

CONTINUING REINJECTION RETURNS IN THE PALINPINON GEOTHERMAL PRODUCTION FIELD NEGROS ORIENTAL, PHILIPPINES

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ABSTRACT

Reinjection (RI) returns continue to affect the Palinpinon field to date. Two recent cases were investigated using various geochemical techniques to illustrate this reservoir phenomenon.

In Palinpinon-?, the southwest Puhagan wells displayed typical RI return indicators, when PNSRD was utilized above its original acceptance of 60 kg/s in the first quarter of year 2000. The RI well began accepting up to 760 kg/s after it was worked-over in June 1999. Thermal and mass front breakthroughs were detected immediately from chemical and physical measurements, and thus were mitigated immediately by reducing the RI load in PNSRD to an optimal level of 70kg/s or less.

In Palinpinon-2, condensate injection in SG3RD has resulted to returns, causing dilution of reservoir fluid in production well NJ3D. A mixing simulation using the CHILLER software was made to demonstrate the dilution process. No thermal decline was observed due to possible reheating of the returning condensate by the formation prior to mixing with the production reservoir.

1.0 INTRODUCTION

The Palinpinon geothermal field is located near the southern tip of the island of Negros in the Central Philippines (Fig. 1). The field has been subdivided into two major production sectors, namely, Palinpinon-I and Palinpinon-2 (Fig. 2). The Palinpinon-I sector centered in Puhagan host the 112.5 MWe Palinpinon-I power plant which has been in operation since June 1983. The Palinpinon-2 sector west of Palinpinon-I is further subdivided into the Balas-balas, Nasuji, and Sogongon sub-sectors. The commissioning of the modular plants occurred in

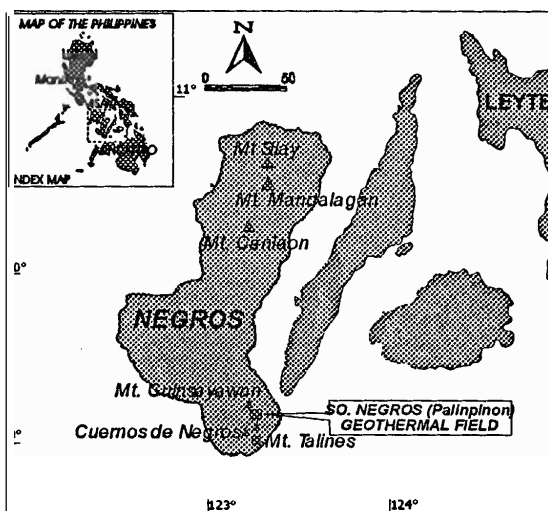


Figure 1. Location map of the Palinpinon geothermal production field

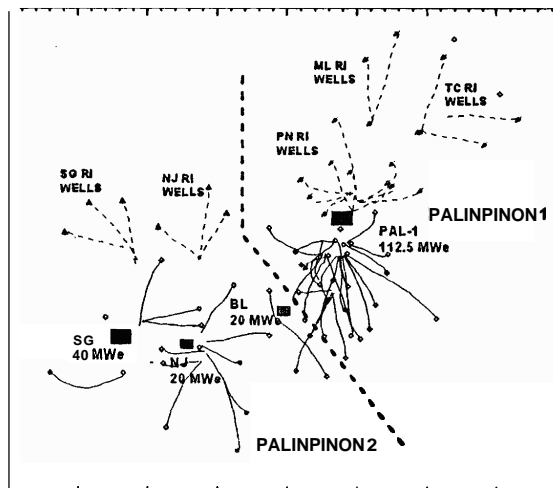


Figure 2. Palinpinon field locations of power plant and well tracks

December 1993 (Nasuji; 20 MWe), September 1994 (Balas-balas; 20 MWe), January-April 1995 (Sogongon land 2; 40 MWe). The total installed capacity of the whole Palinpinon field is rated at 192.5 MWe. To date, a total of 73 wells (48 production; 25 reinjection) have been drilled in the field.

The waste brine in the production wells in Puhagan and Balas-balas are presently being injected into reinjection wells PN5RD, TC2RD, TC3RD, TC4RD, MLIRD, ML2RD, and OK3R. Except for PN5RD, drilled in Puhagan about 500 m north of the production wells, the other reinjection wells are drilled at a distance of 2-3 km northwest of Puhagan, in the Ticala and Malaunay reinjection areas. On the other hand, the waste brine from the Nasuji and Sogongon production wells are being disposed into reinjection wells drilled about 1 km to the north of the production sectors. The reinjection areas in the Palinpinon field are located in the postulated outflow portion of the geothermal system.

The return of reinjected brine into the production wells has been observed in the Palinpinon field since the start of field utilization in 1983 in Palinpinon-1 (Seastres et al., 1995; Hermoso and Meorada, 1997) and since 1996 in Palinpinon-2 (Ramos-Candelaria et al., 1997). To minimize the adverse effects due to RI returns, long-term strategies were employed in the field. Since 1989, all reinjection wells in the borefield are sited at least 1.0 km away from the production sector and along the hydrological outflow. The RI wells are also targeted such that uncommunicative geologic faults are intersected. To minimize the generated waste brine, the utilization of wells with high discharge enthalpy (i. e.: steam-dominated wells) are prioritized. The waste brine for injection are also distributed among the RI wells to optimize their injection loads.

By employing various geochemical tools and techniques, the effects of reinjection returns on the production wells are detected. To minimize the adverse effects of reinjection returns to the reservoir (i.e.: temperature and well output declines) the reinjection strategy is then adjusted or altered. This paper will present two cases that were investigated using the various geochemical techniques to illustrate this reservoir phenomenon.

2.0 BRIEF GEOLOGICAL BACKGROUND AND HYDROLOGICAL MODEL

The Palinpinon geothermal field is located on the northern slope of the dormant andesitic Cuernos de Negros volcano complex. As a volcano-related field it is underlain by a suite of

volcanic, sedimentary, and intrusive rocks ranging in age from Miocene to Recent. These rocks were intruded by andesite dikes that are related to the latest volcanism events (Aniceto-Villarosa et al., 1988).

Permeability in the field is related to the numerous faults that transect the area. The faults in the Palinpinon-1 sector of the field have mostly NE and NNE trends while the faults in the Palinpinon-2 sector trend mostly to the NW and NNW. It is believed that the reinjected brine flows from the reinjection to the production sectors along these well-delineated fault structures that transect the field.

Based on geochemistry, reservoir engineering, and drilling data, it is believed that the upflow of the geothermal system is located southwest of Puhagan in the vicinity of the so-called Lagunao Dome located on the northern flank of the Cuernos de Negros volcano. The geothermal system outflows mainly to the northeast towards the Okoy River valley along the delineated NE and NNE trending faults. The production sector in Puhagan and Balas-balas are on this branch of the outflow that is still nearer to the upflow of the system. A minor outflow to the northwest along the NW and NNW faults is also being tapped by the Nasuji and Sogongon production areas (Fig. 3).

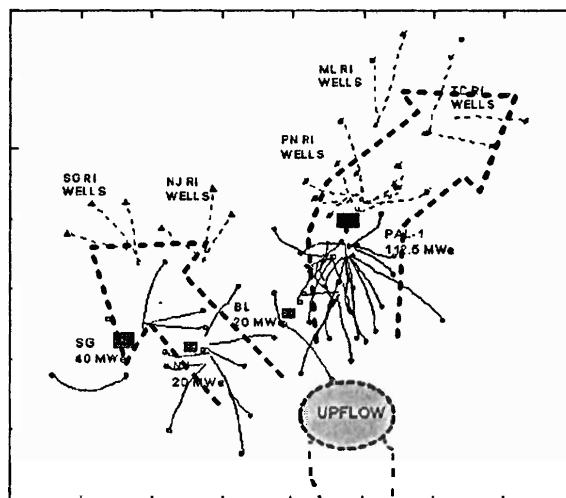


Figure 3. Palinpinon field hydrological model

3.0 GEOCHEMICAL METHODS IN MONITORING RI RETURNS

In the Palinpinon geothermal field, rapid RI returns was primarily caused by the following

factors: (a) close proximity of the RI sector to the production field; and (b) the presence of very permeable fault(s) connecting the RI sector with the production sector of the field. To detect the presence of RI returns in the production wells, the changes with time of the reservoir Cl, Ca, SO₄, silica geothermometer (T-SiO₂), and CO₂, H₂S, CH₄, and H₂ in the total discharge (TD) are monitored along with the molecular ratios of CVCa in the water or liquid phase, and CO₂/H₂S in the steam phase. Other chemical parameters such as stable isotopes ¹⁸O and ²H (deuterium) are also monitored. Physical parameters such as the production wells' discharge enthalpy, and steam and water flow rates are also monitored. Table 1 shows the general changes in these parameters as a response to RI return.

Table 1. Parameters used in detecting RI returns

Parameters	Characteristics	Changes
Cl-res, ¹⁸ O, ² H	Natural tracers	Increase
CO ₂ -TD, H ₂ S-TD, CO ₂ /H ₂ S, CH ₄ , H ₂ , discharge enthalpy	Indicates changes in liquid saturation	Decrease
T-Quartz, CVCa, Cl/SO ₄	Indicates changes in reservoir temp.	Decrease or None

As a result of flashing of the well discharge fluids in the separator, Cl (along with the other soluble constituents including isotopes) is concentrated in the liquid phase while CO₂ and H₂S are concentrated in the steam phase. The resulting brine (with a temperature of about 160°C) is more concentrated in Cl and more degassed than the reservoir and discharge fluids. Cl is progressively being concentrated in the RI sector upon injection since it is not involved in water-rock interaction and remains in the liquid phase. Consequently the injected brine also becomes progressively depleted in CO₂ and H₂S. When the highly mineralized or concentrated and more degassed liquid from the RI sector flows back to the production sector, the well discharges will eventually show a progressive increase in the reservoir chloride and decrease in CO₂ and H₂S in the total discharge, along with the other constituents in the liquid and steam phase. The increase in Cl and decrease in the gas concentrations in the discharges indicates the arrival of the so-called injection mass front.

Other changes in the discharge chemistry of the production wells may indicate a decline in the reservoir temperature brought about by RI

returns, the so-called thermal front. The thermal front is indicated by the decrease in the CVCa and Cl/SO₄ ratios and the silica geothermometer (T-SiO₂). The decrease in the Cl/Ca and Cl/SO₄ ratios are temperature-dependent as these ratios are controlled by anhydrite (CaSO₄) solubility. Anhydrite is a mineral with reverse solubility as it is dissolved with a decrease in temperature. The decline in the Cl/Ca and Cl/SO₄ ratios manifest the presence of RI returns since the Ca and SO₄ concentrations increase in greater proportion than the corresponding increase in the Cl concentration. A decrease in the discharge enthalpy may also accompany these chemical changes. Cross-plots of Cl-res against the Cl/Ca or Cl/SO₄ ratios, CO₂-TD, discharge enthalpy, T-SiO₂, and other parameters are also constructed to establish the trends of these parameters with respect to one another as a result of RI returns.

Other geochemical monitoring tools were also used in detecting reservoir response to RI returns. The correlation of the Fischer-Tropsch (FT) gas equilibria reaction with the pyrite-magnetite (HSH1), pyrite-hematite (HSH2), and pyrite-pyrrhotite (HSH3) developed by D'Amore and Truesdell (1995) are also used to deduce the reservoir response to RI returns as this process affects the equilibria of CO₂, H₂S, H₂, and CH₄ in the reservoir. The calculated data using these methods are plotted in the diagram in Figure 4.

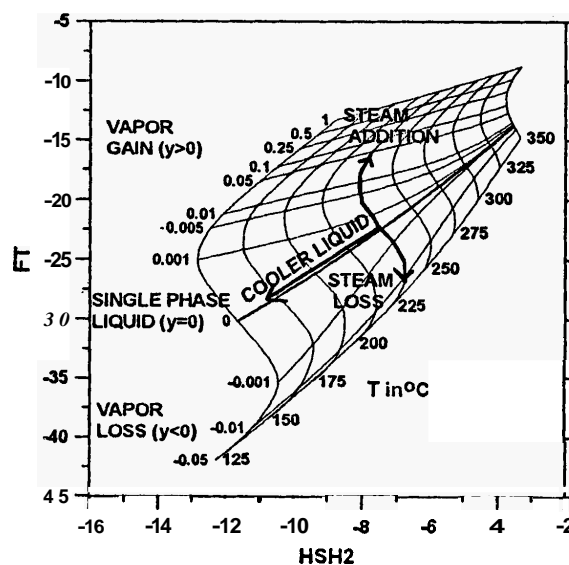


Figure 4. FT-HSH diagram for gas equilibria

4.0 REINJECTION RETURNS FROM PNSRD

PN5RD is a reinjection well in Puhagan drilled in February 1983 towards the north. It had an initial capacity of 65 kg/s. Among the wells drilled in Puhagan, it was the only one that showed negative RI returns to the field. Consequently it has been given first priority in the utilization of the Puhagan RI wells.

As early as 1995, obstruction was tagged inside the well by an 80-mm go-devil at 777 mMD. When the well was completely blocked by silica deposits in August 1999, mechanical work-over of the well was conducted from August 29 to September 11, 1999. The well was cleared to a depth of 2720 m, after drilling had encountered a 0.90-m metal bar stuck at 1261 mMD, then at 1862 mMD. As expected, recovered blockage debris were mostly (~95%) composed of amorphous SiO₂ and some clay. These predominantly silica scales were encountered from the master valve, down to 784 mMD.

The well was reutilized in November 1999, and subsequently its capacity has increased to 160 kg/s, almost 100 kg/s higher than its original capacity. This is believed to have resulted from the greater pressure difference between the reinjection and production sectors, due to the continued mass extraction. In Puhagan, pressures in the production wells have declined from -12 MPag in 1983 to -6 MPag in 1994.

4.1 RI Return

After a month of continuous reinjection in PN5RD at a high load of 130 kg/s, reinjection returns was immediately manifested in a number of wells in western Puhagan by the middle of December 1999. Most evident is the effect on PN19D and PN24D, largely because of these wells' proximity to PN5RD via the postulated RI return path along Puhagan Splay B (Fig. 5). A number of cross plots are shown to illustrate the wells' response.

A Cl-CO₂ plot of PN19D (Fig. 6) shows data points for last-quarter 1999 and first quarter 2000, migrating towards a region of decreased CO₂-td and increased Cl. A CO₂-T(SiO₂) plot (Fig. 7) shows the same data points migrating to an area of decreased CO₂-td and decreased T-SiO₂.

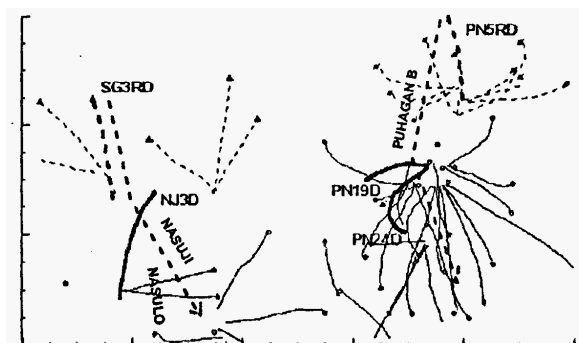


Figure 5. Flow path of reinjection returns from PNSRD and SG3RD

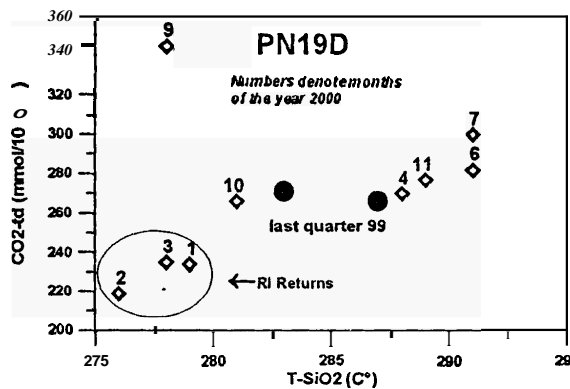
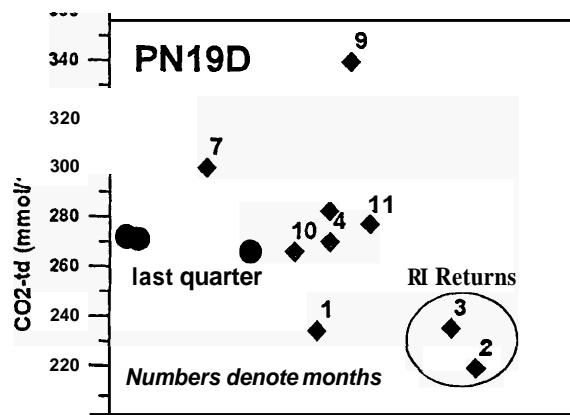


Figure 7. CO₂ vs. T(SiO₂) plot for PN19D from last quarter 1999 to November 2000

A Cl-Cl/Ca cross plot of PN24D (Fig. 8) shows data points belonging to the same period of last quarter 1999 and first quarter 2000 trending towards an increased Cl-res and decreased Cl/Ca ratio. The same is shown by a Cl-T(SiO₂) plot in Figure 9 where data points again migrate towards increased Cl-res and depressed T(SiO₂).

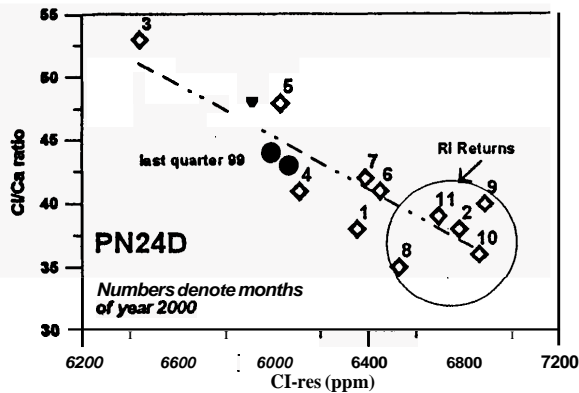


Figure 8. CI vs. CVCa plot for PN24D from last quarter 1999 to November 2000

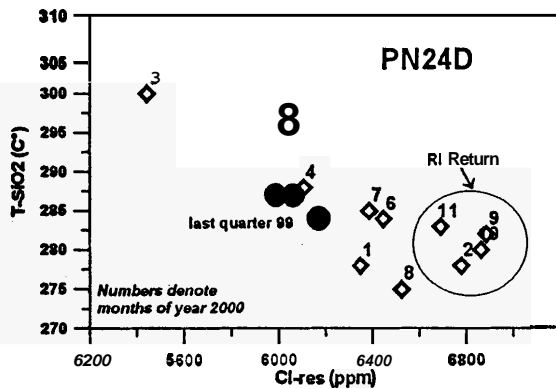


Figure 9. CI vs. T(SiO₂) plot for PN24D from quarter 1999 to November 2000

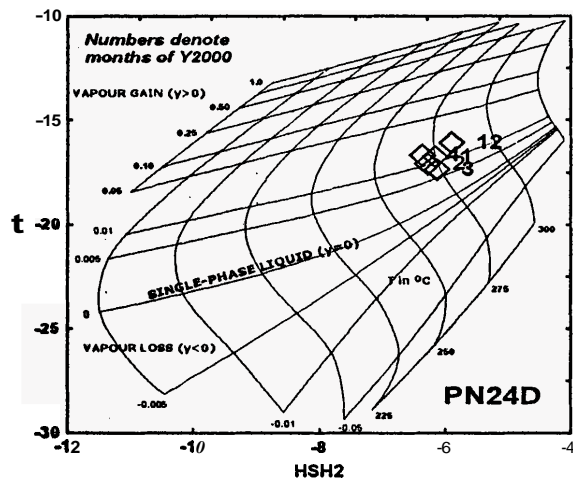


Figure 10. FT-HSH₂ plot for PN24D

An FT-HSH₂ plot is also used to show PN24D's response to the RI return. Figure 10 shows data points from December 99 to first quarter 2000 moving down and left, corresponding to a decrease in temperature and in vapor saturation. This implies a cool liquid inflow.

The effect of the RI return is not solely confined to well chemistry, but also affects physical parameters such as discharge enthalpy. PN24D's discharge enthalpy declined from 1762 kJ/kg in December 1999, to 1259 kJ/kg in February 2000. On the other hand, its mass flow increased slightly from 33 kg/s to 38 kg/s, indicating that there was an inflow of a cooler liquid. The net effect is an output reduction in PN24D of around 2.4 MWe, which when combined with the change in output of all the other wells give a net decline of 3 MWe in the field steam availability during this period.

4.2 Recovery from RI Returns

PNSRD was completely shut from March 8 to April 5, 2000, because of plant downloading to give way to repairs on turbine unit no. 2. Referring again to the crossplots (Figs. 6-9), a recovery trend is observed right after PNSRD's shutdown. This recovery trend is characterized by data points going back to the last-quarter 1999 status, and even beyond, as in the case of the temperature (T-SiO₂) of PN24D in April and May, which improved substantially over the last-quarter 1999 data.

The reutilization of PNSRD in April was now limited to 70 kg/s (although actual loads sometimes go beyond or below this limit for a short period due to operational demands). This was done to avoid a recurrence of the RI returns experienced in the first quarter 2000. However, a mixed response was obtained. In the case of PN19D, inferring from the June-July data and from the more recent November data, there is a continued recovery especially in terms of temperature and gas concentration. In the case however of PN24D, RI returns still continue to plague the well. From the crossplots, it is evident that data points starting August are well within the region of RI return circumscribed earlier by the first quarter data. It is very likely that since PN24D is nearest to PNSRD along the RI return flow path, it receives the bulk of the RI return from PNSRD. A nearby well, PN31D, likewise indicate injection returns at this limited load of PNSRD, albeit to a lesser degree than PN24D.

5.0 REINJECTION RETURNS FROM SG3RD

The injection well SG3RD in the Sogongon RI sector was utilized for the Zero Disposal

System (ZDS) beginning in Dec. 31, 1998. This well was not utilized for injection of large volume of waste brine due to the very rapid RI returns to the Nasuji and Sogongon production wells. To meet the requirements for the Zero Disposal System (ZDS), this well was utilized to dispose mostly the steam condensate from the cooling tower blowdown from the Nasuji and Sogongon power plants, at a rate of 10-30 kg/s, with injectate temperature of about 40-60 °C. Occasionally, the injection rate increased to >30 kg/s due to surface rain water run-off. To date, this well is still being utilized to dispose of the condensate from the two power plants.

Table 2 below shows the average chemical characteristics of the steam condensate mixed with other fluids in the thermal pond before injection into SG3RD.

Parameter	Concentration(pprn)
pH	6.4
Na	26.0
Li	V.L
Ca	2.0
SiO ₂	1.0
K	18.0
Mg	0.45
SO ₄	41.0
Cl	74.0
B	3.0
NH ₃	14.2

6.1 Reinjection Returns in NJ3D

As a result of condensate injection in SG3RD, indications of RI returns were observed in well NJ3D as early as the middle of January 1999. NJ3D is located at a distance of about 1.0 km. south of SG3RD. It is believed that the injectate flows from the RI sector to NJ3D along two major faults that were intersected by the two wells, namely the Nasuji and Nasulo faults (Fig. 5). Figure 11 shows the time plots of the Cl-res, CO₂-TD, CO₂/H₂S, CVCa ratio, and T-SiO₂ for NJ3D. As a result of inflow of very dilute fluid, the Cl-res declined from about 4300 ppm to only 3500 ppm between January and March 1999. The CO₂-TD of the well also decreased during the same period from about 40 mmol/100mol to about 20 mmol/100mol, along with the decline in the CO₂/H₂S ratio. The Cl/Ca ratio appears to have increased between January and May 1999, after which it appears to have stabilized. Significantly, the T-SiO₂

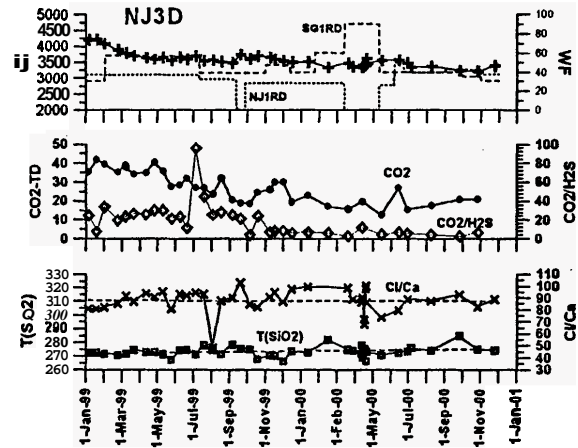
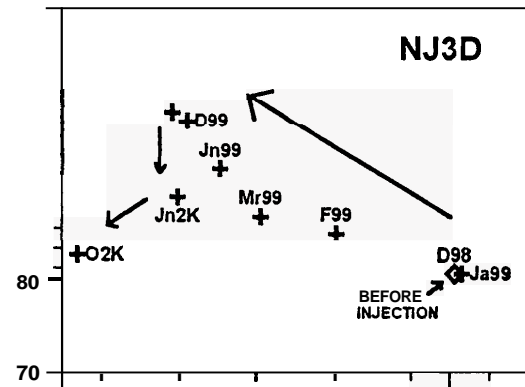


Figure 11. Time plots of selected parameters for NJ3D



appears to be stable and no thermal decline was observed.

The decline in Cl-res and the initial increase in the CVCa ratio are the results of the entry of a highly dilute fluid compared with the brine in the reservoir. The increase in the Cl/Ca ratio in this case may not signify any temperature-dependent reaction (i. e., anhydrite dissolution/deposition). The increase is due mainly to the presence of Ca-poor fluid mixing with a Cl-rich fluid in the reservoir. The decline in the average Cl concentration in the reservoir as a result of the mixing of the two fluids is considerably less than the decline in the average Ca concentration and may result to an initially increasing CVCa ratio. Figure 12 shows the relationship between the Cl-res and the Cl/Ca ratio showing the data points from December 1998 until March 2000 exhibit increasing CVCa ratios with decreasing

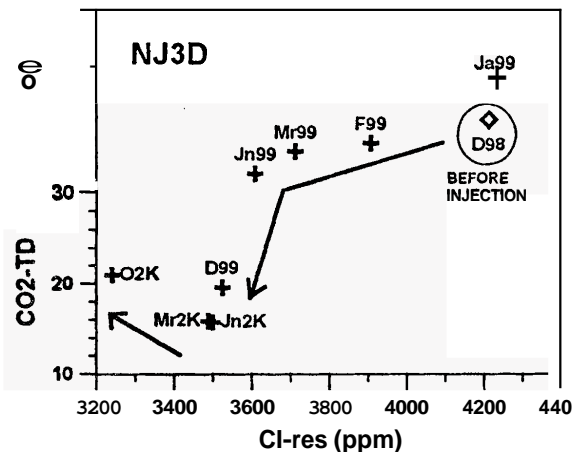


Figure 13. Cl vs. CO₂ plot for NJ3D

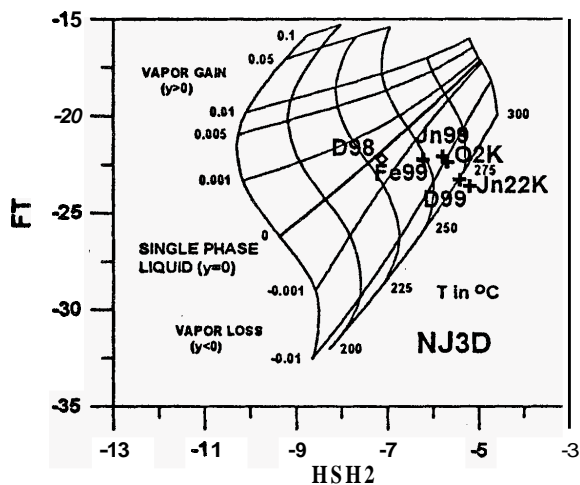
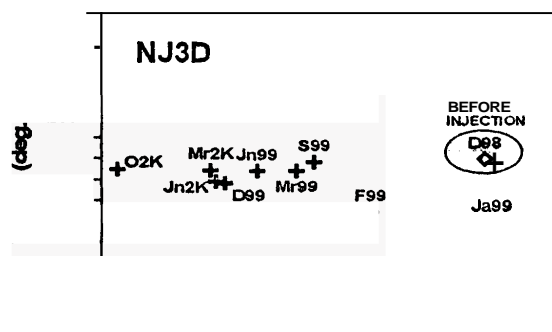


Figure 14. FT-HSH2 plot for NJ3D



Cl-res. The decline in Cl/Ca ratio from 98 to 89, with almost unchanged Cl-res of about 3500 ppm, between March and June 2000 is probably an effect of increased brine return from the neighboring SG1RD at injection load of 80-90 kg/s to accommodate the load of NJ1RD while it is

shut in March to May 2000. The large volume of brine injected compared with the volume of injected condensate in effect "masked" the dilution of the NJ3D discharge. With the reduction in brine RI load into SGIRD to about 40 kg/s from May 2000, while maintaining the 20-30 kg/s condensate injection rate in SG3RD, the Cl-res in NJ3D again exhibited a decline from -3500 ppm to -3300 ppm, along with a slight decline in the Cl/Ca ratio from 89 to 83. This signifies that dilution is again affecting NJ3D.

The entry of relatively more degassed fluid into the reservoir of NJ3D is presented in Figure 13 showing the plot of CO₂-TD - Cl-res. The plot shows decreasing CO₂-TD along with decreasing Cl-res between December 1998 to March 2000 as a result of the entry of very degassed and diluted fluid into NJ3D. Figure 14 is an FT-HSH2 plot for NJ3D showing the effects of the entry of highly degassed fluid. The data migrated from the saturated line (with y=0) in December 1998 to a more degassed region (with y<0) beginning in January 1999.

It is significant that even with RI returns from SG3RD, NJ3D still does not show large temperature decline. In the FT-HSH2 plot in Figure 14, the data points even migrated towards the higher temperature region of the diagram. The Cl-res - T(SiO₂) plot also shows almost stable temperatures even with continued decline in Cl-res (Fig. 15). Figure 16 was constructed for NJ3D to ascertain which SiO₂ species controls silica solubility. It appears that the silica solubility in the reservoir is generally controlled by quartz and that the calculated T(SiO₂) still approximates the measured temperature based on downhole surveys. This supports the conclusion that even with cool condensate injection in SG3RD at rate of 30 kg/s, there is still no observed thermal decline even after two years.

5.2 CHILLER Simulation

Mixing simulation using the CHILLER software was conducted to estimate the amount of condensate that mixes with the reservoir brine. The simulation was premised with two assumptions: 1) the highest temperature attained by the injectate before mixing is 100 °C; and 2) the chemistry is not altered until the injectate is mixed with NJ3D in-situ fluid.

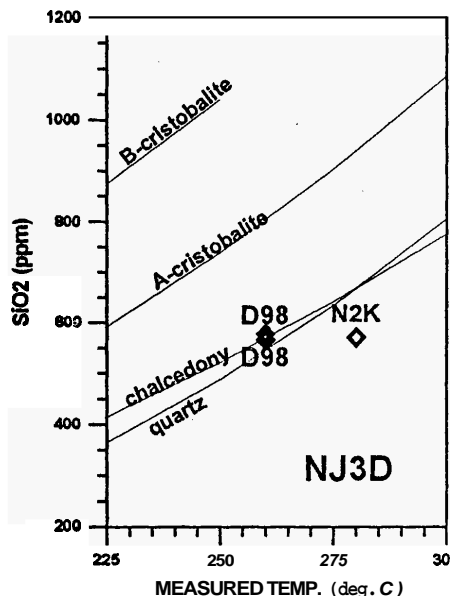


Figure 16. Silica solubility plot for NJ3D

Figure 17 shows the plots for the $T(\text{SiO}_2)$, Ca-res, and Cl-res in NJ3D along with the resultant concentrations at different fraction of injectate mixture. As shown in the Ca and Cl plots in the figure, the injectate fraction that can produce the observed changes in the Cl and Ca in NJ3D is estimated to be at least 10%. In the $T(\text{SiO}_2)$ plot, there should have been thermal declines observed even with an injectate fraction of 2%. The actual $T(\text{SiO}_2)$ plot in NJ3D however shows stable, albeit erratic, trend. The absence of thermal decline, as observed in the chemistry and downhole measurements in NJ3D, suggests that the condensate has been reheated sufficiently before it flows into NJ3D.

At present, condensate injection into SG3RD is on-going with rate of 20-30 kg/s. At higher rates, thermal decline may already be detected. Even with the present injection rate, there is still a probability that thermal decline may still be detected at a much later time. To minimize this probability, it has been proposed to drill a shallow well (at most 500 m depth) to dispose a portion of the condensate and relieve the load at SG3RD.

6.0 SUMMARY AND CONCLUSIONS

Reinjection returns continue to affect the production wells in Palinpinon-? and Palinpinon-2. By monitoring the trends through time of Cl,

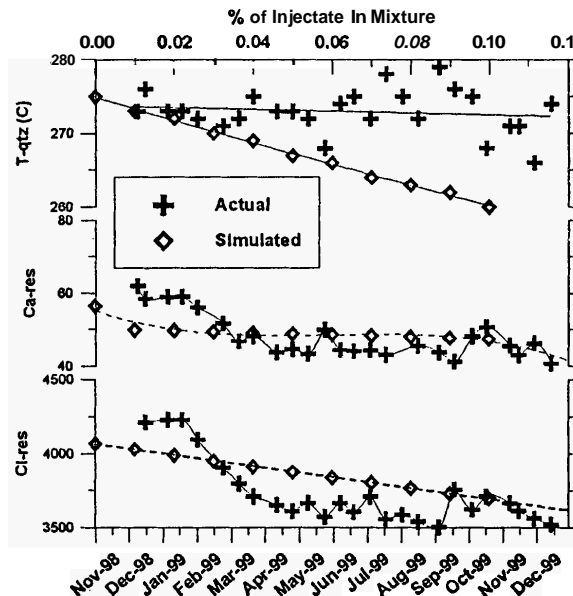


Figure 17. Plots for chiller simulation results vs. observed chemical trends in NJ3D

Ca, SO_4 , $T(\text{SiO}_2)$, CO_2 , H_2S , CH_4 , H_2 , and the molecular ratios Cl/Ca and $\text{CO}_2/\text{H}_2\text{S}$, among others, and by using geochemical tools such as FT-HSH2 and cross-plots of the chemical parameters, the effects of RI returns on the production wells can be detected and corrective actions taken to minimize the adverse effects. Computer mixing simulation using softwares such as CHILLER can be used to estimate the fraction of the injectate that mixes with the reservoir fluid.

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