to or are at saturation. There is a noticeable difference between the quartz and Na-K-Ca geothermometer temperatures, with quartz being the lowest. Using either geothermometer, the overall qualitative relationship is consistent with measured enthalpies. If the Na-K-Ca temperature is used as a reservoir maximum, a boiling curve projects back to the equilibration curve at about 100°C, suggesting this is a maximum temperature where steam loss is affecting the reservoir; it could be as low as about 275°C.

Monitoring of this parameter will allow a qualitative assessment of the degree of steam loss from the reservoir subsequent to commissioning. Comparing with 1976 data, as reported by Giggenbach (1982), two wells had decreases in log K by two log units, consistent with approximately 1% steam loss in the formation of one of the wells, and the decrease in excess enthalpy noted for the other.

DOWNELE SAMPLE OF MONITOR WELLS

All monitor wells (Figure 1) were sampled at the end of 1987 by means of a Klyen downhole sampler modified to seal in gases; several reinjection and some production wells were also sampled. Samples were often collected at more than one depth to assist in interpretation of any production-related changes.

The results of some of the downhole sampling are shown in the inset of Figure 2, with trends from initial (often discharge) conditions shown, where available. Regular sampling of the monitor wells will assist in detecting changes in fluid chemistry (either dilution by steam-heated waters or returns of injected waters) before they reach production reservoirs, and may allow for modifications in reservoir management.

Sampling was conducted in static wells, closed from bleed for several months; these are the conditions under which monitor wells will be maintained during production. In contrast, many of the previous downhole samples (and all of the...
The reinjection scheme at Broadlands has been designed to reduce the potential for reinjection returns to the production zones. Interference tests in West Bank wells (McGuinness, 1985) have shown that the shallow permeable rhyolite which will receive the reinjected fluids, and the rhyolite to the southeast, is not in good hydrological connection with the zone of production. Furthermore, the pressure drop in the reservoir associated with this small degree of interconnectedness (perhaps only to vapour) with the production reservoir. The degree of permeability between the south and southeast reinjection wells with the East Bank production zone is not well known at present.

At present the baseline of the West Bank production zone and the marginal reinjection and monitor zones is well established but not of the East Bank is reasonably understood, and will soon be confirmed through discharge testing. Any changes in production fluid chemistry subsequent to commissioning should be readily identified through the planned monitoring programme.

Dilution by steam-heated waters, even to very small degrees such that enthalpy-chloride changes are not clearly detected, should be identified by noticeable increases in CO₂/H₂S ratios without a corresponding total CO₂ increase. Rejection returns will show up as a mirror image trend to dilution, in that they will be very high in chloride but also about 15°C (the reinjection temperature) below the mixing trend. Rejection in production waters is evidence for there being some degree of interconnectedness (perhaps only to vapour) with the production reservoir. The presence of dilution. Returns of high chloride reinjected water in conjunction with an enthalpy decline may be seen as a trend related to steamloss. Some thermal buffering of the reinjected water by the production zone is evidence for there being some degree of interconnectedness (perhaps only to vapour) with the production reservoir. The presence of dilution. Returns of high chloride reinjected water in conjunction with an enthalpy decline may be seen as a trend related to steamloss. Some thermal buffering of the reinjected water by the formation should result in trends distinct from those due to steam loss.

CONCLUSIONS

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REFERENCES


The rest of this page is for the taking of copious notes.