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REINJECTION RETURNS AND ITS MANAGEMENT: THE PALINPINON-1 (PHILIPPINES) EXPERIENCE AFTER TWENTY YEARS OF FIELD UTILIZATION (1983 - 2003)

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ABSTRACT

The Palinpinon-1 sector, one of the two sectors that comprise the Southern Negros Geothermal Production Field in Negros Oriental, Philippines, has been utilized for electrical power generation since June 1983. The sector hosts the 112.5 MWe Palinpinon-1 power plant. Along with the 80 MWe Palinpinon-2 sector, the whole field supplies power to the islands of Negros, Cebu, and Panay in the Central Philippines. Between 1983 and 1988, waste brine from the geothermal wells was injected in the reinjection wells in Puhagan at a distance of less than 1.0 kilometer from the production wells. The effects of returning reinjected brine were immediately observed in the various production wells. A number of wells experienced thermal decline that resulted to output reduction, with a few wells becoming unproductive. Beginning in late 1989, brine injection was transferred to the Ticala and Malaunay injection sectors at a distance of 2 - 3 kilometers northeast of the Puhagan production bore field. This reduced the adverse effects of brine injection, with a number of wells recovering their downhole temperatures and improving their outputs. A number of wells with acid input even showed reduced acidity when reheated returning brine displaced or mixed with the inflowing acid fluid. The transfer of injection, from infield to outfield, also provided an artificial reheated recharge to the reservoir.

To lessen the adverse effects of brine injection in Palinpinon-1, several measures were adopted. The utilization of injection wells drilled at a distance of at least 2-3 kilometers along the outflow were prioritized. The injection wells were also targeted to intersect faults that have the least hydrological communication to the production sector. To minimize the volume of waste brine generated the utilization of high enthalpy wells was also prioritized. The volume of brine injected into the various injection wells was also optimized to minimize the adverse effects while maintaining the beneficial recharge to the production sector. These measures were implemented to ensure the sustainability of the Palinpinon-1 sector of the Southern Negros Geothermal Production Field.

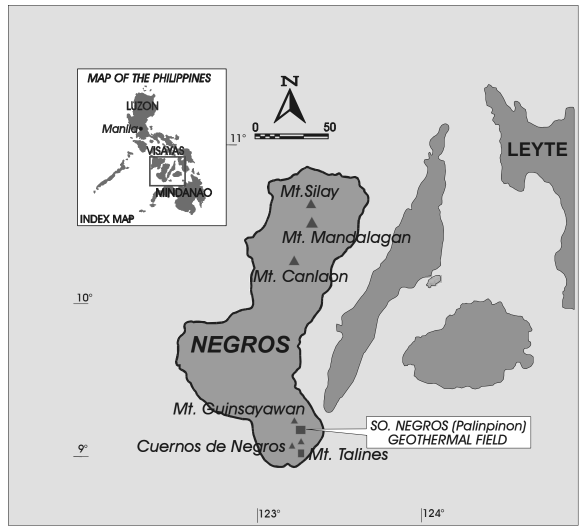

Figure 1. Location of the Southern Negros geothermal field.

1.0 INTRODUCTION

The Southern Negros Geothermal Production Field (SNGPF) was jointly developed by the Philippine National Oil Company Energy Development Corporation (PNOC-EDC) and the National Power Corporation (NPC). The field is located near the southern tip of the island of Negros in the Central Philippines, approximately 500 kilometers south of Manila (Figure 1). The field has been subdivided into two major production sectors, namely, Palinpinon-1 in the East and Palinpinon-2 in the West. The Palinpinon-1 sector hosts the 112.5 MWe Pal-1 Power Plant that is being operated by NPC since June 1983. On the other hand, the Palinpinon-2 sector hosts the four modular power plants that have an aggregate capacity of 80 MWe. The modular power plants in Palinpinon-2 were commissioned between December 1993 and April 1995, about ten years after the start of utilization of Palinpinon-1. Presently the entire SNGPF has a total rated capacity of 192 MWe, with 48 wells for production and 26 wells for reinjection.

The SNGPF is a liquid-dominated high temperature geothermal system. Waste brine is also produced from the production wells in the process of discharging steam to supply the power plants. The waste brine from the production wells are being disposed by injection into the various reinjection wells. This mode of field utilization has resulted in various changes in the geothermal reservoir, some of which are detrimental while some are also beneficial. This paper will be discussing the effects of brine injection as observed in the Palinpinon-1 sector for the past 20 years.

2.0 GEOLOGICAL BACKGROUND

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 (Aniceto-Villarosa et al., 1988). The subsurface geology and stratigraphy of the field has been established by drilling the numerous production and reinjection wells. The oldest rock unit that has been intersected by the drilled wells is the Early to Middle Miocene Puhagan Volcaniclastic Formation (PVF) which is composed of andesitic lavas and breccias interbedded with minor calcareous sedimentary rocks. Overlying the PVF is the Early Pliocene Okoy Sedimentary Formation (OSF) which is composed mostly of limestones and calcareous siltstones and minor intercalations of propylitic andesites and andesite breccias. Overlying the OSF is the Late Pliocene to Early Pleistocene Southern Negros Formation (SNF) which is composed of highly chloritized and silicified intercalated andesite lavas, tuff breccias, and volcaniclastic breccias. These older rock units had been intruded by numerous microdiorite and andesite dikes that are related to the later volcanism events. The youngest rock unit in the field is the Early Pleistocene to Recent Cuernos de Negros Volcanics which is composed of relatively less

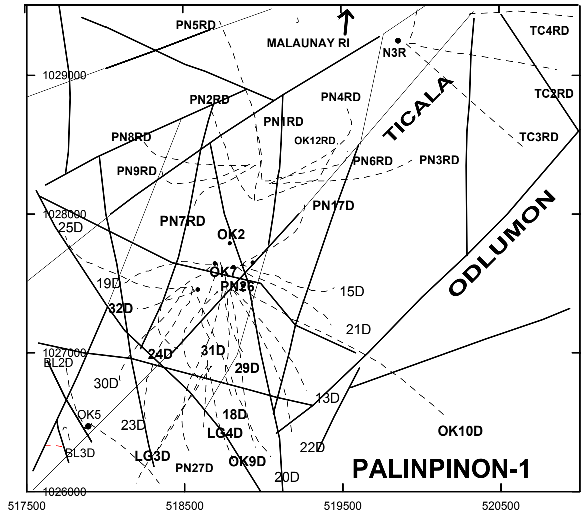

Figure 2. Palinpinon-1 well distribution.

altered pyroxene hornblende andesite lavas and volcaniclastics, dacite tuffs, and tuff breccias.

Permeability in the field is generally related to the numerous steeply dipping faults that transect the area (Urbino et al., 1988). The faults transecting the Palinpinon-1 sector of the field have mostly NE and NNE trends while the faults in the Palinpinon-2 sector trend to the NW and NNW (Figure 2). Permeability may also be encountered, although to a lesser degree, in the lithologic contacts, dike intrusions, or primary porosity of the volcaniclastics in the SNF (Hermoso and Mejorada, 1997).

3.0 HYDROLOGICAL MODEL AND RESERVOIR CHARACTERISTICS

Based on geochemistry, reservoir engineering, and drilling data, it is believed that the upflow of the geothermal system is located south of Puhagan and southeast of Nasuji (Amistoso et al., 1993) in the vicinity of the so-called Lagunao Dome (Hemoso and Mejorada, 1997) located on the northern flank of the Cuernos de Negros Volcano (Figure 3). Fluid geothermometers and downhole temperature measurements indicate increasing subsurface temperatures towards this portion of the field. An enthalpy-chloride diagram for the Puhagan production wells suggests a pre-exploitation reservoir temperature of 328°C and a chloride concentration of 4150 mg/kg. This fluid temperature is close to the maximum fluid temperature of 333°C that was measured in well

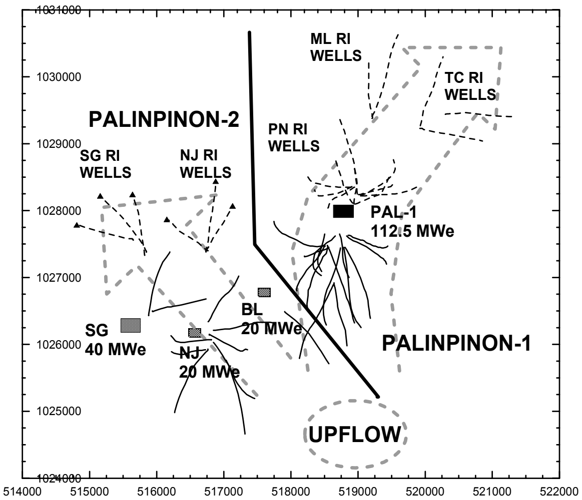

Figure 3. Hydrologic model of the Southern Negros field.

PN18D (Hermoso and Mejorada, 1997). From the postulated upflow zone, the 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 near to the upflow. A minor outflow to the northwest along the NW and NNW faults is being tapped by the Nasuji and Sogongon production areas.

4.0 TRACER TEST RESULTS

To prove the interconnection of the production wells in Puhagan to the reinjection wells, a number of tracer tests using sodium fluorescein dye and radioactive isotopes were conducted. Hermoso and Mejorada (1997) summarized the results of these tracer tests, as discussed below. Sodium fluorescein tracer test was first conducted in July 1983 in injection wells OK12RD and PN6RD. Positive tracer returns were detected in just 1.5 hours after injection, confirming a direct connection between the two wells.

In August 1984, sodium fluorescein tracer was injected in PN1RD to determine its interaction with the production sector. Sixteen of the twenty-one production wells were monitored. Positive tracer returns were confirmed only for the central Puhagan wells PN26, PN28, OK7, and OK2. PN26 showed the fastest and strongest response. Arrival times ranged from 40 to 90 hours, equivalent to flow velocities of 5.6 to 16.5 m/hr. The tracer returns in the other monitoring wells could not be ascertained as a result of interference with the viewing process by the degraded by-products of sodium fluorescein. It was also learned that sodium fluorescein decays irreversibly at the high temperatures present in a geothermal system.

The radioactive tracer Iodine-131 was first used in August 1981 in well OK2. Of the monitored wells only wells OK7, OK12RD, and PN13D were found positive but with a very low total tracer return of <1%. In August 1983, Iodine-131 was again injected in OK12RD. Direct communication was established between OK12RD and easterly production wells PN17D, PN15D, PN21D, and OK10D, in addition to the central Puhagan wells OK7, PN28, and PN26. About 17% of the fluid injected in OK12RD returned to these monitoring wells, with mean transit times of 4 to 15 days.

In August 1985 Iodine-131 was injected in reinjection well PN9RD to determine the interaction of the westerly reinjection wells with the production sector. Strong returns were detected from PN9RD to OK7, with return time of 1.08 days, a mean transit time of 5.7 days, and 30% tracer recovery. Positive returns were also detected in PN29D, PN26, PN28, PN18D, PN30D, PN23D, and PN31D, with tracer returns of 0.4 to 7.0%, and total tracer recovery of 45%.

5.0 GEOCHEMICAL METHODS IN DETERMINING REINJECTION RETURNS

In the Palinpinon-1 sector, rapid reinjection returns was primarily caused by 1) close proximity of the injection sector to the production area; and 2) the presence of very permeable fault(s) connecting these two sectors. To detect the presence of returning injection fluid in the discharges of the production wells, the behavior with time of the various chemical parameters in the liquid and steam phases of the well discharge is monitored. Table 1 shows some of

Table 1. Chemical parameters used in detecting RI returns.

Parameters	Characteristics	Changes
Cl-res	Natural tracers	Increase
CO_2-TD, CO_2/H_2S,	Indicate changes in liquid saturation	Decrease
T-Quartz, Cl/Ca	Indicate changes in reservoir temperatures	Decrease or None

these chemical parameters and their behavior as a response to brine injection returns. Physical parameters such as the wells' discharge enthalpy, downhole temperatures and pressures, steam flow rates, and water flow rates are also monitored.

6.0 REINJECTION STRATEGIES ADOPTED FOR THE PALINPINON-1 SECTOR

6.1 1983 to 1988

The 112.5 MWe power plant in the Palinpinon-1 sector of the SNGPF was commissioned in June 1983. During its first year of operation the average power generation only ranges between 10 to 15 MWe, as transmission lines across the island of Negros were still being constructed. The mass withdrawal rate was approximately 590 kg/s. The reinjection rate at the time ranges between 53 to 240 kg/s.

From 1984 to 1989, the plant load was increased to 54 MWe. The rate of mass withdrawal increased from 325 to 538 kg/s, while the reinjection rate increased from 154 kg/s to 326 kg/s that was distributed among the various Puhagan reinjection wells. It was during this period that widespread reinjection returns affected a number of Puhagan production wells. The chloride concentration along the reinjection lines showed a progressive increase as a result of widespread injection returns observed in the production wells in Puhagan (Figure 4).

In 1986 the abandoned exploration well N3 in Ticala and OK3 in the Malaunay sector were connected to the sector's fluid collection and disposal system (FCDS) to be used as reinjection wells. This was to relieve some of the injection loads from the Puhagan reinjection wells. This measure apparently was not that successful in mitigating the problem as the bulk of reinjection remained in the Puhagan injection wells.

As a result of rapid returns of cooler (160°C) injection fluids into the production sector, a number of production wells exhibited declines in their respective outputs. Wells that are affected by reinjection returns generally displayed declines in their discharge enthalpies, increased mass flows and water flows like PN26 and PN29D. In the case of OK7, PN26, and PN17D the quenching effects of cooler reinjection water

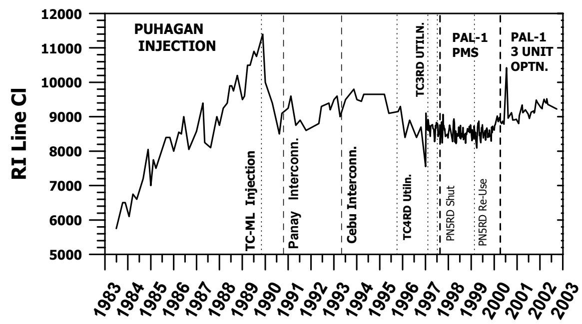

Figure 4. Palinpinon-1 reinjection line chloride concentration.

resulted to declines in output to non-commercial levels in 1986 to 1988.

6.2 1989 to 1996

As a result of the unfavorable experience from 1983 to 1988 with regards to reinjection returns, it was decided to revise the field's reinjection strategy. This involved the partial relocation of some of the reinjection loads from Puhagan to areas farther down the hydrological outflow.

Between 1989 and 1991 drilling of new reinjection wells commenced. Wells TC1RD and TC2RD were drilled in the Ticala area to augment N3R. ML1RD and ML2RD in the Malaunay area were also drilled to augment OK3R. TC3R was drilled and commissioned in mid-1993 beside N3R, TC1RD, and TC2RD. These wells are located about 2 to 3 kilometers northwest of Puhagan along the hydrological outflow of the system. These wells were put on line to the FCDS in late 1989 to early 1990, thereby reducing the injection load in the Puhagan injection wells from 326 kg/s in 1986 to 100 kg/s in 1990. The reinjection line chloride concentration (Figure 4) showed a drastic decline as a result of this transfer of injection load indicating a general field-wide response. The number of wells affected by injection returns declined during this period. Reinjection returns, however, was still observed in a number of Puhagan production wells, even with the partial transfer of injection loads. This is a result of continuous injection into the highly permeable Ticala Fault that provides a hydrological connection for wells N3R and TC3R in Ticala to the Puhagan production area (Figure 2).

When the island of Panay was connected to the Negros power grid in October 17, 1990, the station load was further increased. Increased mass withdrawal for power generation also resulted to increased volume of waste brine for injection. The injection load in the Puhagan injection wells increased from 100 kg/s to 180 kg/s (Hermoso and Mejorada, 1997). As a result of the interconnection of Cebu to the Negros grid in 1993, the rates of production, mass extraction, and brine injection increased causing a more pronounced effects of reinjection returns.

In order to increase the injection capacity for the Palinpinon-1 sector TC4RD was drilled and utilized between the first and fourth quarters of 1995. This well has partially reduced the effects of injection returns in Puhagan (Figure 4). As of late 1996, 350 kg/s of waste brine is disposed in 8 injection wells, mostly in the Malaunay and Ticala sector. In order that the steam production requirements can be met without producing large volume of waste brine, increased utilization of high enthalpy or less watery wells was given higher priority at this time. The wells from the Lagunao sector that tap the shallow steam cap were connected to the FCDS in October 1996. To further reduce the detrimental effects of N3R and TC3R, it was decided to decommission these wells in November 1996 and re-drill TC3R.

6.3 1997 to 2002

TC3R was re-drilled towards the southeast and has been re-named TC3RD. It was re-commissioned in early 1997. Shortly afterwards PN2RD and PN3RD in Puhagan were shut and were no longer utilized for brine injection. Only PN5RD was utilized among the Puhagan injection wells as this was previously established to have the least hydrological connection to the production sector. This well, however, was shut in July 1997. At this time all of the waste brine for Palinpinon-1 were injected into the Ticala and Malaunay injection wells.

The scheduled preventive maintenance and servicing of the three turbines of the Palinpinon-1 Power Plant that began in August 1997 until April 2000 has reduced the station load requirement. This also reduced mass extraction and waste injection volumes. During full load operations of the power plant, mass extraction ranges between 400 kg/s and 600 kg/s. The equivalent mass injection rate ranges between 250 kg/s to 400 kg/s. During low loads and with only one or two turbine generators in operation, the mass extraction is between 200 kg/s and 300 kg/s, with injection rates of 100 to 200 kg/s.

During this period of lower rates of mass extraction and injection, reduced effects of injection returns were observed, as shown by lowered and stable reinjection line chloride trends (Figure 4). PN5RD was re-utilized in February 1999 at a load of 50 kg/s. It was cleared of mineral blockages in August to September 1999. Increased injection of 130 to 160 kg/s in this well in November 1999 caused injection returns in a number of westerly production wells in Puhagan. The effects of injection returns to these production wells were reduced when injection into PN5RD was reduced to 50 kg/s.

With the resumption of full operation of the power plant that started in April 2000 and continued until as of this writing, the effects of brine injection were again observed, as attested by increased level of injection line chloride concentration (Figure 4). The detrimental effects of injection returns (temperature decline, output decline), however, were only observed in only a few production wells in the Palinpinon-1 sector of the field.

7.0 MITIGATING MEASURES ADOPTED TO ADDRESS EFFECTS OF REINJECTION RETURNS

7.1 Shifting of In-field Injection Wells

Beginning in 1983 until late 1989, the main strategy used in addressing the adverse effects of brine injection returns was to inject waste brine into different injection wells in Puhagan. Since these wells were drilled close to the production sector (less than 1.0 km) the well utilization scheme proved ineffective in addressing the problem. It was recognized that only PN5RD is the least hydrologically connected to the production sector. The later reinjection wells were therefore drilled farther from the production sector, in the Ticala and Malaunay areas.

7.2 Outfield Injection

Beginning in 1989, injection wells were drilled and utilized in the Ticala and Malaunay areas, about 2.0 to 3.0 kilometers from Puhagan. This scheme provided longer distances between the

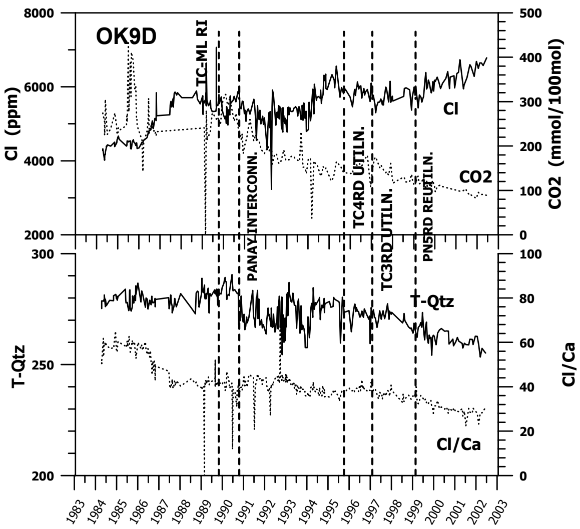

Figure 5. OK9D well chemistry.

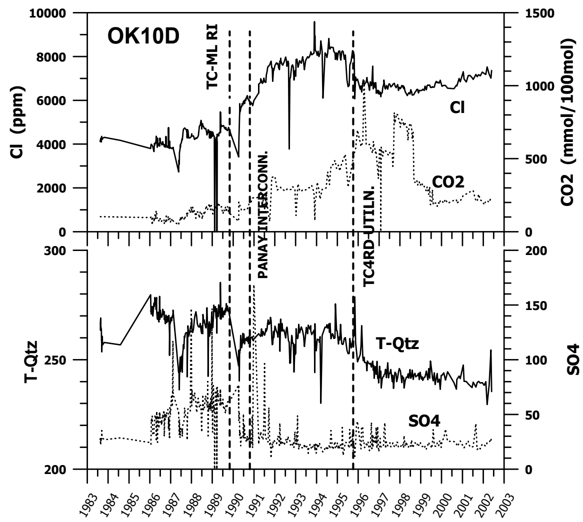

Figure 6. OK10D well chemistry.

production and reinjection areas. Injection returns were still recognized in a few wells as indicated by increased chloride and decreased gases in the discharges. The temperature declines, however, were not as severe, such that the returning brine has been sufficiently reheated, as in the case of OK9D (Figure 5). The Odlumon Fault provided this channel for reheated injection brine (Figure 2).

Another beneficial effect of the outfield injection scheme has been to improve the chemistry of a number of wells with observed acidic or high-sulfate inflow, as in OK10D (Figure 6). The well has a relatively high sulfate concentration in the discharge such that anhydrite blockages easily develop in the well. With the advent of reheated injection returns from the Ticala injection area, the high-sulfate inflow has been diluted or displaced, preventing the formation of anhydrite mineral deposition (Seastres et al., 1995).

Outfield injection, however, may not be totally effective, as proven by the experience with N3R and TC3R. Even when these wells were drilled far from the Puhagan production area, these are still very well connected hydrologically to Puhagan along the highly permeable Ticala Fault. It was decided therefore to decommission these two wells for injection when replacement wells were available. Later injection wells were also sited or designed such that highly permeable faults were either cased-off or intersected at deeper levels.

7.3 Utilization of Wells with High Discharge Enthalpy

In order to minimize the amount of injected brine in Palinpinon-1, a number of high enthalpy wells were given priority in utilization in lieu of the low enthalpy or more watery wells. Wells undergoing pressure drawdown or those that tap the shallow steam cap have discharge enthalpies of >1700 kJ/kg and low water fractions in their discharges. Wells OK2, PN30D, PN32D, and PN33 are such wells. In the later part of 1996, LG3D and LG4D in the Lagunao sector were also connected to the FCDS to further increase the field steam capacity without increasing the injection volume.

7.4 Plugging of the Upper Feed Zones of Highly Communicative Injection Wells

The top zone plugging method was first used in Palinpinon-1 in 1995. This involves plugging of the communicative upper permeable zones among the selected wells in Puhagan. This drilling methodology is conducted by mixing sodium silicate and calcium chloride along a section of the well's slotted liner to form a quick-setting gel- or resin-like material. As a result of its viscous nature, the mixture may isolate the target section of the borehole, including the annulus. This will act as a bridge plug that will allow the cementing of the upper sections of the hole. The isolation of the upper permeable zone of the selected Puhagan injection wells was expected to prevent the entry of cool injection brine into the reservoirs plumbing system and promote a more efficient reheating of the injected brine by permitting it to proceed deeper into the lower and hotter portions of the well before entering the reservoir's convective system (Hermoso and Mejorada, 1997).

PN2RD and PN3RD were subjected to top-zone plugging work-over operation in 1995 and 1996. The initial results were promising as reinjection returns from these two wells were momentarily not observed. With continuous injection, however, it appears that the cement plugs in the permeable zones collapsed, resulting to renewed injection returns from these two wells (Hermoso and Mejorada, 1997).

7.5 Optimization of the Reinjection Loads

It was recognized that outfield injection into the Ticala area, specifically in TC3RD, and infield injection in PN5RD have both detrimental and beneficial effects. At lower injection loads, pressure support for the reservoir is minimized resulting to increased pressure drawdown and inflow of cool acid or meteoric fluid. At loads higher than 100 kg/s in TC3RD, a number of wells will experience thermal decline (Figure 5) while lower loads may remove the neutralizing effect in wells with previously observed acidic inflow like OK10D.

Similar effects are also observed in PN27D that is affected by PN5RD (Figure 7). At injection load lower than 50 kg/s, pressure support for PN27D is reduced resulting to increased drawdown and boiling (increased chloride and CO_2) and cool acidic inflow (increased SO_4 and decline in T-Quartz).

The optimization of the loads in the various injection wells in Palinpinon-1 balances the positive effects of injection returns against the detrimental effects.

8.0 SUMMARY AND CONCLUSIONS

The Palinpinon-1 sector of the Southern Negros Geothermal Field that has been in operation since June 1983 experienced the effects of returning brine from the injection wells to the production wells. The change in the well discharge chemistry of the production wells is one of the tools used in recognizing the effects of injection returns. In its twenty years of utilization, PNOC-EDC has implemented several

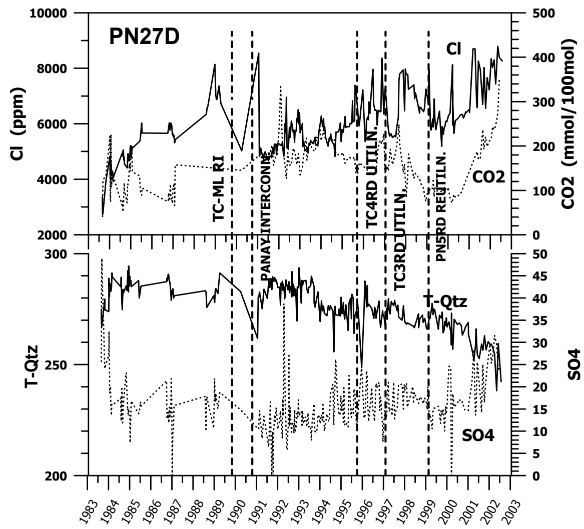

Figure 7. PN27D well chemistry.

measures to address the problem of injection returns. As a result of the adverse effects of infield injection, later injection wells were sited far from the production sector at a distance of about 2 – 3 kilometers along the outflow of the system. Highly permeable faults in these wells were cased-off or intersected at deeper levels. To reduce the brine generation during steam production, high enthalpy wells were given priority for utilization. Top-zone plugging of the communicative permeable zones in the injection wells was also attempted in the field, but only with limited or short-term success. To balance the detrimental and beneficial effects of brine injection returns, the injection load of the different injection wells is optimized. These measures were implemented to help sustain the Palinpinon-1 sector of the SNGPF in its almost twenty years of utilization.

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