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ACID STIMULATION OF GEOTHERMAL RESERVOIRS

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ABSTRACT

Successful mechanical cleanouts and acid stimulations in production and injection wells at the Berlin, Ahuachapán, Chinameca and San Vicente geothermal fields were performed over the past 12 years, providing great improvements in power generation and permeability enhancement in injection wells. The application of these techniques delivered an accumulative increase of more than 70 MWe in power production and 900 kg/s of injection capacity. Chemical stimulations, using a drill rig to clean up to four zones, have given improvements close to 200%, while acid jobs through the well head have given 40%, when cleaning only the first permeable zone. It has been applied to production wells with mud and cutting damage, production wells with calcite scaling and injection wells with silica scale and mud damage or positive skin values, and has also been successfully applied in injection wells with negative skin. The fluid treatment mostly used in Berlin production wells is the Mud Acid 10:5, RPHF 5% for wells with calcite scaling in Berlin and Ahuachapán Field, and RPHF 6-8% in injection wells with low permeability and high silica scaling potential. Pressure transient tests and analysis of the data have quantified the amount of improvement after the cleanouts and stimulations were executed. The reduction of the skin factors suggests that the stimulations influenced the matrix of the formation. The criteria for the design of the acid treatment such as type of rock formation, number and thickness of the permeable zones, extent of skin damage, and level of steam fraction are crucial to take the decision if the well needs to be chemically cleaned. The parameters such as the type of acid for the fluid treatment, strength of the acid, composition and volume of the fluid treatment, and the selection of additives and the results of the acid dissolution tests as well as the operation parameters are very important to take into account in order to obtain excellent results.

1. INTRODUCTION

The use of non-traditional energy sources has become one of the key elements to address the world's demand for energy resources and at the same time, ensure sustainable development. The importance of geothermal energy is emphasized due to the fact that Central America has a limited reservoir of fossil fuels in its own territory. Moreover, the Central American region imports around 75% of its energy, and geothermal energy use for power generation in some of these countries represents around 10-25% of their national electricity production. In fact, according to the World Energy Council, this is one of the richest areas which have geothermal resources.

Despite its estimated potential of 4,000-megawatt (MWe) capacity for power generation, the actual installed capacity is only 508 MWe. Most of the projects perform below their potential because of two core factors: a) Reduction of the supply and b) low productivity or injection due to scales on production pipelines and/or skin damage effect. Damage can be caused by several reasons, such as: entrance of drilling muds, migration of clay formations, silica and calcite mineral scales and cuttings entering into the formation when drilling in total loss of circulation.

In this document, the results of twelve years of research of chemical stimulation undertaken in El Salvador geothermal fields are discussed, where different formulas/additives were used and patented by various companies. Over forty-nine stimulation treatments have been performed using a variety of acid systems injected in volcanic formations mainly composed of interlayered andesitic-basaltic andesite and dacite with fine and lithic tuffs. The results of the laboratory analysis of the data indicate that it is actually the combination of a well-designed treatment and special mixture of acids that improves significantly the stimulations of the geothermal reservoirs.

The improvements can be perceived when the wells are stimulated using either the wellhead or drilling rig. In Berlin Geothermal Field, Usulután, three to four permeable zones (payzones) with cumulative thickness of 200 meters were stimulated using the drilling rig, and an increasing in output from 8 to 11 MWe per well was achieved. This is due to the fact that the field presents a high fraction of steam (>25% and high temperature >280°C) in the case of wells TR-5C and TR-4B. Nonetheless, in Ahuachapán, the increase was lower mainly because of the less fraction of steam (14-16%).

When stimulating wells through the wellhead (Figure 1a), the reported increase is about 4-5 MWe. When treatment fluids are injected through the wellhead, the first permeable zone and most important one, usually located below the production casing, is the primary production zone that absorbs the acid and benefits the most from the procedure, in the case of wells TR-5B and TR-4C.

The power generation has increased up to 3 MWe in wells with calcite (in Ahuachapán) with low vapor fraction (14%) and lower temperature (230°C) problems, i.e. wells AH-34A and AH-32st.

The total value for chemical cleaning through wellhead ranges from $150,000.00 (TR-5B) to $325,000.00 US dollars (TR-18). Investment was lower for production wells with formation damage caused by the ingression of drilling mud and cuttings (based on cost of additives, hydrochloric acid and ammonium bifluoride for the year 2006). On the other hand, higher investment was made to clean production wells with similar problems and calcite scaling potential.

Chemical stimulation of wells with drilling rig (Figure 1b) adds to the total value, an extra US$1 million for drilling services, pumping services and water supply, besides the amount of additives, chemical and personnel used to inject the chemical mixture per wellhead. It is noteworthy that the improvement in the stimulation in this case is much more effective because 3-4 areas are cleaned at a gain of 200% (Case well TR5C).

To date, the acid stimulation technology is applied not only to clean damage of a production or reinjection well that has been in operation, but is applied as part of the completion stage immediately after the well has been drilled.

2. CHEMICAL STIMULATION TECHNOLOGY

All around the world, there is a variety of geothermal projects that performs exceptionally well during its initial production, but with time the productivity drops usually due to cooling processes, decrease in reservoir pressure by overexploitation and/or mineral scaling such as, amorphous silica, calcite, anhydrite and sulfides, inside the production casing or formation pipelines.

On the other hand, reinjection is a technique currently used to control both the reservoir pressure and the invasion of cold fluids from the upper aquifers due to overexploitation. This particular practice prevents contamination of the environment instead of disposing waste fluids on the surface, which contain high contents of total dissolved solids (TDS).

Both injection and production wells can be clogged, reducing their production capacity and injectivity below their existing potential. The main reasons for these obstructions may be:

1. Invasion of drilling fluids (mainly bentonite mud) inside the micro fractures of the reservoir;
2. Entry of rock fragments or cuttings, during the drilling process while encountering a total loss circulation;
3. Entry of great amounts of Total Dissolved Solids;
4. Reinjection water with high silica scaling potential;
5. Formation of fine-grained solids displaced by clay migration;
6. Entry of amorphous silica fragments from the reinjection pipelines due to the cooling and heating processes s after maintenance;
7. Calcite scaling in the perforated liner and/or production casing.

The key to ensure a continuous flow for power generation is to control all the possible causes of obstruction. It is a well-known fact that the geothermal industry has been using similar technology and practices of the oil industry for the last 50 years.

Since oil and gas wells show analogies with regards to scaling problems and mud damage, similar techniques may be applied to prevent permeability problems in order to improve injectivity and productivity capacity in geothermal wells. A cost-effective and widely used solution is the application of acids to dissolve scales and obstruction produced by solids.

In El Salvador, the geothermal production and absorption in wells are mainly through natural and secondary fractures. These fractures are usually millimetres to centimetres in thickness and are partially sealed by minerals of hydrothermal alteration such as calcite and silica. These conditions may be caused by the production processes themselves or natural phenomena prior to the drilling of the well.

The main purpose of an acidification treatment is to dissolve these minerals, restore the permeability of the microfractures and to remove the deposits of scales inside the pipeline.

Over the last twelve years, several wells in four of the geothermal fields have been chemically stimulated: Berlin, Ahuachapán, Chinameca and San Vicente. Below is a summary of the chemical stimulation performed in El Salvador from 2000 to 2011.

FIGURE 1: a) Chemical injection through well head, b) Chemical injection with a drill rig and c) Chemical injection with a coil tubing.

3. FIELD DESCRIPTION

3.1 Berlin Geothermal Field

The Berlin geothermal field is located at the northern flank of the volcano Tecapa Berlin in El Salvador (Figure 2). The field has production wells located at elevations of 647-1100 masl. The average production is from 4 to 8 MWe, with a steam fraction of 25-28%, having a total production of 104 MWe. The production area, with high permeability and high temperature, is located at -900 and -1000 masl, with an average temperature of 260-300°C. Fourteen injection wells are located in an area of lower permeability and three of them were designed to work with injection pumps.

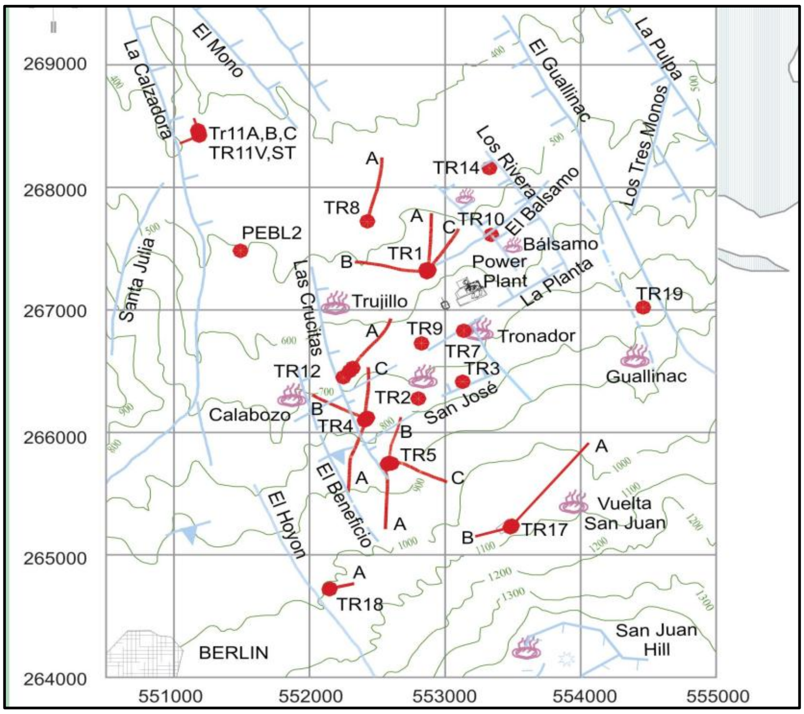

FIGURE 2: Berlín Geothermal Field

In 2000, the power plant encountered some difficulties in generating electricity at full capacity due to problems with reinjection. Commonly, these wells have low intrinsic permeability, due to low permeability fractures found during drilling and are usually sealed with secondary minerals such as quartz, calcite and epidote.

Several efforts were implemented by the company using mechanical cleaning and chemical stimulations (Barrios et al., 2007). These works were executed using coil tubing (Figure 1c) and drilling rig. And since 2003, chemical cleanings has been conducted through the wellhead mainly to minimize costs. In 2000-2011, nearly 85% of the existing production and injection wells in Berlin, with damage formation have been restored under mechanical and chemical cleaning.

This technique currently used, has allowed increasing over the past twelve years, about 900 kg/s in the injection capacity and close to 70 MWe in generation output. The procedure of stimulation has improved well injection considerably; however, the injected geothermal fluid always contains high content of dissolved solids and silica, thus, this technique is now considered as part of the normal maintenance program.

Due to an urgent need to maintain injection capacity in 2002-2003, both mechanical cleanout and acidizing jobs were performed on three injection wells with negative skin at the Berlin Geothermal Field. This combination resulted in injectivity gains of 60% in well TR-10 and 50% in well TR-7. Well TR-1B recovered only 30% of its injection capacity using only a high pressure acid job, which apparently cleaned only some parts of the micro-fractured walls and performed some acid hydro-fracturing. With originally negative skin factors, these three wells were not initially considered strong candidates for any acid stimulation. Chemical stimulation was apparently effective in cleaning parts of the walls inside the micro-fractures as well as the wellbore and the bottom part of the hole. The acid jobs apparently did not precipitate any insoluble reaction minerals.

Two variations of fluid treatment involving a pre-flush of 10-15% HCl and a main-flush using a mud acid formulation 10% HCl-5% HF and a 6%-7% and 8% sandstone acid formulation were provided by service companies. Both fluid treatments gave excellent results by dissolve silica scale and formation cuttings.

Enhancing permeability as well as gaining injection capacity through mechanical cleaning and chemical stimulation has been proved to be viable in restoring the injectivity of the low permeability injection wells. However, other injection system improvements in the Total Injection Program (RTB) have been undertaken so that the power plant consistently could operate at its full output and the need for work- overs has been reduced. Besides, several filter systems have been installed in a couple of wells (TR-14 and TR-14A), so the period of chemical cleaning could be reduced from every two years to every five years.

3.2 Ahuachapán Geothermal Field

The geothermal field of Ahuachapán-Chipilapa is located at the northern slopes of the Laguna Verde – Las Ninfas Volcanic Complex (Figure 3). In Ahuachapán, the production zone of the geothermal field is associated mainly with highly fractured volcanic rocks, where the active faults NW-SE, NS, NE-SV and EW are responsible for the permeability. The reservoir rocks show high injectivity index values, productivity and transmissibility, since permeability is completely secondary to geological faults in a lithological area called Unit IV, formed by andesites and breccias.

The average power generation per well is 5 MW, and 85 MWe are currently produced from 95 MWe of installed capacity. The wells are located at an altitude of 600-1050 meters above sea level with the production area to +300 m above sea level, with a fraction of steam ranging from 15% to 90% and the reservoir temperature between 210 and 240°C.

From 2000 to 2004, three wells were chemically stimulated in order to remove the damage from drilling mud that entered the formation during drilling, and to dissolve the calcite deposited, within the

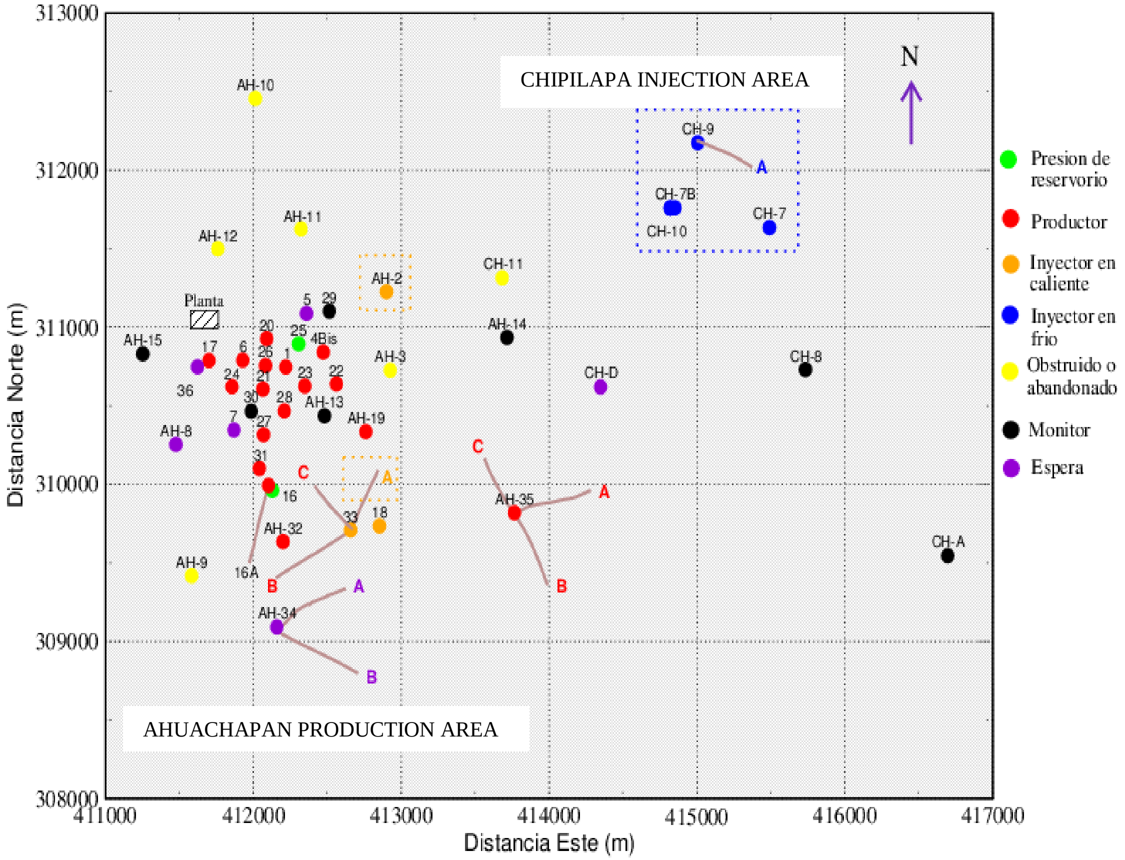

FIGURE 3: Ahuachapán-Chipilapa Geothermal Field

formation and production casing. For well AH-35B, a coil-tubing was used and for wells AH-33B and AH-35A a rig to clean more than three permeable zones. Wells with calcite scaling potential are located to the SE and SW of the power production area.

In 2005, wells AH-34A and AH-32st were cleaned through the well head in order to dissolve drilling mud and calcite in the formation. Only well AH-32st has been connected to the power plant and well AH-34A is waiting for the surface installations, which will be connected in the near future.

In 2007, wells AH-35C and AH-33C wells were drilled and chemically stimulated immediately after drilling, with remarkable results. In 2009, the first reinjection well, CH-10, was cleaned through the well head to remove the damage caused by amorphous silica scaling, contained in the geothermal brine. Its cleaning lowered the pumping pressure of the injection system from 9 bars to 6 bars. Two years later (Jan, 2011), well CH-9 was also acidized to lower the pumping pressure on the injection system (RTA) (Figure 4).

Even if chemical stimulation works were undertaken in the Chipilapa field, problems with increased well head pressures and pumping pressures are still occurring. This is mainly due to the fact that the brine continually carries great amount of TDS and that the fluid contains high silica scaling potential. Therefore, the installation of filters close to the injection well heads, was carried out to reduce the number of acidizing works, from every two years to every five years.

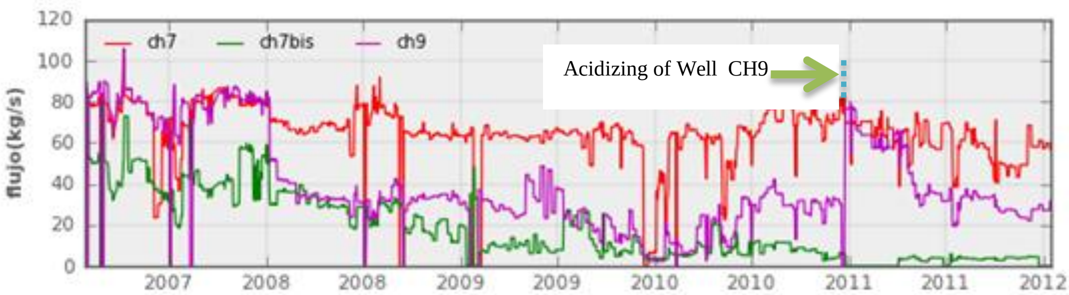

FIGURE 4: Injection history in Ahuachapán-Chipilapa geothermal Field

3.3 Chinameca Geothermal Field

This geothermal field is located at the slopes of El Limbo and Pacaya volcanoes (Figure 5). It is in the drilling exploration stage and six wells have been drilled to date. The first two wells, CHI-1 and CHI-2, were drilled in the late 70's while wells CHI-3, CHI-3A and CHI-3B, were drilled between 2007-2008 mainly for production purposes and recent results of well CHI-4A, north of pad CHI-3, showed that it can be an injection well.

Rock permeability from the reservoir is linked to a fractured lithologic formation associated to andesitic-dacitic lavas. The reservoir is found at an altitude between 0 to -200 m above sea level and the average temperature is 235°C. Since the reservoir formation has low to medium fracturing, well CHI-3 was chemically cleaned at the end of drilling stage. The purpose was to eliminate the damage or skin caused by the entry of mud and cutting into the formation. The results showed a moderate increase in the injectivity index from 1.3 l/s-bar to 1.50 l/s-bar. Wells CHI-3 3A, CHI-33B and CHI-4A were not acidized because the thermal recovery was needed quickly to be able to discharge them and determine their power potential.

3.4 San Vicente Geothermal Field

This field is located at the northern slopes of the San Vicente Volcano (Figure 6). As in Chinameca, it is in the exploration phase with four wells drilled from 2005 to 2007 (SV-1A, SV-2A y SV-3) and a pre-existing well that was drilled back in the 70´s (SV-1). The wells SV-1 and SV-1A present high reservoir temperature (240°C) but low permeability, with calcite scaling potential. As for wells SV-2A and SV-3A, they showed low temperature (190°C) and high permeability.

Due to the low permeability of wells SV-1 and SV-1A, they were chemically stimulated to dissolve drilling mud, cuttings and calcite mineral. Prior to the acidizing work, SV-1A was submitted to a hydraulic fracturing to increase its injectivity. The application of both techniques allowed improvements on the injectivity index and wellhead pressure.

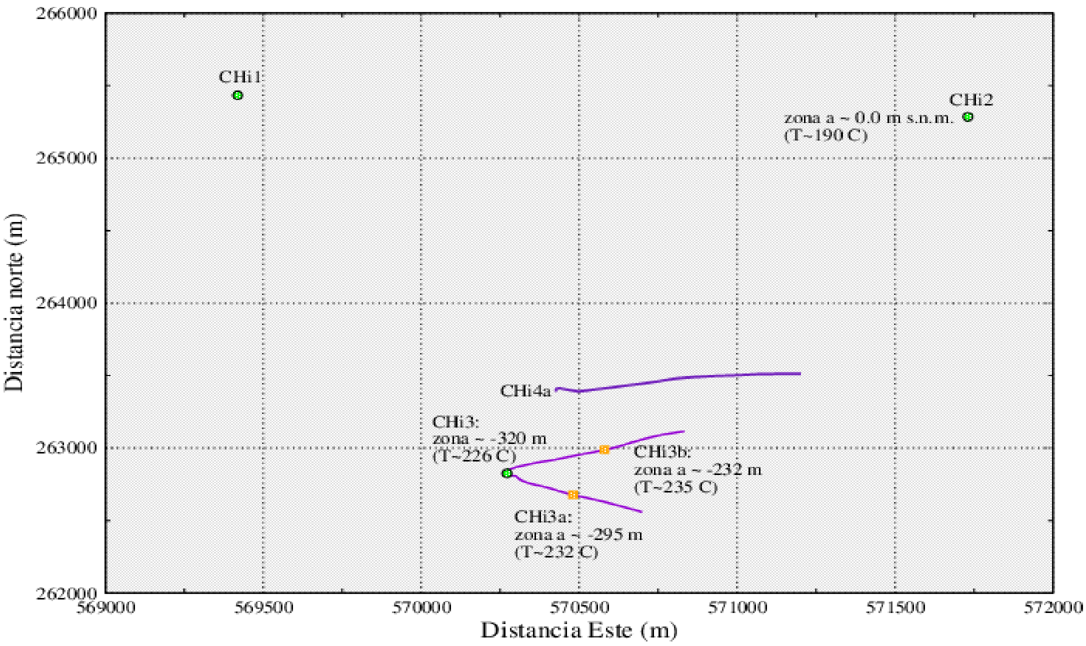

FIGURE 5: Chinameca Geothermal Field

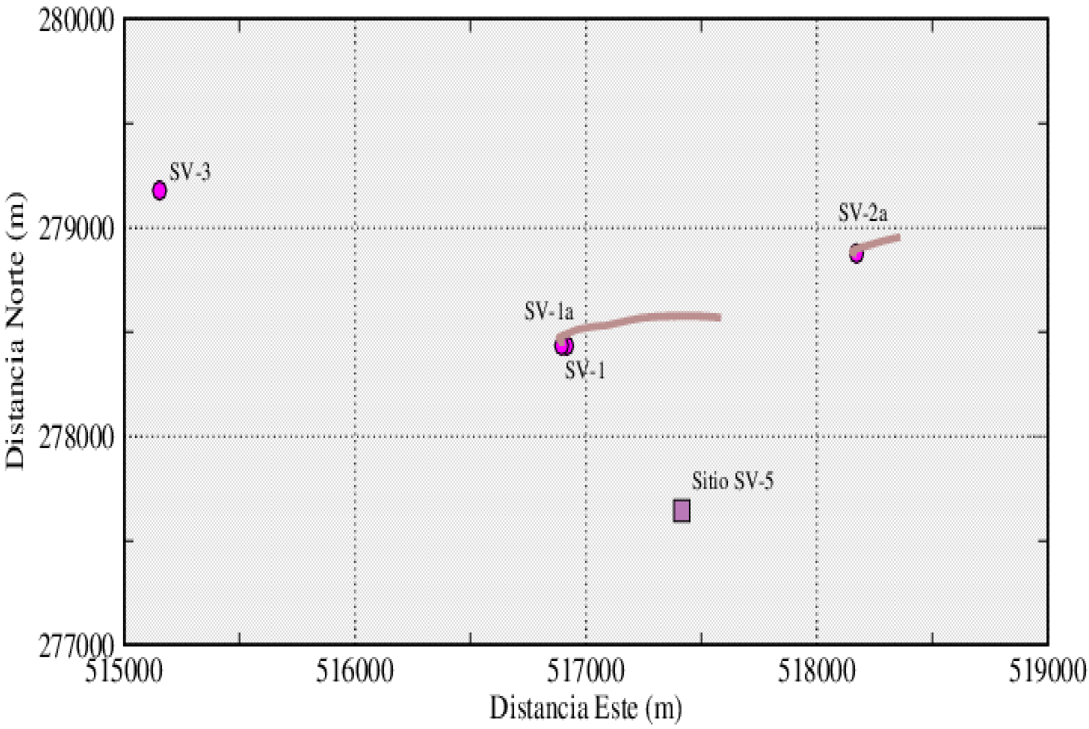

FIGURE 6: San Vicente Geothermal Field

4. WELL TEST ANALYSIS

Formation damage usually termed as skin (s) is created when viscous mud during drilling enters the wellbore, producing a seal that retards fluid flow. The skin effect is usually observed as an area of lower permeability adjacent to the wellbore that adds hydraulic resistance to the flow of the reservoir fluid (Malate et al., 1998). Pressure transient tests in the form of injectivity and pressure falloff are performed in the wells before and after acid stimulation in order to assess the improvement in the wellbore in terms of injectivity index and other reservoir parameters such as permeability and skin. Mechanical pressure gauges (Kuster) as well as digital Calidus and Kuster K-10 PTS logging tools are used before and after mechanical cleaning and acidizing.

The pre and post-acid pressure fall-off data for the wells are analysed to determine the skin effect and other wellbore/reservoir parameters to assess improvement from the stimulation. Normally, a positive skin (S) denotes formation damage of the well after drilling while a negative skin suggests a stimulated well (Malate et al., 1998).

Computer-aided approach can be applied to pressure transient analysis, by constructing a type curve matching and pressure derivative calculation (Figures 7 and 8). The data can be tested under various combinations of well/reservoir models and boundary conditions with Saphir software (Kappa Engineering, 2000).

For the Berlin reservoir temperatures of 260-300°C and pressures of 120-140 bars and an average porosity of 10% was assumed in the model for the three wells. A homogeneous reservoir model with wellbore storage and skin and an infinite boundary condition was applied in the analysis.

At very early times, during the pure wellbore storage regime, the reservoir response is negligible, but on a log-log scale, the pressure and the derivative curves follow a straight line of unit slope, the pressure derivative passes through a "hump" until the wellbore effect is negligible and the observed pressures are due to the reservoir response where radial flow governs. The skin controls the amplitude of the pressure (derivative) response (Malate et al., 1998).

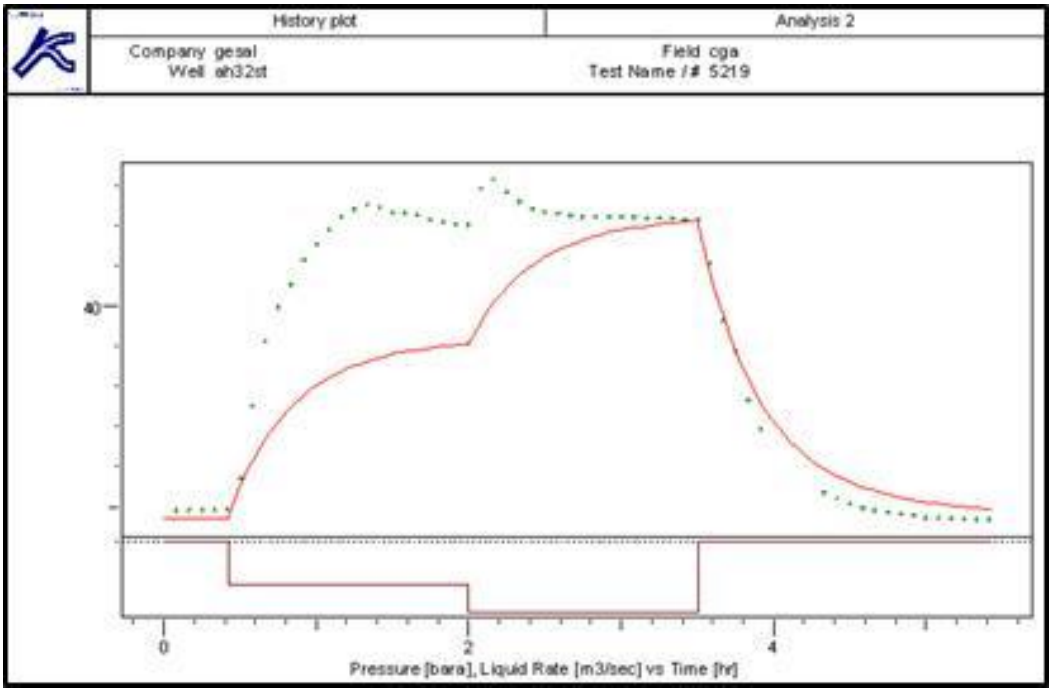

FIGURE 7: Injection m3/s-Pressure (bara) vs. time (hr) analysis of well AH32st.
Saphir, version 3.0018 (Kappa Engineering, 2000)

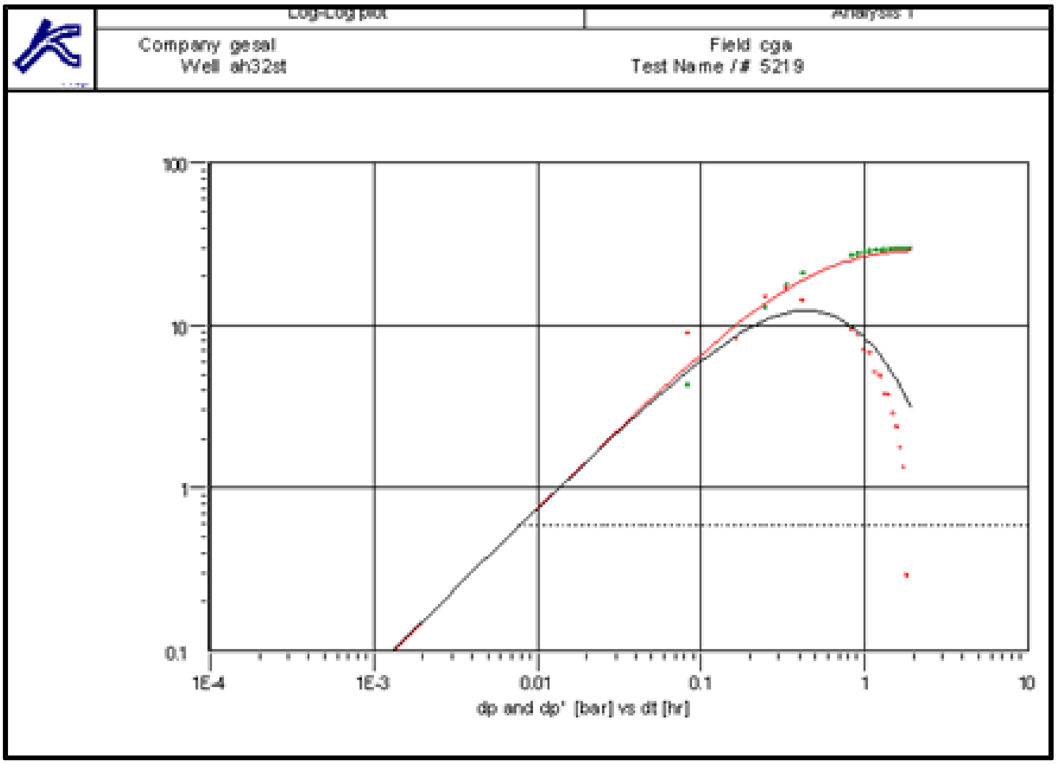

FIGURE 8: Log-Log plot Analysis of skin in well AH32st.
Saphir, version 3.0018 (Kappa Engineering, 2000)

5. DESIGN OF THE ACID TREATMENT FOR GEOTHERMAL WELLS WITH FORMATION DAMAGE

The criteria used to analyse and evaluate whether or not a well should be chemically cleaned are the following:

1. Type of rock formation, hydrothermal alteration in the mineralogy.
2. Number and thickness of permeable zones. It is crucial to know the well´s injectivity index.
3. Extent of skin damage caused by drilling, calcite and silica scaling, etc. The more positive is the skin, the better chances to have a major improvement on the well´s permeability, hence greater production and injection capacity. Therefore, transient tests are needed.
4. Level of steam fraction. The higher the steam fraction (over 20%), the more profit can be obtained from the production well.

The parameters taken to design an acid treatment are: 1) Type of acid for the main treatment, 2) Strength of such acid for the main treatment, 3) Volume of the main treatment, 4) Pre-flush and Main-flush and Post-flush composition and volume, 5) Additive selection: corrosion inhibitors, corrosion inhibitor intensifiers, clay controllers, fine and iron controllers, 6) Operational parameters: injection rate, injection pressure, etc. and 7) Results of acid dissolution tests.

6. ACID MIXTURES USED IN GEOTHERMAL WELLS

1. For wells with mud, cuttings and silica scale damage with low content of calcite (<10%), the pre-flush treatment is usually Hydrochloric Acid HCl 10-15%. This applies if the formation does not have hydrated low temperature zeolites such as chabasite or stilbite.

2. When the main damage is due to mud, cuttings or silica scale, the main acid treatment used to eliminate the skin can be of two types:

   - Highly concentrated acid mixture (6-8%) and delayed RPHF (Retarded Phosphonic Hydrofluoric) created from Phosphonic acid, hydrochloric and hydrofluoric acid. This mixture has been used in injection wells in Berlin and Chipilapa field to dissolve silica minerals and and/or debris of formation.
   - Mud Acid Mixture (**HCl:HF**) consists of hydrochloric acid and hydrofluoric acid. This mixture is used in most of the production wells of Berlin Field, with low content of calcite, high steam fraction, skin damage or skin values of 20. Given the well´s characteristics, the results have been outstanding.

3. Nonetheless, if calcite is found both on the formation as in scales inside the pipeline (casing and liner), the pre-flush is usually a high volume of HCl 15% and the main-flush of choice is usually RPHF at low concentrations (5%), as this is the only acid capable of dissolving silica and other remaining mud without causing insoluble precipitates of CaF2 Fluorite, when in contact with calcite (Malate et al., 1998). The following formulations have been used: a) three acids such as HCl, Phosponic acid and HF or b) Clay Acid (HCl, HF and Boric Acid). These two mixtures have been successfully used in El Salvador in wells with high potential of calcite scaling providing excellent results in Ahuachapán and Berlin geothermal Fields.

4. When calcite is present in the formation and casing, coexisting with low temperature zeolites, the acid mixture mostly used has been Acetic Acid at 10% and HCl 15% with Phosphonic acid such as in well SV-1.

In order to effectively apply the stimulation technique, Lageo has made contact with three international companies with experience in this type of operations over the world. Some of them have experiences more than 50 years and some are just starting. LaGeo has benefited from the fact that these companies' experts has transferred their knowledge, monitored and provided consulting and also on how to keep improving the mixtures to make the acid treatments more effective.

Typically volume ratios of acid mixtures used are as follows:

1. Wells with high contents of silica and damage caused by mud and cuttings:
   Pre-fluish: 50 gal / ft thick permeable zone
   Main Flush: 75 gal / ft thick permeable zone

2. Wells with potential of calcite and mud damage:
   Pre-flush: 100-120 gal / ft thick permeable zone
   Main Flush: 75 gal / ft of thick permeable zone

The strength (effectiveness) of the acids used is as follows:

1. For calcite scaling (alone or in combination with hydrated zeolites) in HCl 15% with Phosphonic acid or Acetic Acid 10%.
2. For wells with silica scaling: RPHF 6-8%
3. For cases with the presence of calcite formation and/or damage from drilling mud, or calcite scaling in the formation of the well: RPHF 5% with a large volume of HCl 15% as a pre-flush.
   Large volumes of HCl 10-15% as a pre-flush are pumped to address calcite scaling on the Ahuachapán, Berlin and San Vicente geothermal fields.
4. To clean drilling mud and / or cuttings in the formation with low content of calcite: HCl:HF (10:5) or Mud Acid as the main flush.

Following the injection of pre-flush and main flush, diluted acid mixtures are pumped after the injected acid. All of these treatments include water injection as well as cooling and displacement procedures. This is done to separate the reservoir fluids from treatment fluids and prevent the acid from being depleted before entering the formation. Cooling is typically 4-5 times the total volume of the inner casing. The intention is also to cool the pipe to reduce the concentrations and volumes of corrosion inhibitors.

Acid mixtures include the following additives: a) Corrosion inhibitor, b) Corrosion Intensifier, c) Iron chelating agents, d) Iron Stabilizer agents, e) Clay Controller, Fine Controllers and f) Surfactants. Corrosion inhibitors and corrosion inhibitor intensifiers are designed to last for 12 hours. These are applied to protect the production pipes and the slotted liner while injecting the mixture. Iron chelating agents are added to avoid formation of ferric chloride compounds, iron hydroxides that can precipitate in the formation after the acid is spent.

7. CHEMICAL STIMULATION RESULTS 2000-2011

From 2000 to 2004, there was an improvement of 27.1 MWe and 369 kg/s of injection capacity (Figure 9). During this period, ½ Million US dollars were invested on a flexible pipeline for chemical stimulation. There was also an investment/expenditure of close to a Million US dollars on chemical stimulation performed with the drilling rig. For that reason, in 2003 chemical stimulations were performed with the injection of the mixture through the wellhead, reducing costs significantly.

Chemical stimulation through well head usually called chemical cleaning, makes it possible to clean only the first permeable zone or production zone which is usually below the production casing. The amount invested or spent per wellhead in the geothermal fields in El Salvador was in the range of $ 150-$315 thousand US dollars. This mostly depended on the volume of total mixture used, providing only a 40% improvement with respect to the attained improvement with the rig, which can be done one zone at a time (up to four).

In 2005, the accumulative improvement in injection capacity was 272 kg/s and 13.89 MWe of production. In 2006, the improvement in injection capacity was 50.0 kg/s and 13.7 MWe of production. The accumulative improvement in the injection capacity until 2011 was 900 kg/s and the overall improvement in production from 2000-2011 was 72 MWe.

Period	Wells	Results
2000-2003	*Production*:TR-5C, TR-4B, AH-35 A, AH-35B(3) *Injection:* TR-14(2), TR-1C, TR-11ST, TR-1 A,TR-12 A, TR-10, TR-7,	14 Chemical stimulation increased the steam to produce 30 MWe and more than 200 l/s of injection capacity.
2004-2007	*Production*: TR-4C, TR-5 A, AH-34 A, AH-32ST, AH-35C, TR-5B, SV-1 y SV-1A. *Injection*: TR-1C, TR-1 A, TR-1B, TR-7, TR-11 A(5), TR-7, TR-8 A, TR-14, TR-14 A,	20 Chemical stimulation increased the steam to produce 20 MWe and more than 400 l/s of injection capacity.
2008-2011	*Production*: TR-17 A, TR-17B, TR-18, CHI-3, AH-35B, TR-9, TR-4, TR-5C. *Injection:* TR-11 A(2), CH-10, TR-14, TR-14 A, CH-9 A, TR-8,	15 Chemical stimulation increased the steam to produce 22 MWe and more than 300 l/s of injection capacity.
Total: 49 Chemical stimulations performed in 12 years, some of them through Well Head and some with coil tubing and drill rig.		

FIGURE 9: Chemical stimulation results (years 2000-2011)

8. ENVIRONMENTAL CONSIDERATIONS

The 2000-2011 stimulation programs were performed to abide with all Health, Industrial Safety, Security and Environmental standards. With this in mind, careful preventive measurements were taken in all processes during the acid stimulation. The supervision started during the mobilization of the rig, transportation of injection equipment from the contractors and chemicals, followed by pre-stimulation tests, storage/handling of liquid/solid chemicals, and the mixing and injection of chemicals. Discharge of production wells did not cause any damage to the environment. There were no incidents involving company staff and third parties. Minor adverse impacts included temporary vapor emissions during mixing of acids, and malodorous smell during discharge, but did not cause any harm or disturbance.

9. CONCLUSIONS

1. Given the general conditions of the geothermal fields of production, in terms of temperature, mineralogy and managing of geothermal energy reserves, acid stimulation is an effective technique of maintenance costs of energy production;
2. For producing wells with problems of calcite, the best results in terms of increasing production (compared to initial production) were obtained by using HCl RPHF 5% pre-flush and main- flush, compared with treatments with HCl:HF (Mud Acid 10:5) with HCl and pre flush post flush and treatments with HCl alone or in acetic acid alone;
3. The best results for reinjection wells have been attained with RPHF mixture at high concentrations (7-8%);
4. For producing wells as the ones in Berlin, with little calcite and extensive damage by the entry of drilling muds and cuttings, the best results have been achieved when applying the mixture HCl:HF (Mud Acid 10:5);
5. For wells with problems of calcite and the presence of hydrated zeolites, as in the case of well SV-1, Acetic acid 10 % has been the most effective mixture;
6. Injecting the mixtures with the drilling rig presents close to 200% improvement as they are able to clean more than one zone at a time (approx. 2 to 4);
7. The injection of chemical mixtures with wellhead offers an improvement of 40% as only one area can be cleaned, but offers a higher profitability, because it employs only half or one third of what would be used when cleaning with rig or flexible pipeline (coil tubing);
8. The maximum amount invested in a chemical cleaning with wellhead has been less than half a million US dollars, while the maximum amount invested in a chemical stimulation with rig in a production well has been more than 1.3 million US dollars.

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