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Silica Scaling as a Predominant Factor of the Production in Cerro Prieto Geothermal Wells, Mexico

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ABSTRACT

The Cerro Prieto field is one of the most studied geothermal reservoirs in the world, therefore, several methods and techniques have been used to solve or minimise some problems that impact on the production of wells. However, the silica scaling problems maybe the hardest to minimise, since it occurs both in the reservoir and well casing. The scaling problems of wells in Cerro Prieto represent a major problem, the geothermal brines produced by wells contain dissolved minerals that have high tendency to precipitate and cause a decrease in power generating efficiency. Removal of the scale involves taking the well off line while physically cleaning the deposit downhole. This process restores the well efficiency in some cases, but it is extremely costly and time consuming. Comision Federal de Electricidad (Mexican Electricity Utility) which operates the field has to do about 12 workovers each year n wells affected by silica scaling. To understand the silica scaling mechanisms is very difficult due to several variables involved. Some models have been used to explain the silica deposition in geothermal fields but today geothermal research has not reached the best result to eliminate or minimise these problems.

This paper mainly deals with silica scaling problems and presents a simple preliminary model to determine the silica scaling amount precipitating into the well, while the flow ascends in the production casing to the wellhead.

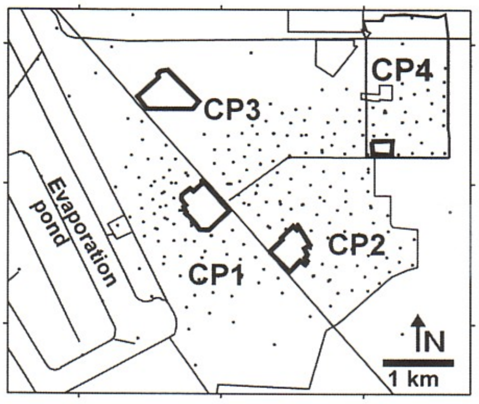

Figure 1. Cerro Prieto wells location

1. INTRODUCTION

Cerro Prieto geothermal Field is located in Baja California State, in Mexicali Valley 35 miles south of the USA border. Cerro Prieto is one of the largest geothermal fields in the world; and began exploitation in 1973. After 31 years in production, more than 250 wells have been drilled with depths ranging from 1000 to 4500 m. The bottom hole temperatures in most of the production wells are between 280 °C and 367 C°, the highest being measured in CP 3 and CP 4 areas. At present there are an average of 150 production wells, allocated in four production areas identified as CP I, CP 1, CP 2, CP 3 and CP 4 (see figure 1). At present, there is an installed power generating capacity of 720 MWe, distributed in four power plants. The steam flow rate necessary to generate the electricity by the power plants is about 6,500 metric tons per hour.

2. BRINE AND GAS CHEMISTRY

A typical brine chemical composition of separated brine at atmospheric pressure is shown in Table 1. However, several types of brine with different chemistry conditions are found in the Cerro Prieto production areas. The chemistry of these types of brines varies and the differences depend on several factors including the geology of the resource, temperature, pressure and water source.

Table 1. Typical chemical analysis of brine from Cerro Prieto Wells in PPM. Not include CP 4 area.

	CP 1	C P 2	CP 3	TOTAL
Na	6,445	9,915	8,659	7,942
K	1,455	2,710	2,274	2,047
Ca	292	445	387	351
Cl	11,766	18,627	16,125	14,823
SiO_2	931	1,028	891	983
Total	20,462	32,899	28,262	27,378

As can be seen the following relation among cations and anions components in the brine (Mercado et al, 1989):

Cations: $Na^{+} > K^{+}>Ca^{2}+>Mg^{2}$

Anions: $Cl^{-} > HCO_3^{-} > SO^{2-}_4$

A typical main gas composition in steam is shown in Table 2.

The brines produced at Cerro Prieto wells have been difficult to handle. The mixture of water, elements and gases in the flow contains enormous amounts of energy and the high temperature solution of elements and compounds, causes production limitations in geothermal operations. The brine produced at Cerro Prieto wells has originated from the mixing of the Colorado River, water with sea water evaporated to about six times its normal salinity (Truesdell et al., 1981). This mixture circulated deeply and was heated by magmatic processes. During deep circulation Li, K, B, SiO_2, and minor quantity of Na were transferred to the rock. Oxygen isotopes in the fluid are in equilibrium with reservoir calcite (Hurtado et al., 1983).

Table 2. Typical chemical analysis of main gases in the steam, from Cerro Prieto Wells in % by weight. Not Include CP 4 area.

GASES	CP 1	CP 2	CP 3	TOTAL
Carbon Dioxide (CO_2)	1.233	1.032	1.711	1.220
Hydrogen Sulfide (H^2S)	0.047	0.058	0.061	0.060
Ammonia (NH_3)	0.007	0.006	0.008	0.007
Others	0.021	0.026	0.042	0.029
TOTAL	1.038	1.120	1.822	1.375

3. SCALING PROBLEMS

Scaling in Cerro Prieto field occurs in both the geothermal reservoir and in the production casing. As a consequence of this, a greater number of supporting wells are necessary to obtain continuous production of steam, due to production decrease due to scaling, and the maintenance and workover periods. The cost of descaling is high because the method used requires drilling equipment.

Hurtado et al., (1983), realized an investigation on scale characterization at Cerro Prieto, they pointed out the principal mineral deposition in the production line of the Cerro Prieto wells are: Calcite, Sphalerite galena, Luzomite, and amorphous silicate. Almost all wells analyzed in his study were of CP I area. Mercado et al., (1989), realized a report about geothermal scaling in Cerro Prieto wells. They prepared some scaling profiles which are show in figure 2.

In addition, Hurtado et al., (1990) realized a report on scale control studies at the Cerro Prieto geothermal plant. This study included wells with scaling problems and methods to eliminate the silica plugs in pipes.

In the main, three types of scale occur at Cerro Prieto field: Calcium carbonate (Calcite), Amorphous silica (SiO_2), and Metallic sulphides, principally iron, lead and cooper (Ocampo et al., 2003).

CP 1 area wells showed deposits of calcite and silica scale, with calcite tending to occur at greater depth than silica, but there is a considerable overlap.

CP 2, CP 3, and CP 4, production areas have been showing silica and lesser sulphide scale, the sulphide tending, to occur at greater depth. The three types of scales formed in response to changes in producing fluids as it moves through the reservoir and up the wells.

The reservoir fluids are saturated with silica, the sulphides and calcite as a result of water-rock reaction. When the fluid boils as it travels up the wells, it cools and loses steam, then increases the concentration of dissolved minerals in the liquid phase and causes deposition inside the pipe. It also loses dissolved CO_2 gas, which causes a change in pH. Silica forms principally in response to the concentration and sulphides as a result of cooling, and calcite in response to pH changes.

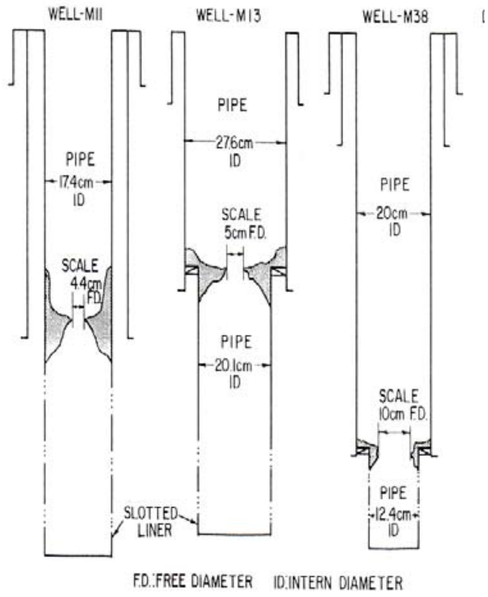

Figure 2. Cerro Prieto wells scaling profiles

The amount of silica and sulphides dissolved in a geothermal reservoir essentially is a function of temperature Silica is controlled by quartz, which reaches maximum solubility at about 340 °C.

The main silica scaling formed in Cerro Prieto production casing is from boiling point to bottom hole. Figure 3 shows a schematic of the event.

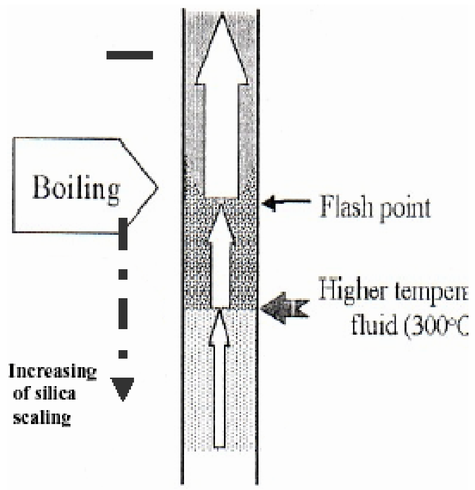

Figure 3. Boiling point depth.

The sulphide minerals become oversaturated as soon as the fluid cools below reservoir temperatures, although the iron sulphides tend to form only after cooling has advanced beyond saturation, as a result of slow reaction rates. The amorphous silica, which forms from dissolved SiO_2, becomes saturated only after considerable boiling and cooling.

Calcite scale deposition is a more complex function of physical chemistry (for example, total salinity, pH and concentration of calcium and dissolved CO_2) and the pH change upon boiling compared to the rate of cooling upon boiling. Calcite always is saturated in the reservoir fluid, and there is always a chemical potential to form calcite, which develops when the fluid boils. However, unlike silica and the sulfides, calcite becomes less soluble as temperature increases. As result, the most severe calcite scale deposition tends to occur from lower temperature geothermal fluids (below 220 °C to 240 °C) and it is relatively unusual to find calcite scale at wells as hot as those found in the CP 1 area. Even though there is a chemical potential for scale formation, the reaction rates are just slow enough to prevent it. For this reason, it may be that the CP 1 area scale is forming as a result of special conditions. One possibility is that the scale forms only when there is wellbore mixing between deeper, hotter and shallower, cooler component. Both components would be calcite-saturated, but the mixture would be oversaturated and have a particularly high scaling potential after flashing.

CFE personnel at Cerro Prieto made statistical analysis of workovers between 1988-1991. The results pointed out that the percentage steam recovery after workover in 11 wells, using a mechanical scale removal inside the production casing, was 45% with respect to the initial steam flow rate produced. Gutierrez Puente, H. and Mendoza, M.A., (1995) pointed out that each year in Cerro Prieto geothermal field, 12 to 16 wells are repaired a consequence of silica scaling that had caused a production decrease. Ocampo et al., (1997) analysed 27 workovers of Cerro Prieto wells, during 1994 to 1997. The results showed lowest steam recovery in wells cleaned inside the production casing. The best results were obtained in wells that were deepened.

4. SILICA PRECIPITATION

The prediction of silica scaling rates is obviously complex but determination of supersaturation is an important guide. Figure 4 shows the observed silica deposition rates in Cerro Prieto and Ohaaki geothermal field as a function of supersaturation.

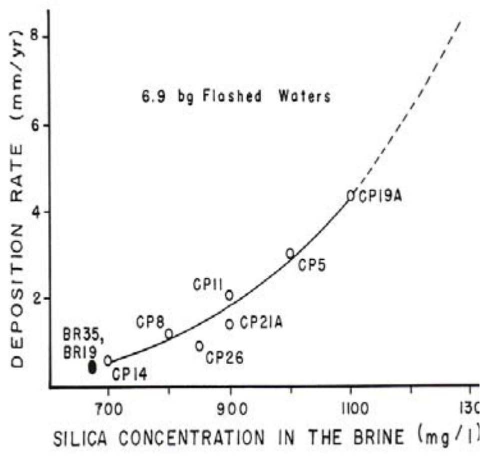

Figure 4. Silica concentrations for Cerro Prieto Wells

There are few works on methods or mathematical models applied on silica deposition in Cerro Prieto wells. Arellano, et al., (1991), developed a procedure to diagnose production abatement in Cerro Prieto wells. They found as, the main factors related to production decline the following:

- Surface pipeline scaling.
- Mechanical damage in the wellbore.
- Entrance of cooler fluids.
- Reservoir and well scaling.

The procedure proposal was applied to 17 wells from the Cerro Prieto geothermal field. Besides, a silica deposition rate parameter (Rd) was designated, which represents the potential for silica scaling in the production formation on the wellpipe. This may be used as a forecasting tool for scaling in a given well.

As can be observed the majority of the wells show a strong decrease in production. For cases grouped along the vertical line corresponding to Rd=0, the decrease in production was probably due to causes independent of the silica scaling process. It is important to observe that for all cases in which the Rd value is greater than 10 kg/h, a strong decrease in production is observed (in almost all cases the decrease in production is greater than 40 % per annum). A Rd value of 10 kg/h could be taken as the minimum value that indicates a dangerous level of reservoir scaling.

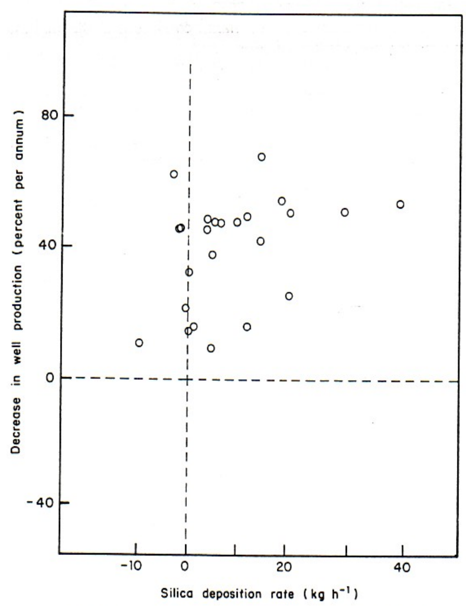

Figure 5. Silica deposition vs. decrease in production for Cerro Prieto wells

Beal et al., (1997), estimated a range of the silica subsurface deposition between 0 to 120 pounds per hour, in some CP 2 and CP 3 wells from chemical data of Cerro Prieto wells.

4.1 Preliminary silica deposition model

About 27 production wells were analyzed to obtain a preliminary mathematical model to calculate the silica deposition in Cerro Prieto wells while the fluids ascending to the wellhead. Therefore, the enthalpy production data was plotted against silica deposition in the well. The silica deposition was determined from chemical data at wellhead condition and downhole conditions, the difference between silica concentration (wellhead and downhole) determined the silica deposited inside the well. Figure 6 shows the correlation found between production enthalpy and silica deposition.

From the correlation obtained, a model to calculate the silica concentration in the fluid while it ascends to the wellhead was obtained. The preliminary models corresponds to a first order differential equation that is a function of the mixture quality and silica concentration.

$$C = C_0 e^{-k(1-x)} \qquad (1)$$

C= Silica concentration at any depth of the pipe

C_o= Silica concentration at downhole condition

x= Water fraction in the fluid.

k = constant

The model has been tested and will be integrated in a wellbore model. Figure 7 shows a plot of silica concentration (ppm) against water fraction (1-x) for well 600 of Cerro Prieto Field. The difference between wellhead and downhole concentration gives the silica deposition amount. It is necessary to include the silica deposition proposal model into wellbore two-phase models, since it calculates the water fraction (1-x) or quality (x) and flow rate water and steam ratios in each pipe section.

5. CONCLUSION

1. The complex of chemistry compounds contained in geothermal brine and steam creates operational limitations in power plants. The extreme scaling and corrosion characteristics of geothermal brine can cause important and, at times, catastrophic failures in plant operation. Production wells and gathering systems, plant vessels and generating equipment, injection lines and wells are all exposed to the extreme and harsh conditions of geothermal brine.

2. Scaling in Cerro Prieto field occurs in both reservoir and production casing. As a consequence of this, a greater number of supporting wells is necessary to obtain sufficient steam flow rate production.

3. The cost of descaling is high because in Cerro Prieto field the method usually used requires drilling equipment.

4. Three main types of scale occur at Cerro Prieto field: Calcium carbonate (calcite), Amorphous silica (SiO_2), and Metallic sulphides.

5. CFE personnel at Cerro Prieto made statistical analysis of workovers between 1988-1991, the results pointed out that steam flow rate recovery (percentage) after workover in 11 wells using a mechanical scale removal, inside the production casing, was 45% with respect to the initial steam flow rate.

6. Each year in Cerro Prieto geothermal field, 12 to 16 wells are repaired as a consequence of silica scaling that caused a production decrease.

7. The best result obtained with workover in wells with scaling problems has been by deepening the production zone.

8. The studies done about calculation silica deposition in Cerro Prieto reveal that values of 10 kg/hr could be taken as the minimum value that indicates a dangerous level of reservoir scaling

9. A mathematical silica deposition model was developed to determine the silica concentration at different depth of the production casing while the fluid ascends from the downhole to wellhead. The model was derived from first order differential equations, and will be included into two-phase flow wellbore models. The silica model proposed determines the silica concentration in the production casing from thermodynamic and geochemical characteristics of the fluids produced.

10. The silica model has been testing in several Cerro Prieto wells to validate the results.

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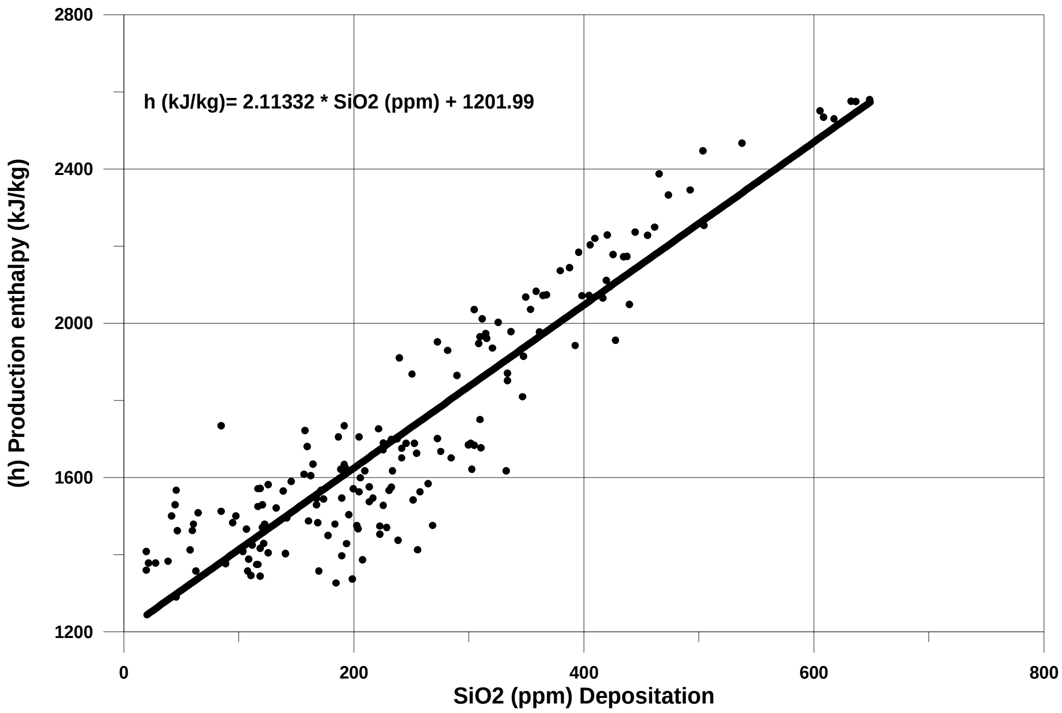
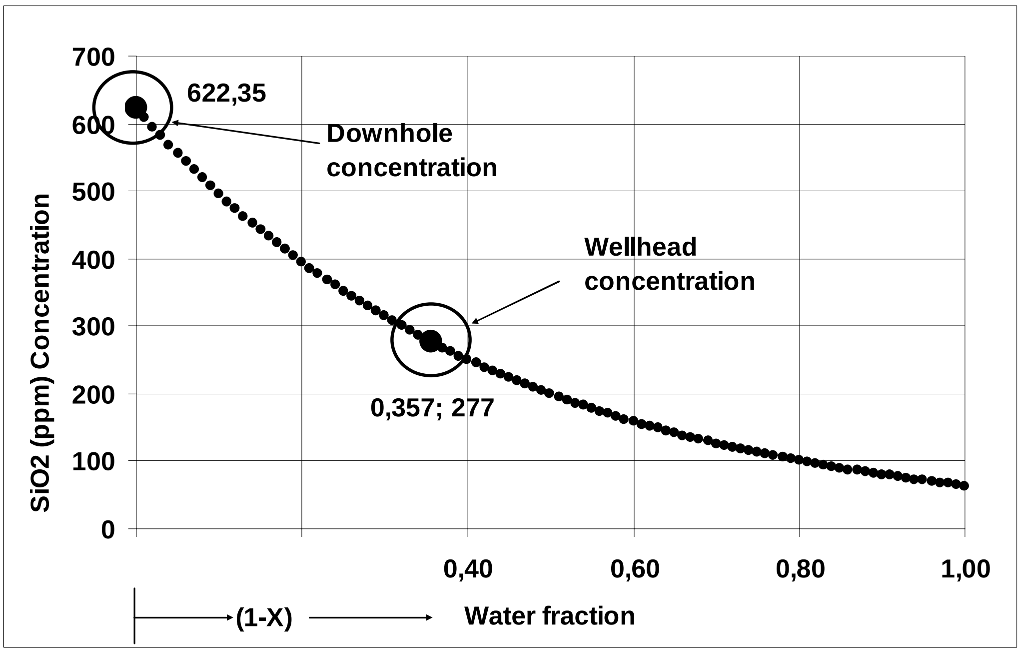


Figure 6. Silica deposition vs. production enthalpy for Cerro Prieto wells



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