Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Chemical Tracer Test in Las Pailas Geothermal Field, Costa Rica

Yalile Torres-Mora[1] and Gudni Axelsson[2]

[1]ICE, UEN PySA, CSRG, Apartado postal 10032-1000, San José, Costa Rica

[2]ÍSOR, Iceland GeoSurvey, Grensásvegur 9, IS-108 Reykjavík, Iceland

[1]ytorres@ice.go.cr, [2]Gudni.Axelsson@isor.is

Keywords: Test tracer, geochemistry, cooling, Las Pailas Geothermal Field, Costa Rica.

ABSTRACT

Commercial exploitation of the Geothermal Field Las Pailas began in July 2011 with the first production unit. This binary and combined cycle unit produces 42 MWe, using 80 kg/s of steam and 380 kg/s of brine, with a separation temperature of 160°C and 140°C reinjection temperature. With the start of operation of this unit, geothermal installed capacity in Costa Rica reached 13% of the total energy consumed in the country.

Due to the complex hydrogeology of the system and the proximity of the central production area with the reinjection sector, temperature decrease phenomena in some wells have been detected after two years of operation. Because of natural variation in fluid chemistry in the production zones, is difficult to monitor reinjection returns using the fluid's own chemical composition. This has led to the use of chemical tracers oriented towards hydrogeological system characterization.

This paper presents the methodology, results, and interpretation of tracer tests carried out in the geothermal field of Las Pailas. Sodium benzoate tracer was injected in a reinjection well and tracer returns monitored throughout the rest of field.

1. INTRODUCTION

Las Pailas Geothermal Field (Figure 1) is located in the Cordillera de Guanacaste in north-western Costa Rica, on the southern flank of the Rincon de la Vieja Volcano. For the operation of the 42 MWe Pailas I unit, a total of six production wells was used, three hot reinjection wells and one cold reinjection well. Cold re-injection well is used for injecting plant condensate and brine from the lagoon collection. Mass of liquid re-injected is 380 kg/s at temperature of 140°C. Another unit, the 55 MWe capacity Las Pailas II is now undergoing feasibility assessment.

Figure 1: Location of Las Pailas Geothermal Field in Costa Rica

Reservoir fluid in Las Pailas Geothermal Field is liquid dominated. The main feed zone from the wells produce fluids that are neutral NaCl, high salinity and with low gas content. Fluid temperatures range from 240°C to 255°C.

It has been observed from the development stage that aquifers with different chemistry as well as temperature exist. These together with pressure drop associated with the exploitation of the field could cause undesirable phenomena during production.

Due to a number of factors such as Las Pailas reservoir being located inside and under the "Law of National Parks", permit required from the owners of the area and the lack of permeability in peripheral areas, the reinjection zone was located very close to the main producing area (Figure 2). This, coupled with the complex hydrogeology of the system has caused a temperature decrease phenomena during operation of the Las Pailas Geothermal Field in less than two years. The chemical complexity of the fluids from different production zones has not permitted monitoring of reinjection fluid using the original components of the fluid. This led to the use of chemical tracers for studies aimed at characterizing the hydrogeological system.

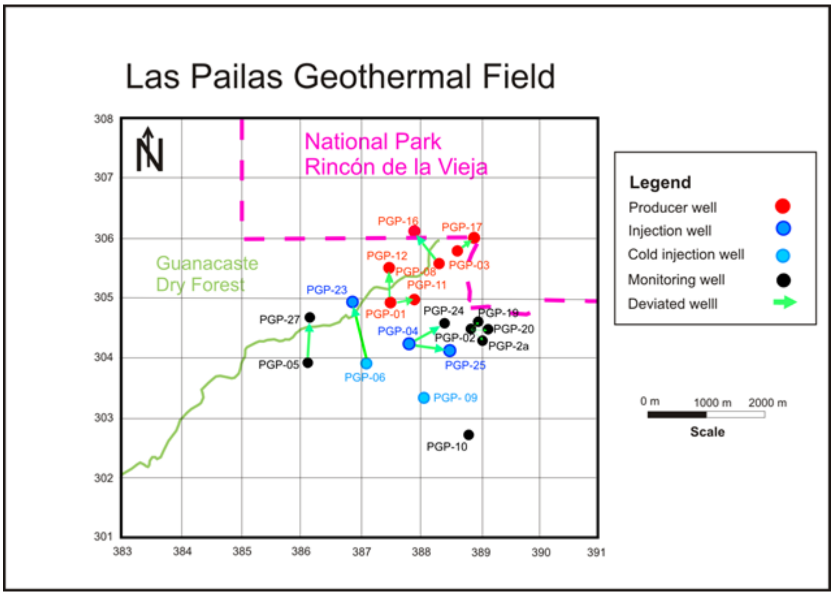

Figure 2: Location of the deep wells in Las Pailas Geothermal Field in Costa Rica

2. CHEMICAL COMPOSITION OF FLUIDS FROM LAS PAILAS

The results obtained from the different assessments of deep wells show that the fluids on surface have conductivities between 17000 to 20000 uS/cm. The fluid is characterized as sodium-chloride, neutral and with high salt content. As regards the content of non-condensable gases, vapor wells in Pailas are characterized by low non-condensable gases. The values range from 0.02 to 0.25% (w/w).

Las Pailas field wells have different aquifers; these have different chemical characteristics and temperatures (Figure 3). There is a higher salinity common aquifer in the northern and central part of the field that corresponds to the main aquifer. Most of the wells of Las Pailas produce from this aquifer and its contribution dominates in dynamic conditions (chloride content between 4700-4800 ppm). This aquifer tends to decrease its contribution towards the WSW sector of the field. This sector appears to have other aquifers high in sulfates and lower temperature. The main aquifer does not appear in wells PGP-23, PGP-05 and PGP-27. In addition it has been observed that temperatures show a sharp decline towards the WSW of the field. This indicates that the main reservoir area includes wells PGP-01, PGP-11, PGP-08 and PGP-03. The area where wells PGP-05 and PGP-27 are located show strong decline in thermal conditions. In the PGP-04, there is a temperature inversion which could indicate that the well is located near the periphery of the reservoir.

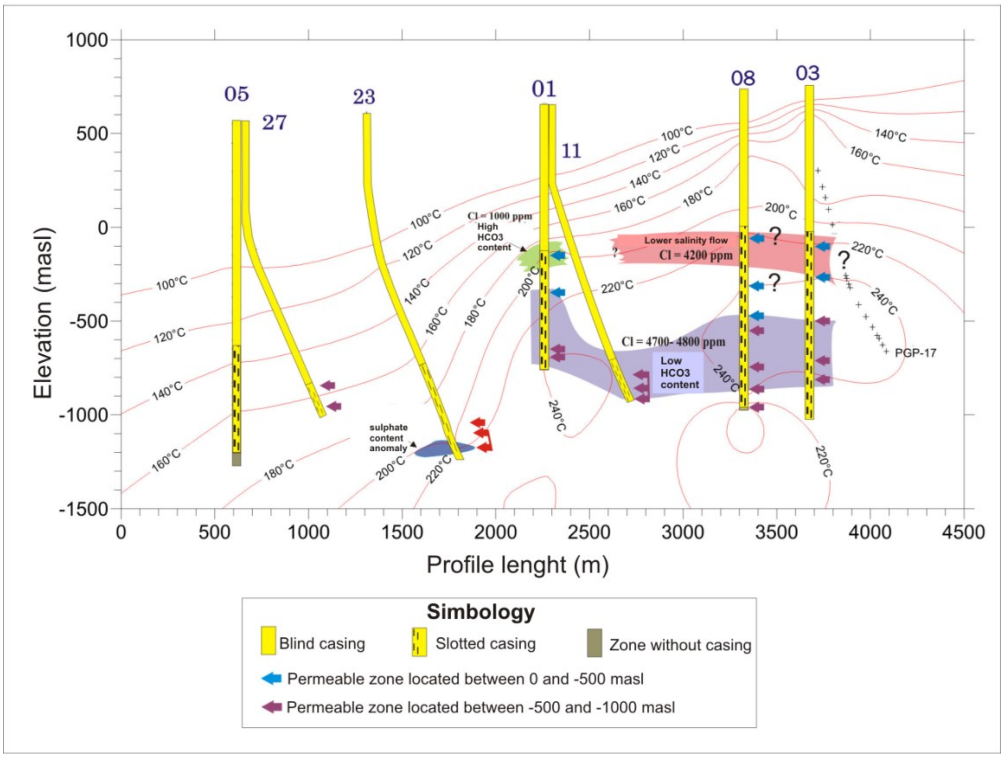

Figure 3: Chemical profile showing the different aquifers in Las Pailas wells.

The importance of knowing the existence of these aquifers is on adequate monitoring to be implemented. These peripheral aquifers can invade production wells during exploitation, causing cooling processes and thereby decreased output. This process could be mistaken as an effect of reinjection.

Figure 4 shows the chloride content of all the wells. As can be seen, wells initially had different concentrations between them, then eventually joining up into three groups. This chemical component being common in geothermal fluids in Miravalles and in many other fields in the world has been used as a natural tracer. However, the chemical complexities of the different production zones of the Las Pailas field have not allowed reinjection monitoring using the original fluid components. An increase in chlorides does not necessarily indicate reinjection fluid return. It could be a contribution from one of these aquifers with higher salinity.

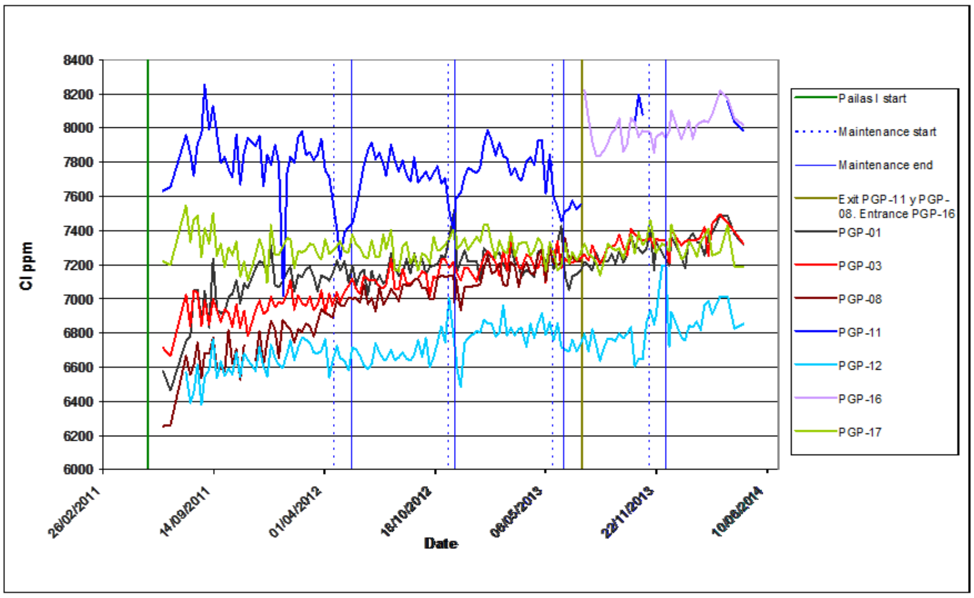

Figure 4: Trends of chloride concentration with time of well fluids in Las Pailas

3. COOLING OF WELL PGP-11 IN DYNAMIC CONDITIONS AND PGP-24 AT STATIC CONDITIONS

3.1 Well PGP-11

Well PGP-11 is a directional production well, located 845 meters and 810 meters away from the reinjection wells PGP-04 and PGP -25 respectively. Chemical analysis of produced fluids show the following: conductivity =18910 µS/cm, chloride = 6643 ppm, sulfates = 36 ppm and calcium = 139 ppm. The well produced a total flow of 132 kg /s with a measured temperature of 254°C. After production unit I became operational there was a gradual decrease in measured temperature (Figure 5) down to 213°C noted from the last temperature survey conducted on March 11, 2012. This well was shut starting July 07, 2013. In recent measurements conducted on March 18, 2013 and on March 11, 2014 the well maintained its temperature at 213°C.

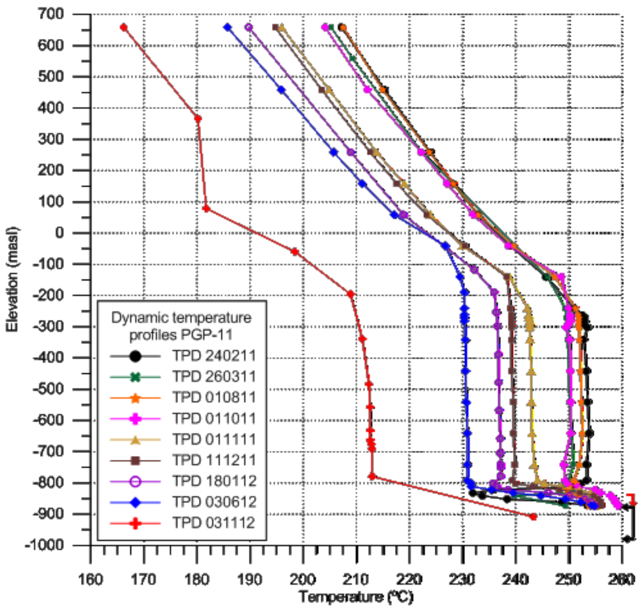

Figure 5: Temperature profiles of well PGP-11

Some chemical variations were also observed. PGP-11 corresponds to a well with higher chloride content in Las Pailas field (Figure 4). With the start of operation of unit I, this well showed a slight increasing trend in chloride, with occasional decreases at some point. The decrease can be related to contribution of production zones with lower salinity. The content of calcium and sulfate show similar behavior.

The increase in the sulfate content indicates the input of production zones rich in sulfates. This is because the fluids that are re-injected have lower sulfate concentration.

Figure 6 show the changing trend of sulfate content with time. Note that when the lower temperature zone begins to show, sulfate content begins to decrease and the calcium content continue to rise. This information could be interpreted that the high sulfate zone contribution to the well mass flow is not cooling the well.

During maintenance of the plant, PGP-25 was pulled out from the reinjection system. Parallel to this, the content of Cl and SO_4 showed a decrease.

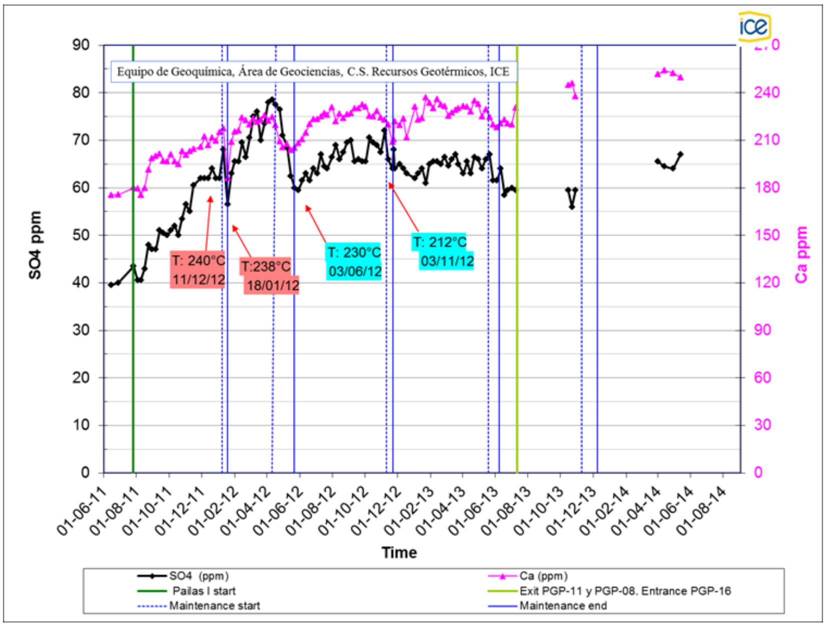

Figure 6: Trends of calcium and sulfate concentration with time in well PGP-11

3.2 PGP-24

Well PGP-24 is a directional production well located in the courtyard of the reinjection zone center (18.2 meters from reinjection well PGP-04 and 37 meters from reinjection well PGP -25). It was designed as a backup production well.

After entry into production of unit I, a decrease in static temperature was identified from 247°C to185°C between 1100 meters to 1030 meters depth (January 22, 2010). A production test was conducted and initial conditions had changed. The chloride, sulfate and calcium content of the fluid increased reaching values of 7091 ppm, 166 ppm, and 221 ppm respectively. Previous concentrations were 6655 ppm, 36 ppm and 133 ppm respectively. The well production declined in this test from 193 kg/s to 85 kg/s total flow. Initially it was thought the reason for the cooling was reinjection returns. The increased chloride content supported this hypothesis. However enrichment in calcium and sulfate content did not coincide with increasing concentration equivalent to the loss of 20% of the vapor fraction.

Subsequently, a series of chemical profiles and temperature profiles (Figure 7) determined that the cooling zone corresponds to the calcium sulfate zone, giving then a movement of fluids.

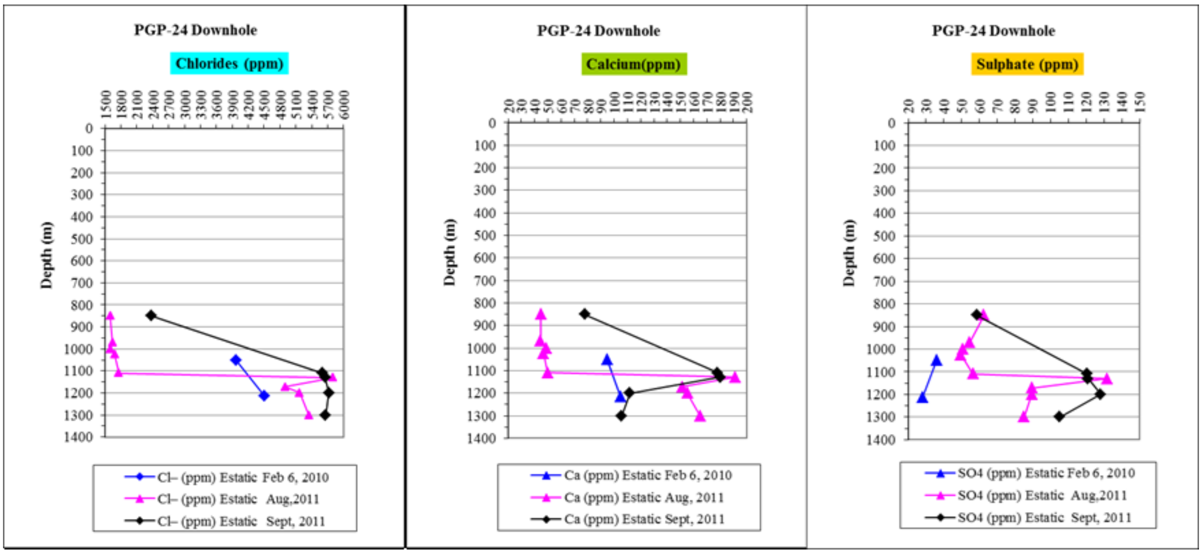

Figure 7: Chemical profiles in PGP-24. Plots show increase in Cl, Ca and SO4 after the start of Pailas Unit I. The highest concentrations of these components are in cooling zone.

4. TRACER TEST

4.1 Results

Due to the need to determine if the cause of cooling in PGP-11 and PGP-24 were results of reinjection or invasion of another aquifer, and the urgency of knowing the hydrogeology of the system to define policies on reinjection and production, a test tracer was performed by injecting sodium benzoate into well PGP-25. This well could be responsible for the effects observed in the wells PGP-11 and PGP-24.

The test was conducted in March 2012. An aqueous solution containing 800 kg sodium benzoate at its maximum concentration was injected into well PGP-25. The tracer was monitored in the following producing wells in the field: PGP-01, PGP-03, PGP-08, PGP-11, PGP-12 and PGP-17. The tracer was also monitored in well PGP-24 under static conditions.

The connection was established between the reinjection well PGP-25 and wells PGP-11 and PGP-24. The tracer was detected in well PGP-11 twenty four hours after injection of the tracer (1.55 ppm) and maximum concentration was reached after 42 hours (4.10 ppm) , indicating a rapid connection between PGP-11 with reinjection well PGP-25.

In the case of PGP-24, the tracer also appeared after 24 hours. The highest concentration of tracer was measured in the zone corresponding to a depth of 1300 meters which does not correspond to the lower temperature zone. However, no sampling was conducted in the zone characterized as sulfated and low temperature. Because of this, it is not possible to determine if this zone had a direct influence from fluid reinjection.

In the case of cooling in PGP-11, results indicate that the cooling effect is caused by the reinjection in PGP-25.

The connection was also established for wells PGP-01, PGP-03 and PGP-08. The tracer return time in these wells was longer than 3 months and with very low concentrations close to the limit of quantification (<0.04). The tracer was not detected in wells PGP-12 and PGP-17.

The information from the tracing test complemented the necessity of moving the reinjection of the central part of the field (PGP-25) to the east side (PGP-19 and PGP-20). This process will take place in short time. Currently the measures taken were: a) shutting-off well PGP-11 and b) to decrease as much as possible reinjection into well PGP-25 while pursuing the transfer of reinjection. With the above measures the output of the plant was kept at 42 MWe and equal to its installed capacity.

4.2 Interpretation of tracer recovery through well PGP-11 and cooling predictions

The tracer recovery data from production well PGP-11 has been interpreted to evaluate the connection between reinjection well PGP-25 and the production well. The results were used to predict the cooling of the production well due to long-term reinjection into the reinjection well. The methodology presented by Axelsson et al. (2005) was applied.

4.2.1 Tracer recovery interpretation

First the amount of tracer recovered through well PGP-11 was estimated by integrating the product of the water mass flow rate and the tracer concentration over the monitoring period. The following equation was used:

$$m(t) = \int_0^t C(s)Q(s)ds \tag{1}$$

where m(t) indicates the cumulative mass recovered in the production well (kg), as a function of time t, C indicates the tracer concentration (kg/L or kg/kg) and Q the production rate of the well in question (L/s or kg/s, respectively). The average water flow-rate for well PGP-11 during the observation period (84 days) is estimated to have been about 65 kg/s on the average. Thus the amount of tracer recovered during that period is estimated to be about 209 kg, or about 26% of the injected mass. It may be mentioned that the main uncertainty in this estimate is caused by uncertainty in flow rate measurements.

The next step in the analysis involves a simulation of the tracer recovery by the flow-channel model of Axelsson et al. (2005), using the tracer analysis software TRINV. This model assumes that the injection and production well are connected by 1 – 3 flow-channels, each with a certain pore-volume and dispersivity. The flow-channels connect the main feed-zones of the two wells, and the pore volume is determined by the corresponding channel length and its cross-sectional area and porosity. In this case two flow-channels were used. The results of the simulation are presented in Figure 8 and the model parameters in Table 1.

Table 1: Model parameters used to simulate sodium benzoate recovery for the well pair PGP-25 / PGP-11 in Las Pailas. The parameter u denotes the mean flow velocity, A the cross-sectional area, ϕ the porosity and α_L the longitudinal dispersivity of the flow-channel. The variable M_i denotes the calculated mass recovery of tracer through the corresponding channel, until infinite time, while M denotes the total mass of tracer injected.

Channel length, x (m)	u (m/s)	$A\phi$ (m^2)	α_L (m)	M_i/M (%)
1000 1300	6.4×10^{-2} 2.5×10^{-2}	0.33 6.1	54 690	2.7 19.2
			Total	21.9

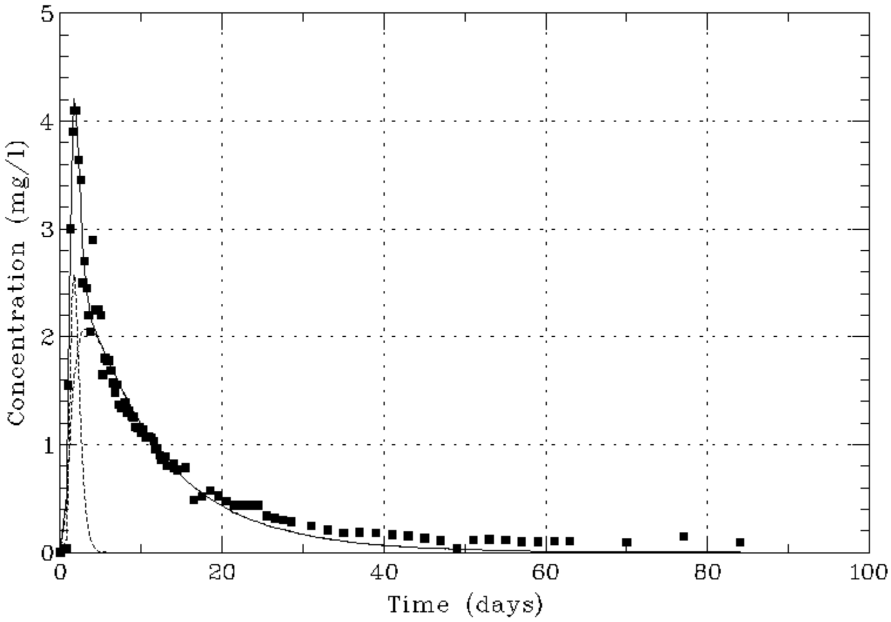

Figure 8: Observed and simulated sodium-benzoate recovery in well PGP-11 following injection into well PGP-25. The black squares show the observed recovery while the lines show the simulated recovery, with the broken lines showing the recovery for the two separate channels and the solid line the combined simulated recovery.

The fit to the data is quite good, as can be seen in the figure. The model parameters, furthermore, show that the connection between the two wells is rather direct as the two flow channels are of relatively small volume, or 3300 and 79,000 m^3, respectively, if a flow-channel porosity of 10% is assumed. Counteracting this is the relatively high dispersivity of the second channel.

4.2.2 Cooling predictions

The last stage of the tracer interpretation involved calculating cooling predictions for well PGP-11 during long-term reinjection into well PGP-25, based on the flow-channel parameters in Table 1. An average injection rate of 155 kg/s is assumed for well PGP-25, at a temperature of 140°C, and a total production rate of 100 kg/s for well PGP-11. To calculate the cooling predictions an assumption needs to be made on the aspect ratios of the flow channels, i.e. the ratio between the height and width. The smaller the aspect ratio is, the more pessimistic the predictions are, and vice-versa. Figure 9 shows the predicted cooling for well PGP-11 for a period of two years, for an average aspect ratio, i.e. in-between a pessimistic and optimistic one.

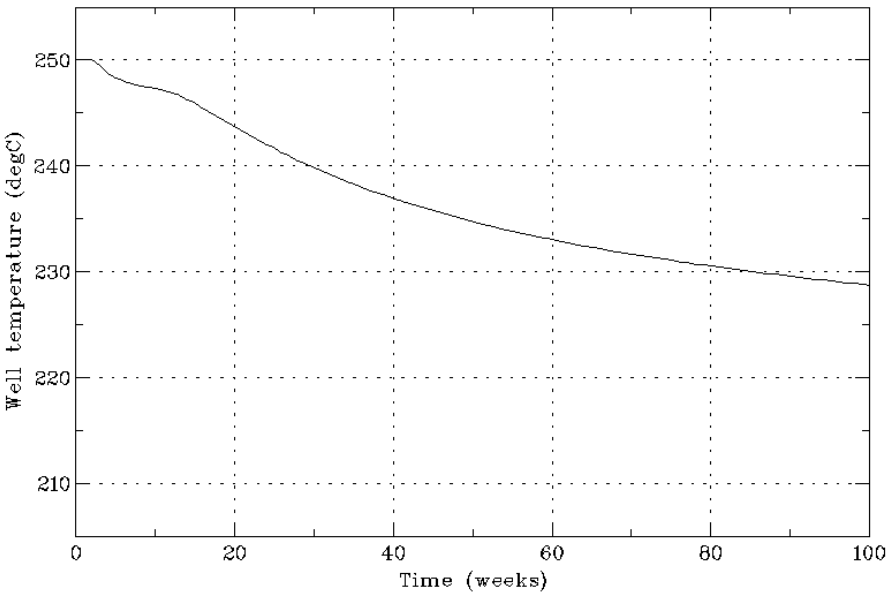

Figure 9: The predicted cooling of production well PGP-11 in Las Pailas during reinjection of 140°C fluid into Well PGP-25. The predictions are based on the results of the tracer recovery model in Table 1 and the assumption of an average flow-channel aspect ratio.

The figure shows a quite drastic and rapid cooling of well PGP-11, which results from the relatively direct connection between the two wells, evidenced by the very rapid tracer recovery and flow-channel parameters. The uncertainty in the cooling predictions must be noted, both because of the assumptions on aspect ratios and also because flow-channel dispersion is actually neglected. Including the latter would result in a more optimistic prediction. The prediction in Figure 9 can be compared with the actual cooling of well PGP-11, which is of the order of 213 °C.

5. CONCLUSIONS

With the tracer test, connection was established between reinjection well PGP-25 and production wells PGP-11 and PGP-24. The tracer was detected in well PGP-11 twenty four hours after injection (1.55 ppm) and maximum concentration was reached after 42 hours (4.10 ppm), indicating a rapid connection between PGP-11 with the reinjection well PGP-25. Tracer was also detected well PGP-24 after 24 hours while the well was in static condition.

The observed change in trend in sulfate and calcium concentrations in well PGP-11 show that when the lower temperature zone begins to contribute, high sulfate content begins to decrease and the calcium content continue to rise. This information together with the result of the tracer test could be interpreted such that the sulfated zone contribution to the production well mass flow is not cooling the well. Consequently, the cooling effect observed in PGP-11 is caused by reinjection returns coming in from well PGP-25.

During the 84 day observation period of the tracer test, as in the case of PGP-11, the amount of tracer recovered is estimated to be about 209 kg, or about 26% of the total injected mass.

For the cooling predictions in well PGP-11 a simulation using tracer analysis software TRINV was used. In this case two flow-channels were used. The results showed drastic and rapid cooling of well PGP-11 (the predicted cooling for well PGP-11 for a period of two years) arising from direct connection between PGP-11 and PGP-25, as evidenced by the very rapid tracer recovery and flow-channel parameters.

Although the tracer was detected after 24 hours in well PGP-24, it was not possible to determine whether the well is being cooled by reinjection. The highest concentration of tracer was measured in the zone of 1300 meters which does not correspond to the zone of lower temperature. However, because no sampling were conducted in the zone characterized as sulfated and low temperature, it is not possible to determine if this zone had a direct influence from fluid reinjection.

Cooling of production wells PGP-11 and PGP-24 and the results of the tracer test, were used as basis for moving the reinjection in the central part of the field (PGP-25) to the east side (PGP-19 and PGP-20) and also define production and reinjection strategies for ensuring the sustainability of the field. This process will take place in short time.

Currently the measures taken were to shut well PGP-11 and to decrease as much as possible reinjection into the well PGP-25 while pursuing the transfer of reinjection. With the above measures the output of the plant was kept at 42 MWe and equal to its installed capacity.

REFERENCES

González, C. & Torres, Y: Informe de la prueba de producción del pozo PGP-24, Las Pailas. CSRG ICE, internal report (in Spanish), (2010)16 pp.

González, C: Informe de la prueba de producción del pozo PGP-24, Las Pailas. CSRG ICE, internal report (in Spanish), (2011) 8 pp.

González, C: Informe de la prueba de producción del pozo PGP-11, Las Pailas. CSRG ICE, internal report (in Spanish), (2012) 6 pp

Axelsson G., Björnsson, G., and Montalvo, F.: Quantitative interpretation of tracer test data. Proceedings, World Geothermal Congress 2005, Antalya, Turkey, (2005), 12 pp

Torres, Y and Fajardo, H: Geochemical Characterization and integral analysis of data Las Pailas Geothermal Field, Costa Rica. Presented at "Short Course V on Conceptual Modelling of Geothermal Systems",organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, February 24 - March 2, 2013. (2013), 11pp