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GEOTHERMAL RESERVOIR MANAGEMENT IN EL SALVADOR CASE HISTORIES OF AHUACHAPÁN AND BERLÍN

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ABSTRACT

A general review of the management strategies, production and chemical changes which have occurred in the reservoir of Ahuachapán and Berlin geothermal field is given with emphasis on the main processes resulting from intensive mass extraction during thirty one and fourteen years of commercial exploitation respectively.The Ahuachapán geothermal field has been monitored systematically since 1975 when continuous power generation started and the Berlin geothermal field started in 1992. Two main process are affecting the reservoir specially at Ahuachapán Geothermal Field (AGF): a) boiling is present in the shallow part of the system and it is characterized by increasing enthalpy in the production wells, higher gas and water chemical content; b) dilution or cold fluid inflow occurs in some parts of the reservoir where the declining pressure induces inflow from neighboring aquifers (lateral or vertical). Such physical-chemical processes are not observed yet at Berlín Geothermal Field (BGF). The injection could produce similar effects like boiling and dilution together, and must be carefully analyzed and monitored. Tracer tests could be helpful to determine how the injection is affecting the neighbor wells but also the chemical and isotopic monitoring.

1. INTRODUCTION

El Salvador is located in Central America close to the “Pacific Rim” where large amount of active volcanoes and geothermal areas are located. Several geothermal areas have been explored and some of them are under commercial exploitation (Ahuachapán and Berlin in El Salvador, Momotombo and San Jacinto Tizate in Nicaragua, Zunil and Amatitlán in Guatemala and Miravalles in Costa Rica).

The Ahuachapán geothermal field at the eastern part of the country has been exploited over the last 30 years and several management strategies have been undertaken, therefore some lesson have been learned. The Berlin field at the western part of the country started the commercial operation in 1992 when two back pressure (2x5) were on line, this development allowed to probe the reservoir and resource capacity and behavior. In 1999, after a several studies including a numerical reservoir assessment two condensing type units (2x28) went on line. Figure 1 shows the El Salvador fields’ locations and other Central American fields.

FIGURE 1: Ahuachapán location and Central America fields

This paper describes the behavior of both fields and how the field management has been applied in order to make correct and sustainable decision for the mass and energy extraction.

2. FROM EXPLORATION TO START UP OF COMMERCIAL OPERATION

The Ahuachapán geothermal field (AGF) was explored in 1968 as part of energy research project of the United Nations Development Program (UNDP). After drilling and successful well testing at AH-1 the feasibility for commercial exploitation was undertaken, from 1968 to 1975 several wells were drilled and two condensing units (2x30 MW) went in operation. Figure 2 shows the actual well site and plant location at the Ahuachapán – Chipilapa geothermal field.

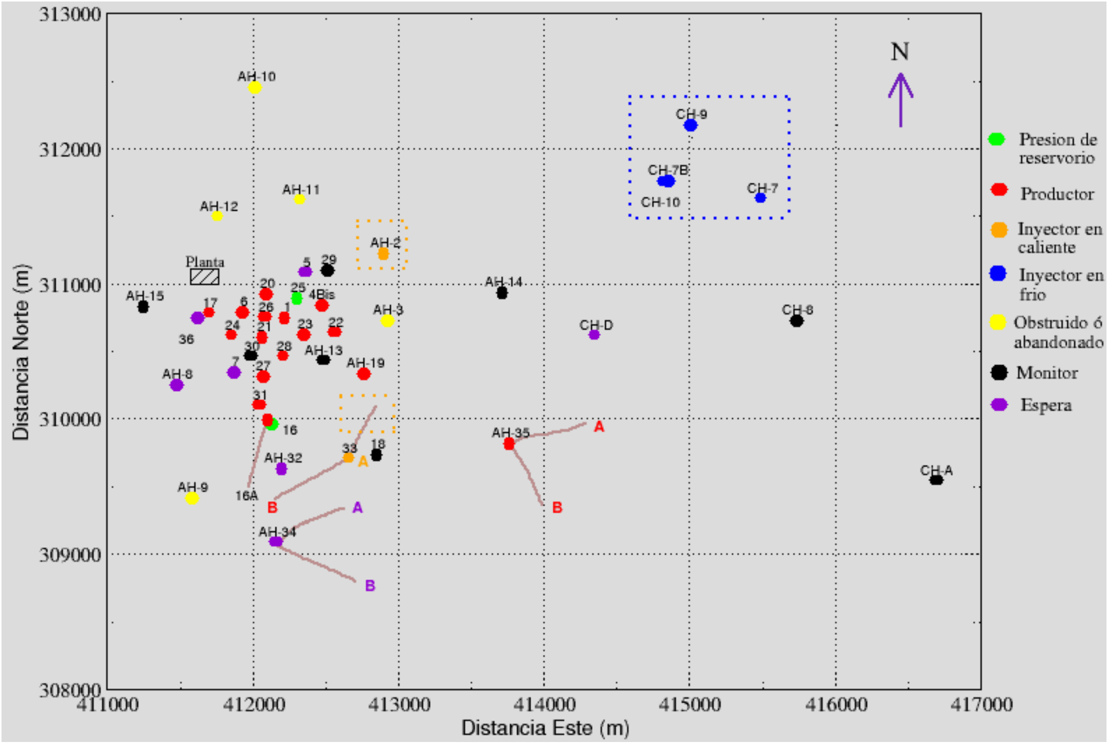

FIGURE 2: Ahuachapán – Chipilapa wells location

At this early stage of the geothermal development the injection was not considered beneficial for the reservoir as a pressure recharge alternative, therefore the water was disposed to the neighboring spring or the Paz river at the Guatemala border.

From 1976-1982, the first large scale injection test were made, mainly at the center of the Ahuachapán field, but due to some cooling effects the injection was stopped, later on in 1978 a 81 km long concrete channel went in operation to dispose off the brine into the Pacific ocean.

In order to improve the thermal efficiency Comision Ejecutiva Hidroelectrica del Rio Lempa (CEL) decided in 1978 to install a new double-flash unit (35 MW). This unit started operation in 1981. Almost 14 MW has been produced from low pressure (1.4 bar) steam coming from separated water (5 bar). When the three units went on line together, the reservoir pressure decreased almost 15 bars and for this reason only two units have been in operation since this period of time. During 1984 the field management was changed to “seasonal exploitation” that means large use during dry season and reduced extraction during wet season (main hydroelectric period), this strategy produced quite good results and the reservoir pressure was reduced and stabilized around to 19-20 bar.

Several studies are available for this field, including among others ELC 1982, LBL 1991, ELC 1993. Those studies recommend to implant the injection in order to stabilize the reservoir pressure. At this stage, the injection became the main issue for the reservoir management. Due to the lack of high-pressure steam at the Chipilapa wells, CEL decided to construct 5 km long, 24" diameter pipeline to dispose the brine at those wells (CH-9, CH-7 and CH-7bis), this line started operating in 1999. In 2004 a complete pumping station went on line in order to increase the injection capacity from around 220 kg/s (gravity) up to 550 kg/s (pumping).Figure 3 shows the reservoir pressure history from 1975 until 2005 at 200 m.a.s.l monitored at the well AH-25 and the total mass extraction and the mass injected.

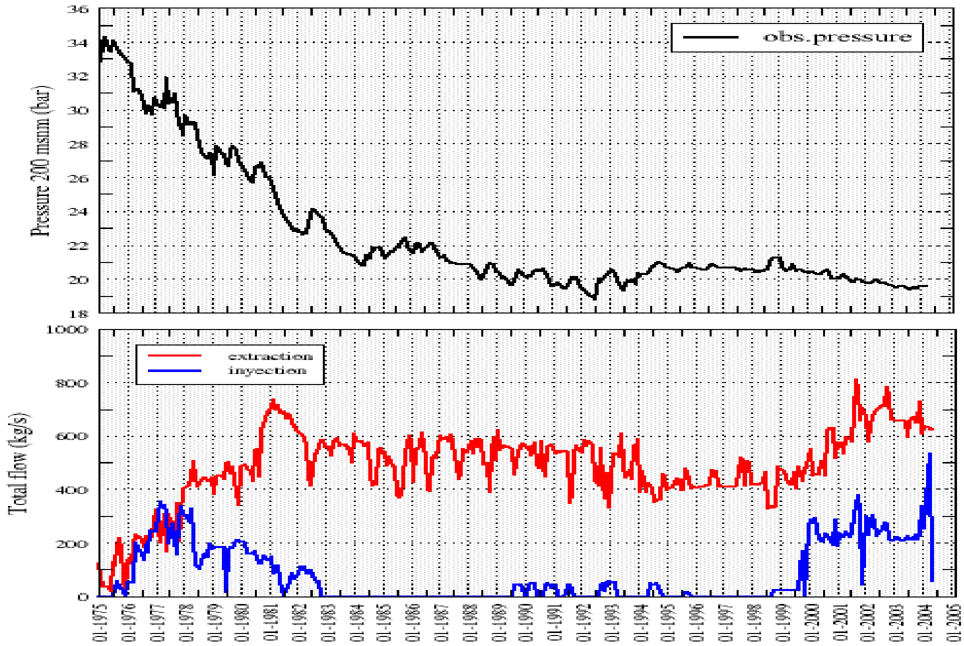

FIGURE 3: Reservoir pressure at Ahuachapán field

The exploration of the Berlin geothermal field (BGF) started at the same period of Ahuachapán, due to low success of the drilling at the well TR-1 the exploration drilling stopped in 1968 and continued in 1980 when 4 additional wells were drilled and the feasibility for commercial exploitation was evaluated (ELC, 1981). In 1992 a "step by step" exploitation strategy was considered and two small backpressure units 2x5 MW went on line. This option allowed an early development of the geothermal resource in order to improve the knowledge of the system and to get early profit for future investments.

With the beginning of the commercial operation, several studies were carried out ELC 1993, GENZL 1995, CFG 1995, all of them with the main issue to evaluate the reservoir capacity and the development of the resource. According ELC numerical simulation results the long-term capacity of the reservoir is at least 100 MW with more than 90% probability.

The reservoir behaves with minor pressure drop during backpressure operation. From 1997 to 1999, 10 additional wells were drilled in order to reach the steam production and water injection, 9 producer wells and 13 injection wells have been used to operate the 2x28 MW condensing units since 1999.

The field management issues were to steam extraction from the south and injection to the north although some injection has been undertaken into the production zone, at the moment none significant cooling effects are observed. Figure No 4 presents the well field location at the Berlin geothermal field and Figure 5 shows the pressure decline and total mass yield from the Berlin field.

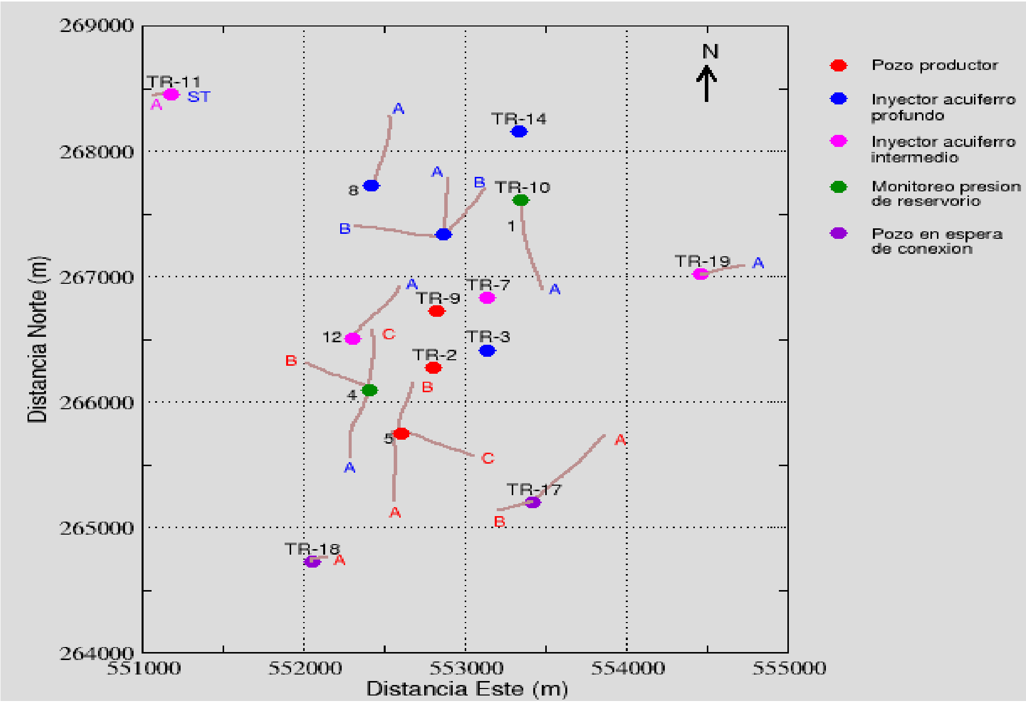

FIGURE 4: well field location at the Berlin field

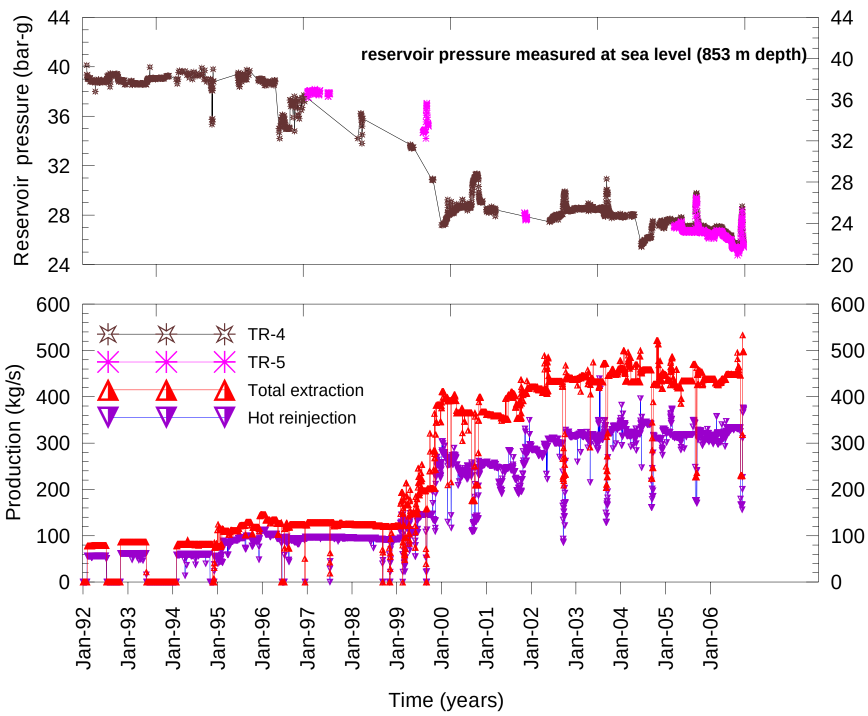

FIGURE 5: Reservoir pressure and total mass extracted at the Berlin field

3. LONG TERM EXPLOITATION

A long-term exploitation condition means the system has not exactly been yielding heat and mass in stable conditions for at least 5 years, in that sense both fields could be considered in this condition.

The long-term exploitation at the Ahuachapán field has presented the following effects:

1- As is common in several liquid dominated reservoirs, a fast pressure draw down at the beginning has been observed, this decline follows the liquid falling effects. After, two-phase condition due to boiling of some part of the reservoir (steam cap) has also been observed. The pressure has been maintained around 19-20 bars for long period of time and the production characteristics of the wells are almost stable.
2- Some cooling effects were observed during the early injection stage, later on the behavior of the producer wells has been affected by cold water inflow (dilution, decreasing enthalpy) and boiling (increase enthalpy).
3- After six years of injection at the Chipilapa area, no significant effects have been observed in the production field at the moment. According to numerical modeling some part of the injected brine has reached the production field as pressure recharge. The pressure decline is lower than the expected one, considering the actual extraction level.
4- The fluid chemistry indicates that the main process affecting the reservoirs could be dilution and boiling, some degassing has been also observed. The production wells to the southern part of the systems present calcite scaling and the injection of calcite inhibitor must be applied.

Figure 6 presents the steam and water production of well AH-6. This well is in boiling condition despite the dilution affecting the geothermal fluid.

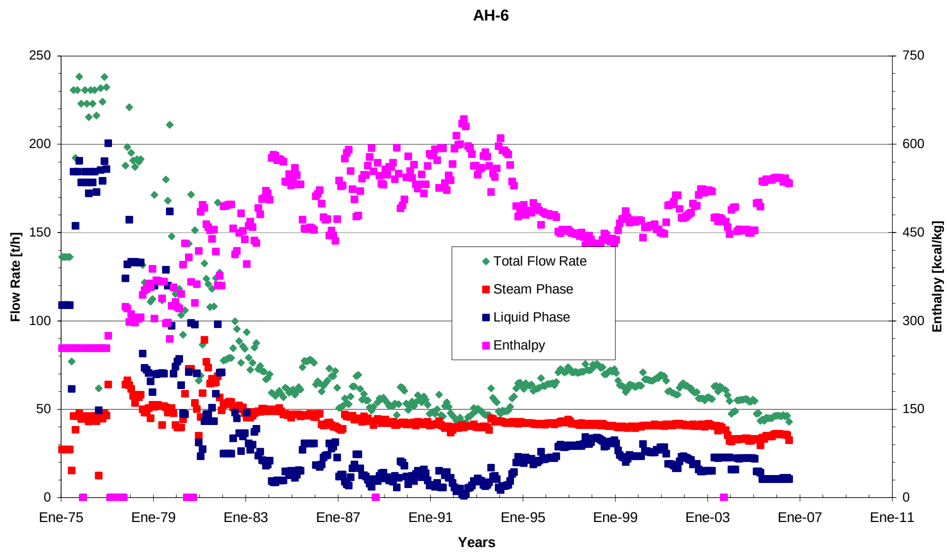

FIGURE 6: Production history for well AH-6

Figures 7 and 8 present the comparison between measured enthalpy and chemical enthalpies from NaKCa and SiO_2 geothermometers. The chloride content trend show the dilution process but the boiling seems to be the main physical process affecting well AH-6.

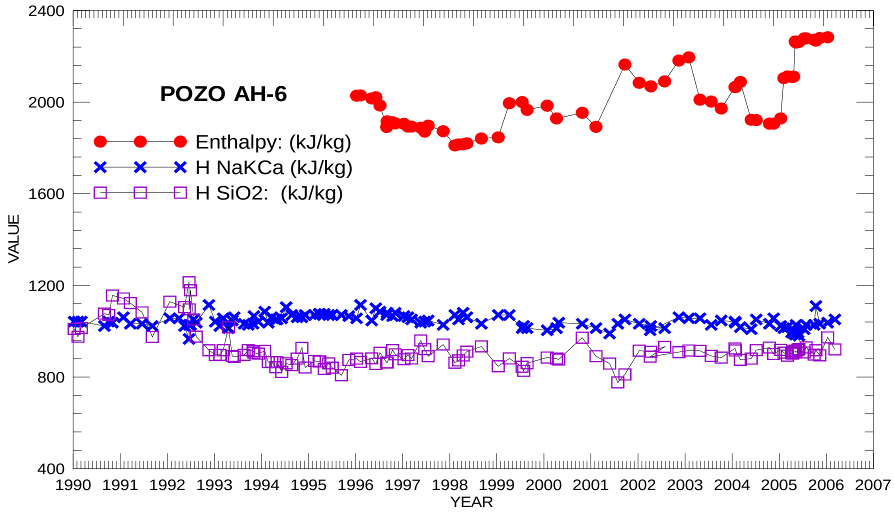

FIGURE 7: Enthalpy evolution comparison

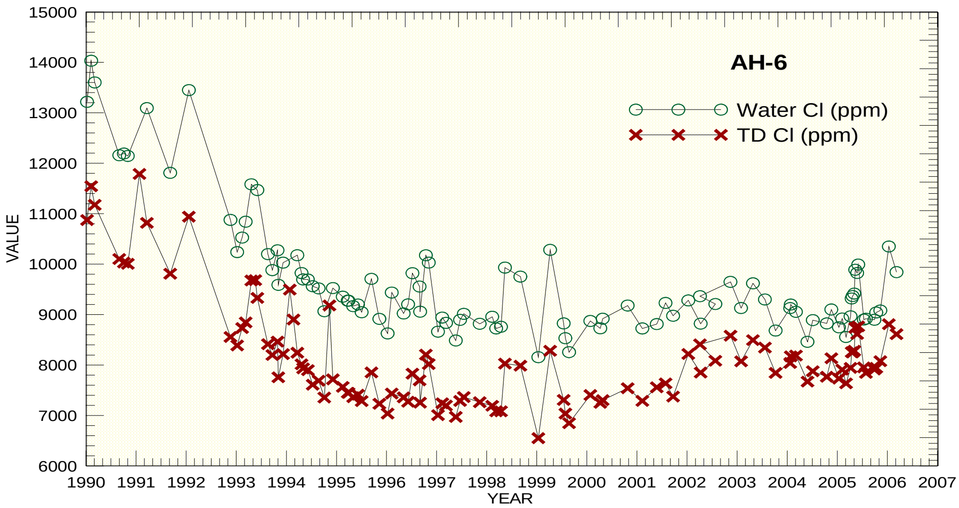

FIGURE 8: Chloride history for well AH-6

Figure 9 presents the history of well AH-27 where declining enthalpy has been observed since 2002, however, the actual values are similar than those from 1981-1983, but the steam flow rate shows a decreasing trend from 2002. Figures 10 and 11 show the chemical evolution regarding the enthalpies comparison and chloride content. Data shows that from 1997 the well was in boiling process but again from 2002 the measured enthalpy declining shows an apparent dilution process. Due to the fact that the chloride content seems to be stable, the declining in enthalpy, in this case, is mainly due to the lack of steam in the well feed zone. In the meantime other wells have been showing, in the last years, an increase in water flow rate, showing that the geothermal field is perhaps open.

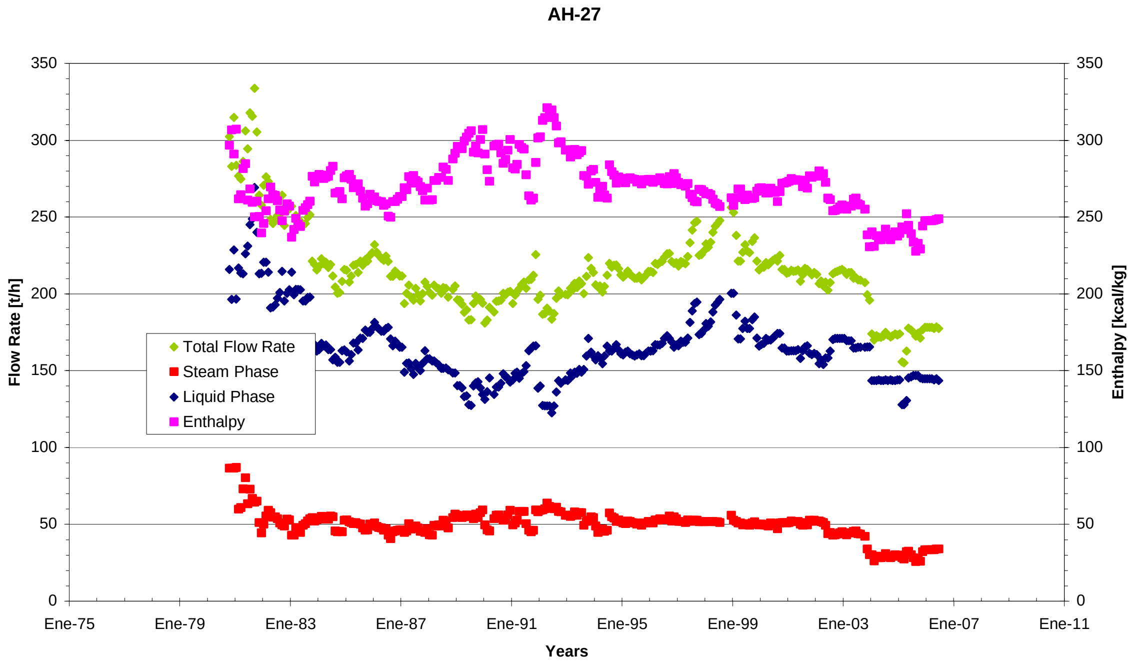

FIGURE 9: Production history for well AH-27

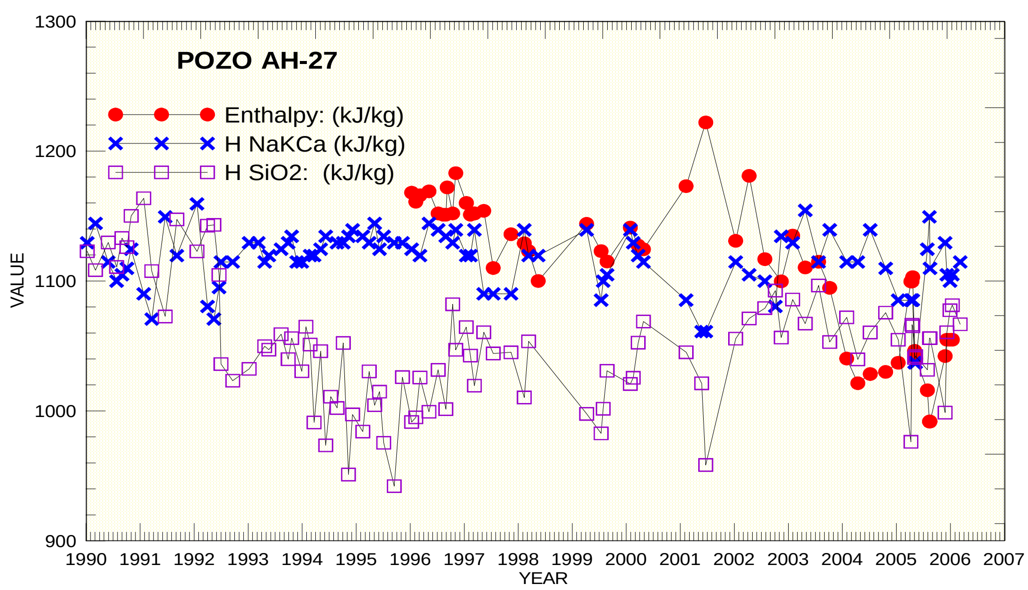

FIGURE 10: Enthalpy evolution comparison

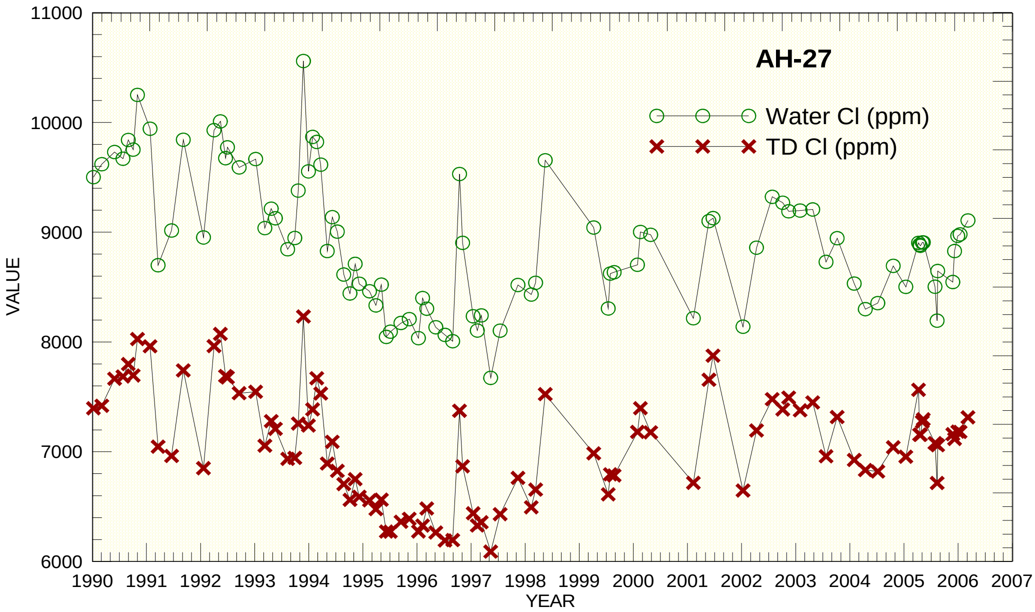

FIGURE 11: Chloride history for well AH-27

At the other side of the country, at the Berlin field the long term exploitation affects in different way the reservoir:

1- The extraction during back pressure units operation the reservoir pressure declines to almost 2 bar, when large amount of mass was extracted the pressure draw down increase to 10-12 bar, none physical or chemical significant effects for this declines has been observed at the moment. A steam cap area was observed in well TR-18 A located to the southern part of the field; actually it is not possible to correlate this condition with the extraction into the actual steam field.
2- The main constraint of the Berlin field is due to the lack of injection capacity, at least 15 injection wells have been drilled into the northern zone of the field but low permeability was observed at this area, perhaps due to some permeability border. The injection wells have been affected by silica scaling during long term operation and acid job cleaning has been required to clean the permeable zone of silica and mud damage.
3- Some cooling effects and tracers returns have been observed at the production wells due to the injection in wells TR4 A and, mainly, in well TR-12 A.

Figure 12 presents the steam history for well TR-2. This well is located to the center of the field and presents stable production condition, but naturally decreasing trend in liquid and steam.

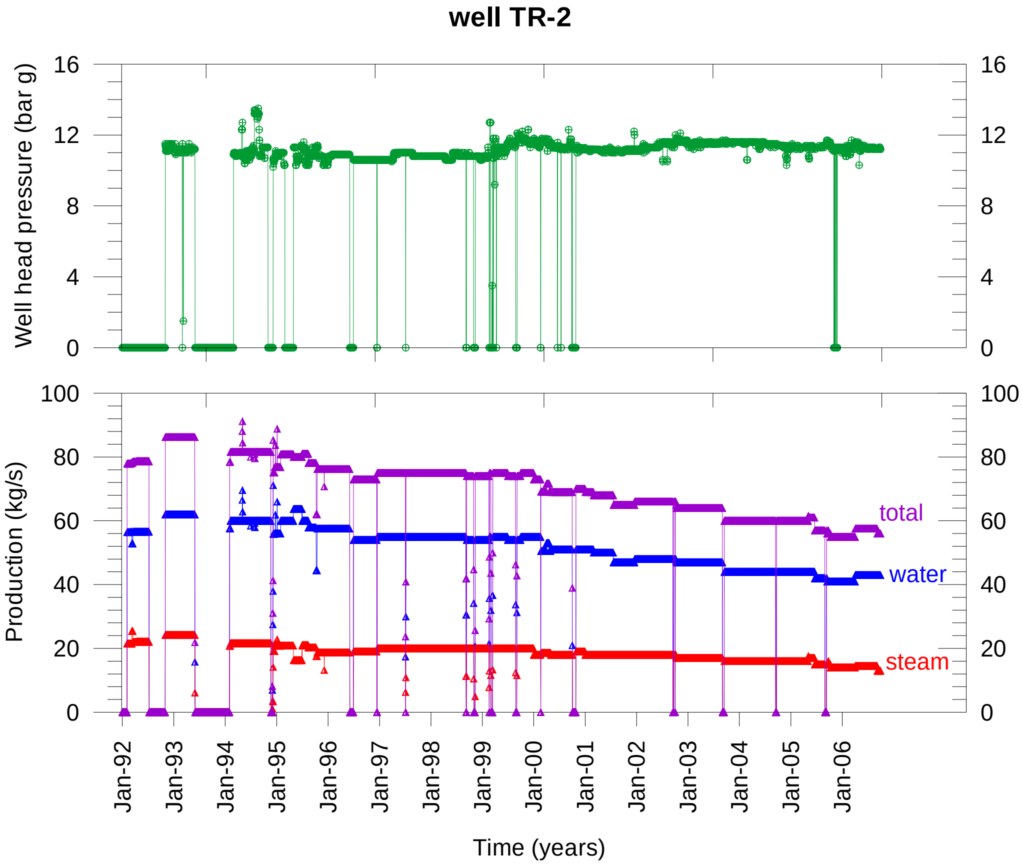

FIGURE 12: Production history of well TR-2

Figure 13 presents the enthalpy comparison between the measured and the calculated from chemical geothermometers and Figure 14 shows the chloride history for well TR-2. Despite the data variability it can be figured that the chemical condition in the fluid discharged is quite stable in geotemperature and chloride content, but is noticed in the probable occurrence of boiling in the local reservoir.

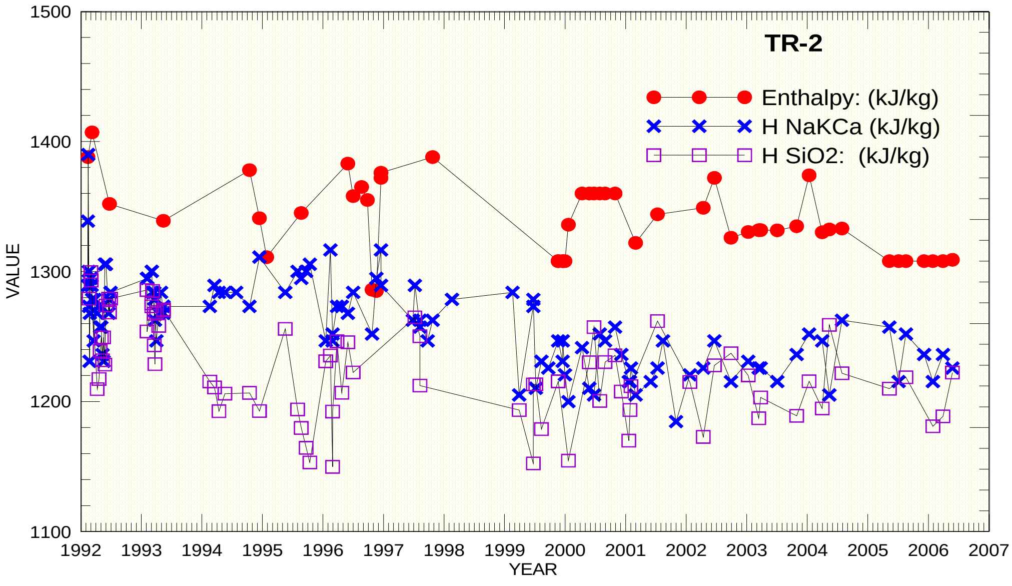

FIGURE 13: Enthalpy evolution comparison

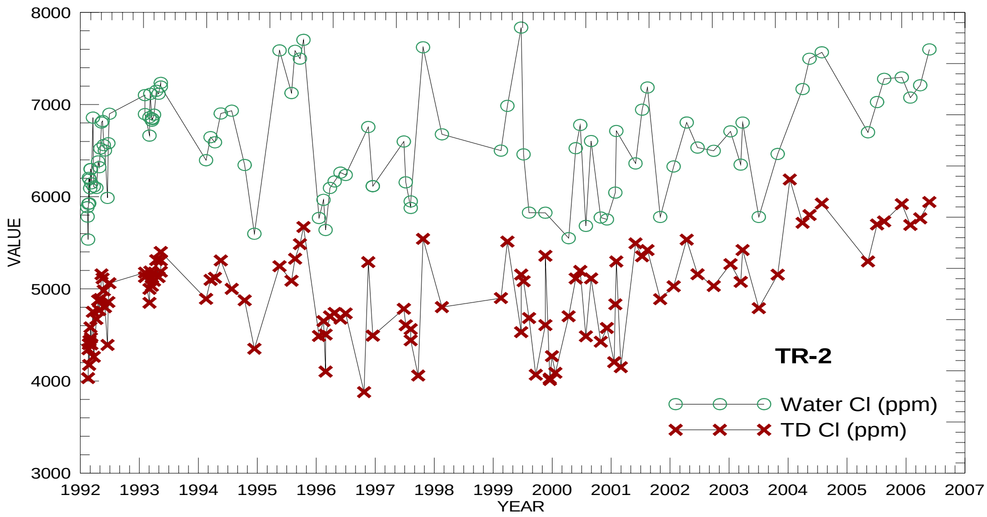

FIGURE 14: Chloride history for well TR-2

Figures 15 and 16 present the injection history for wells TR-14 and 8A. In the TR-14 several acid cleaning jobs were carried out in order to clean the formation from silica scaling, additional solid filter has been installed to prevent the solids to enter the formation and reduce the absorption capacity.

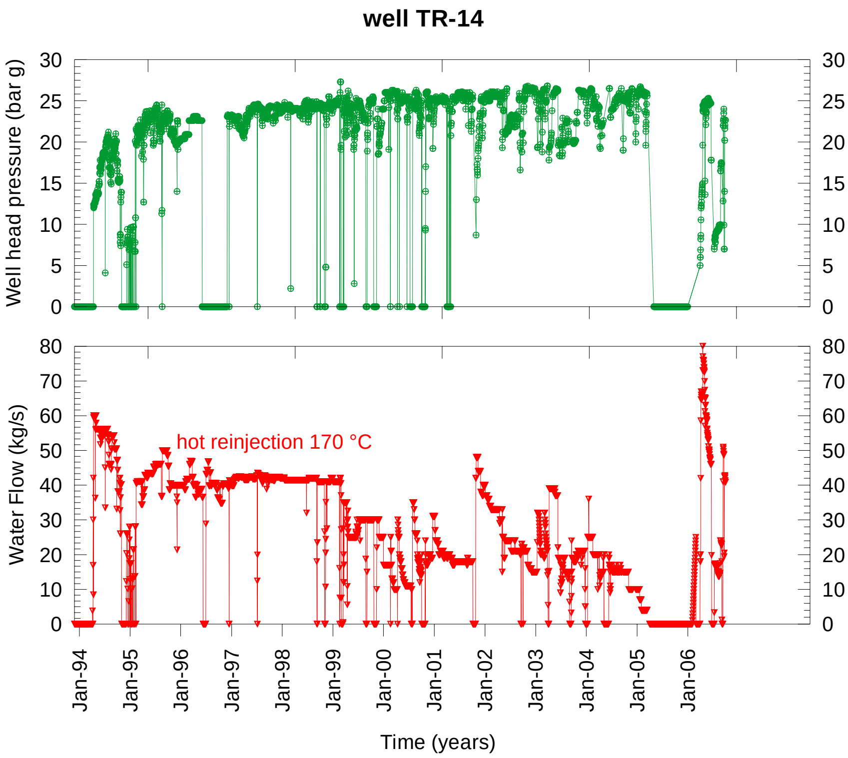

FIGURE 15: Injection history for wells TR-14

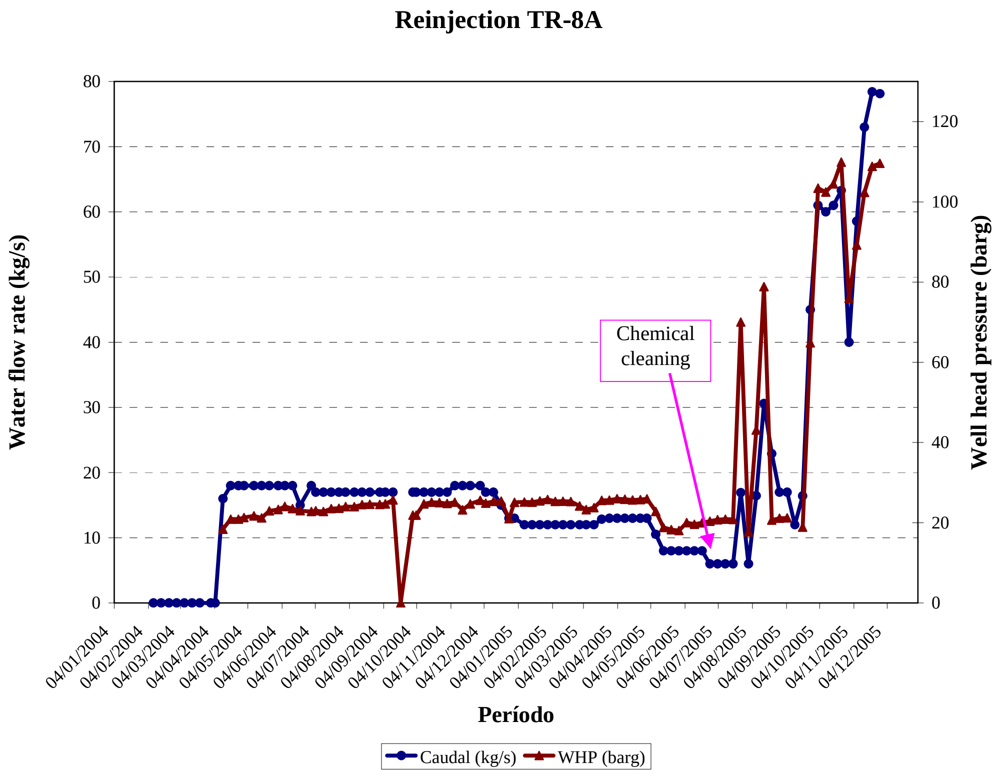

FIGURE 16: Injection history for wells TR-8A

Several acid stimulation jobs were also carried out in the production wells in order to increase the steam availability, despite the injection capacity constraint. Relatively high success has been obtained up to 200% increase in the steam production was observed at some wells. Figure 17 shows the results of acid stimulation in the production well TR-5B and Figure 18 for production well TR-4C.

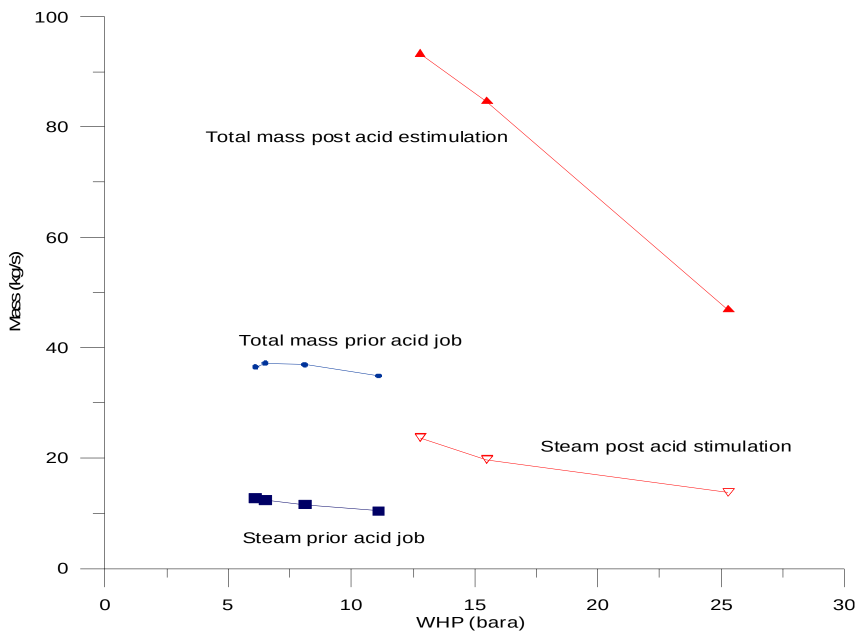

FIGURE 17: Acid stimulation results at TR-5B

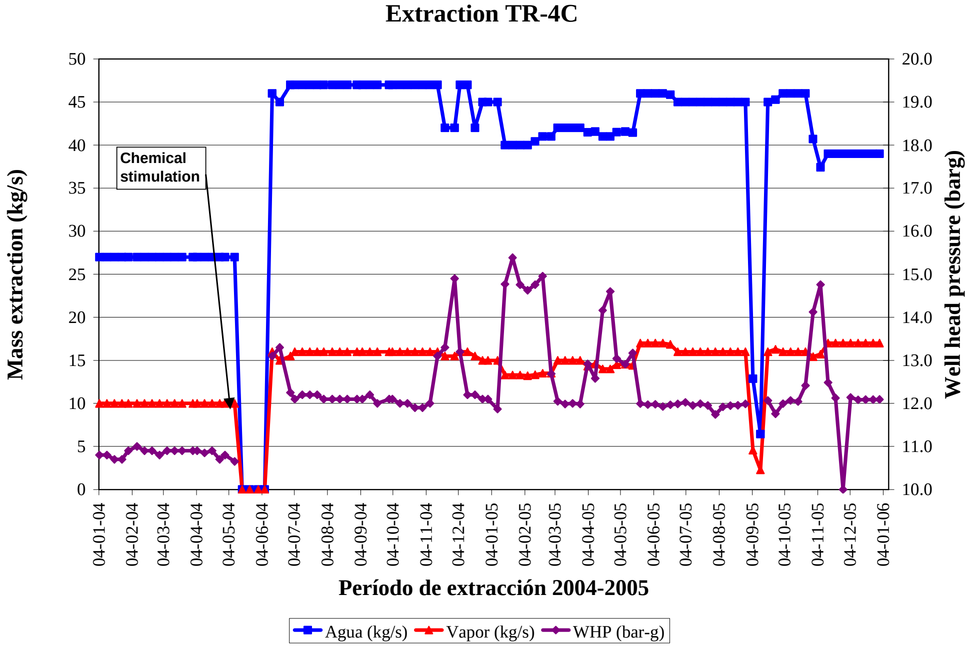

FIGURE 18: Acid stimulation results at TR-4C

4. FUTURE DEVELOPMENT

LaGeo is carrying out (under construction) four geothermal projects, in order to achieve its strategic goals: Third unit (44 MW), Binary unit (9.2 MW) and Total Injection unit. All of them at the Berlin geothermal field and the Optimization project (25 MW) at the Ahuachapán field.

During 2003-2004, LaGeo joint with its partner ENEL carried out several studies in order to do the feasibility for those projects (ENEL, 2004).

At Ahuachapán field the scope of the Optimization projects is as follows:

1- To increase the mass and steam extraction in order to reduce the reservoir pressure up to 18 bars. The power is expected to increase around 10 MW with the continuous operation of the three units already installed. At the moment the field is in operation with the three units and the power generation ranges between 78-80 MWe, the pressure of the reservoir is around 18.6 bar. No significant effects have been observed at the moment at the whole field.
2- To improve the gathering systems in order to increase and optimize the steam production.
3- To drill 3 new production wells and make up wells in order to increase the steam availability.
4- To carry out acid stimulation jobs in some wells affected by calcite scaling.
5- To drill 2 injection wells to increase the injection capacity.
6- To increase the injection and pumping capacity by the construction of one additional injection line to Chipilapa and put on line one additional pump. This line is under construction and will start to operate early next year.

Despite of one year of continuous operation at lower pressure condition the field looks to be enough to maintain the production condition required for the project.

The day by day monitoring must be continue in order to follow the behavior of the wells. Finally it will be necessary to correct (if required) the decision making to ensure a sustainable exploitation of this geothermal field.

Regarding the Berlin field the main aspects of the future development are as follow:

1- To increase the steam production to almost 80-90 kg/s at 6-9 bars to run the new unit, this steam will be yielded from the southern part of the field where the pressure interference is expected to be lower. The steam cap observed in TR-18 A and its large dry production (more than 30 kg/s of steam) could indicate any constraint for the steam availability.
2- To increase the injection capacity to almost 200-250 kg/s, mainly to the eastern part of the field where ENEL is drilling 3 wells into TR-19 pad.
3- To increase the injection capacity with a pumping station at TR-1 pad, the total capacity will be 250 kg/s at 15 bars.
4- To maintain the injection capacity using a periodically acid cleaning jobs.
5- The Binary units will reduce the brine temperature from 180 to 140 °C, this condition could conduct to silica scaling problems in the injection systems, and the chemistry monitoring must be stressed to prevent the lack of injection capacity.

The future development at the Berlin field looks to be amazing but like at Ahuachapán the monitoring and the correction of the decision making is necessary for a confident field management.

5. MAIN ASPECTS OF THE MANAGEMENT

After several years of commercial exploitation, it is possible to share some points of view regarding how the field management could be done, although Malcolm Grant wrote “a geothermal reservoir is completely well known when it is over”, we consider, it is not possible to have a definite and unique solution for every field, it is also not possible to do nothing. All the suggestion will be taken under consideration and the state of the art technology in the geothermal industry is used in order to achieve our field management.

As is common in several geothermal systems around the world, the reservoirs are mainly liquid dominated, therefore, when they are under exploitation the liquid level is reduced and this causes the pressure draw down, this boiling in shallow part of the reservoir where the shallow permeable layer are located, in another part cold fluid and mixing process are common. The chemistry of fluids clearly indicates this physical-chemical process.

The mass extracted in the past was returned to the systems due to environmental constraint, by now the injection is and must be an important aspect of the sustainable resource management, at the moment the reservoir management without injection is inconceivable.

Normally, in modern geothermal power stations, there are two or three injection systems: cold and hot injection, the cold injection is the brine coming from the silencer and storage in a pond, later on is injected by pumping or by gravity in cold injection wells, this brine cause large silica scaling problems. In our experience, the hot injection, are using several temperature ranges 115, 150 and 180 °C, the temperature selected depends on how many flashing cycles have been designed for the geothermal utilization.

The injection strategy used at both fields is doublet type (production in one area and injection in another one) despite of that some injection flow is still in the production zone in both field.

Some cooling effects have been observed in the production zone due to the injection with no significant effects. After several tracer tests we conclude that there are some hydraulic connection between production and injection zones. This is mainly observed when the tracer were injected specifically close to the production area, but when injected far away (Chipilapa case and North Berlin) any tracer return have been observed all of them using short and long half life tracer.

From the chemical and isotopic point of view any evident changes related to injection have been observed. In order to minimize the future cooling and possible chemical effects LaGeo is planning to stop the injection into the production zone in both fields (TR12 A, TR-4 A, TR-3 and AH-33 A).

6. CONCLUSIONS

1. It is possible to achieve a sustainable commercial exploitation of a geothermal resource with a correct and well done field management.
2. Any field around the world has its own characteristics therefore requires a specialized group to conduct the management and the field monitoring as an important part of the resource development.
3. The normal behavior of a liquid dominated reservoir is to reduce the reservoir pressure during the early stage of exploitation, this it is not a dramatic situation if there is injection into the system and a complete monitoring is available. The monitoring must include at least mass extraction and injection, chemistry of fluid, reservoir pressure monitoring, tracer tests and geothermal surface monitoring.
4. Two main processes are affecting the reservoir especially at AGF: a) the boiling is present in the shallow part of the system. It is characterized by increasing enthalpy in the producers wells, higher gas and water chemical content;,b) dilution or cold fluid inflow occurs in some part of the reservoir where the declining pressure induce inflow from neighboring aquifers (lateral or above). Such physical-chemical processes are not observed yet at BGF. The injection could produce similar effects like boiling and dilution together, and must be carefully analyzed and monitored. Tracer test could be helpful to determine how the injection is affecting the neighboring wells but also the chemical and isotopic monitoring.

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