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A Decrease of Calcium Carbonate Scaling Potential Due to an Increase of CO_2, a Case Study: PGM-29, Miravalles, Costa Rica

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ABSTRACT

Well PGM-29 is located in the southeastern sector of the Miravalles Geothermal Field; in this area all of the wells present high calcium carbonate scaling tendencies. From February 1997 to April 1998 a 5 MWe backpressure unit rented from the Comisión Federal de Electricidad of Mexico (CFE) was installed in this well. During that time, the mass production of PGM-29 was 200 kg/s and the chemical composition of the produce fluid was sodium-chloride-bicarbonate type waters with a content of non-condensable gases in the steam of 5% w/w at 7.0 bar absolute separation. Due to the high scaling potential (1296 kg of $CaCO_3$ per day) dosages of calcium carbonate inhibitor were from 4 to 8 ppm. After several years of being out of commercial production, in January 2007 another 5 MWe backpressure unit owned by ICE (Instituto Costarricense de Electricidad) was installed in PGM-29.

During this second production period the chemical composition of PGM-29 fluids remained the same type but the TDS increased around 700 ppm and the non-condensable gases in the steam went up to 88% w/w. According to the chemical inhibition monitoring system, there were no calcium carbonate deposits although this well has been characterized by a high scaling potential. This behavior was related to an increase of CO_2 concentration has an effect in the bicarbonate-carbonate equilibrium that increases calcite solubility.

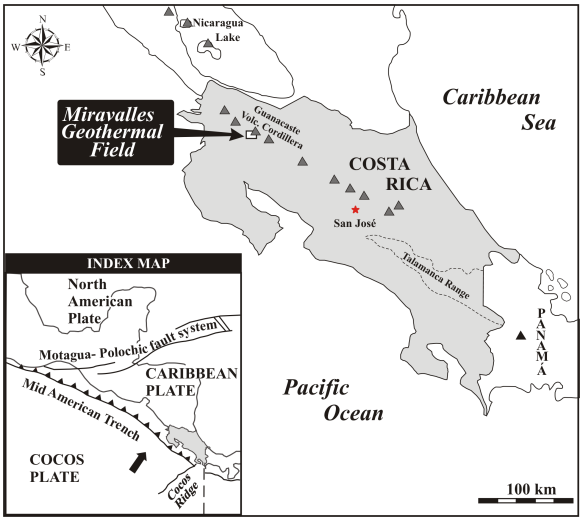

Figure 1: Location map, modified from Vega et al. (2005).

PGM-29 has been producing continuously since January 2007 and the non-condensable gases content has decreased to a value around 22% w/w. Calcite saturation indexes calculated utilizing WATCH software (v. 2.3) indicate that PGM-29 fluids are only slightly oversaturated in this mineral and experience has shown that calcite is not forming. Under these circumstances, in PGM-29 a dose of 2.5 ppm of inhibitor is injected as a precaution in case the CO_2 content decreases and a very strict monitoring plan is maintained in order to detect any change in chemical composition of its fluids that would modify the calcite saturation conditions.

1. INTRODUCTION

The Miravalles Geothermal Field (**Figure 1**) is located in the north-western part of Costa Rica. Deep drilling started in 1979, when a high-temperature reservoir was discovered. Subsequent drilling stages completed the steam necessary to feed three flash plants commissioned in 1994, 1998 and 2000, and one binary plant in 2004, totaling an installed capacity of 163 MW. Three wellhead units of 5 MWe each have produced for different periods, and one of them is still producing and belongs to ICE (Instituto Costarricense de Electricidad).

During the year 2008, the geothermal energy installed capacity was 7.0% of the total installed capacity of Costa Rica, and the energy produced at Miravalles during the same year represented 12.1% of the total energy generated in the country (Mainieri, 2009).

At Miravalles, 53 wells have been drilled, 31 of them are or could be used for producing steam and 13 for brine reinjection. Among the production wells, 5 produce acid fluids and 4 of them are now producing by means of deep neutralization of such fluids. The total production of the wells in Miravalles is about 300 kg/s of steam, and about 1350 kg/s of brine (about 800 kg/s are used for a binary plant) are injected back to the reservoir.

2. CHEMICAL EVOLUTION OF PGM-29

Well PGM-29 was drilled between June 2nd and July 26th, 1994. The total depth of this well is 1400 meters. The production zones are located at 720 and 1380 meters depth below surface. The deepest production zone is the most productive.

Well PGM-29 is located in the southeastern sector of the Miravalles Geothermal Field, were the sodium-chloride-bicarbonate aquifer (Na-Cl-HCO3) has been encountered (Figure 2). Most of the wells in Miravalles produce from a different aquifer with a neutral sodium-chloride (Na-Cl). The fluids from the Na-Cl-HCO3 after flashing at 98°C and cooling to ambient temperature present pH values between 7.4 and 8.2, chloride contents from 4,000 to 4,300 ppm, bicarbonate from 160 to 215 ppm, silica from 550 to 560 ppm, calcium from 60 to 70 ppm, and TDS (total dissolved solids) between 8,000 and 8,400 ppm. A remarkable characteristic of those fluids is their high values of non-condensable gases. CO_2 is the main gaseous component

(>98%). The fluids from this aquifer are saturated in calcium carbonate, thus the wells in this area present high scaling tendencies. Production from these wells without inhibition systems will clog the casing in a few days.

From February 1997 to April 1998 a 5 MWe backpressure unit rented from the Comisión Federal de Electricidad of Mexico (CFE) was installed in this well. During that time, the mass production of PGM-29 was 200 kg/s and the chemical composition its fluids was sodium-chloride-bicarbonate type water with a content of non-condensable gases in the steam of 5% w/w at 7.0 bar absolute separation. Due to the high scaling potential (1296 kg of $CaCO_3$ per day) dosages of calcium carbonate inhibitor were from 4 to 8 ppm (**Figure 3**). On April 1998 the backpressure unit was shut down and PGM-29 was closed.

On May 29th 2001 PGM-29 was produced during a 12 hour production test. Compared to 1997-1998 period, the fluids showed an increase in chloride and TDS values of 250 and 500 ppm respectively. On the other hand, the non-condensable gas content rose between 19.82 and 32.98% at 7.0 bar absolute separation. The total maximum mass flow was 211 kg/s (González, 2001).

From December 15th to 16th a production test was carried out. The tendencies of increasing chlorides and TDS were the same observed during the 2001 test. Non-condensable gas contents were from 23.15 to 23.49 % w/w. The total maximum mass flow was 190 kg/s (González and Torres, 2004).

The PGM-29 2001 and 2003 production test, behavior of increase in chloride, TDS and non-condensable gas was associated with an activation of other production zone, caused by hydraulic fracturing linked to the reinjection zone around PGM-28 after the start of Miravalles 3 27,6 MWe power plant.

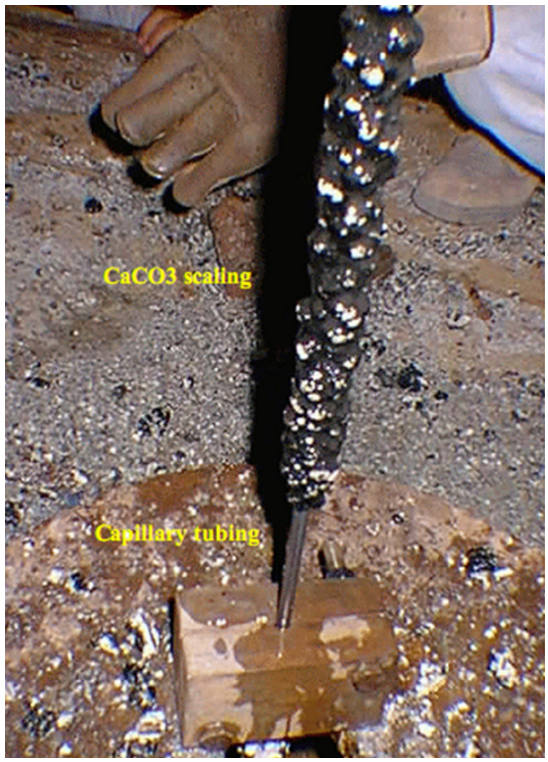

Figure 3: Calcite scaling on capillary tubing in well PGM-29, after a stop of the inhibition system due to an electrical system failure. Accumulated time of stop of the system was less than 48 hours.

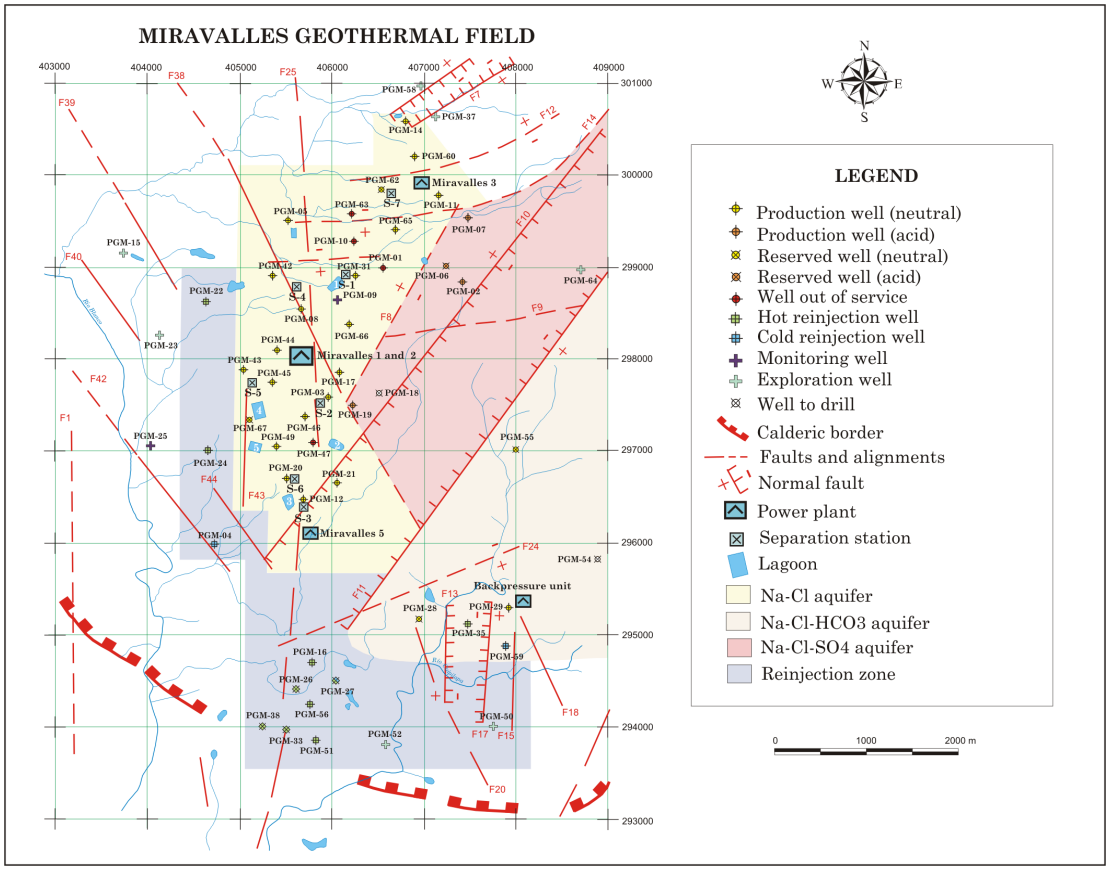

Figure 2: Miravalles Geothermal Field.

During December 2006 a production test was conducted in PGM-29 in order to evaluate this well prior the start of another 5 MWe backpressure power plant. The chemical composition of PGM-29 fluids remained the same type but the chloride increased up to 400 ppm and TDS up to 700 ppm. The most significant change occurred in the non-condensable gases in the steam whose values increased up to 88% w/w. Figure 4 shows both the chloride and non-condensable gases in steam during the production history of PGM-29.

3. CHANGES IN CALCIUM CARBONATE SATURATION

During the 2006 production test and before the start of the inhibition system, a baseline test was carried out in order to carefully determine the calcium carbonate inhibitor dose. The baseline used was the Ca/Cl ratio when the calcium carbonate was not inhibited. When there is no $CaCO_3$ scaling inside the well (i.e. the inhibition systems is working properly) this ratio will be higher compared to the baseline. The inhibition head was placed at 1000 meters depth and a 5 ppm inhibitor dose was applied. Soon after, it resulted that the Ca/Cl ratio was exactly the same compared to the baseline. This situation suggested that PGM-29 fluids were not inhibited at all. Consequently, the inhibition head was lowered 100 meters and the dose was increased to 7 ppm. This decision was taken based on the hypothesis that the flashing point was lower (temperature profiles had not been done yet). Again, the chemical analyses showed similar results to the baseline. The inhibition head was removed to the surface and inspected after several hours of this behavior. The inspection showed no signs of any scaling (Figure 5).

This situation seemed contradictory because PGM-29 had been characterized by a high scaling potential. This behavior was related to an increase of non-condensable gases because the chemical reaction that describes calcium carbonate formation indicates that an increase of CO_2 concentration will cause equation (1) go to the left. This has an effect in the bicarbonate-carbonate equilibrium that increases calcite solubility.

$$2HCO_3^- + Ca^{2+} \Leftrightarrow CaCO_3 + H_2O + CO_2 \quad (1)$$

Figure 5: The inhibition head was inspected on 8th December 2006.

It was known that, deep CO_2 injection tests performed in geothermal wells have been successful in United States for counteracting calcium carbonate scaling. However, the economical feasibility of those experiments has been questioned (Corsi et al., 1985).

Calcite saturation indexes calculated at different times and non-condensable gas in steam concentrations are shown in Figure 6. Calculations were made with WATCH speciation software (v. 2.3; 2004).

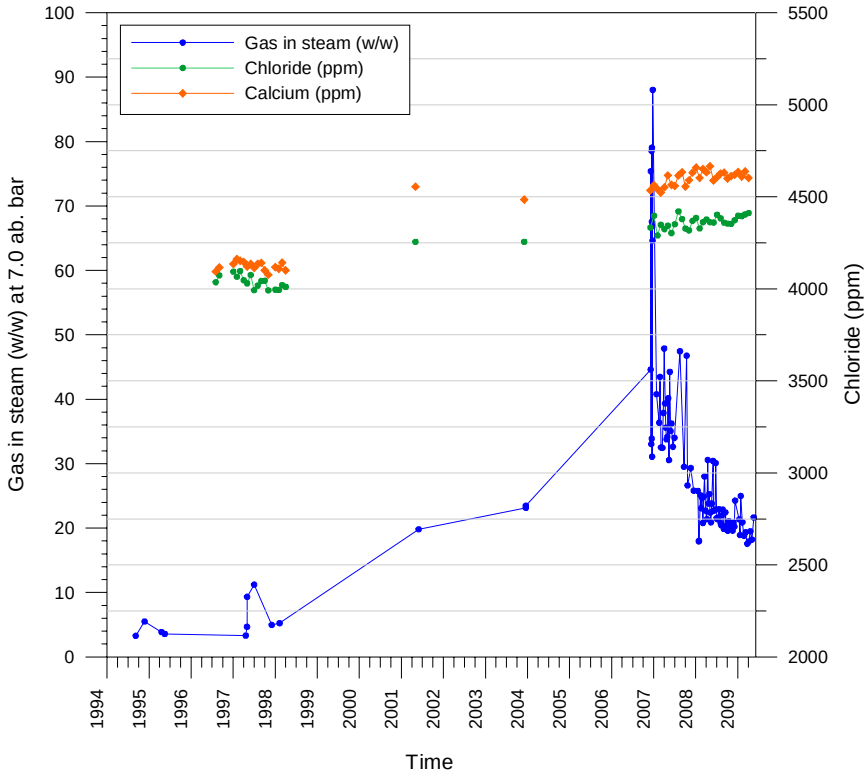

Figure 4: Non-condensable gas in steam and chloride in PGM-29 fluids.

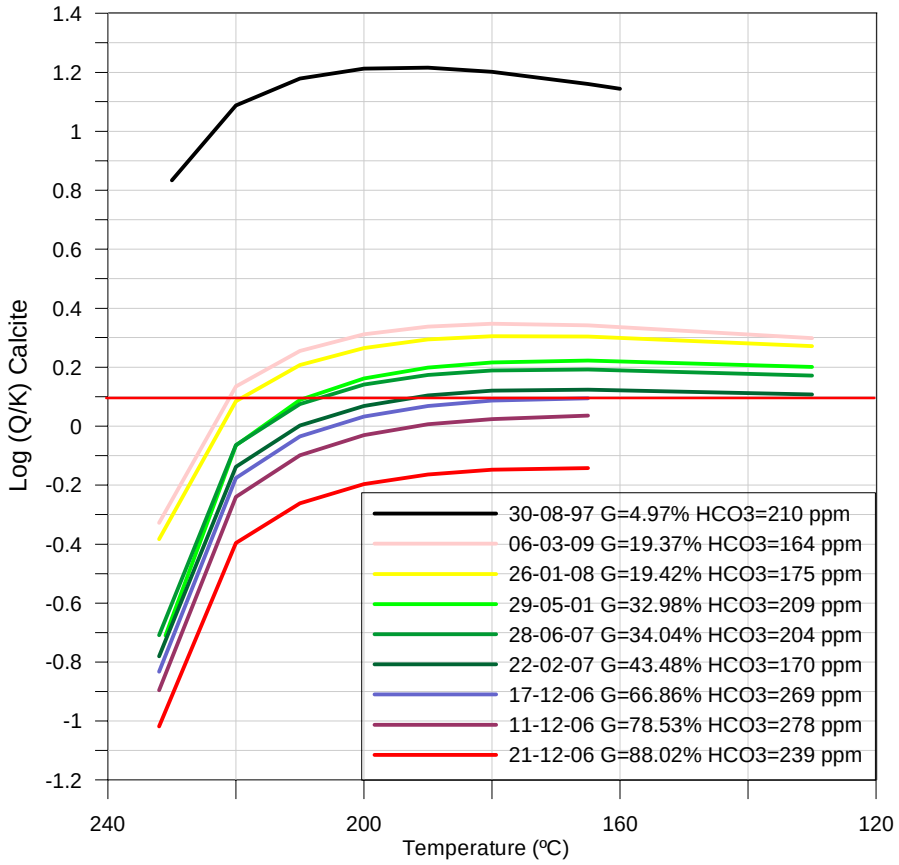

Figure 6: Calcite saturation indexes.

It is observed that below 34% of a non-condensable gases value calcite reaches oversaturation. However, from 21st to 22nd July, 2008 a baseline was conducted while the fluids were having gases values from 27.49 to 38.45%. These results indicated that even at 27.49% the kinetics of the reaction in PGM-29 did not present $CaCO_3$ scaling. At present an inhibitor dose of 2.5 ppm is injected at PGM-29 as a precaution even though calcite is not expected to form. Chemical sampling is conducted twice a week for inhibition monitoring purposes. Furthermore, gas sampling is performed monthly. The risk to the well is that a decrease in gas content in PGM-29 fluids could cause a severe scaling tendency like the one observed during 1997-1998 period.

4. CONCLUSIONS

During 2001 and 2003 production tests, the changes observed in PGM-29 fluids like the increase in chloride, TDS and non-condensable gas, indicated activation of other production zone (gas-rich zone), caused by hydraulic fracturing linked to an increase of the reinjected mass in PGM-28.

The increase in CO_2 caused a change in calcite saturation that was reflected in a scaling tendency decrease of PGM-29 fluids. The decrease in scaling tending was modeled using WATCH speciation software to validate the observations. The calculations suggest same risk of scaling remains at the present production conditions with 22% w/w gas and so a small amount at anti-scalant is still being injected as a precaution in case the CO_2 content decreases.

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