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REAMING CALCITE DEPOSITS OF WELL PV8 WHILE DISCHARGING: A SUCCESFULL OPERATION AT RIBEIRA GRANDE GEOTHERMAL FIELD, SÃO MIGUEL ISLAND, AZORES

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ABSTRACT

Calcium carbonate minerals are found in hydrothermal altered rocks and the geothermal water is generally saturated with it at the prevailing reservoir conditions. In production wells the water is degassed and depending on the fluid chemistry can cause deposition of calcium carbonate (calcite or aragonite). The resulting reduction in well diameter over a relatively short section impacts the power plant production. Calcite scaling causes problems in many exploited geothermal fields around the world. Calcite inhibition systems (CIS) by use of inhibitors are found to be effective but often mechanical reaming is also required from time to time.

At Ribeira Grande geothermal field, calcite scaling is mitigated by the application of a chemical scale inhibitor. A small amount of inhibitor is continuously injected by impulses down-hole, below the boiling depth via a capillary tube. For geothermal well PV8, despite this action, mechanical cleaning is sometimes needed due to the high rate of calcite deposition. Until 2017, reaming these deposits with a drilling rig involved quenching the well with cold water prior to the operation. This methodology has several disadvantages when compared with a methodology that involves reaming deposits with the well discharging, namely in what concerns casing integrity, cooling of geological formations and delaying well production.

This paper presents the calcite cleaning operation carried out at well PV8 in a dynamic condition. It required design of wellhead equipment to seal against the drill pipes and to divert the steam/water flow to a separator. The truck mounted drilling rig and equipment is owned by EDA RENOVÁVEIS and the drilling crew for this task were the regular power plant maintenance personnel which had received training. The reaming operation, which lasted only one day, was monitored closely and the very positive results attained are also discussed.

1. INTRODUCTION

In the archipelago of Azores (Portugal), high enthalpy geothermal resources are exploited in São Miguel and Terceira islands. The regional government's policy of maximizing the use of clean, renewable and endogenous energy sources supports the expansion of geothermal projects in the Azores.

At Ribeira Grande geothermal field (São Miguel island), a 240ºC liquid-dominated reservoir is exploited by EDA RENOVÁVEIS, S.A., Company that operates two binary ORC (organic Rankine cycle) geothermal power plants – Ribeira Grande and Pico Vermelho, with a combined capacity of 23 MWe. Nowadays, the production from these two power plants represents 42% of the total power production of the island (Figure 1).

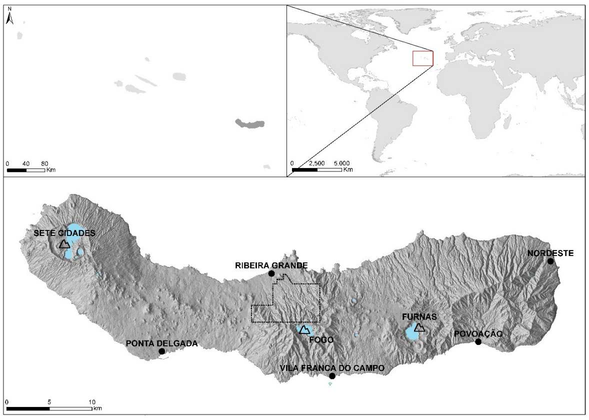

Figure 1: Location of the Azores Archipelago and São Miguel Island, with indication of concession area (EDA RENOVÁVEIS).

At Terceira island, the 3.5 MWe Pico Alto geothermal power plant started operating in October 2017 and at the present date is responsible for 11% of the power consumption in the island.

The formation of calcite scaling inside wellbores is present at Ribeira Grande geothermal field since the start of the exploitation. According to the temperature data taken inside the wellbores, upon boiling at a flash point temperature (~240°C), the fluid become supersaturated related to calcite (Calcite Saturation Index, SI>0), increasing the potential for the deposition and obstruction of the wells. To prevent geothermal production wells of clogging, it was implemented in each well a mechanical system for down-hole injection of a chemical inhibitor.

The use of a calcite scaling chemical inhibitor is a successful method adopted in preventing the formation of scaling in the geothermal wells of the Ribeira Grande geothermal field. Nevertheless, well PV8, which supplies brine and steam to Pico Vermelho power plant, develops a small rate of calcite scale deposition, despite the injection of the inhibitor. Calcite deposits in well PV8 were, until 2017, mechanically reamed using EDA RENOVÁVEIS small drill rig Ingersoll Rand RD-20, always maintaining the well quenched by the injection of cold water.

2. RIBEIRA GRANDE GEOTHERMAL FIELD

2.1 Brief characterization of the Ribeira Grande reservoir

The Ribeira Grande geothermal field is an extensive, high-temperature geothermal system (with temperature reaching at least 250ºC), hosted by volcanic rocks (mainly a succession of trachytic to basaltic lavas and pyroclastic rocks) on the northern flank of the Fogo volcano. The heat source is probably connected with the body of magma or young intrusive rock from Fogo volcano, and the isotopic signature of produced brine and condensate indicates a meteoric origin for the water in the system.

Well data from the geothermal field indicate that a sequence of pyroclastic rocks altered to clay forms a relatively impermeable cap at the top of the reservoir. The lower limit of the reservoir (at least in the northwest, lower-elevation Pico Vermelho sector of the field) seems to be formed by impermeable clastic volcanic rocks at or near the transition zone between subaerial and submarine deposits.

The permeability of the Ribeira Grande geothermal reservoir is associated with fractures in volcanic rocks of the Fogo volcano. The principal flow direction into and within the reservoir at deeper levels is upward and northwestward, following the northwest trend of faulting created by the regional tectonic setting, though there is probably some lateral flow toward the margins of the reservoir as well. At shallower levels (around -400 m elevation), lateral, northwesterly flow appears to predominate over upward flow, forming an extensive, relatively shallow reservoir in the Pico Vermelho sector.

According to the conceptual hydrological model of the field (GeothermEx, 2016), geothermal water with a maximum temperature of 250°C enters the reservoir in an upflow zone that is probably located in the southeastern part of the field (east or northeast of the Cachaços-Lombadas sector).

The chemical composition of the geothermal water is relatively homogeneous throughout the field, being mainly sodium-chloride type with high HCO_3. The reservoir contains predominantly liquid water but boiling occurs and forms a steam or two-phase zone at the top of the reservoir in some sectors of the field. Progressive boiling of the reservoir water as it flows northwestward reduces the content of non-condensable gases in the Pico Vermelho sector compared with the Cachaços-Lombadas sector, although the difference is generally minor and does not suggest that boiling is extensive.

2.2 Completion of well PV8

PV8 is a vertical well with a large diameter production casing that supplies geothermal fluid to the Pico Vermelho power plant (Figure 2). It is one of the most profitable wells in the field, delivering an average flow rate of 26 kg/s, which represents about 3.5 MWe in the production of this power plant.

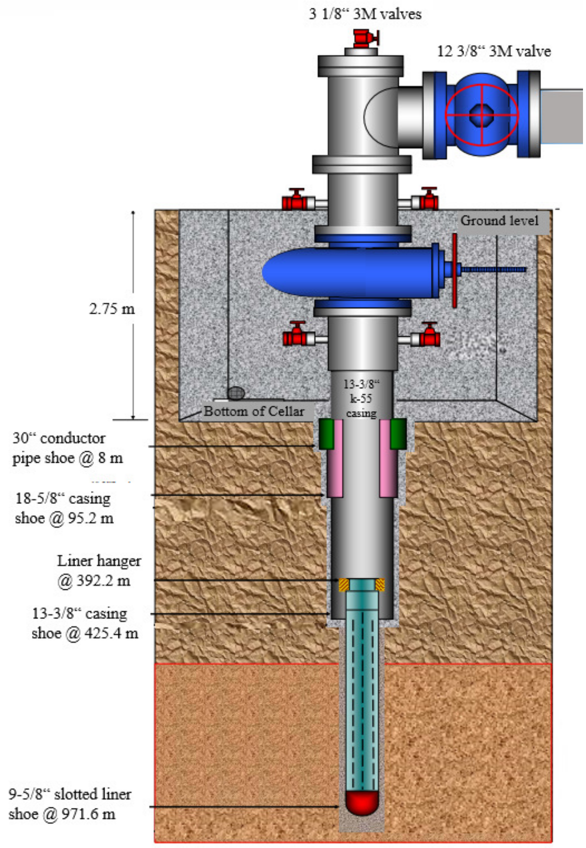

Figure 2: Technical profile of well PV8 (adapted from GeothermEx. Inc, 2006).

As shown in Figure 2, PV8 was completed with 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 971.6 m depth. The wellhead comprises a 12" ANSI 900 master valve, connected to the 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. The 12" spool with two side outlets is connected to the top of master valve and to the bottom side of the Tee that supports the 12" ANSI 900 lateral valve connected to the power plant pipe line. Above the Tee there is a 3" ANSI 900 gate valve, which allows the installation of the lubricator used in the calcite inhibition system.

2.3 Pressure and temperature curves at well PV8

Based on measured temperature and pressure curves (lines with symbols), the respective saturation temperature and pressure curves (solid lines) were calculated and are shown in Figure 3. On the depth axis, there is a schematic representation of the well casing program, with the 13-3/8” casing shoe at 425.4 m and the slotted liner shoe at 971.6 m. Total loss of circulation (TLC) during drilling occurred at 508.7 m.

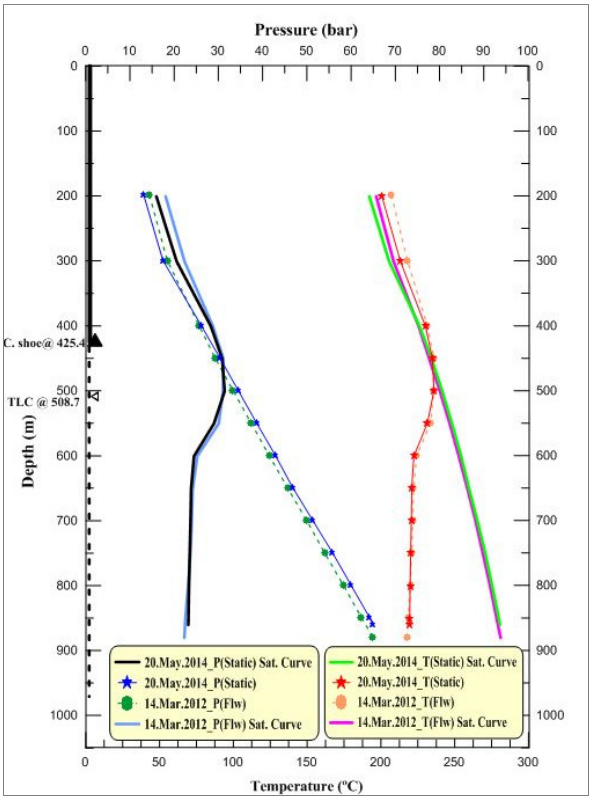

Figure 3: Pressure and temperature logs at well PV8 (Pereira, 2014).

Analyzing the plots, we observe that the maximum temperature is located at 450-550 m depth, followed by a temperature reversal below this depth. This depth matches with the main loss of circulation found during drilling and corresponds to a hot permeable zone, with temperatures of 231-237°C. Below 600 m, it could exist more permeable zones, but with reduced permeability when compared to the upper zone. The intersection of the saturation curves with the measured temperature and pressure logs indicate that the boiling point occurs at approximately 460 m depth, inside the slotted liner.

Observing the pressure static plot, we can infer that the water level inside the well PV8 is near 100 m depth.

3. CALCITE SCALING POTENTIAL IN WELL PV8

Calcite is a very common carbonate mineral deposit that forms in geothermal wells drilled in reservoirs with temperatures ranging from 140 to 240ºC. In these reservoirs, geothermal fluids are usually calcite-saturated and become calcite supersaturated after boiling to lower temperatures, reducing the CO_2 in the water phase due to its transfer to the steam phase. The degassing of CO_2 increases the pH of the water phase and increases the concentration of the carbonate ion (CO_3^{2-}). It is mostly this increase that is responsible for making initially calcite saturated geothermal water, supersaturated through boiling (Arnórsson, 1989; Thorhallsson, 2006).

Calcite deposits are primarily found where water starts to boil in the well. Further boiling, which leads to cooling of the water, will cause successively decreasing supersaturation because the solubility of calcite is retrograde, it increases with decreasing temperature. Therefore, calcite scales are found over a 200-300 m long section in the well above where flashing occurs but are not found below or above that section (Arnórsson, 1989; Thorhallsson, 2006).

The Saturation Index (SI) is used as an indicator for the deposition of minerals in geothermal waters, and it is expressed by the following equation:

$$SI = \log\frac{Q}{K} \qquad [1]$$

where Q is the reaction quotient or activity product of the mineral which is being analysed in the dissolution reaction at 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 mineral is saturated in the solution; if Q > K, the mineral solution is supersaturated and the SI > 0; if Q < K, the mineral solution is under-saturated and SI < 0 (Thorhallsson, 2006).

To analyze the potential for calcite scaling in well PV8, WATCH program was used. This program calculates the final types of concentrations, solubility products and activity products, using the initial fluid concentrations as input (steam and water sampled at surface) and considering that the fluid adiabatically boils, starting by the reference temperature (240 °C for well PV8) (Bjarnason, 2010).

Table 1 shows PV8 geothermal fluid chemistry and production data of the well, which was used as input data on WATCH.

Table 1: General data and deep fluid concentration at separator pressure (mg/kg) in well PV8 (Pereira, 2014).

<table>
<tr><th>Date</th><th colspan="2">Separator Pressure</th><th>Measured Temp.</th><th colspan="2">Enthalpy</th><th>Flow rate</th><th colspan="2">Real Formation Temp.</th><th colspan="4">Hypothetical Formation Temp.</th></tr>
<tr><td>19.11.13</td><td colspan="2">4.5 bar.a</td><td>148 °C</td><td colspan="2">1144 kJ/kg</td><td>31 kg/s</td><td colspan="2">240 °C</td><td colspan="4">300 °C</td></tr>
<tr><th colspan="13">Liquid sample</th></tr>
<tr><th>pH/Temp</th><th>CO_2</th><th>B</th><th>SiO_2</th><th>Na</th><th>K</th><th>Mg</th><th>Ca</th><th>F</th><th>Cl</th><th>SO_4</th><th>Fe</th><th>TDS</th></tr>
<tr><td>9.6/18 °C</td><td>167.86</td><td>4.7</td><td>555</td><td>1334</td><td>246</td><td>0.025</td><td>1.93</td><td>22</td><td>1900</td><td>205</td><td>0.08</td><td>5140</td></tr>
<tr><th colspan="13">Gas sample</th></tr>
<tr><td colspan="3"></td><th>CO_2</th><th>H_2S</th><th>NH_3</th><th>N_2</th><th>CH_4</th><th>H_2</th><td colspan="4"></td></tr>
<tr><td colspan="3"></td><td>4820</td><td>24.2</td><td>47.1</td><td>39.2</td><td>0.121</td><td>0.109</td><td colspan="4"></td></tr>
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Based in the data from Table 1, WATCH program computed several results for different product concentrations. For the present study it was just utilized the concentrations of calcite 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 two temperatures of reference, 240°C (real or most approximately value for formation temperature on the site) and 300°C (hypothetical formation temperature). Although the use of the same initial sample concentrations, these results could be important in the observation of the changes in the calcite scaling index, when using a higher formation temperature. The minimum temperature chosen was 140°C, which is less than it could be observed in the well (Pereira, 2014).

Analyzing the plot in the Figure 4, the SI > 0 (SI > 0.7 for all temperatures), meaning that the fluid in the well PV8 is supersaturated for all the temperatures selected. Even if the reservoir had the same mineral concentrations in the water at a higher formation temperature, in the order of 300°C, the calcite saturation index would be higher than zero and the water supersaturated (black curve in the graph). Figure 4 also shows a decrease in the SI value with the decrease of the temperatures and consequently a minor probability of scaling (Pereira, 2014).

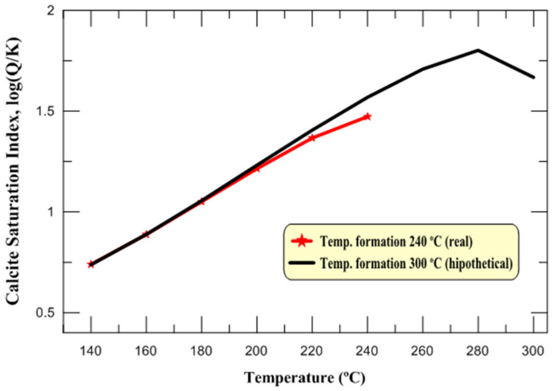

Figure 4: Calcite saturation index of the fluid samples of well PV8 (Pereira, 2014).

4. INIHIBITION OF CALCITE SCALING IN RIBEIRA GRANDE GEOTHERMAL FIELD

During the 25 years of exploitation of the Ribeira Grande geothermal reservoir, chemical inhibition has been proving to be the best choice to keep the wells flowing continuously to the power plants. Every production well of the 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.

NALCO pHREEdom(R) 5200M is a formulation of a liquid polymeric dispersant and a patented inhibitor specially designed to prevent deposition of calcium carbonate. This product is very effective in extreme conditions of temperature, pressure and in a wide range of pH environments (NALCO, 2006).

The chemical inhibitor injection system is shown in Figure 5 and comprises the following equipment:

- Metering pump for continuous injection by impulses 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 assembled on the top and a ram BOP (valve) connected at the bottom. The lubricator allows the installation of the downhole equipment in the well under pressure;
- Downhole equipment: an inhibitor chamber (high pressure valve) and a sinker bar;
- Nickel-Iron-Chromium INCOLLOY Alloy 825 capillary tubing (¼" OD), used to conduct the inhibitor from the surface to the downhole equipment.

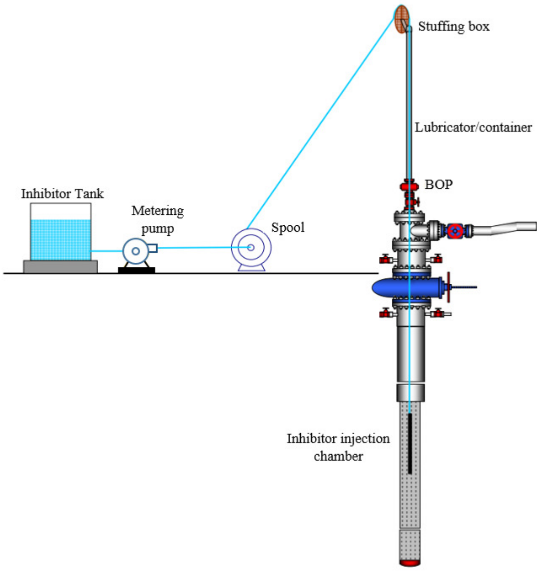

Figure 5: Inhibitor system installed in production wells (Pereira, 2014).

The inhibitor is supplied pure and diluted with decalcified fresh water, in the proportions calculated for each well, at an automatic mixing station located at Pico Vermelho power plant (Figure 6).

Figure 6: Station for water decalcification and inhibitor dilution (EDA RENOVÁVEIS).

The pre-diluted inhibitor is then transported in a small dedicated tanker truck and transferred into the inhibitor tanks located at each wellpad. Through an electrical metering pump, the inhibitor flow rate can be adjusted according to the calculated inhibitor concentration to apply. The most common inhibitor dosage is 3 ppm in well fluid, but in well PV8, the applied dosage is about 9 ppm. The injection of inhibitor is made continuously, by impulses, when the well is producing. Following the preventive maintenance plan, every six months, the system is removed from the well to inspect calcite deposition and evaluate the mechanical condition of the downhole tools. When needed, go devils are run in hole.

5. MECHANICAL CLEANING OF CALCITE SCALING IN WELL PV8 WHILE DISCHARGING

5.1 Introduction

Reaming calcite scaling in wells while discharging has a long history in some countries, where calcite scaling has great impact on the production. In Iceland this method has been used for over half a century in Hveragerdi and in Svartsengi geothermal field for a period of 14 years where the calcite deposition is controlled to be 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 in Hveragerdi.

This method, in opposition of reaming calcite deposits by quenching the well with cold water, prior to the operation, has significant and important benefits:

- Temperature in the wellbore and formation does not change;
- The well is ready to be reconnected to the power plant immediately after the operation, since it does not require time to re-heat and start to flow. The total time that the well is out of service is reduced;
- The casing and the cement bond keep the same properties, because there are no thermal cycles;
- The calcite cuttings are swept out of the well, rather than being pushed out into the formation or fall to the bottom of the well.

5.2 Wellhead configurations used in mechanical cleaning of scaling in wells discharging

There are different wellhead configurations used on reaming operations in high temperature wells while discharging: a) using a stripper and a rotating head or b) using stripper and a gland. The configuration a) can be used in deeper geothermal wells, with higher temperature and pressure. The configuration b) is smaller and more adequate for wells that operate with wellhead pressure below 20 bar and, preferably, when the calcite scaling depth isn't very deep, reducing the time of the cleaning operation

Despite the high level of security of the configuration a), a large rig is required with a high substructure to provide room for the wellhead equipment. It uses a rotating head (Figure 7 - B), a complete BOP stack installed bellow (as for normal drilling) and a spool with outlets for the exit of the BOP's cooling water. Below the spool, the pressure control equipment (Figure 7 – A) is composed by a special stripper and a Tee for the well flow discharge to the silencer line. Here, wellhead pressure is maintained by water inside the stripper. Between the Tee and the master valve there is one spool with outlets to use in case of need for the injection of cold water to quench the well.

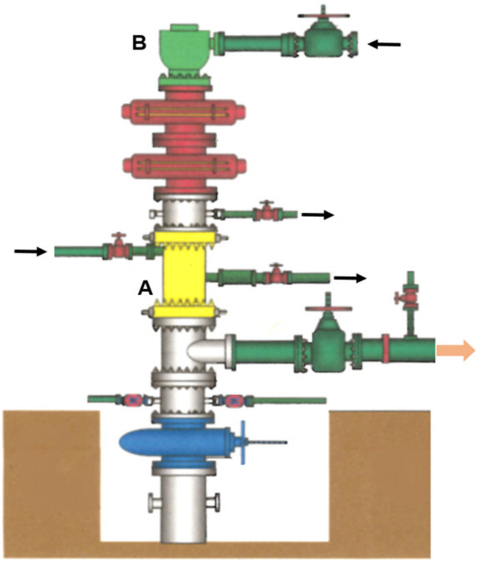

Figure 7: Wellhead configuration a) (Pereira, 2014).

In the upper part of the wellhead, the most important component is the rotating head which is normally responsible for diverting the flow during drilling, but in this assemblage its function is to hold the cold-water pressure during the cooling of the internal parts of the BOP stack equipment (rotating head, pipe ram BOP and ram block BOP). This wellhead configuration is currently in use in Iceland and the stripper mechanism shown has been continuously developed, increasing the reliability of the reaming operations.

In configuration b) the wellhead has two main components, the stripper (Figure 8 – A) and the gland (Figure 8 – B). The stripper is a type of diverter with two lateral outputs, separated internally by a flange with a metal seal to allow drill pipes 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 drill pipes. The drill pipes operated with this method must be outside flush to enable sealing by the stripper and ensure long service life of the metal seal.

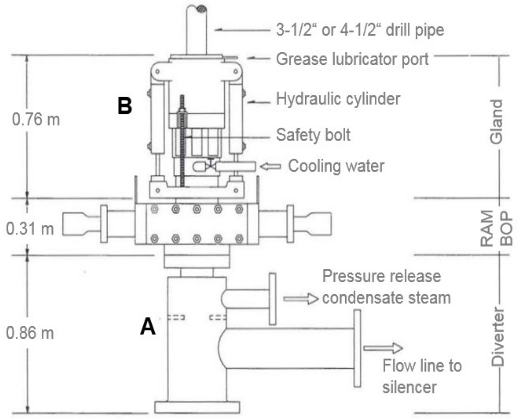

Figure 8: Wellhead configuration b) (Pereira, 2014).

5.3 Wellhead configuration used PV8 cleaning operation

Considering the configuration of the wellhead equipment of the geothermal wells at Ribeira Grande field, with lack of available space above the master valve, allied to the small dimension of the drill rig Ingersoll Rand RD20, with only about 0.6 m of free space below the rig table, it was developed a wellhead configuration that could be classified as type b) stripper and gland, but with some adaptations to well PV8. From these adaptations, the most crucial was the drawing and manufacture of the pressure control module, to function as a gland.

The pressure control system used in well PV8 (Figure 9) is composed by the following set of equipment installed above the 12” master valve and discharging Tee:

1) Pressure control module (PCM), with:
    a. A 12" ANSI 900 blind flange, with threaded bore and retaining sleeve, and
    b. The cooling containment chamber, with 3" side outlet for installation of the safety and flow control valves and, on the opposite side, 1-½" outlet pipe for installation of pressure measuring instruments.

    This equipment is fundamental in the operation, having been designed by EDA RENOVÁVEIS and built by Setilgest (Portugal);
2) 7-1/16" hydraulic pipe ram Blow Out Preventer;
3) Washington tubing Stripper, with high temperature rubber, prepared for the entrance of cold water, controlled by two 2" valves (float valve and gate valve);
4) One set of 3” valves (gate valve and control valve) at the outlet of the containment chamber to control the pressure inside the module and the discharge of heated water, resulting from the mixture of the cooling water and condensed steam of the well.

Figure 9: Pressure Control System: fabricated pressure control module, ram BOP and stripper (blue) before final assembly (Thorhallsson, 2017).

5.4 Operation procedure in well PV8

5.4.1. Preparation of the calcite cleaning operation

Previously to the cleaning operation, PV8 wellhead and wellpad were prepared to receive all the equipment necessary. For this purpose, the inhibitor system, lubricator, 3" top valve, 12" adapter, 12" Tee, 12" side valve were removed from the wellhead, except the master valve. The 12” Tee was installed again on top of the master valve.

To increase the space between the rig table and the master valve it was used a steel substructure to elevate and support the drilling rig, in line with the drill pipes platform. The main equipment that constitutes the pressure control system (without the 2” and 3” lateral valves and the gauges) was assembled outside the steel rig substructure, and lift as one, by a crane. This set is than connected to the 12” Tee, prior to the setup of the rig (Figure 10).

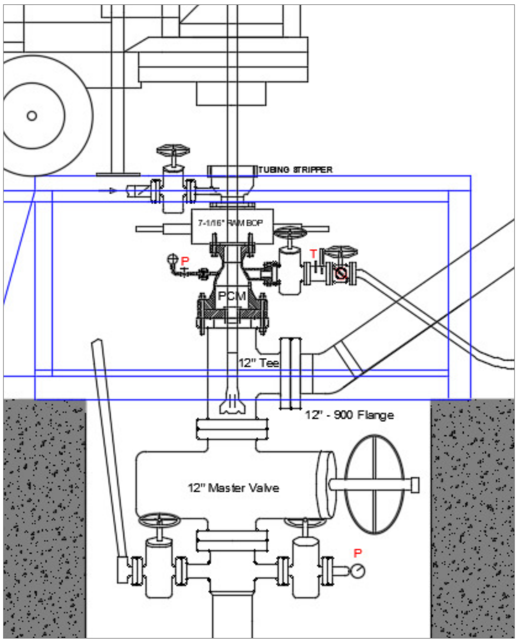

Figure 10: PV8 wellhead scheme, including water pipes assembly (Pereira, 2014).

After this, the cold-water lines were installed together with a 36 m^3 water tank, submersible pump, duplex pump, triplex pump, a set of valves to control water flow after the pumps and 6” aluminum pipes. To allow the discharge of the well and conduct the geothermal fluid to the 6,000 m^3 basin of the Pico Vermelho Geothermal Power Plant, a flow line was installed with one 12” gate valve, one 12” butterfly valve, 3 straight 16” pipe sections, the 8" lip, the atmospheric separator (silencer) and the weir box (Figure 11).

Figure 11: Flow line during cleaning operation (Thorhallsson, 2017).

5.4.2. Water supply system

The water available to conduct this operation should be enough to satisfy both of the following operations:

- Cooling the pressure control system, allowing the progress of the operation;
- Injection of cold water inside the well, using the 3” gate valve of the casing head to quench the well, as a backup scenario.

In case of well PV8, the main origin of water supply was the creek of Ribeira da Pernada, located near Pico Vermelho Power Plant. The water from this creek was conducted by gravity to the 36 m^3 water tank, located near PV8 wellpad and the triplex pump tank. The water line was made using aluminum tubes. The water tank was connected to the duplex pump, that was responsible for the water circulation at the pressure control system and could be derived also to the kill line through the pipe connected to the 3” valve on the casing head, below the wellhead 12” master valve.

For the backup scenario, a submersible pump installed inside the 6,000 m^3 basin of the Pico Vermelho Geothermal Power Plant that temporarily stores some of the reinjection geothermal fluid of the that power plant and connecting it to the 36 m^3 water tank.

5.4.3. Calcite scaling cleaning operation

All equipment, such as pressure control system and water pumps were assembled, connected and tested. To monitor the behavior of the equipment and well during the operation, as well as to register this information, analog and digital instrumentation equipment were installed, namely: Wellhead Pressure (WHP), Pressure in Module (P), Temperature in Module (T) and a water level sensor that was also installed in the weir box (Figure 12).

Figure 12 shows the flow of cold water (blue) and geothermal fluid (red) through the well and the pressure control system with outlets for the flow line (through valves B and A) and for the 6" aluminum pipe (connected to Pico Vermelho power plant basin through valves D and E). Two operation conditions are presented: pressure in the module (P) is lower than the WHP and vice versa.

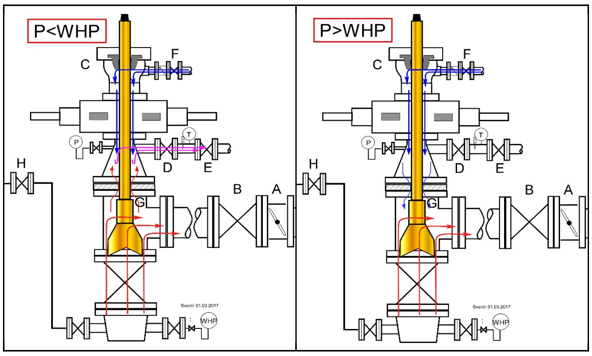

Figure 12: PV8 wellhead configuration: A - 12” butterfly valve (Vanessa), B - 12” gate valve (lateral), C - Washington tubing stripper, D - 3” gate valve, E - 3” control valve, F - 2” float and gate valves, G - 12” T; H- Kill line gate valve; P- Pressure gauge; T- Thermometer (Thorhallsson, 2017).

In the first condition (preferable situation for the operation), the gate valve D was fully open and control valve E start middle open and was gradually opened during the operation to release the condensed geothermal steam from the PCM and maintain a higher pressure inside the well, including the wellhead 12” Tee. In the second condition, when the pressure inside the PCM is higher than the WHP, the valve D is fully open (to register the temperature inside PCM) and the control valve E should be almost closed, forcing the cold water to flow across the PCM retaining sleeve to the 12” Tee, condensing all the geothermal steam inside the PCM, which will seep through the side valves B and A installed in the flow line up to the Pico Vermelho power plant basin.

For the reaming assembly, an 8-1/2" tricone bit (OD), a closed cross-over sub, a 3-1/2” small drill pipe with 2 m length and four 3-1/2" counterweight drill collars were assembled prior to 49 drill rods (with a unit length of 9.14 m and 3-1/2" OD).

Considering the time spent during the cleaning operation, and to preserve the tubing stripper rubber operating life time, cold water was continuously injected through the pressure control system using the duplex pump, in the condition P<WHP of Figure 12. During reaming and cleaning of calcite, the 12” gate valve and 12” butterfly valve were left open to allow the debris to be cleaned through the flow line and silencer (only in this stage was applied rotation to the drill pipes, to minimize the damage of the tubing stripper rubber). The operation summary is presented in chronological order below.

08:00 - Start circulating cold water through the pressure control system
08:43 - Open (100%) master valve
09:00 - Run in hole to 356 m
11:51 - Open Vanessa side valve. Geothermal fluid started to flow through flow line
12:05 - Start reaming calcite at 389 m
12:50 - End of reaming operation (tricone bit free) at 408 m. Still observing whitish fluid flowing to the weir box
13:30 - Translucid water flowing to the weir box. Close side valve Vanessa. POOH 49 drill rods
21:15 - Close master valve

Figure 13 shows the record of the main control parameters during the operation:

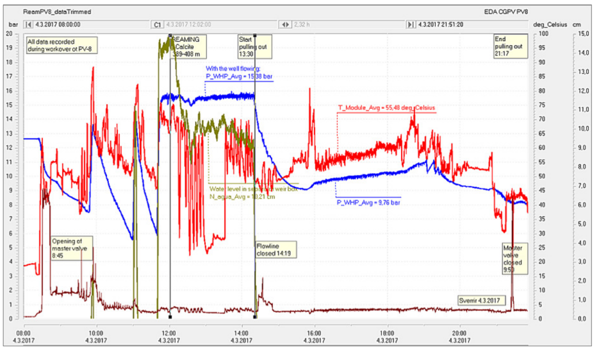

Figure 13: Digital record of the WHP (blue), P in the module (brown), T in the module (red) and water level in the flow tank (green) during the operation (Thorhallsson, 2017).

Analyzing the figure above, we verify that during the operation the pressure in the PCM remained low (less than 1 bar) and the temperature close to 60ºC, assuring the success of the operation. These values were obtained with the 3" valve (E) near its maximum opening and with the duplex pump flow rate between 9.4 l/s and 14 l/s. The cold-water flow was increased gradually during the operation to keep both temperature and pressure low in PCM, reaching a maximum of 14 l/s, after reaming the calcite and while pulling out from hole the reaming assembly.

During the next 2 days, PV8 was prepared to get back into production to the power plant. For that, the original wellhead equipment and the inhibitor system were installed.

The components of the pressure control system were also visually inspected, namely the rubber of the annular sealing valve and the retaining sleeve (main pressure sealing element). The retaining sleeve didn’t show any significative wear, but the rubber of the annular sealing valve has been slightly worn, so it will need to be replaced for the next operation of this type.

6. CONCLUSIONS

The injection of a chemical inhibitor has proved to be a good solution in the prevention of calcite scaling 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 calcite deposits.

Calcite reaming in a well discharging to a silencer pipe line allows large benefits, when compared with the alternative of quenching the well, mainly because it avoids thermal cycling in the well and formation. It also contributes for a better extraction of the scaling cuttings and in the end, there is a reduction of the time that the well is out of service.

The cleaning operation at PV8 was carried out safely on no major technical problems were encountered. The manufactured pressure control module sealed properly the well and its cooling was effective. The selection of this method for reaming calcite scaling combined with the regular inspection of the inhibitor system installed at PV8 improves the production of this important geothermal well at Ribeira Grande geothermal field.

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