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GEOCHEMICAL MONITORING: UNDERSTANDING AND SOLVING PROBLEMS ASSOCIATED WITH GEOTHERMAL FLUID CHEMISTRY

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ABSTRACT

The present document discusses the experience obtained by the geochemical monitoring in the Miravalles y Las Pailas Field and its application in the solution of problems associated with the geothermal fluids chemistry, like calcite scaling in wells, silica scaling in pipes, acid fluids coming from secondary aquifers, increment of non condensable gases in steam, reinjection effects, peripheral aquifers invasion, cooling process, and other effects caused by complex hydrogeochemical conditions. These studies are focused on the practical solution of several problems, and the understanding the sources and variables that cause them.

1. INTRODUCTION

The Miravalles Geothermal Field (Figure 1) is located in the north-western part of Costa Rica. The commercial exploitation started in 1994 with a 55 MW flash plant, in 1995 a wellhead unit of 5 MW is added to the complex, two others flash plants are integrated in 1998 (55 MW) and 2000 (29 MW), and one binary plant is added on 2004 (19 MW), with a total installed capacity of 163 MW.

Las Pailas Geothermal Field (Figure 2) is also located in the north-western part of Costa Rica. The commercial exploitation started in 2011 with a 35 MW (42 MW gross) binary plant.

In both fields, a geochemical and thermo-hydraulic monitoring program was set up from the first productive tests, and during all the exploitation period. The different controls permitted to maintain a detail control of the evolution of the reservoir condition. These controls allowed monitoring and searching for solutions related to different problems detected during the normal operation of the reservoir. Some of these problems are calcite scaling in wells, silica scaling in pipes, acid fluids coming from secondary aquifers, increment of non condensable gases in steam, reinjection effects, peripheral aquifers invasion, cooling process, and effects caused by complex hydrogeochemical conditions.

2. PROBLEMS ASSOCIATED WITH GEOTHERMAL FLUID CHEMISTRY

In the Miravalles Field, except wells PGM-65 (steam only) and the PGM-43 (low bicarbonate content), the remaining 26 production wells connected to the productive system required chemical

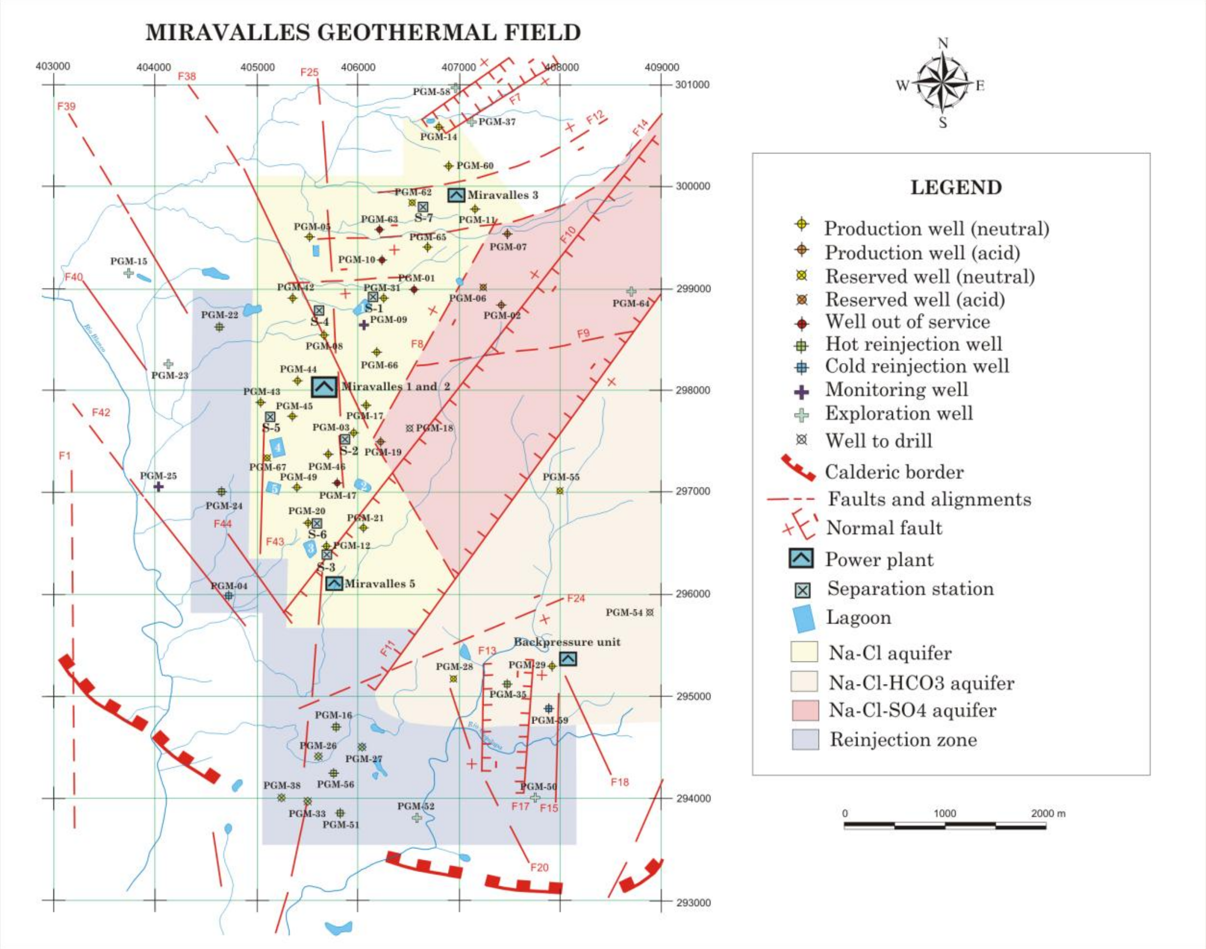

FIGURE 1: Miravalles Geothermal Field

treatments (into the wells at depth). From the beginning of the commercial integration, 22 of them for CaCO3 scaling inhibition and four of them for pH modification (neutralization). In Las Pailas Field, currently is not necessary any chemical treatment.

2.1 Calcium carbonate scaling inhibition

An inhibition system consists on a constant injection of a diluted chemical inhibitor below the boiling point. The structural part of a $CaCO_3$ inhibition system has as main elements, an electrical supply support system, a storage tank, an injection pump, insertion and fastening elements, capillary tubing for injection at depth, injection head and a chemical inhibitor (Sánchez 1995, Sánchez et al, 2005) (Figure 3).

The logistical support of a $CaCO_3$ scaling inhibition system includes the determination of the inhibition requirements of each well and the design of the system, the control program during the productive stages of the well, and the monitoring of the chemical and hydraulic field evolution, focused on defining the inhibition policies.

The $CaCO_3$ formation into the production geothermal wells is related to the boiling phenomena that occur inside them, where the fluids are near the $CaCO_3$ over saturation condition (Figure 4), and it is represented by the equation:

$$Ca^{2+} + HCO_3^- \Leftrightarrow CaCO_3 + CO_2 + H_2O \tag{1}$$

Considering the above equation, it is important to understand which is the limiting reagent in the reaction: the calcium or the bicarbonate.

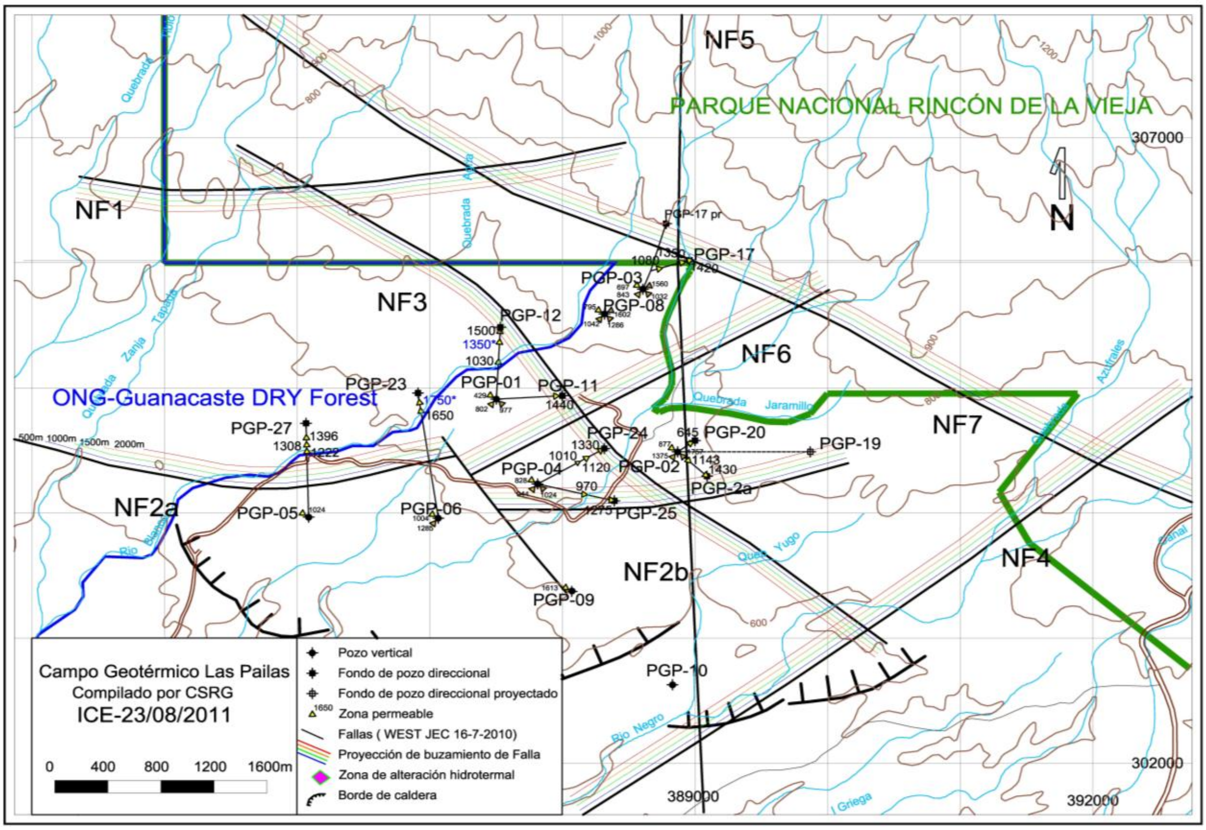

FIGURE 2: Las Pailas Geothermal Field

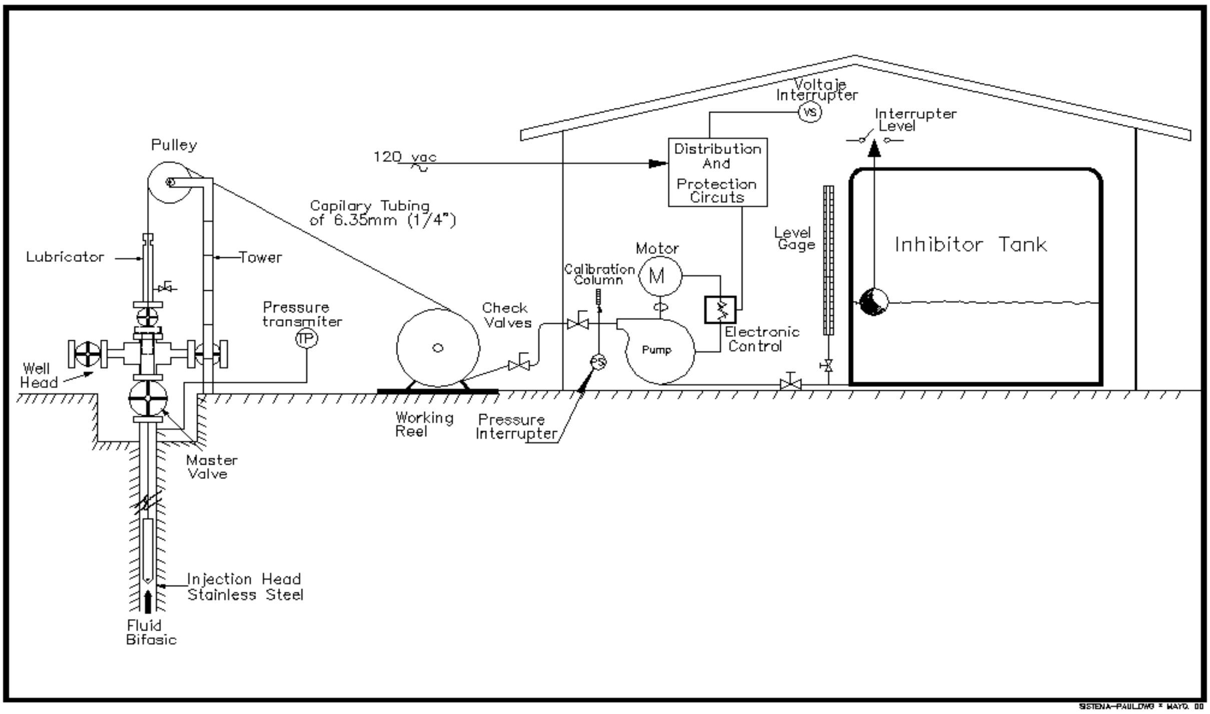

FIGURE 3: Calcium Carbonate Inhibition System

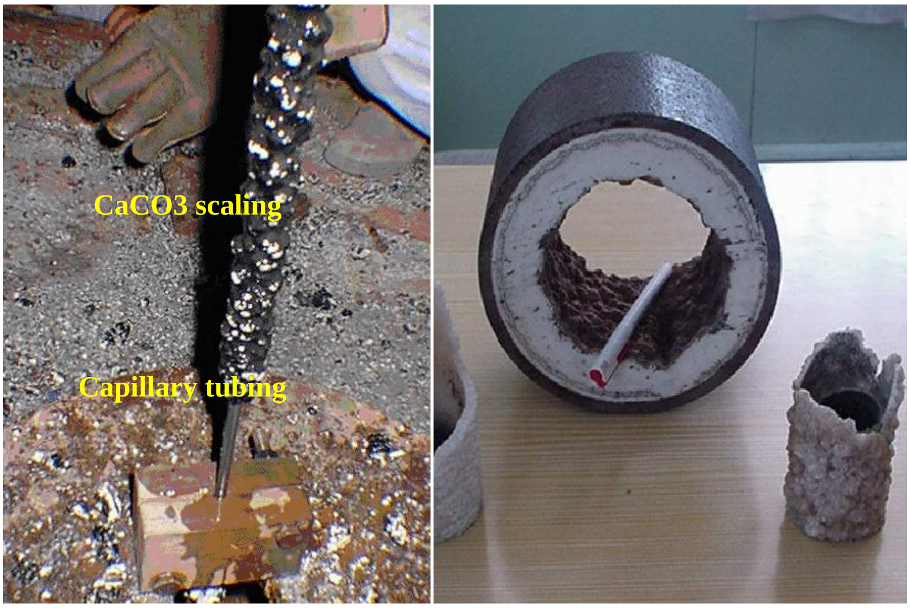

FIGURE 4: Calcite scaling on capillary tubing and casing

In the Miravalles and Las Pailas Fields the limiting reagent is the bicarbonate. From the initial evaluations, CO_2 concentration in the steam and HCO_3^- concentration in the liquid phase are determined, in order to define the scaling tendency of each well. Different software packages can be used for balance calculations to determine the saturation of the fluid under different well conditions (Figure 5). It is important, first, to take in mind that these programs represent an excellent approximation to the reality and second, is highly important to introduce representative data into them. In order to obtain this representative data, samples should be taken under non scaling conditions. In other words, if the sample is taken at the surface when the well is incrusting at depth, the Ca^{+2} and HCO_3^- values introduced into the calculations will be less than real ones, therefore predicted saturation by the software will also lower as well.

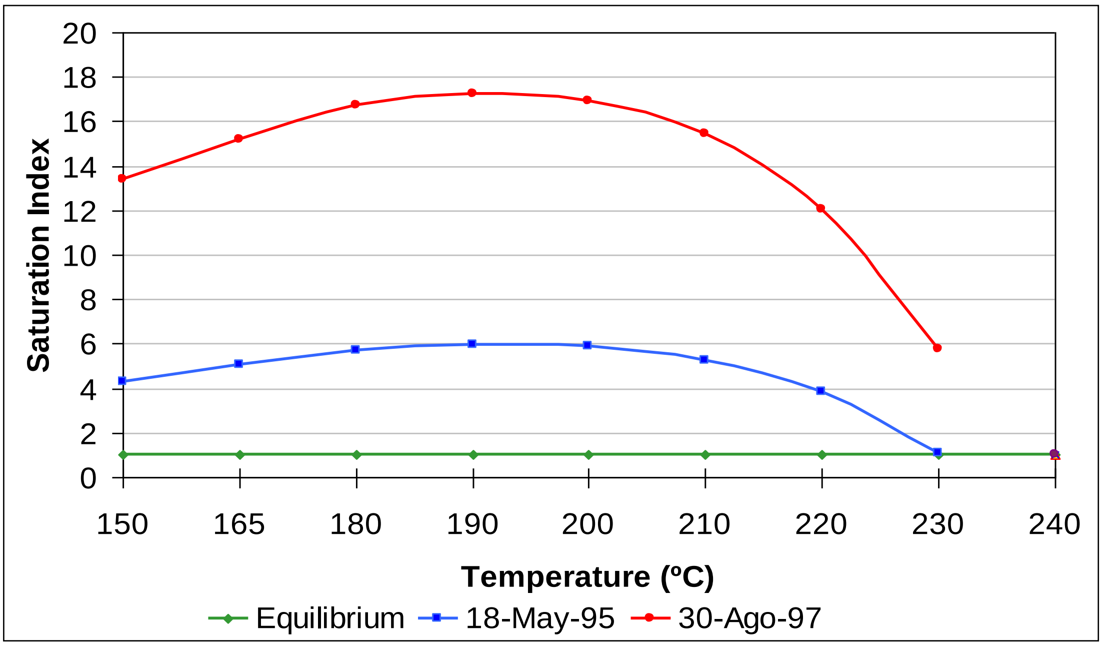

FIGURE 5: Calcite saturation index calculation (WATCH II software), using data from well PGM-29 with samples taken in surface under scaling condition –May 18– and not scaling condition –Aug 30

To determine the injection depth of the inhibitor is necessary to use data obtained from the dynamic temperature and pressure profiles, taking into consideration that these profiles are usually carried out under maximum discharge pressure (MDP) and that the boiling point at maximum flow conditions will differ from few meters to up to hundreds of meters depending on the well permeability, and also that the boiling point will become deeper as the pressure of the reservoir drops.

The monitoring program during the well productive stages consists on a series of periodic samplings to obtain the necessary information for determining if the inhibition system is working successfully. The sampling frequency will depend on how severe the scaling problem is. The reaction time between the analyses stage and the order of the data processing is important, in order to be able to have a fast response (Table 1).

Table 1: Typical $CaCO_3$ inhibition parameters control data

Date	Sample #	Ca^{+2} ppm	Cl^{-} ppm	Ca/Cl*3000 Ratio	Dose ppm	Inhib. Units	HCO_3^{-} ppm
06/01/2004	82901	68	4141	50,0	1,50	11,0	
06/01/2004	82902	68	4155	49,1	1,50	10,8	73
06/01/2004	82903	68	4148	49,2	1,50	10,9	73
	Average	68	4148	49,4	1,50	11,1	73,0

The control values are referred to data obtained under total inhibition and total scaling conditions, the values obtained in the column “Inhibition Unit” (Table 1) indicate satisfactory inhibition, the zero values meaning maximum scaling and intermediate values indicate partial scaling. The Ca^{2+}, Cl^{-} and HCO_3^{-} values of each well are used to determine their scaling range and to control the behaviour of the limiting reactive in time (Figure 6, Figure 7).

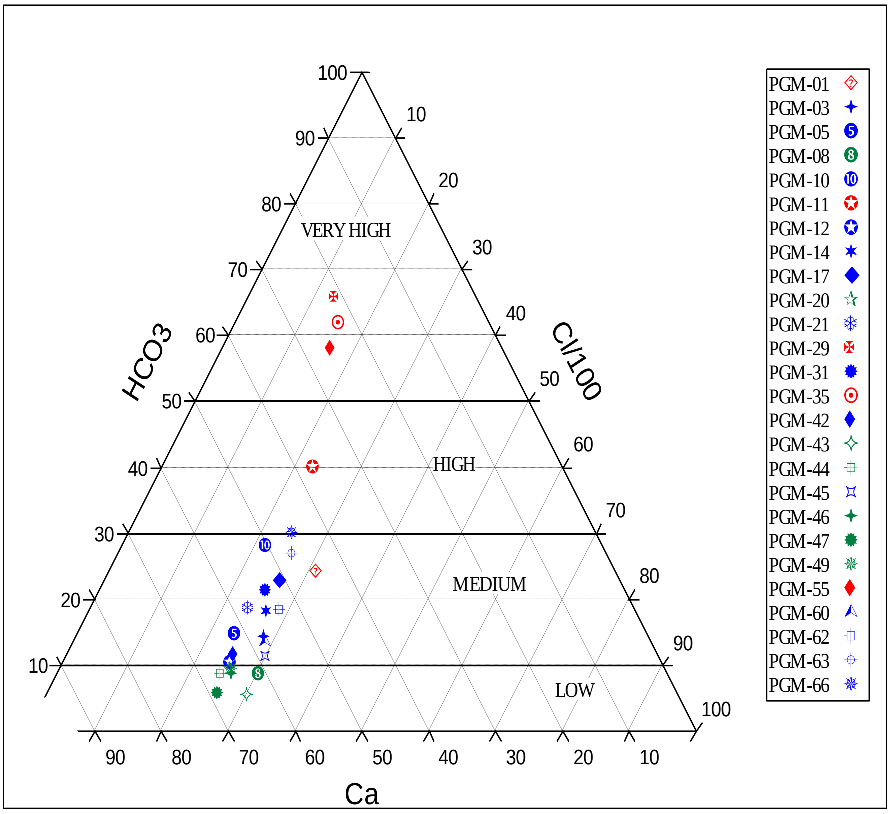

FIGURE 6: Ternary graph, CaCO3 scaling range at the different production wells of Miravalles

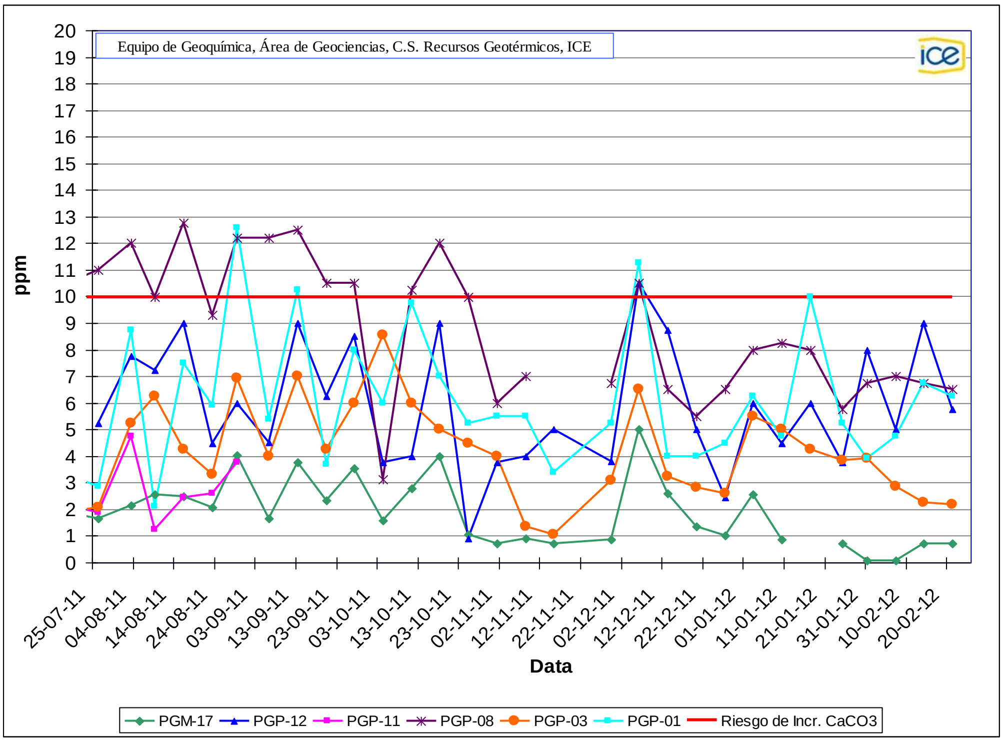

FIGURE 7: Bicarbonate content, in Las Pailas production wells

With the massive exploitation and the displacement of large masses of fluid in the Miravalles field, the bicarbonate concentration of the fluids started to change, requiring a constant update of the dosages applied (Figure 8).

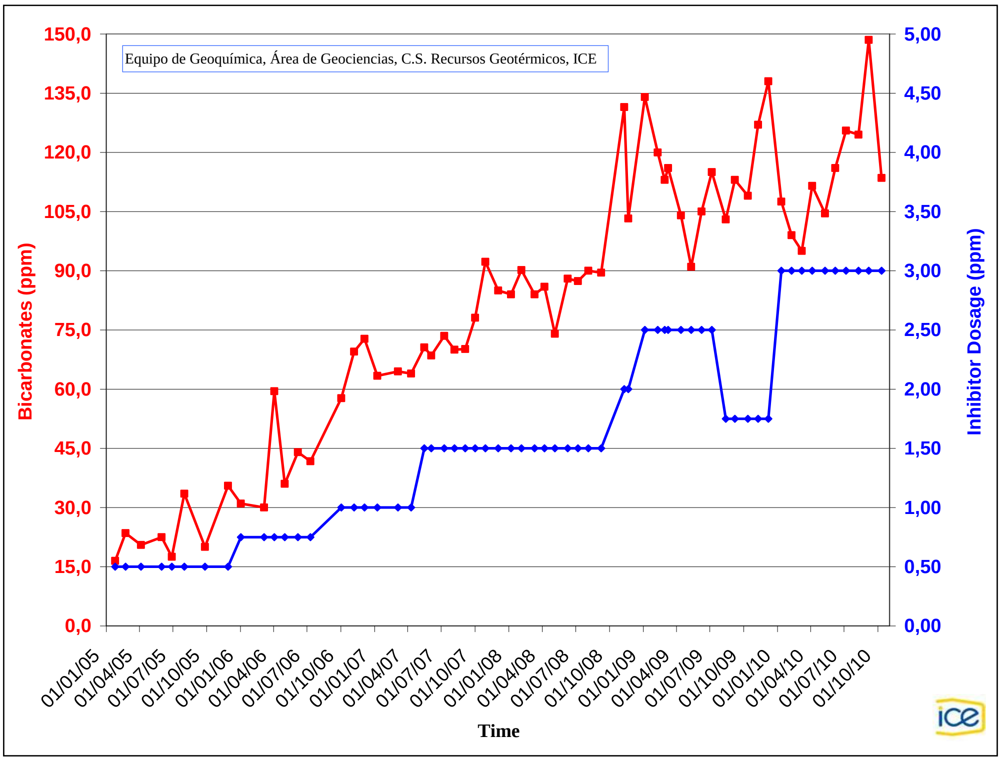

FIGURE 8: Changes recorded through time in the bicarbonate content and the corresponding adjustment of the inhibitor dosage at PGM-49, Miravalles

2.2 Neutralization of acid fluids

The Miravalles field has four wells drilled in an acid sector (PGM-02, PGM-06, PGM-07 and PGM-19). The need to recover the investment in these wells, led ICE to start studies to integrate them online. The first extended neutralization tests in Miravalles were carried out in 1996 (Sánchez, 1997). The neutralization process consists of adding a solution of sodium hydroxide to the geothermal fluid. This neutralizes the H^+ acid groups, thus raising the pH. The injection of the sodium hydroxide must be continuous and it has to be accomplished to an adequate depth within the well, to protect the casings and all the surface equipment against corrosion.

Since February 2000 (PGM-19), October 2001 (PGM-07) and May 2006 (PGM-02), neutralization systems have been used successfully, allowing the steam collected from these acid wells to be used by the generation units. These wells give an equivalent of about 18 MWe to the power plants. Experience has indicated that by using neutralization systems, it is possible to include acidic fluids into production with a controlled corrosion rate and at a reasonable cost.

The infrastructure and devices used on an acid fluids neutralization system is similar to the $CaCO_3$ scaling inhibition system, differing essentially in the fact that most of the neutralization system has a backup support, metallic parts used are made of appropriate alloys that support aggressive environments, and the monitoring is taken in real time. The principal elements of the system are: electrical supply support system, storage tanks, injection pumps, on-line dilution pumps, on-line pH-meter, on-line Fe-meter, introduction and fastening elements, capillary tubing for injection at depth, injection head and a chemical neutralizer product. The problem of the acidity in the Miravalles Geothermal Field and the results of the commercial integration of acid wells have been discussed in previous documents (Sánchez, 1997; Sánchez et al, 2000; Moya et al, 2002; Sánchez et al, 2005).

The logistical part of an acidic fluid neutralization system includes the determination of the neutralization needs of any well and the design of the system, the surveillance program during the productive stages of the well and the monitoring of the chemical and hydraulic evolution of the field, and the establishment of the neutralization politics.

To design the neutralization system it is necessary to carry out laboratory tests to determine an accurate NaOH dosage, in order to raise the pH to an appropriate working condition. This information in addition to well mass flow data are required to establish the pumps required capacity to be used in the tests. The depth of the injection point would not depend on the boiling point location, but on the well completion. In the acid wells of Miravalles, the initial neutralization tests are normally extended for a minimum period of 30 days (Figures 9 and 10).

The control program during the well productive stages consists on an on-line control of pH values and iron content and periodic chemical fluids sampling. They are required to guarantee a satisfactory structural condition of the neutralization system, to determine the correct dosage and to monitoring geochemical changes in the reservoir (Table 2).

Related to the operational pH values and NaOH dosage, a low pH would cause excessive corrosion, and high pH values would generate large deposits inside the well casing and at the surface pipelines (mainly of silica), for this reason is necessary to determinate and monitoring all the variables that affect the natural pH (Figure 11).

2.3 Non-condensable gas evolution

Another problem associated with the fluid chemical characteristics, is the non-condensable gases (NGC) content variation in the steam, especially when the original capacity of the NCG extraction of the power plants is limited.

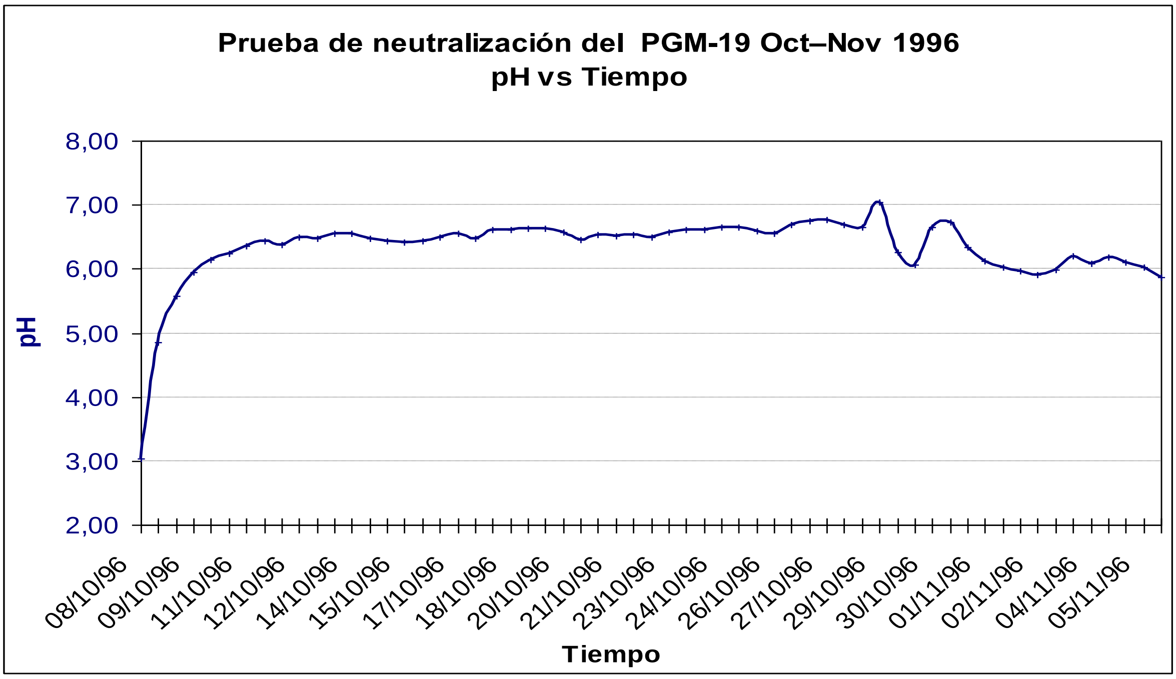

FIGURE 9: pH modification during the initial neutralization test, PGM-19

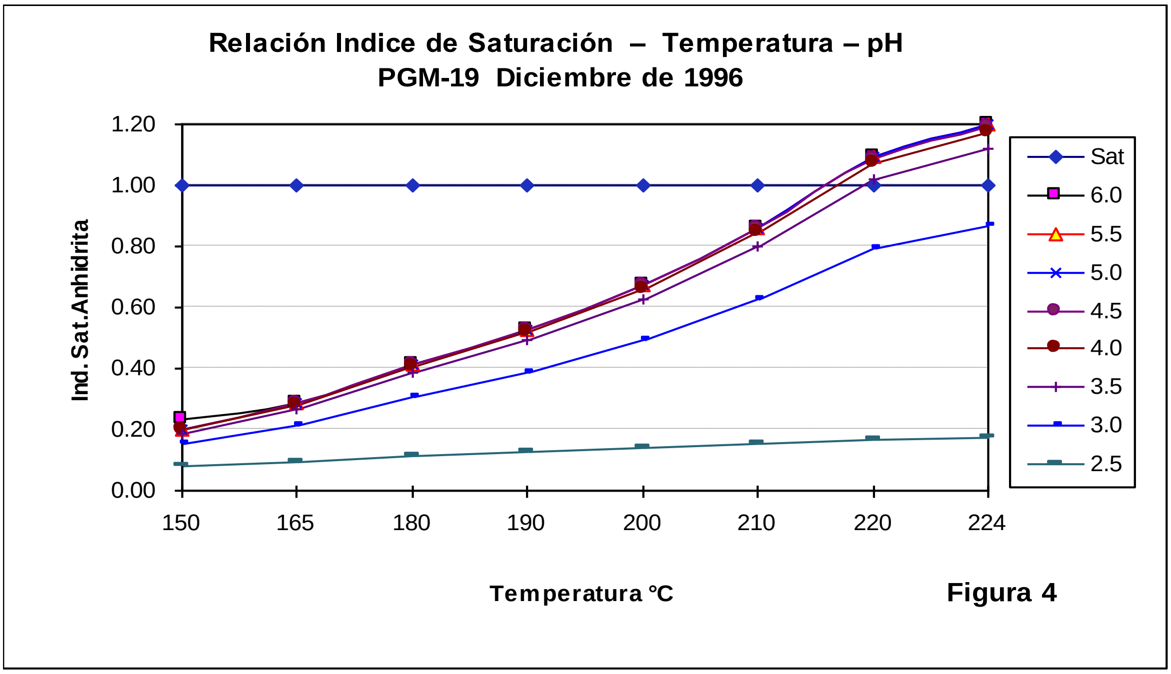

FIGURE 10: Initial test, calculation of possible secondary effects product of the neutralization, PGM-19

TABLE 2: Typical neutralization system parameters control data

Data	Time	Ca+2	Cl-	Rel	pH	Fe	SO4	Cond.	WHP	MF	NaOH	T500	T100
		ppm	ppm			ppm	ppm	uS/cm	b.a	kg/s	ppm	H2O	NaOH
13-Feb-12	08:30	37	3839	28,8	5,31	1,33	349	12320	6,94	45,2	68	93	11
13-Feb-12	08:40	36	3872	28,2	5,30	1,52	353	12290	6,94	45,2	68	93	11
	Av	**37**	**3856**	**28,5**	**5,31**	**1,43**	**351**	**12305**	**6,94**	**45,2**	**68**	**93**	**11**

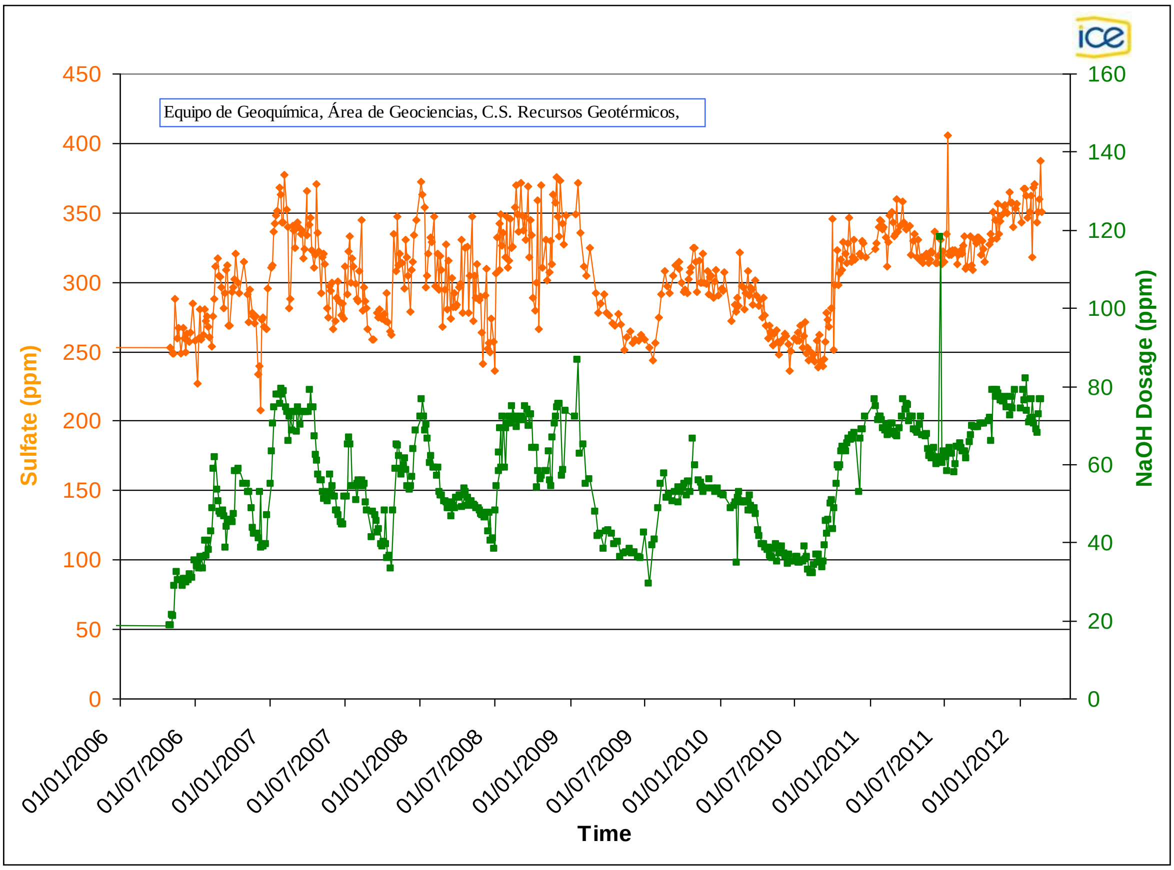

FIGURE 11: Changes in the sulphate content at the time and adjustment of NaOH dosage

Data obtained from the chemical characterization of the first wells drilled in the Miravalles Geothermal Field, prior to commercial exploitation, showed a considerable variability in the non-condensable gases content among them, with an initial range between 0.4 and 1.5% w/w refer to a 7.0 absolute bar separation condition. As other wells were drilled, this range increased.

During commercial operation period, the initial NCG content of the production wells, has been affected by:

1. Hydrological system changes caused by a continuous production. Extraction of masses dragged from other field sectors which are higher or less concentrated in NCG content caused by fluid mass movements.
2. Considerable amount of fraction of the reinjection fluid arrival. Production wells have an important fraction of reinjection fluids, and since this fluid has been previously degassed, this causes a lowering of NCG in the steam.
3. Pressure changes in the system affected by a continuous production. The mass extraction causes a pressure drop of the system, tending to generate a steam phase in the reservoir. This condition enriches the fluid content with steam, but also enriches de NCG amount in it.
4. Peripheral aquifers invasion, due to a pressure drop of the system

All these factors mentioned above are present in the Miravalles Field, and its influence shown variability over the time due to the system evolution, tending to a constant increase in the NCG in steam delivered to the power plants.

Since the continuous exploitation of the Miravalles Field has stimulated an NCG increasing tendency, a strict monitoring of the evolution of the fluids produced by each well has been taken (Figure 12), in

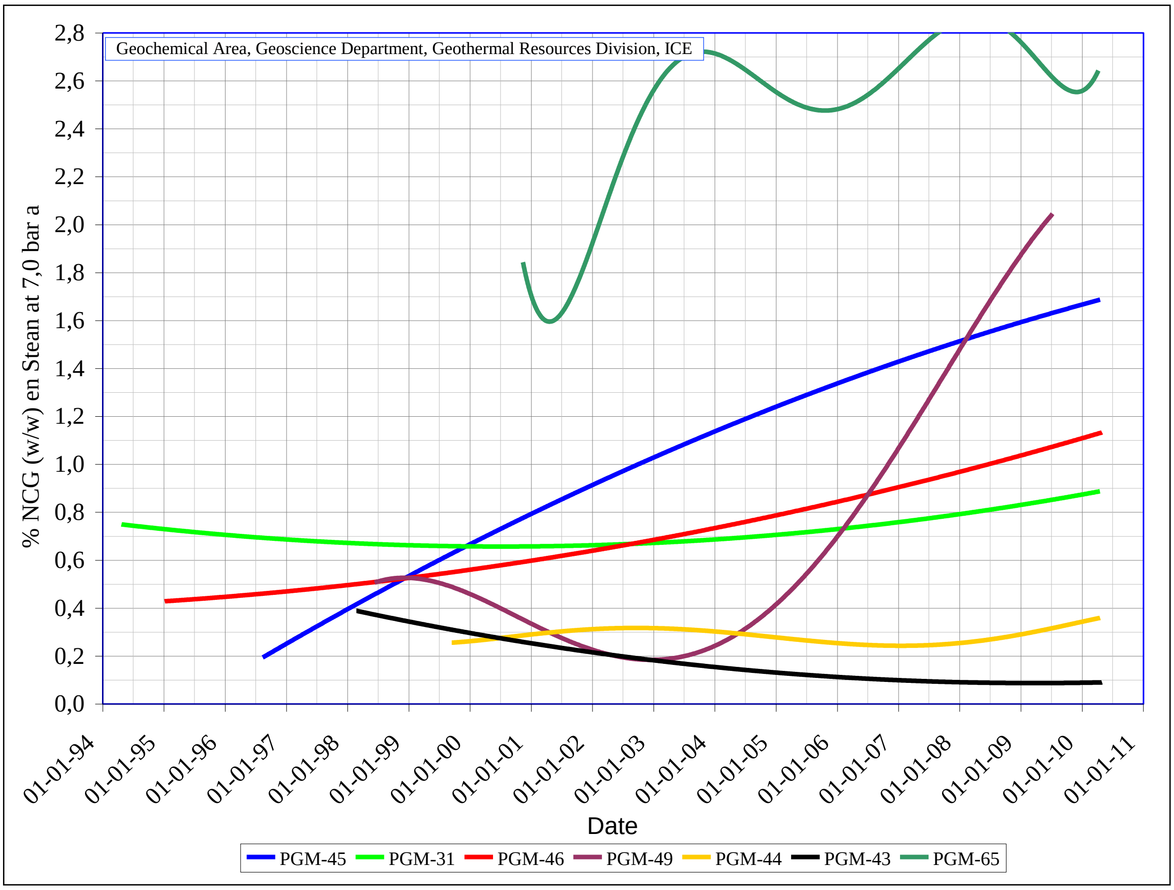

FIGURE 12: Miravalles wells NGC content variation in the steam, at 7,0 bar abs

order to identify the causes that facilitate this process, in search for corrective actions that can be implemented to optimize the use of energetic resources available.

Research has shown that: NCG lowering is related to reinjection influence, which can be noticed in some production wells at the surrounding west sector of the field, and otherwise, an increasing of NCG in the steam concentration is related to a pressure drop of the system, which allows the generation of two phases in the reservoir, therefore dragging out an additional NCG with the steam. This condition also, enables the activation of other production zones chemically different. As result of the analysis, an optimization of the reinjection masses has been recommended, in order to give a higher support to the most affected sectors of the field (Figures 13 and 14).

2.4 Reinjection effects, peripheral aquifers invasion and cooling

Several interrogatives about pros and cons due to reinjection effects in a geothermal field can be analysed as follows: from the environmental point of view it is absolutely necessary, and from the operational point of view, effects resulted from it can be positive or negative depending on the hydrogeology and the management of the reservoir. Effects are decisively negative when a cooling phenomenon takes place in the production zones, or when it increases a previous problem such as the tendency to form CaCO3 deposits (when calcium is the limiting reagent). On the other hand, positive effects happen due to mass recharge and pressure support; as well as lowering an existing problem expected from the formation of CaCO3 (when the limiting reagent is the bicarbonate).

At the initial exploitation of the Miravalles field, the fluid salinity produce by all the production wells were similar, which made the reinjection traceability more clear, considering that the last ones had a 17% higher concentration. Samples taken for the CaCO3 inhibition system monitoring, were used additionally to track changes in salinity over time, and the effects of the operating policies over these changes (rates variation of extraction and reinjection) (Figure 15).

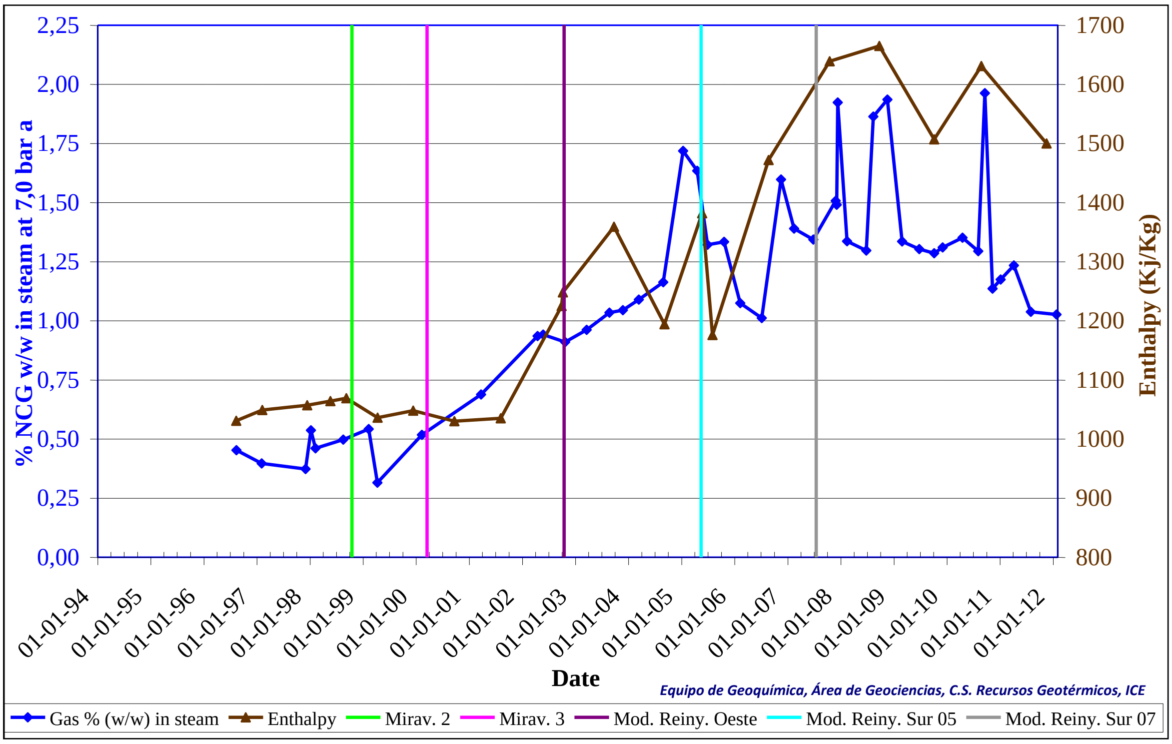

FIGURE 13: PGM-45. Relation of NCG vs. enthalpy. Generation of two phases in the reservoir.

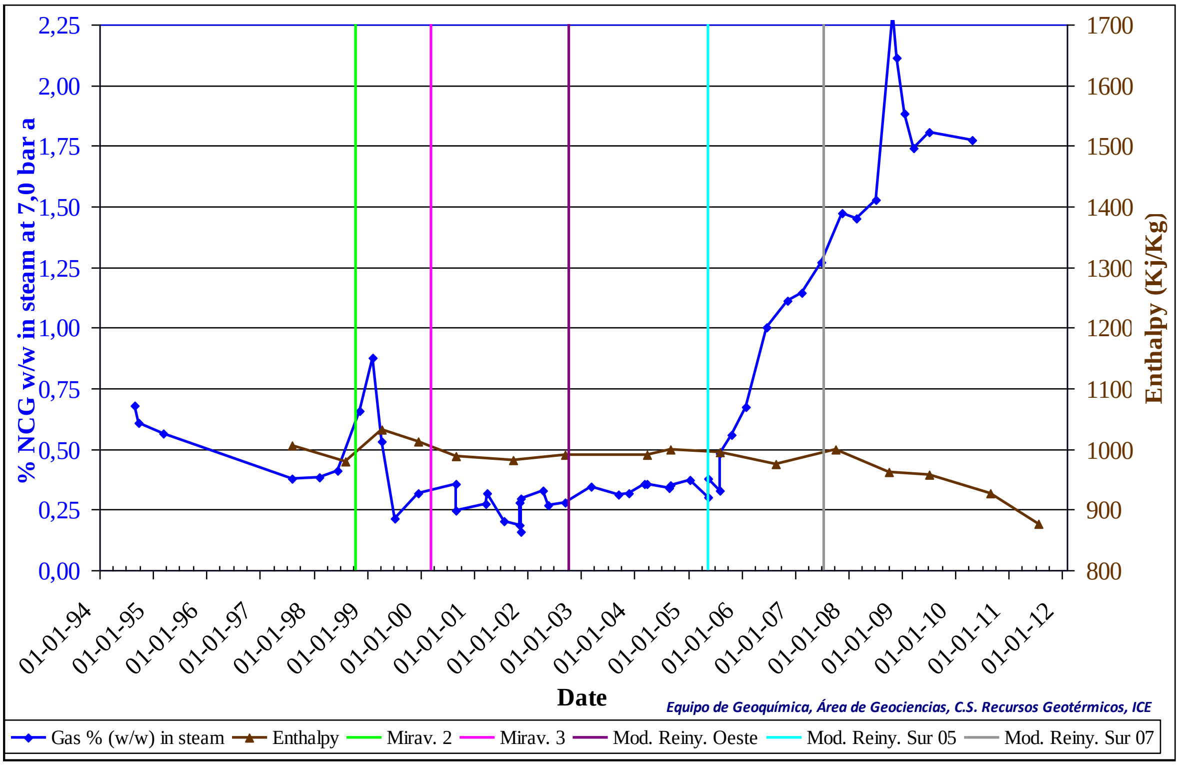

FIGURE 14: PGM-49. Relation of NCG vs. enthalpy. Peripheral aquifers invasion.

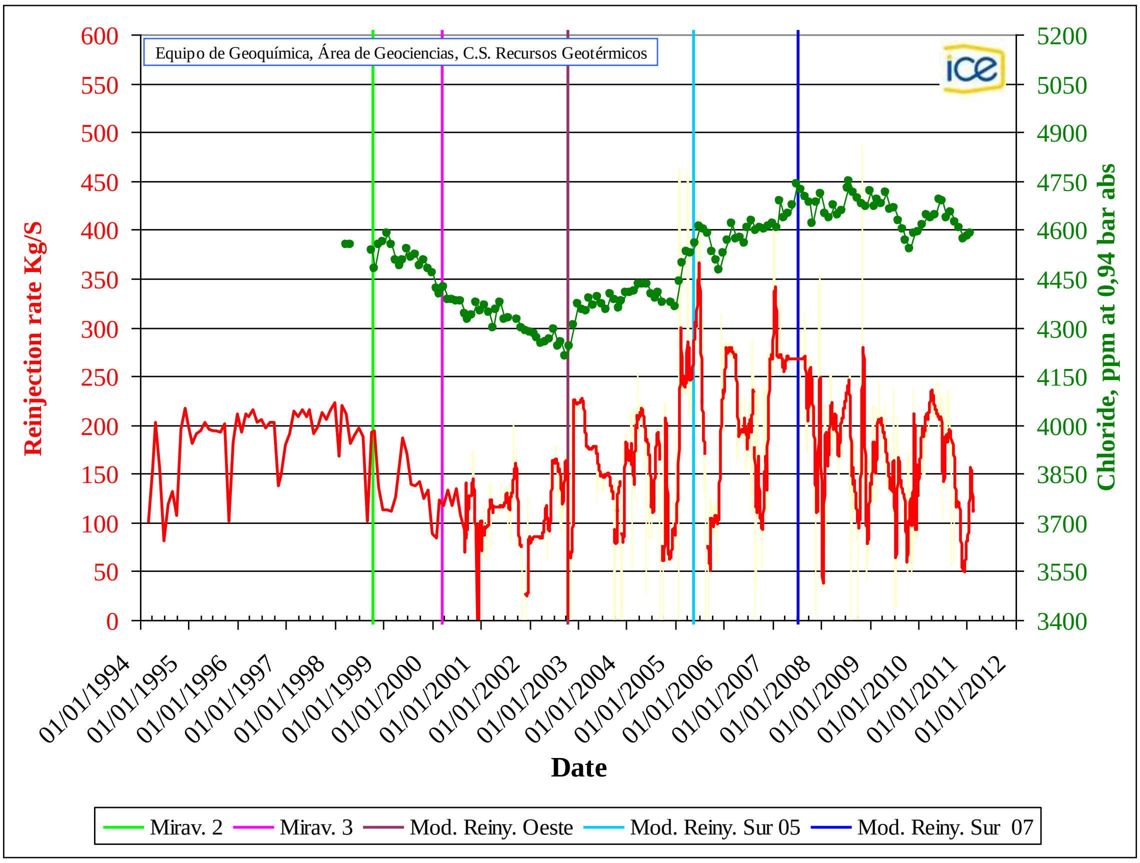

FIGURE 15: Reinjection rate in well PGM-22 and chloride values in production well PGM-42

The monitoring of reinjection effects is useful in the interpretation of cooling process, as mentioned earlier in this document, the reinjection water is characteristic for the high salinity and lowest NCG content. In the following example, a cooling process has been detected in well PGM-49. Using data obtained from the geochemical monitoring, makes possible to determinate that this process is not a consequence of the reinjection, but as a result of the invasion of peripheral waters (Figure 16).

For Las Pailas field, since the start up, a very complex hydrogeological and even more complex geochemical context has been establish, showing that several and different aquifers are present in the wells, determined by clear chemical differences, as well as different thermal and hydraulic characteristics between the production zones of a single well. As a consequence of this complexity, during the monitoring time, the salinity of the mixed fluids produced by a single well has shown important and oscillating variations (Figure 17). This condition led to implement tracer tests, as a complementary tool element to acquire a better knowledge of the true effects caused by reinjection in this field.

3. CONCLUSIONS

Geochemical monitoring represents a low cost activity during the production process, that allow us to obtain useful constant information.

As discussed in this paper, the geochemical monitoring is a useful tool to determine the causes of the problems that affect the production of the geothermal reservoirs.

An adequate interpretation of the data and its integration with thermal, pressure and production data, enable us to provide accurate and fast solutions to specific problems.

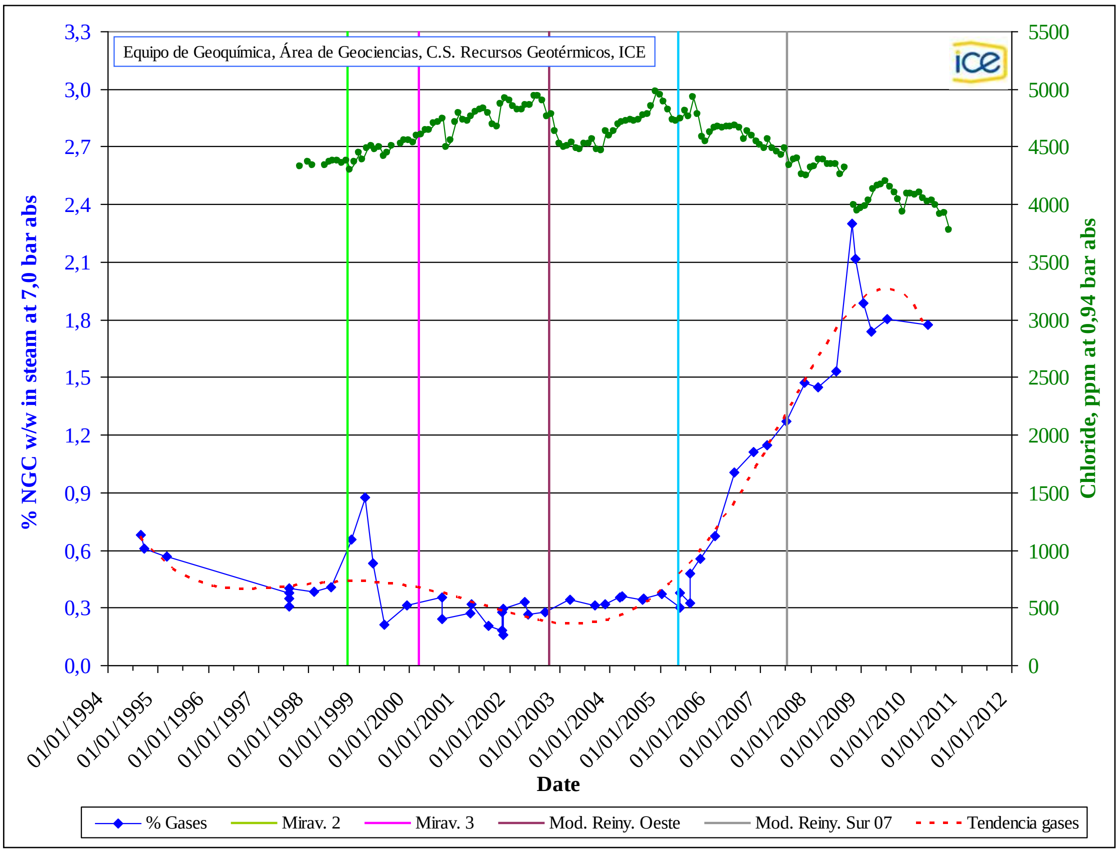

FIGURE 16: PGM-49. Invasion of peripheral waters

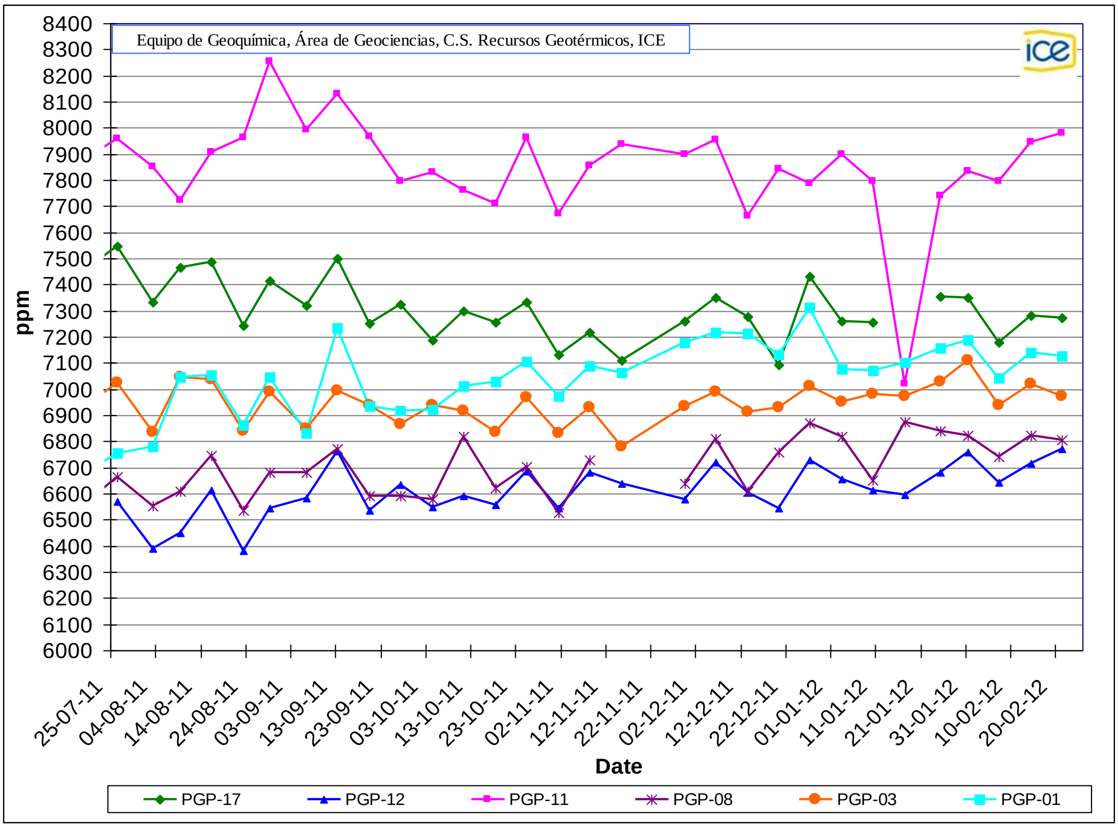

FIGURE 17: Las Pailas, chloride content in production wells

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