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CALCIUM CARBONATE SCALING CONTROL IN GEOTHERMAL WELL PV8 IN SAO MIGUEL, AZORES, COMBINING CHEMICAL INHIBITION AND MECHANICAL REAMING

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ABSTRACT

The formation of calcium carbonate (calcite) is a major scaling problem that occurs in geothermal fields around the world, leading to a quick decline in well output and impacts on power plant production. There are several methods that can be used for the prevention of calcite scaling and the rehabilitation of affected production wells.

In Ribeira Grande geothermal field, in addition to prevention by injection of chemicals to inhibit scaling, reaming is used in well PV8. Currently at Ribeira Grande field, the main method used in reaming involves quenching and cooling the well prior to the operation and this affects well performance. This study pursues the development of a method that involves reaming the calcite without cooling the well by allowing it to flow. The main focus of this report is the design of equipment (kind of a Stripper) and work procedures to enable mechanical cleaning of calcium carbonate deposits inside a well, discharging the deposits to a silencer.

1. INTRODUCTION

Ribeira Grande geothermal field, located on the Azorean island of Sao Miguel, is the only exploited high enthalpy Portuguese geothermal field, with a total installed capacity of 23 MWe in two plants. In progress is a study for the construction of a new 3 MWe power plant at Terceira, another island of the Azores Archipelago.

The formation of calcite scaling inside wellbores has occurred in Ribeira Grande geothermal field since the start of exploitation. According to the temperature data taken inside the wellbores, upon boiling at a flash point temperature (~240°C), the fluid become super saturated in relation to calcite (Calcite Saturation Index, SI>0), increasing the potential for deposition and the obstruction of wells. As a result, a chemical calcite inhibitor was injected through the installation by way of a mechanical system in each well for down-hole injection; this system includes a chemical metering pump, lubricator, valves, stainless steel capillary tubing, tanks and facilities to mix a diluted inhibitor product.

The application of the calcite inhibitor is a successful method adopted to prevent the formation of scaling in the wells. It has demonstrated very good results, with regard to the maintenance of the internal wellbore and, therefore, power production. Despite the success of this method in well PV8, which supplies the Pico Vermelho power plant, a small rate of calcite scale deposition was nevertheless observed. The calcite deposits in well PV8 are usually mechanically cleaned using one small drill rig, Ingersoll Rand RD-20, by reaming out the deposit with a tricone bit (with tungsten carbide teeth for soft formations), while always keeping the well quenched with the injection of fresh water. This report will describe the development of a wellhead assemblage and procedure designed to ream the calcite deposits without cooling the well. Instead, the well is kept hot and flowing to a separator pipe line, where the calcite cuttings can be gathered.

2. RIBEIRA GRANDE GEOTHERMAL FIELD

2.1 Characterization of the field and well PV8

Ribeira Grande Geothermal field, located on the island of Sao Miguel, one of the nine islands that comprises the Portuguese Archipelago of Azores, has been explored since 1990 by the local public company EDA RENOVAVEIS S.A., owned by EDA, S.A., the Power Utility of the region. Two binary power plants were installed in this field, developed with ORMAT technology. The Ribeira Grande Power Plant is located in the southern upper side of the field, and the Pico Vermelho Power Plant is located on the northern side of the field near Ribeira Grande city, the second biggest city on the island (Figure 1). The combined installed capacity of this field is 23 MWe, 13 MWe in the Ribeira Grande power plant, and 10 MWe in the Pico Vermelho power plant. All the electricity produced by these power plants is for the island grid. In 2013, the total generation was over 174 GWh, corresponding to 43% of the total electric energy consumption in Sao Miguel and 23% for the Azores region.

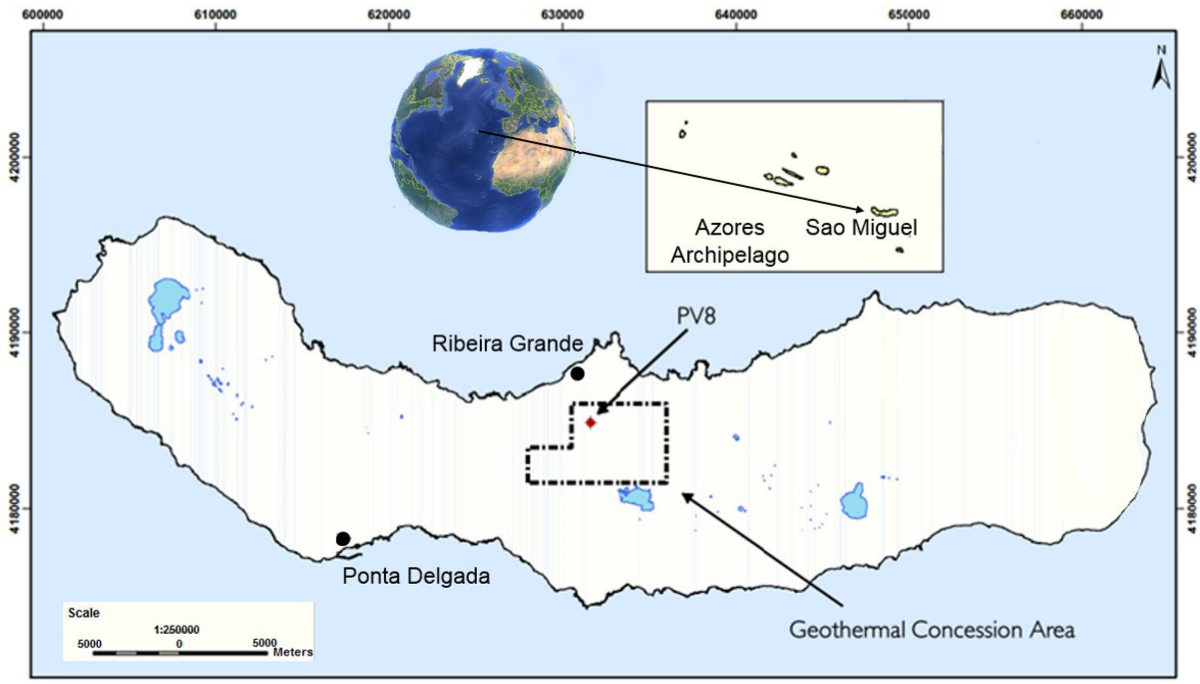

FIGURE 1: Location map of the Ribeira Grande geothermal field on Sao Miguel Island, Azores (adapted from GeothermEx. Inc., 2006)

All the production wells in the Ribeira Grande geothermal field have a tendency towards deposition of calcium carbonate $CaCO_3$ (calcite) scaling. For that reason, each well requires a chemical scale inhibition system that blocks the formation and progress of this kind of scaling in the wells. The chemical inhibitor concentration is adjusted according to the chemical properties of the geothermal fluid produced by each respective well.

Well PV8 is a vertical well with a large diameter production casing that is supplying the Pico Vermelho power plant. It is one of the three most powerful wells in the field, delivering a normal flow rate of 26 kg/s, which represents about 3.5 MWe in the production of this power plant. Well PV8 has a similar profile to recent wells drilled after 2005 in the geothermal field, completed according to the large diameter well profile: a 13-3/8" production casing, API K55, 68 lb/ft and a 9-5/8" slotted liner, API K55, 40 lb/ft, with shoe located at a total depth of 971.6 m. The wellhead has a 12" ANSI 900 master valve connected to a casing head, which is welded to the top of the 13-3/8" production casing. The casing head has two side outlets connected to 3"ANSI 900 gate valves, one of which is linked to the wellhead gauge and the other to the choke line but, when needed, as a kill line for the injection of cold water during well interventions. The 12" spool with two side outlets is connected to the top of the master valve and to the bottom side of the Tee that supports the 12" ANSI 900 lateral valve which is connected to the power plant pipe line. Above the Tee, on top of the wellhead is assembled a 3" ANSI 900 gate valve, which allows the installation of the lubricator used in the calcite inhibition system. Figure 2 presents the technical profile of the well, including casings and wellhead components.

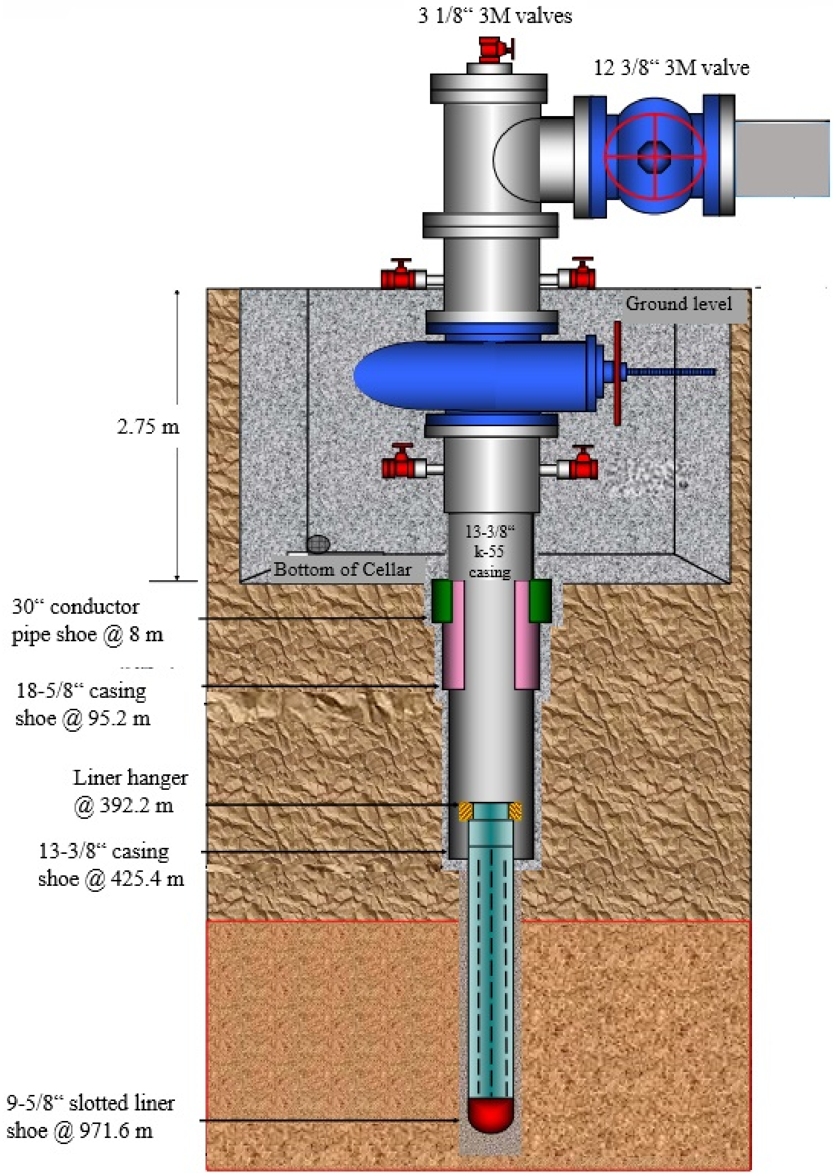

FIGURE 2: Profile of well PV8 (adapted from GeothermEx. Inc, 2006)

After the completion of well PV8, as is common in all wells of this field, extensive well tests were conducted that include an injectivity test (in the completion phase), flow testing (after the drill rig leaves the site), and several pressure/temperature surveys, which are very important in the evaluation of the formation pressure and temperature.

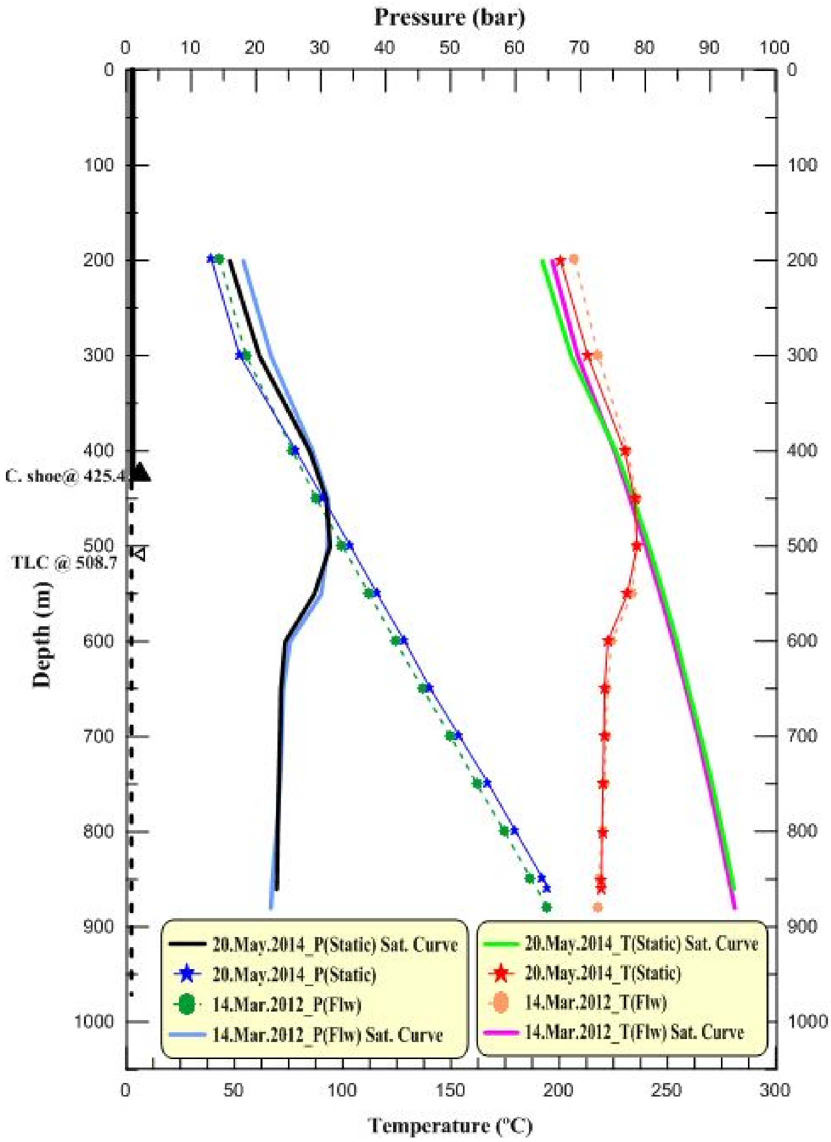

FIGURE 3: Temperature, pressure and saturated curves for well PV8, measured in static and flowing surveys

Figure 3 shows the temperature and pressure downhole logs made in static and dynamic (flowing) surveys inside well PV8, using Kuster KTG/KTP mechanical tools. Based on the temperature and pressure curves, represented by the lines with symbols in Figure 3, the respective saturation temperature and pressure curves according to steam tables are shown by solid lines. In the dynamic survey, the control valve of the well was 10% open, to reduce the flow rate from the well to the power plant.

This was done to maintain the integrity of the tools, allowing for running in and out inside the well against the flow. The dynamic survey was performed from the bottom of the well up to a depth of 300 m. From 300 m to the surface, the logging was made in static conditions, with the control valve totally closed. Observing the flow curve for pressure, one can see the change in the gradient above 300 m after stopping the flow. If electronic tools were used to do the surveys (i.e. a Kuster K10G memory tool) instead of mechanical tools, the real pressure variation above 300 m could be seen, in this case, probably a curve instead of a straight line between the two measurement points. As described in the legends for Figure 3, the left side plots are related with pressures and the right side plots with temperatures. One can see on the depth axis a schematic drawing of the well casing program, with the 13-3/8" casing shoe located at 425.4 m. Total loss in circulation during drilling occurred at 508.7 m, and the total depth of the well with the slotted liner shoe is 971.6 m.

Observing the static plot using the pressure gradient from the bottom to the depth of 300 m, one can infer the water level inside well PV8, probably at a depth of 100 m. Analysing the plots, the main thing to be observed is the maximum temperatures located at 450-550 m depth, followed by a small decrease (temperature reversal) below this depth to the bottom of the well. In fact, this depth matches the main circulation loss found during the drilling of the well and corresponds to the hot permeable zone, with temperatures of 231-237°C (static temperature log). Regarding the temperature profiles, below a depth of 600 m, additional permeable zones could exist, but with reduced permeability when compared to the upper zone. The intersection of the saturation curves with the measured temperature and pressure logs indicates that the boiling point is located inside the slotted liner at around 460 m.

2.2 Calcite scaling in well PV8

2.2.1 Calcite scaling formation

Calcite scaling is one of the three known naturally occurring polymorphs of calcium carbonate (C_aCO_3) minerals, besides aragonite and vaterite, and is one of the most common carbonate deposits that occur in geothermal wells. Calcite scale is white coloured and can easily be distinguished from silica (another type of common scale in geothermal sites) by putting a drop of hydrochloric acid on a piece of scaling; if gas bubbles are formed, it is calcite (Thorhallsson, 2006). Usually calcite is extensively spread in the altered rocks of geothermal systems, often in the amount of 1% by volume, but it can be much more abundant at some levels in specific parts of the sites. Normally, the high abundance of calcite deposits results from large amounts of boiling water rising to upper levels (Arnórsson 1989). According to several studies made in geothermal sites, calcite scaling is quite common in wells drilled in reservoirs with temperatures in the range of 140-280°C. The Ribeira Grande geothermal field falls into this category, with an estimated formation temperature in the range of 235-245°C. In this type of reservoir, geothermal fluids are usually calcite-saturated and become calcite supersaturated inside the wells, after boiling and flashing to lower temperatures reduces the CO_2 in the water phase due to its transfer to the steam phase. Therefore, the release of CO_2 by degassing increases the pH of the water phase, and increases the concentration of carbonate. .It is mostly this increase in concentrations that produces the change from saturated water to super saturated water with respect to calcite, resulting in precipitation (Arnórsson, 1989).

The following chemical reaction shows how the carbonates contribute to calcite scales:

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

Solubility product based on: (1)

$$CaCO_3 \Leftrightarrow Ca^{+2} + CO_3^{-2}, \text{ I.e}$$
$$Ksp = [Ca^{+2}][CO_3^{-2}]$$

The calcite deposits are mainly found inside wells just above the flashing zone. The flashing depth can be moved up and down if changes in the flow rate are made (by changing wellhead pressure). In reservoirs with temperatures above 260°C, calcite scaling is not as problematic because the dissolved calcite in geothermal waters decreases with increasing temperature.

2.2.2 Calcite scaling potential of well PV8

The Saturation Index (*SI*) is used as a measure of mineral deposition in geothermal waters, defined as:

$$SI = log\frac{Q}{K} \tag{2}$$

where Q is the reaction quotient or activity product of the mineral which is being analysed in the dissolution reaction in a non-equilibrium state, and K is the equilibrium constant or solubility product. When in the mineral solution $Q = K$, the system is in equilibrium and $SI = 0$, meaning that the studied mineral is saturated in the solution; if $Q > K$, the mineral solution is super saturated and the $SI > 0$; if $Q < K$, the mineral solution is under saturated and $SI < 0$.

In order to identify the state of the fluid in well PV8, with regard to calcite scaling potential, the WATCH program was used to calculate log Q and log K, needed for the *SI* equation. This program is very helpful in analysing calcite scaling potential. The WATCH program calculates the final types of concentrations, solubility products and activity products, using the initial fluid concentrations as input (steam and water sampled at the surface), taking into consideration that the fluid boils adiabatically, starting at the reference temperature (240°C for well PV8) (Bjarnason, 2010).

Table 1 shows the liquid fluid samples, gas data analysis, and the general data taken from well PV8 on 19.11.2013, all of which was then used as input to feed the Watch program. The general data came directly from the main installed sensor readings in the pipeline and power plant (pressure, temperature, flow rate. For WATCH calculations, the enthalpy must be known and is determined by well testing or measuring the flow of both phases. The liquid and gas concentrations are obtained from chemical analyses from two laboratories. The total CO_2 value related to the liquid sample was calculated using the values of the available concentrations of HCO_3 and CO_3 from the laboratory analyses.

TABLE 1: General data and deep fluid concentrations at separator pressures (mg/kg) in well PV8

General data to input into the WATCH program												
Date	**Separator pressure**		**Meas. temp**	**Enthalpy**		**Flow rate**	**Real formation temp**			**Hypothetical formation temp**		
19.11.13	4.5 bar.a		148°C	1144 kJ/kg		31 kg/s	240°C			300°C		
Liquid sample												
pH/Temp	**CO_2**	**B**	**SiO_2**	**Na**	**K**	**Mg**	**Ca**	**F**	**Cl**	**SO_4**	**Fe**	**TDS**
9.6/18°C	167.86	4.7	555	1334	246	0.025	1.93	22	1900	205	0.08	5140
Gas sample												
			CO_2	**H_2S**	**NH_3**	**N_2**	**CH_4**	**H_2**				
			4820	24.2	47.1	39.2	0.121	0.109				

Based on the data in Table 1, the WATCH program computed several results for different product concentrations. For the present study, the calcite concentrations were computed for the given range of temperatures (300°C, 280°C, 260°C, 240°C, 220°C, 200°C, 180°C, 160°C, 140°C), considering 2 (two) reference temperatures, 240°C (real or most approximate value for the formation temperature on the site) and 300°C (the hypothetical formation temperature). The same initial sample concentrations were used; these results could be important for observing changes in the calcite scaling index, when using a higher formation temperature. The minimum temperature chosen was 140°C, which is less than that actually observed in the well.

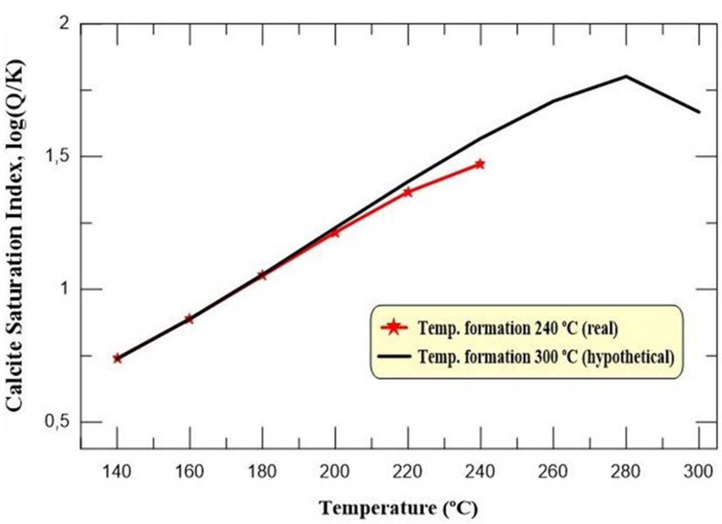

FIGURE 4: Calcite saturation index of fluid samples from well PV8

In analysing the plot in Figure 4, it is clear that the *SI* > 0 (*SI* > 0.7 for all temperatures), meaning that the fluid in well PV8 is super saturated for all the temperatures selected. Even if the reservoir had the same mineral concentrations in the water at a higher formation temperature, for example 300°C, the calcite *Saturation Index* would be higher than zero and the water would be super saturated (black curve in the graph). Figure 4 shows a decrease in the *SI* value with a decrease in temperature; consequently, there is a minor probability of scaling.

In order to maintain good control of well PV8's performance, a monitoring plan was developed, taking into consideration frequent go-devil surveys; results will be utilized to quantify the progress of scaling deposits with time and evaluate the continuous condition of the borehole.

2.2.3 Historic occurrences in well PV8

Well PV8 started to produce for the Pico Vermelho power plant in December of 2006. After less than one year in operation, the first problem related to calcite scaling deposits in the borehole occurred, forcing closing of the well and resulting in the need for a workover operation to release the stuck 1/4" diameter capillary tubing for the calcite inhibitor, and to clean deposits from the well. The first symptom of this problem was verified by the power plant operators as a gradual decrease in the flow rate (about 80 ton/h) for the same opening of the control valve (22%) and a wellhead pressure which declined from 16.2 bar to 12 bar. During the extraction operation of the inhibitor downhole equipment for inspection, it was realised that the capillary tubing was stuck in the hole due to calcite scaling and it was not possible to finish the work. About 5 months later, it was possible to release the tubing and recover the downhole equipment by injecting aqueous HCl into the well in order to dissolve the calcite and then lift the tubing out of the well using a crane. The well was quenched during this operation.

After this occurrence, a study was made to try and understand the probable causes for the problem, keeping in mind that the water on this side of the geothermal field was very similar to the rest of the field and the scale inhibitor product always worked well for wells located in the upper part of the field which supply the first power plant.

EDA Renovaveis analysed and then modified the following items in well PV8, and consequently in some other wells in the field:

- Injection of a new type of product for the inhibition of calcite, selected according to the water chemistry of the well;
- Adjusted the inhibitor concentration according to each well specifications;
- Adjusted the depth of injection of the inhibitor product in each well to below the onset of boiling; and
- Adjusted the maintenance plan for the inhibitor system, reducing the time interval for replacement of the life-limited parts, concerning pumps, tubing and downhole equipment, based on experience.

Table 2 shows the well intervention history of well PV8, significant occurrences due to calcite scaling and actions taken to recover the output. All the interventions executed inside the well, reported in the following table, were made with the well quenched.

Table 2 shows that during the first 6 years that well PV8 was able to produce, on average, about 37 % of the time it was out of service because of occurrences related to calcite scaling. The total power production was, however, not affected due to management of the other wells connected to the Pico Vermelho power plant. Since November, 2012, the date of the last workover, up to the present date, the well has been producing normally to the power plant, despite evidence of partial calcite deposition in the wellbore, according to go-devil surveys that are made every 1.5 months to monitor the diameter open to flow.

Figure 5 shows a photo taken during a fishing operation of the capillary tubing made in well PV8, where the top of the master valve can be seen after removing the annular BOP. The BOP had to be removed in order to allow the passage of the tangled inhibitor tubing out of the well. This part of the work must always be executed in as short a time as possible while continuously pumping cold water at a high rate; there is no well control device mounted above the master valve. In Figure 5, it is possible to observe the large block of calcite deposited on the outside of the tubing, indicating that for some reason the chemical inhibitor was not totally effective in the prevention of scaling.

TABLE 2: Main historic occurrences in well PV8, since the start of production of the power plant

Date	Historic Occurrences
December, 2006	Pico Vermelho power plant and well PV8 start operating.
September, 2007	Decreasing flow rate and wellhead pressure in well. Inhibitor tubing got stuck during the extraction operation.
February, 2008	Operation to release the inhibitor equipment from the wellbore. Injection of aqueous HCl from surface and lifting out with a crane.
December, 2008	Attempt to clean calcite scaling in wellbore using a Coiled Tubing unit, without success.
July, 2009	Reaming of the wellbore using the Ingersoll Rand RD-20 rig with 12-1/4" and 8-1/2" tungsten tricone bits. The reaming was successful.
December, 2010	Rupture in the inhibitor tubing during extraction to inspect, losing large amount of the capillary tubing.
January, 2012	Fishing operation to recovery the capillary tubing.
October, 2012	Rupture in the inhibitor tubing during extraction for inspection, losing about 180 m of the capillary tubing.
November, 2012	Fishing operation to recovery the capillary tubing.

Figure 6 shows a diagram of the calcite deposition in the wellbore of well PV8, according to the reaming operation executed in 2009. After fishing, the calcite reaming operation was executed from 270 m to about 540 m depth. This depth is in accordance with the analysis of the plots in Figure 3, where the flash point was estimated to be around 460 m depth. Usually the reaming operations done in the well PV8 were conducted down to about 700 m, without rotating the bit below 550 m, to optimize the operation. As the well was already killed, the remaining part of the well could be checked after the fishing and reaming operation with a go-devil.

FIGURE 5: Recovery of inhibitor tubing during the workover operation conducted in Well PV8 in December, 2014

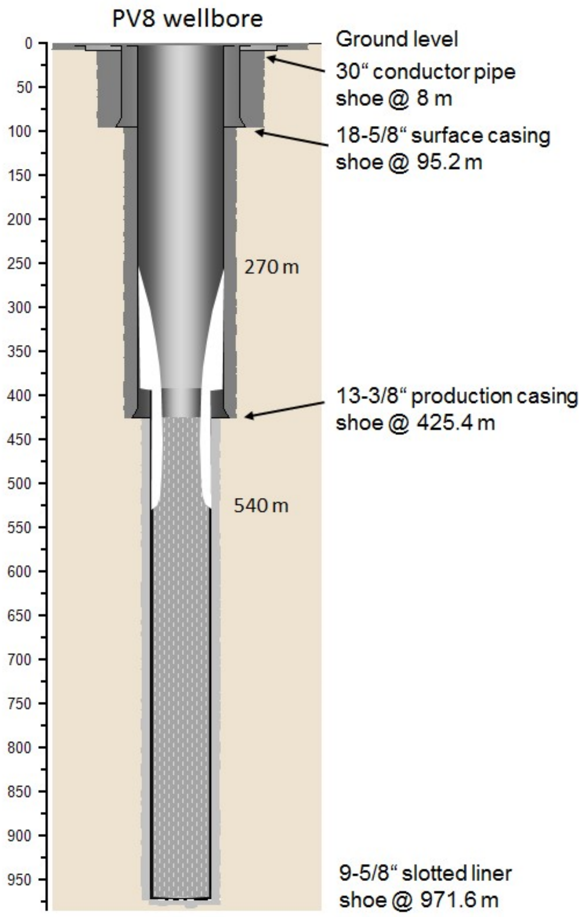

FIGURE 6: Representation of calcite deposits in Well PV8 wellbore in 2009

3. METHODS TO CONTROL CALCITE SCALING IN RIBEIRA GRANDE GEOTHERMAL FIELD

3.1 Inhibition by chemical injection in the wells

According to the chemical composition of the geothermal fluid, it has a large tendency to form calcite deposits in the boreholes. Chemical inhibition was adopted as the best choice, in order to avoid expensive workover operations related with reaming or chemical cleaning of the wells and taking them out of service. Every production well of both power plants in Ribeira Grande field has installed an inhibitor system that allows the injection of a chemical calcite inhibitor inside the wells at a calculated depth, according to the estimated flash point depth, as shown in the case of well PV8 (Figure 3).

The main inhibitor system used for the chemical injection in the wells is shown in Figure 7, and consists of the following equipment:

- Metering pump for continuous injection of a small dose of chemical inhibitor at pressures up to 59 bar;
- Lubricator set, consisting of a 5 m long 3" steel pipe with a stuffing box mounted on the top and a ram BOP (valve) connected on the bottom. The lubricator allows the installation of downhole equipment in the well under pressure;
- Downhole equipment consists of the inhibitor chamber (high pressure valve) and a sinker bar;
- Nickel-Iron-Chromium INCOLLOY Alloy 825 capillary tubing (1/4" OD), used to transport the inhibitor from the surface to the downhole equipment.

In Figure 7, the assemblage of the inhibitor system equipment in the well is shown. The pre-diluted inhibitor is transported from the automatic dilution station at the plant (Figure 8) and discharged in the inhibitor tank, which supplies the chemical inhibitor to the well. With an electrical metering pump, the flow rate can be adjusted to the quantity of calcite inhibitor desired, according to the calculated inhibitor concentration to be maintained. This injection is made continuously when the well is producing, only stopping for periodic extraction of the downhole tools for inspection, according to the preventive maintenance plan.

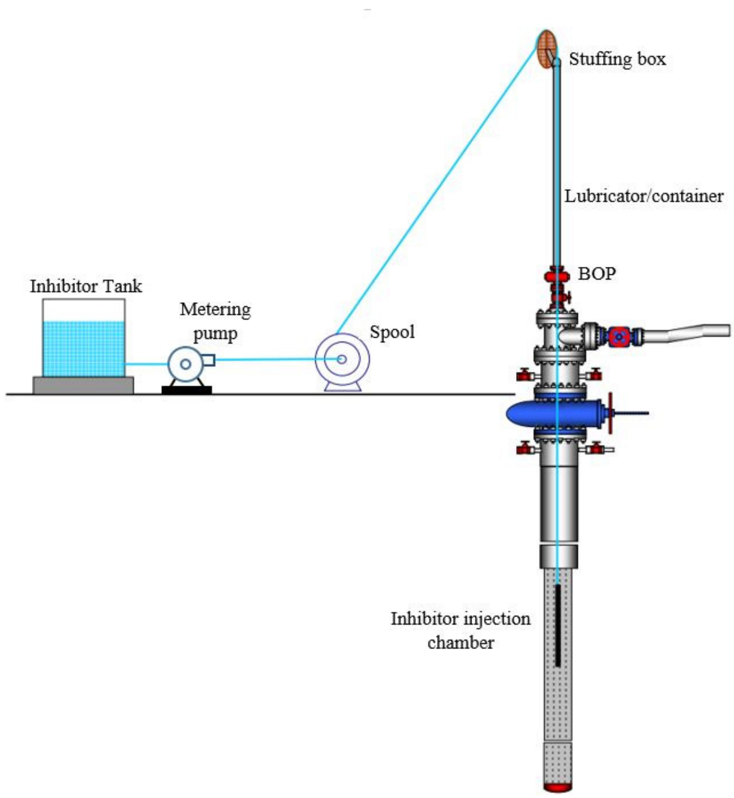

FIGURE 7: Inhibitor system installed in production wells

Considering the lower efficiency of the old chemical inhibitor, based on a carboxylic acid aqueous solution, it was decided to replace it. When the new wells started to produce, the decision was made to use the calcite chemical inhibitor *NALCO pHREEdom(R) 5200M*, a formulation of liquid polymeric dispersants and a patented inhibitor, specially designed to prevent the deposition of calcium carbonate.

FIGURE 8: Station for water decalcification and inhibitor dilution

This product is very effective in extreme conditions of temperature and pressure and in a wide range of pH environments (NALCO, 2006). Until now, the use of this new calcite inhibitor was recognized as a good solution for the prevention of calcite scaling.

In the mixing station shown in Figure 8, the calcite inhibitor is diluted with fresh water after decalcification in the proportions calculated for each well. Mostly the wells in the field receive a calcite inhibitor dosage of 3 ppm in the well fluid but, according to the particularity of well PV8, the final dosage is about 9 ppm.

3.2 Detection and control of calcite progress using calipers in the wells

The deposition of calcite scaling in the boreholes and wells can be detected with time if data from the wells is frequently gathered; normally it is possible to observe a decrease in the flow rate and wellhead pressure. When that occurs, the amount of calcite scaling inside the casing is probably already significant. Even when inhibition by chemical injection is being used, the presence of calcite scaling on the capillary tubing can be seen during its periodic extraction for inspection and for running Pressure/ Temperature surveys.

Go-devils and calipers are probably the best tools for detecting the location and for monitoring the amount of calcite scaling, through variations in the diameter open to flow.

Figure 9 shows different types of tools used in down-hole surveys for detecting calcite scaling; they are described below:

A. Go-devils of different diameters, constructed and used by EDA RENOVAVEIS for detection of calcite inside the casings by running in the well on a wireline until it stops;
B. Go-devil on a sinker-bar with interchangeable baskets of different diameters, used in Iceland;
C. Electrical caliper logging tool, with 2, 3, 4 arms or multi-fingers, used all over the world in geothermal, gas and oil industry. Such tools and cables have temperature limitations and are used when the wells are quenched;
D. Kinley Microscopic multi-finger caliper tool; this is used for sophisticated work above the pressure and temperature of the electronic caliper tools (maximum of 315°C).

EDA Renovaveis developed and uses Go-devils, as shown in Figure 9A, in a full range of diameters, from 3" - 12". This go-devil has a basket made of copper wire soldered with silver and has a copper pin in the connection between the basket and the sinker bar to work as a safety pin. The go-devil is normally run in the wellbore, starting at the maximum to the minimum diameter allowable and is lowered until is stops at the scale obstruction at their respective depths. In case the go-devil basket gets stuck inside the well, the pullback strength in the wireline should be enough to break the safety pin, permitting the recovery of the sinker bar and wireline. The copper material is favoured for ease of later fishing or milling operations. The go-devil shown in Figure 9B is also constructed from copper wires and easy to drill-out materials. Both go-devils are suspended by wireline and can be used in very high temperature wells without losing performance.

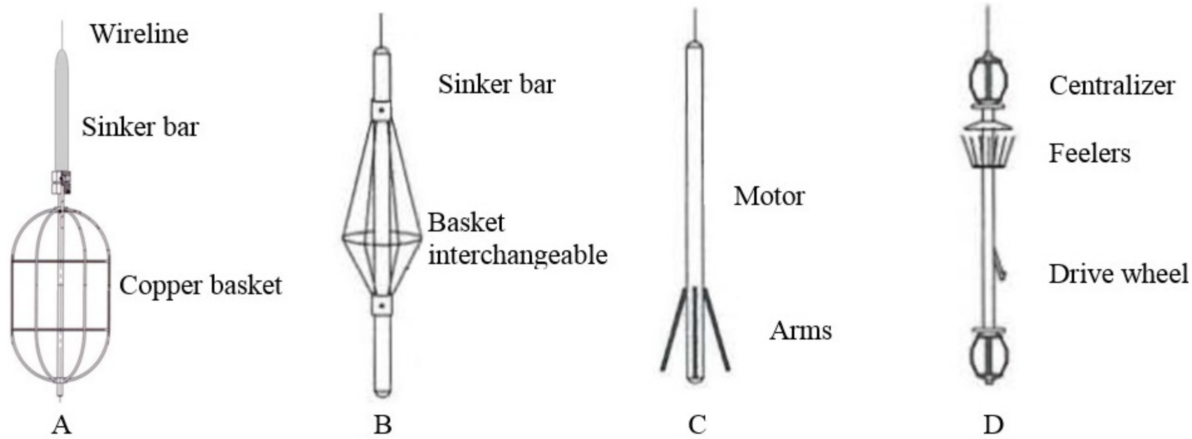

FIGURE 9: Go-devils (A and B) and caliper logging tools (C and D) used in calcite scaling surveys (modified from Molina, 1995)

The caliper logging tools shown in Figure 9C can be mechanical or electronic. These tools are equipped with mechanical arms (from 3 to 60 units) and are opened down hole with a small electric motor installed in the logging probe. The recovery data from caliper logging tools are collected continuously when connected to the surface read-out unit through an electrical cable and inspected in real time, or the data can be saved in a memory slot inside the tool and analysed after pulling out. In the surveys, the tools are run in the wells through a lubricator and begin measuring the diameter of the wellbore from the bottom to the surface, after opening up the arms. Because of the electrical parts and the cable, the maximum service temperature for these tools is about 150 - 180°C.

The Kinley Microscopic caliper shown in Figure 9D can operate in wells outside the temperature and pressure ranges of the electronic calipers, up to a maximum of 315°C. Generally, the well is logged in a single pass from the bottom to the surface, using the caliper feelers independently to record its movements in the chart inside the tool.

EDA RENOVAVEIS frequently uses go-devils, as shown in Figure 9A, for calcite scaling monitoring and fishing operations in the wells. Less frequently, accurate caliper logs related with corrosion, isolated pits or integrity of casing are made.

3.3 Wellhead pressure control to change the localization of the calcite

The depth of calcite deposition can be changed from about 50 m up or down in the borehole by varying the flash point location. The pressure at a certain depth is related to the pressure in the wellhead and is controlled by opening the control valve. If the well has available pressure and flow rate, it is possible to adjust the scaling deposition depth. Usually, the main idea is to allow the calcite to scale inside the production casing, where it is possible to ream it without damaging the slotted liner.

In the case of well PV8, it is not possible to use the wellhead pressure to move the position of calcite scaling up about 60 m to a level inside the production casing, because usually it is producing at around 16 bar WHP in order to have the flow rate required for the power plant. It is thus not practical to manage the production by increasing the WHP in order to avoid scaling inside the slotted liner.

3.4 Mechanical reaming of calcite with the well quenched using a small rig

Reaming calcite scaling consists of cleaning the scaling deposit from inside the well by using a tricone bit or a tapper milling tool, running it in the well after quenching and maintaining a constant injection of cold water. Mechanical reaming is a common operation executed in well PV8 when fishing for the inhibitor tubing trapped in the wellbore by calcite scaling. The company owns a small truck-mounted drill rig, Ingersoll Rand RD-20, with a top-drive, 50 ton of hook load capacity and has a qualified crew. The rig is very well suited for this kind of workover operation.

The reaming operation is normally executed in 2 days, but the fishing can vary from 1 to 2 weeks, depending on the amount of tubing lost and the round trips required until catching the inhibitor chamber and weight bar. In this case, it is always necessary to make a final round to the bottom to make sure that the well is open. The injection of cold water throughout the fishing and cleaning operations is prejudicial to well production considering the following aspects:

- Scale sediments fall to the bottom and cross to the formation through the slotted liner, which will make the well shallower, and decrease permeability (by blocking formation fractures);
- Cooling the formation near the wellbore;
- Cooling and retracting the production casing;
- Negative effect of repeated thermal cycling of the cemented casings as it can cause it to break;
- Time of the total workover operation, including the fishing prior to reaming, in some cases; and
- Recovery time after the operation in order to regain the initial conditions of the well (mainly temperature with negative effect in the production).

Figure 10 shows the rig setup used for fishing and reaming operations in the wells in the Ribeira Grande geothermal field, where the drill rig is supported by a steel substructure and the crew work at an upper level platform at about 2 m above ground.

The preparatory work done before the workover operation includes: disassembling the wellhead components above the master valve and disconnecting from the power plant pipe line. After this the substructure is installed where the drill rig will be settled on the well pad. Then the drill rig, pumps, water tanks and water pipes and hoses are rigged up.

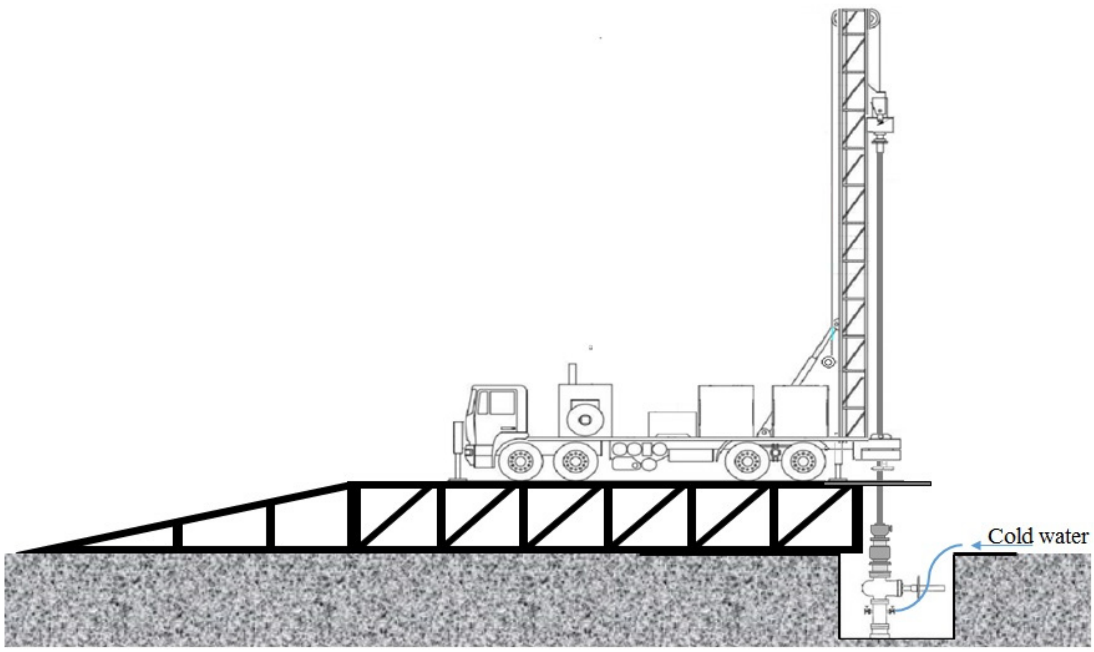

FIGURE 10: Reaming of calcite with the well quenched using a small drill rig (no scale)

On the day of the operation, the well control equipment, composed of a 9API 3000 annular blowout preventer (BOP) and a Ø7 1/16 rotating head, is connected to the master valve. The first tricone tungsten teeth bit used is Ø8 1/2 and it runs easily through the annular BOP. The well is killed by a triplex pump injecting cold water at 20 l/s (usually starting at 40 bar) through the Ø3 1/8 kill line valve, located on the casing head and monitored by a pressure gauge connected to the other Ø3 1/8 valve of the casing head. Once the well has been quenched and is in suction, with a wellhead pressure less than zero (WHP < 0 bar), the pumping of cold water is changed over to a centrifugal pump, which keeps the flow rate at around 20-30 l/s, with less consumption of fuel than the triplex pump and can supply a high flow rate.

The Ingersoll Rand RD-20 rig used for this operation has standard Ø4 1/2 Atlas Copco type drill pipes, in 30´ lengths, and the bottom hole assembly (BHA) is simply the tricone bit + float valve + cross-over to the drill pipes. There is no need to use additional drill collars in the drill string as the well is always quenched and the scale deposits in the wellbore are soft to ream. The tricone bit is also cooled by the injection of cold water inside the drill pipes during reaming. After reaming in the slotted liner section, the $\mathbf{\emptyset 8\frac{1}{2}}$ bit is pulled out of the well and changed over to a Ø12 1/4 bit to repeat the same operation inside the production casing. With the conclusion of the calcite cleaning, the equipment is moved off the well pad and the wellhead components are reconnected to the master valve and power plant pipe line and the chemical inhibitor system is installed again. The well recovers rapidly and can start to produce again two days after the workover operation.

3.5 Methods to overcome calcite scaling damage inside the formation

Methods for overcoming calcite scaling damage inside the formation are related to acid cleaning, described in the next chapter, or deepening or sidetracking from an existing well or modifying the casing program design for new wells:

- *Deepening the well*, is an option when knowing the existence of a new favourable productive layer (through the geology of wells near this location). For drilling inside the well, taking out the existing slotted liner can be considered, followed by drilling with the same bit size. The alternative is to drill with a small bit size inside the slotted liner and installing a new slotted liner below the old one;

- *Deviation of the well by side-tracking,* can be done if there are problems with calcite scaling blocking the slotted liner or indications of mechanical problems in the casing when it is not possible to remove the liner. One option is to initiate side tracking inside the casing, using what is called a casing exit system. It consists of a whipstock (special tool which is settled in the casing) to open a "window" in the casing form, while another hole is drilled as a sidetrack. The sidetrack can then have a new liner installed;

- *New well design*, can be considered if the flash point and loss of circulation depths are known and are consistent for wells drilled in the same area, with calcite scaling deposits inside the slotted liner. In this case the design of new wells with a deeper production casing is feasible to locate the flash point inside this casing. Future reaming operations would then be inside the production casing and the liner would not be affected by scaling that occurred out in the host rock; and

- *New well design, considering shallow wells open-hole*, which can produce from the steam cap of a reservoir, avoiding the formation of calcite in the wellbore (same principle as done at Svartsengi geothermal field, in Iceland) (Björnsson, 1999).

3.6 Acid cleaning of calcite scaling

Acid cleaning is also a method that can be used to remove calcite deposits from the wellbore or the formation. This method consists of injecting a solution of HCl and water into the well through the wellhead or inner string. The HCl is very effective in removing deposits by dissolving the carbonates and even other scale products, especially when HF is added as a booster. This is considered an expensive method and should not be done often (Morales, 2012).

4. MECHANICAL CLEANING OF SCALE DEPOSITS IN WELL PV8 WHILE DISCHARGING

4.1 Main wellhead configurations for workover

The adoption of methods to ream calcite scaling in wells while discharging has a long history in Iceland and in some other countries where this problem has a great impact on production. In Iceland, this method for reaming scales has been used for over half a century in a field where the calcite deposition is controlled to occur inside the production casing and no chemical injection of a scale inhibitor is implemented. The annual workover operations are relatively inexpensive and the wells recover their original output even after 30 years in operation.

The following section presents types of wellhead configurations used in reaming operations in high temperature wells.

4.1.1 Mechanical reaming of calcite scaling using a stripper and a gland

This method of using a gland and a special stripper was developed and implemented in Iceland in the early 1980s with the intension of reaming calcite scaling with wells discharging to a silencer pipe line to eliminate the thermal cycles in the well and formation and to extract the scaling cuttings. Figure 11 shows the general configuration and the main components used for this method.

The dimensions of the components are small and easy to connect and very useful in wells with a shallow cellar. A small rig can easily stand on the ground or on a steel substructure. It is not represented in the drawing, but a high pressure piston pump should always be connected to the kill line valve, in case of any occurrence with the need to kill the well (has occurred once). The configuration shown is recommended to be used in wells with wellhead pressures up to 20 bar; when flowing, the pressure on the stripper and gland components is greatly reduced because of metal seals in the wellhead and a condensing chamber for steam that bypasses the seals.

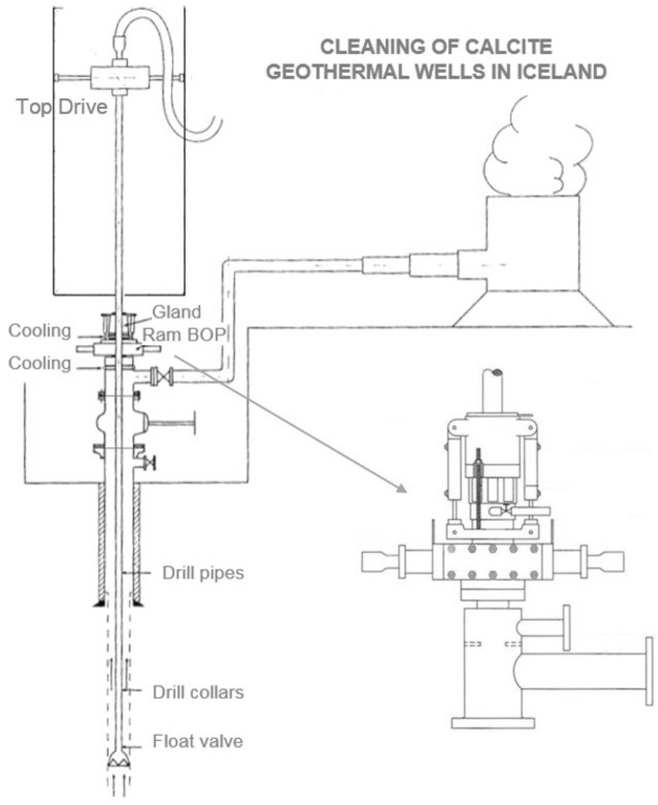

FIGURE 11: Mechanical reaming of calcite scaling in Iceland in the 80s and 90s (adapted from Molina, 1995)

The operation starts after all the components in Figure 11 are mounted and the tricone bit is inserted inside the diverter from below. After that, the lateral valve connecting the diverter to the pipe line silencer is opened and cold water is injected through the upper lateral outlet on the diverter. The flow of cold water running in the gland and diverter must be adjusted during the operation to quench the steam and cool the condensing chamber. After opening the master valve, the drill string is run in the hole until reaching the top of the scaling plug to start drilling out the scale deposits.

Figure 12 shows a wellhead configuration that was used in Iceland for scale reaming operations of wellbores at Svartsengi geothermal field. The wellhead has two main components, A - the stripper and B - the gland. The stripper is a type of diverter with two lateral outputs, separated internally by a flange with a metal seal to allow drill pipes to pass through it. In this diverter the well pressure is controlled when the fluid is flowing to the silencer pipe line. The gland is included in the top section of the wellhead and it works like a stuffing box or stripper, with an internal seal against the drill pipes when compressed vertically by the effect of the hydraulic cylinders. This gland and the internal ram rubbers of the BOP are continuously cooled by water during the reaming operation and the grip of the hydraulic cylinders is adjusted with the presence of leakage between the gland and the drill pipes. The drill pipes operated with this method have to be outside flush in order to enable sealing by the stripper and ensure long service life of the metal seal.

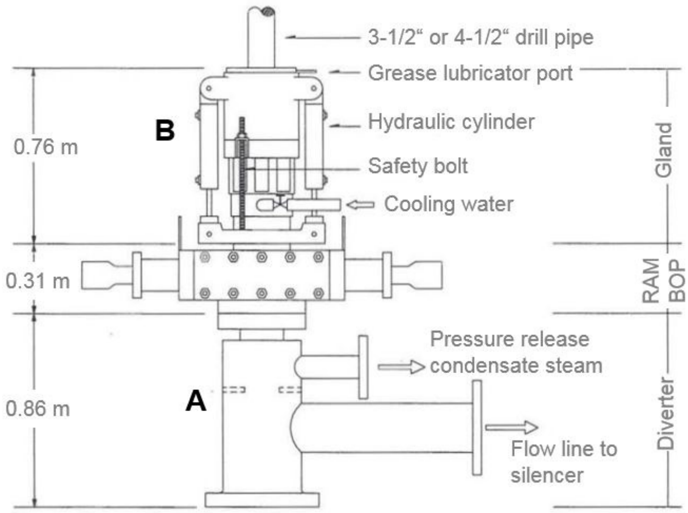

FIGURE 12: Wellhead configuration prototype used in Iceland (adapted from Molina, 1995)

4.1.2 Mechanical reaming of calcite scaling using a stripper and a rotating head

The main principle of using this method for reaming scales is similar to the one explained in the last section, but in this case the operation can be done in deeper wells, with a high range of pressure and temperature, as compared to the configuration considered before. This wellhead configuration provides a higher level of security of the operation, since the total length is greater for the seal and a complete BOP stack is installed as for normal drilling. For this operation, a large rig is required with a higher substructure to provide room for the wellhead equipment.

The wellhead configuration of Figure 13 is currently in use in Iceland at Reykjanes and the stripper mechanism included in it has been continuously developed, increasing the reliability of the reaming operation. Here, full wellhead pressure is maintained by water inside the spool marked A.

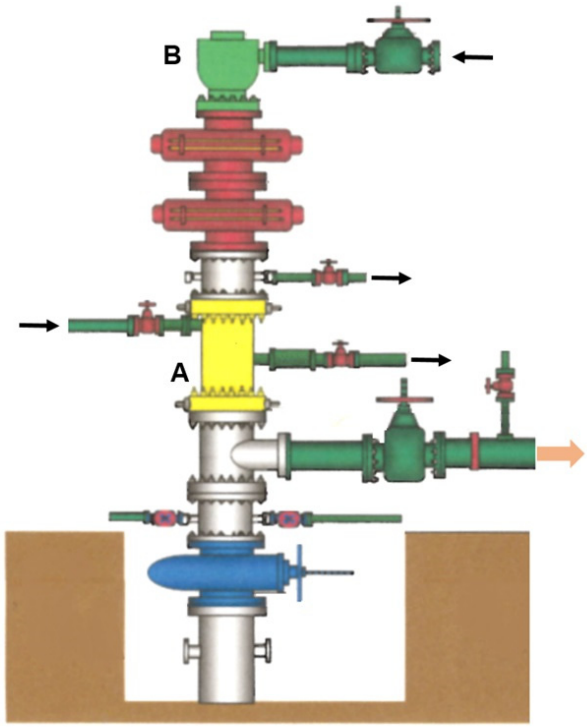

FIGURE 13: Wellhead configuration used nowadays in Iceland (Jardboranir, pers. comm.)

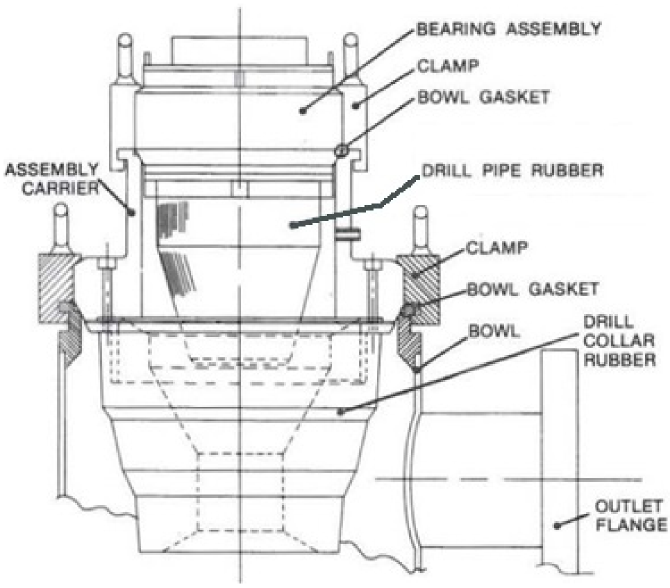

FIGURE 14: Standard rotating head model for geothermal wells (Molina, 1995)

Reaming with this process requires an accurate management of pressure and temperature inside the wellhead components. In the upper part of the wellhead is the most important component, the rotating head (label B in Figure 13). The rotating head is normally responsible for diverting the flow during drilling, but in this assemblage its function is to hold the cold water pressure during cooling of the internal parts of the BOP equipment (rotating head, ram pipe BOP and ram block BOP).

Figure 14 shows a cutaway of a standard rotating head preventer which uses two internal rubbers (for pipes and collars); the position of the rubbers, the bearing assembly and the outlet flange that is used for the injection of the cold water can be seen. In this particular configuration, the drill pipes and drill collars are outside flush, because they have to pass through the internal plates of the stripper of the same diameter. The rotating head shown (Williams Tools Co., Inc) is constructed to hold 34.5 bar when rotating and about 140 bar when in static utilization (Molina, 1995).

The main component of the wellhead shown in Figure 13 is the stripper (labelled A). Inside it are two steel plates with aligned holes, with almost the same size of the drill pipes' outside diameter; the stripper is used to build up the pressure of the geothermal fluid in the Tee below. Cold water is injected in port 1 to condense the steam which crosses the bottom steel plate in the stripper and leaves the stripper via output 2, at a higher temperature (Figure 15). The flow of cold water in the stripper is increased or decreased by means of gate valves in order to maintain a low temperature inside the equipment and to balance pressure inside the stripper to match the pressure of geothermal fluid in the wellhead Tee.

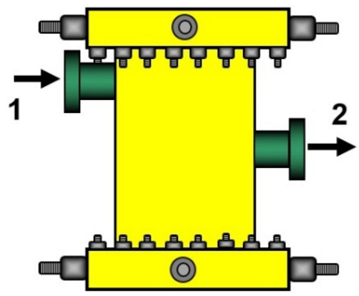

FIGURE 15: Stripper developed for reaming in geothermal wells in Iceland

4.2 Design of stripper mechanism for use in well PV8 while discharging

In this section the author proposes a design for a wellhead and stripper device. Most of the other equipment selected is from commercial pressure control equipment known in the drilling industry and used for workover operations. The design of the stripper mechanism to be used in well PV8 considers the following aspects:

- Specifications of the available drill rig;
- Optimization of the existent steel substructure where the rig will be settled;
- Dimensions of the cellar of the well PV8;
- Total height available for the wellhead configuration, including stripper, ram BOP and rotating head;
- Operating conditions of well PV8 during discharge (wellhead pressure and temperature);
- Acquisition of drill components, drill pipes, drill collars, cross-overs subs; and
- Adaptations on the rig table and pipe handler.

The specifications of the equipment are selected to meet the dimensions of well PV8's cellar and the pressure and temperature to enable the reaming operation.

4.2.1 Well PV8's cellar

The cellar of well PV8 has the following dimensions:

Height is 2.75 m;
Width is 2.5 m;
Length is 3 m;
Height from top of master valve to ground level is 0.51 m.

4.2.2 Steel rig substructure

The existing steel substructure to settle the rig has the following dimensions:

Substructure height= 1.61 m, concrete pads = 0.20 m, combined substructure height = 1.81 m;
Width of the substructure is about 2.7 m;
Total length of the 5 drilling rig modules, including the ramp, is 19.5 m.

4.2.3 Stripper mechanism

The stripper mechanism will be constructed of a heavy wall pipe reducer **12**-ANSI 900 x 7 1/16-3M with a holed steel plate welded inside the bottom flange and with a 3" flanged pipe on the lateral output, as shown in Figure 16.

The top flange 7 1/16-3M connects to the single ram double studded BOP and the bottom flange is **12** ANSI 900 to connect to the Tee.

The steel material grade to use in the stripper tools is AISI 4130 Annealed or equivalent, which is similar to the master valve flanges. In the centre of the steel plate there is a threaded steel sleeve which can be replaced when the internal clearance to the pipes exceeds the acceptable due to wear.

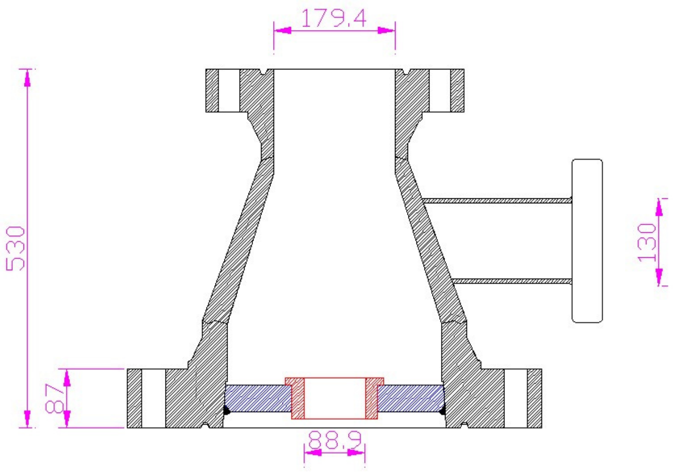

FIGURE 16: Design of the stripper for reaming calcite operation in well PV8, considering the presented dimensions in mm

The main function of the welded steel plate is to reduce the pressure and let the drill string pass through. Above the plate, the flowing cold water condenses the steam that bypasses the steel sleeve and allows the operation of the ram BOP and rotating head rubbers at low temperature and pressure.

4.2.4 Single Ram pipe BOP

To allow the installation in the available space under the rig table and the master valve, the selected BOP for use in the workover wellhead is a Single Ram Pipe BOP, prepared for work with pipes with 3 1/2 OD. Figure 17 shows the specifications of the chosen Ram BOP from the constructor *Shaffer* (Varco, 2002), which has a total height of 285.5 mm, one of the smallest in the market.

Single Ram Blowout Preventer Shaffer Model Chasovoy Hydraulic Cylinder		
Nominal flange	$7\frac{1}{16}$" - 3000	
Type of connection	Stud x Stud	
Overall height (mm)	285.5	
Overall length, bonnets closed (mm)	1,638.3	
Overall length, bonnets open (mm)	2,051	
Overall width (mm)	523.7	
Working pressure PSI (bar)	3,000 (207)	
Test Pressure PSI (bar)	10,000 (690)	
Ring Gasket	R-45	
Maximum operating pressure to close and open PSI (bar)	3,000 (207)	
Ratio	8.47:1	
Volume of hydraulic fluid (l)	2.27	
Piston stroke	103.2	

FIGURE 17: Specifications of the single ram double studded BOP selected for reaming calcite operation in Well PV8; the BOP shown in the picture is not the selected one

4.2.5 Rotating Head

The rotating head selected to mount on the wellhead is a *Washington Series 1400* (shorty), which has a maximum service pressure of 300 PSI (20.69 bar), as shown in Figure 18. This equipment will be used to keep the pressure of the cold water in the upper part of the wellhead. The maximum pressure rating is high enough to also hold the pressure of the well while discharging (about 15 bar), in case something happens to the steel plate seal welded in the stripper.

Nominal Flange	A	B	C	Sleeve Bore D	Body Bore E	F	G	Ring Gasket	Outlet Flange
$7\frac{1}{16}$" - 3000	$34\frac{3}{4}$"	$28\frac{1}{4}$"	17"	$24\frac{1}{8}$"	$7\frac{1}{16}$"	$12\frac{9}{16}$"	12"	R-45	7"

Dynamic Test Pressure (Rotating)	300 PSI	
Static Test Pressure	500 PSI	
Maximum rpm (intermittent)	150 rpm	
Stripper rubber mounting	Bolt-on	
Top drive	Yes	
Oil system	Self-contained pressurized	

FIGURE 18: Rotating head selected for reaming calcite in well PV8 (Washington Rotating Control Heads, Inc., 2012)

4.2.6 Drill rig Ingersoll Rand RD-20

The rig available for workover operations is an Ingersoll Rand RD-20, manufactured in 1986 and purchased by *EDA Renováveis* in 2005. The rig has been used by EDA for maintenance operations in geothermal wells and for drilling shallow water wells.

The main specifications of the rig are listed below:

- Manufactured in 1986, with complete overhaul in 2003;
- Hydraulic top-drive unit, with pullback capacity of 50 tons and pull-down capacity of 13.6 tons;
- Maximum depth rating of 1200-1500 m, depending on the drill sting;
- Rotary torque of 1000 kg. m;
- Mounted on a 4 axle Pettibone truck; and
- Rig Handler converted to work with 4 1/2OD Atlas Copco drill pipes, with 30′ length.

In Figure 19, the drill rig that will be used in the reaming operations of well PV8 is shown. Modifications on the handler and rig table will be performed to allow handling of the outside flush drill pipes with a new diameter. This also requires the acquisition of rotary slips and safety clamps to support the 3 1/2 OD pipes and collars during the operation. For the initial part of running into the hole, the pressure inside the well will push the drill string up due to a piston effect.

FIGURE 19: Drill rig Ingersoll Rand RD-20

4.2.7 Drill Collars and Pipes

In order to optimize the total height and weight of the wellhead equipment, the selection of the drill pipes and drill collars is for outside flush drill pipes with 3 1/2 OD. According to the specifications of the rig, the length of the collars and pipes should be 30′ in length.

According to the main specifications for drill collars and drill pipes shown in Table 3, the total weight of each drill pipe is 166.53 kg and drill collar is 362 kg. Usually when discharging, the WHP in well PV8 is around 16 bar, so we can consider utilization of drill collars to overcome a wellhead pressure of 20 bar. In this case it will need 4 drill collars (corresponding to 36 m DC length) to equalize the piston effect with the weight of the drill string to use the drill pipes.

TABLE 3: Specifications of drill pipes and drill collars for reaming operation (Thomson International, Inc, 2012)

	Flush drill pipes	Flush drill collars
Outside diameter (inch)	3-1/2"	3-1/2"
Inside diameter (inch)	1-3/4	1-1/2"
Length (m)	9.1	9.1
Weight (kg/m)	18.3	39.73
Thread type	2-3/8 IF	2-3/8 IF

To reach a depth of 600 m will require 4 drill collars and 62 drill pipes.

4.3 Cleaning procedure using the Ingersoll Rand RD-20 rig

The pull-down required in a reaming operation was calculated, considering the diameter and weight of the drill string, as reported in Section 4.2, when referring to the specifications of drill pipes and drill collars. Figure 20 shows the pull-down force required to overcome the pressure inside the well, considering 4 (four) different wellhead pressures. In the drill string to be utilized, the use of 4 (four) drill collars was considered followed by the drill pipes. Observing the Figure, for the usual WHP =15 bar, the use of 3 drill collars (27.3 m) would be enough to overcome the pressure in the wellbore. After 27 m, the operation could proceed normally, without any pull-down or arrangements in the rig table to hold the drill string from being pushed up when adding a new drill pipe.

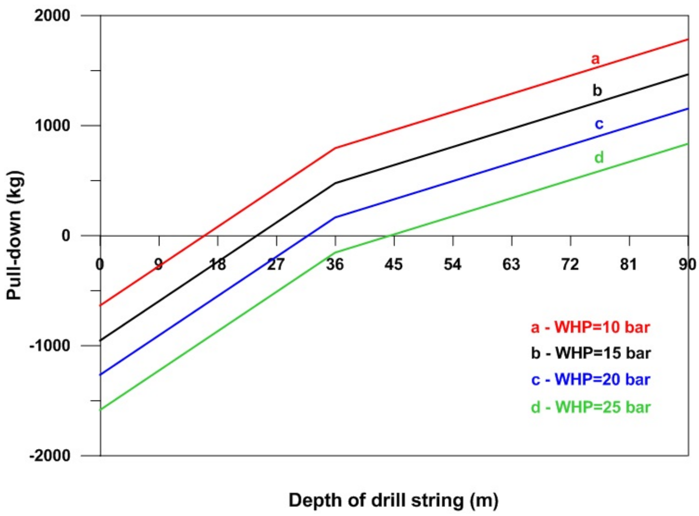

FIGURE 20: Pull-down required to overcome pressure inside well using 3 ½ OD drill rods and pipes

4.3.1 Cleaning procedure

The cleaning operation will take place after running the go-devil logging tool to confirm the calcite scaling depth for each internal diameter. Figure 21 shows a scheme with the main equipment (wellhead equipment, drill rig, rig substructure and silencer pipe line) mounted at the well pad to perform the reaming operation.

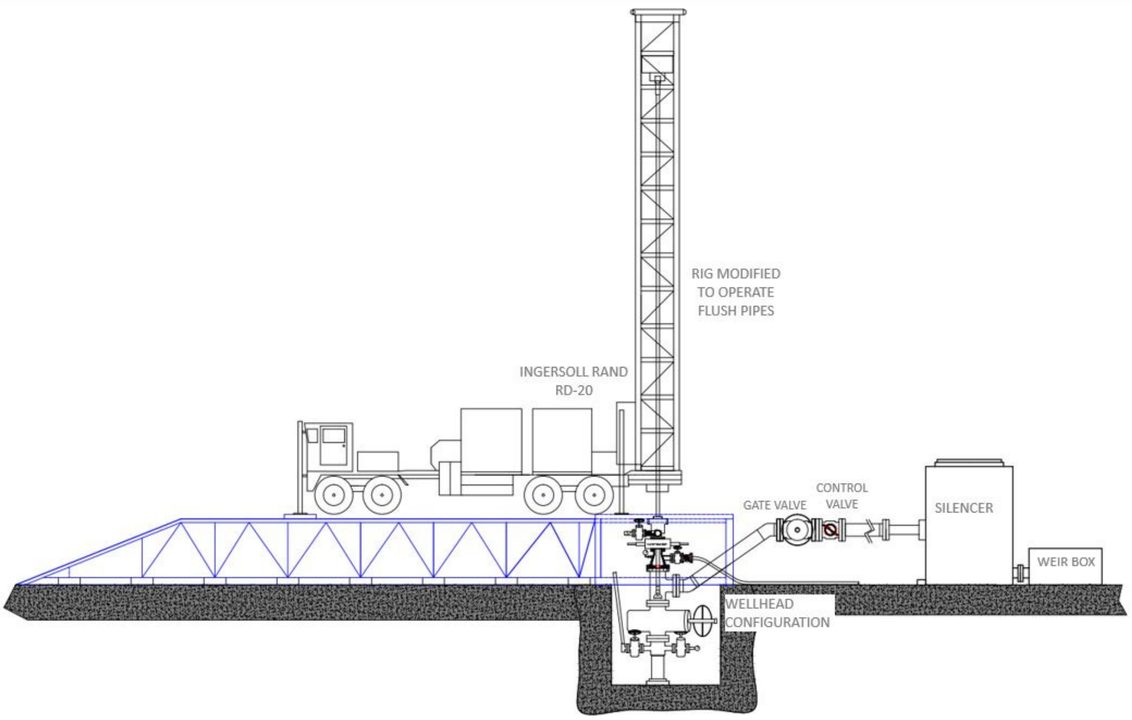

FIGURE 21: Drill rig settled to reaming calcite operation while discharging to the silencer pipe line

According to the dimensions presented in Point 4.2, the total length of the wellhead configuration (Tee, Stripper, Ram BOP and Rotating head) is about 2.25 m, but above ground level it is just 1.88 m, because half of the Tee height in inside the cellar. Considering that the total elevation of the rig (steel substructure, concrete pads and wooden supports) is 1.93 m, the wellhead can fit the available space, with enough free space under the rig table to lift the top of the rotating head, in case rubbers need to be replaced.

The proposed procedure for reaming calcite scaling in well PV8 consists of the following:

4.3.2 Assemblage of equipment and materials on the well pad of the well

1. Close the master valve and disassemble the wellhead equipment above it, including the lateral valve that connects the wellhead to the power plant separator pipe line.
2. Mount the rig steel substructure on the well pad. Install the 12" Tee above the master valve.
3. Mount the silencer pipe line connected to the lateral output of the 12" Tee, locating the control valve (butterfly valve) near the Tee, as shown in Figure 21.
4. Position of the drill pipe trailer is aligned with the drill rig, triplex pump parallel to the drill rig, and the centrifugal pump that will be used to pump cold water inside the stripper near the cellar.
5. The stripper, ram pipe BOP and rotating head are bolted in place. First the BHA (bottom hole assembly) composed of 8-1/2" bit, float valve sub and a 2 m length drill collar (3 1/2 OD) is passed inside the bolted assembly prior to it being mounted on the wellhead Tee, as the bits are too large to pass through the wellhead assembly above.
6. After installing the equipment with the BHA to the Tee, the 4" valve is connected to the rotating head (label 1 in Figure 22) and a 3" valve connected to the stripper output (label 2 in Figure 22) to conduct the cold water with the condensate to the waste pit. Temperature and pressure gauges should be connected to the stripper output before the 3" valve.
7. High pressure hoses and pipes are connected from the centrifugal water pump to the rotating head valve (non-returning valve at the end of the hose, before 4" valve, (label 1 in Figure 22), from stripper output valve (label 2 in Figure 22) to the waste pit pipe line and from the triplex pump to the 3" valve in the casing head (kill line label 4 in Figure 22). Check the supply of cold water to the pumps.

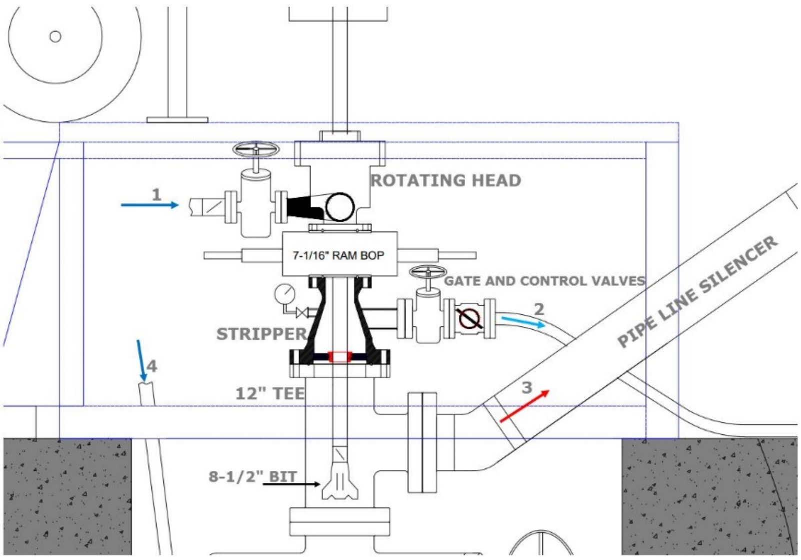

FIGURE 22: Wellhead configuration during reaming calcite operation (zoom of the wellhead); the connected pipes are rotated 90° in the Figure for better illustration

4.3.3 Operation procedure

1. Settle drill rig at the top of the steel substructure as shown in Figure 21, level the rig table, connect the first rod to the BHA and torque it.
2. Open the 4" and 3" valves on the rotating head input and stripper output and start pumping in cold water. Slowly close the valve on the stripper until the pressure reaches about 3 - 4 bar.
3. Check that the butterfly control valve is ~10% open and then open gradually the 12" master valve to fully open.
4. Control the flow rate of the geothermal fluid (steam and water) to the silencer pipe line and the pressures in the well and in the stripper.
5. Pull-down the first drill collar until the top of it gets to the rig table and hold the collar with slips. Below the table hold the collar with slips and steel cables to keep the collar in that position during the time the top drive picks up the second collar.
6. Continue with the same procedure until the third collar, which should be enough to overcome the well pressure; after that just start holding the pipes in the rig table with slips.
7. Run in the drill pipes to the depth of the bit tag on top of the calcite scaling (according also with the logging tools' measured depth) and start the reaming operation, adjusting the control valve opening to the minimum flow required to bring out the calcite cuttings to the silencer.
8. The calcite reaming operation continues until all the scaling is reamed and the cuttings are out of the well, which will be at about 600 m depth.
9. Pull out the BHA, paying attention to the need to hold the BHA with pull-down, when the drill collars reach the rig table.
10. Close the master valve, stop pumping cold water and disconnect the pipes and hoses from the 4" and 3" valves. Disassemble the connection between the stripper and the 12" Tee. Lift up the bolted assembly (stripper, ram pipe BOP and rotating head) to change over to the 12-1/4" bit.
11. Connect all the equipment again and repeat the same procedure (from steps 2 to 9) to do the reaming operation inside the production casing in the upper part of the well until 392.2 m depth (top of liner hanger).
12. After finishing the cleaning operation and extracting the BHA, the master valve is closed and the centrifugal pump stopped. The Tee and bolted assembly (stripper, ram pipe BOP and rotating head) are removed from the wellhead above the master valve.
13. The go-devil logging operation is conducted to check if the well is OK to resume production to the power plant. If it is OK, all the equipment, including drill rig, rig substructure, pumps and pipe line silencer are carried off of the well pad.
14. Mount the permanent wellhead equipment and lateral 12" valve on the well and start production to the power plant.

4.4 Benefits of cleaning wells while discharging

Reaming calcite while discharging, compared to reaming with the well quenched, has the following benefits:

- Calcite cuttings are removed from the well during the operation and do not deposit in the bottom or inside the formation (clogging the inner spaces) as it occurs when it is quenched;
- Temperature in the wellbore and formation do not change, as the well does not have to be quenched with cold water;
- Casing keeps the same properties and cement bond remains good, because there is no thermal cycling due to changes of temperature; and
- Total time for the well out of service is reduced.

The selection of this new method for reaming the scale deposits, combined with a monitoring program, improves production, maintenance of equipment, and material performance.

5. CONCLUSIONS

The accurate use of the methods referred to in this report guarantees improvement of the productive life of wells and, consequently, the maintenance of geothermal fields. For the case analysed, the adoption of the procedure for reaming calcite scaling in well PV8 while discharging (without quench), will achieve immediate results, preserving the good conditions of the cemented casing and reservoir and, at the same time, the calcite cuttings are carried out from the well avoiding letting them fall to the bottom of the slotted liner. The utilization of both methods – *chemical inhibition* and *reaming,* for controlling calcite deposition in well PV8 will prevent non desirable fishing and cleaning operations and, therefore, reduce unexpected time breaks in well production. To minimize the non-productive time of the well, preventive measures for controlling calcite deposition and scheduling cleaning operation should be carried out.

In order to deal effectively with problems related with calcite scaling in the wells, the following steps should be considered:

1. Identification of the type of scaling and the main reason for its deposition in the well.
2. Install down-hole equipment for treating the water with a scale inhibitor. If already installed, improve inhibitor selection and dosage.
3. Removal of any scale that forms in spite of chemical inhibition by mechanical reaming or chemical cleaning with acid.
4. Deepening or side tracking of wells are methods for recovering output lost to damaged casings or scaling out in the formation.

The main conclusions of the study are presented below:

- The tendency for the formation and deposition of calcite in the boreholes of the Ribeira Grande geothermal field imposed the application of methods for prevention of this occurrence and rehabilitation of the wells in case it occurs;
- The injection of the calcite scaling chemical inhibitor NALCO pHREEdom (R) 5200M, since November 2012, has proven to be a good solution in the prevention of calcite deposits in the wells of Ribeira Grande geothermal field. However, in well PV8, the inhibitor only delays the formation of calcite, making it necessary from time to time to ream the well to remove the deposited calcite or fish for broken capillary tubing; and
- Calcite reaming in a well when it is discharging to a separator pipe line allows large benefits: reduction of the time the well is out of service; the temperature in the formation near the well is maintained (because no cold water is used to quenched the well); no thermal cycling in the casing and, therefore, no effect on the properties of the cement or casing steel.

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