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Review of Corrosion and Scaling Problems in Cerro Prieto Geothermal Field over 31 Years of Commercial Operations

Juan De Dios Ocampo[1]-Díaz, Benjamín Valdez-Salaz[2], Michael Shorr[2], Israel Sauceda[1]-M., Navor Rosas-González[2].

[1]Universidad Autónoma de Baja California, Facultad de Ingeniería
[2]Instituto de Ingeniería, Blv. Benito Juárez y Calle de la Normal s/n, Mexicali, B.C., México, c.p. 21900

E-mail: juandios@uabc.mx

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ABSTRACT

More than 35 years have passed since the first wells were drilled in Cerro Prieto, since then about 250 wells have been constructed in different field locations. Presently an average of 150 wells are supplying steam to four power plants with a capacity of 720 MWe. The fluids produced by wells are a mixture of steam-water in different ratios. The brine produced has different chemistry conditions depending on several factors including the geology of the well, downhole temperature, downhole pressure, and water source. The scaling and corrosion characteristics of brine have caused difficult problems during the Cerro Prieto development. There are a variety of problems associated with brine produced by wells such as reservoir formation plugging, well and line plugging, reduced steam-brine flow, casing fracture, superficial equipment damage, power plant equipment damage, power production losses, etc. Comision Federal de Electricidad (CFE), who operates the field, has employed different programs and methods to avoid, minimize, and help the control of the scaling and corrosion problems. This paper describes the main experiences in handling of corrosion and silica scaling problems experienced in Cerro Prieto field through its 31 years of commercial operation.

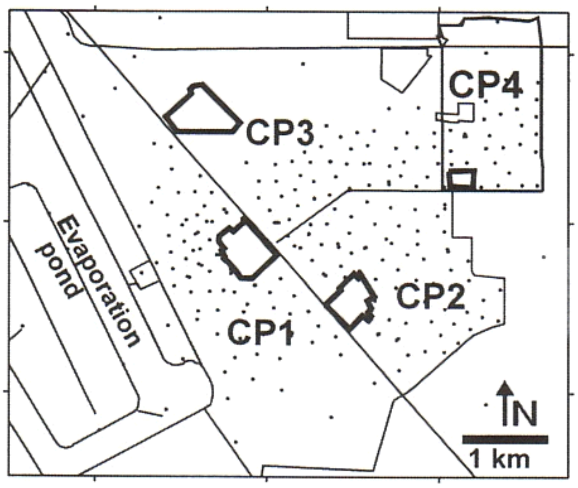

Figure 1. Cerro Prieto well locations

1. INTRODUCTION

Cerro Prieto geothermal field is located in Baja California in Mexicali Valley 35km south of the USA border. Cerro Prieto is one of the largest geothermal fields in the world, This field began exploitation in 1973. At the present day, after 31 years in production, there are more than 250 wells drilled at different depths, and an average of 150 wells are in production, allocated in four production areas identified as CP 1, CP 2, CP 3 and CP 4, (see figure 1). There is an installed power generating capacity of 720 MWe, distributed over four power plants. The steam flow rate necessary to generate the electricity in the four power plants is about 6,500 metric tons per hour.

2. PRODUCTION CHARACTERISTICS

Each production well in Cerro Prieto geothermal field has its own characteristics. These are determined by factors related to the productive strata of the reservoir, and by those of the well itself. These well factors include the depth, casing length and diameter, finishing and mechanical conditions. Cerro Prieto reservoir has a wide range of temperatures, pressures, enthalpies, flow rates, and chemical composition of fluids. Table 1 shows the production data for each Cerro Prieto area, as measured in December 2003.

Table 1. Characteristics of Cerro Prieto Production Areas

Produc. Area	# Produc. wells	Steam flow rate (t/h) high press.	Steam flow rate (t/h) low press.	Water flow rate (t/h)	Mixture flow rate (t/h)
CP 1	20	450.00		850.0	1,300.0
CP 2	58	2,021.0	281.0	3,518.0	5,821.0
CP 3	54	1,825.0	131.0	2,594.0	4,550.0
CP 4	16	950.0	69.0	765.0	1,785.0
Total	148	5,246.0	481.0	7,727.0	13,456.0

2.1 Chemical characteristics

The typical brine chemical composition of Cerro Prieto areas is shown in table 2. Table 3, shows the main gases in the steam produced by Cerro Prieto wells.

3. GEOTHERMAL BRINE ASPECTS

Geothermal brine can be extremely difficult to handle in field operations. This mixture of water, elements and gases contains enormous amounts of energy for power production. The high temperature solution of elements and compounds, however, causes operational limitations in geothermal power plants. These limitations are due to the severe scaling and corrosion characteristics of geothermal brine and steam. Different types of brine with different chemistry conditions are found in various areas around the world. Substantial differences can even be found within the various wells of a given field. The chemistry of these different brines varies and the differences will depend on several factors including the geology of the resource, temperature, pressure and water source.

The chemistry from different fields can vary substantially. Higher temperature resources with the higher water ratios have increased levels of silica that cause tremendous scaling and deposit problems. By contrast, dry steam fields do not experience the silica problems, but instead have aggressive corrosion problems associated with hydrogen chloride and hydrogen sulphide attack. Still other geothermal fields are hit with a double misfortune and encounter both scaling and corrosion problems at the same time.

Table 2. Typical brine chemical composition (PPM) at atmospheric pressure composition, not include CP 4 area

	CP 1	CP 2	CP 3	TOTAL
Sodium (Na)	6,445	9,915	8,659	7,942
Potassium (K)	1,455	2,710	2,274	2,047
Calcium (Ca)	292	445	387	351
Chloride (Cl)	11,766	18,627	16,125	14,823
Silica (Si)	931	1,028	891	983
Total Dissolved Solids (TDS)	20,462	32,899	28,262	27,378

Table 3. Main gases in the steam (PPM) % by weight, not include CP 4 area

	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

3.1 Problems Caused from Geothermal Brine.

The scaling and corrosion characteristics of brine and steam cause difficult problems in geothermal operation. The diversity of problems associated with handing geothermal brine can be extreme -- making it critical to understand the chemistry of the brine for successful field operation. Geothermal brine causes a variety of operational problems and includes the following:

1. Reservoir, Well and Line Plugging
2. Reduced Steam/Brine Flow
3. Equipment Repair or Replacement
4. Power Production Losses

All of these problems are directly associated with chemical characteristics of geothermal brine. Plant design can address some of the corrosion problems with the selection of corrosion resistant materials. The use of high alloy metals can be used, but often becomes cost prohibitive. Plant operating conditions can help reduce scaling problems.

3.2 Scaling in Geothermal Fields.

Scale is a major problem in geothermal operation. The plugging and deposit problems caused by scale can reduce well production, and create expansive cleaning costs. Different types of scales are found in various geothermal areas and sometimes even within the various wells of the same field. The major species of scale in geothermal brine typically include calcium, silica and sulphide compounds. Calcium compounds frequently encountered are calcium carbonate and calcium silicate. Metal silicate and metal sulphide scales are often observed in higher temperature resources. Typical metals associated with silicate and sulphide scales include zinc, iron, lead, magnesium, antimony and cadmium. Silica can present even more difficulties, as it will form an amorphous silica scale that is not associated with other cations. All of these scale types can present challenging operating problems for geothermal plants.

Calcium carbonate scale frequently causes operational problems in the brine handing systems. It typically forms as a result of the evolution of CO_2 from the liquid phase. CO_2 evolves any time a pressure drop occurs. Pressure drops occur in the flash vessels and also in localized areas of production well pumps or elbows in surface piping. As CO_2 evolves, the liquid phase will experience a corresponding pH increase. At elevated temperatures, even small amounts of calcium in the brine will precipitate with the pH increase. Fluids containing calcium (even small amounts) have the potential to form calcium scale, especially in the production wells. A “hydrodynamic” component associated with the fluid flow to the well and also through the well pipe will aggravate calcium scaling conditions. Calcium carbonate scale can form in production wells, plant vessels and equipment, and injection lines and wells.

Silica-related scale is the one of the most difficult scales occurring in geothermal operation. Silica is found in virtually all geothermal brines and its concentration is directly proportional to the temperature of the brine.

When pressure is dropped in the flash vessel, steam flashes and the temperature of the brine decreases. In the flash vessel, the brine phase becomes more concentrated and the silica, already unstable, becomes even more unstable. Under these conditions, silica precipitates as either amorphous silica or it will react with available cations (e.g Fe, Mg, Ca, Zn) and form silicate deposits. These deposits are extremely tenacious and can occur throughout the plant and injection system.

Sulphide scales can also be encountered in geothermal operation. Sulphide scales have been observed at high temperature as well as in low/medium temperature resources. Sulphide scales are associated with other metal cations, forming scale compounds that are very hard and difficult to handle. Sulphide scale has been observed in production wells with two phase flow and has caused plugging or choking of the brine flow from the well.

3.3 Scaling in Cerro Prieto Field.

Three main types of scale occur at Cerro Prieto field: calcium, carbonate (calcite), amorphous silica (SiO_2), and metallic sulphides (principally iron, much lesser lead and cooper), Ocampo et al., (2003).

CP1 area wells experience deposits of calcite and silica scale, with calcite tending to occur at greater depth than silica, but there is a considerable overlap. CP2 and CP3 area wells experience silica and to a lesser extent sulphide scale, the sulphide tending to occur at greater depth. All three types of scale form in response to changes in produced fluid as it moves through the reservoir and up the wells. The reservoir fluids are saturated with silica, sulphides and calcite as a result of water-rock reaction. When the fluid boils in the wells or the reservoir (or both), it cools and loses steam, concentrating the dissolved minerals. It also loses dissolved CO_2 gas, which causes a change in pH. Silica forms principally in response to the concentration and cooling, sulphides form in response to cooling, and calcite forms in response to the pH change. The amounts of silica and sulphides dissolved in a geothermal reservoir essentially are a function of temperature; increasing as temperature increases. Silica is controlled by quartz which reaches maximum solubility at about 340 °C. Because of this, it generally is true that the hotter the reservoir the more scaling occurs when the fluid cools, with or without boiling. This explains the greater amounts of silica and sulphide scales in CP 2 and CP 3 compared CP 1.

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 the iron sulphides tends to form only after cooling has advanced beyond saturation, as 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 initial 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 always is a chemical potential to form calcite which develops when the fluid boils. However, unlike silica and sulfides, calcite becomes less soluble as temperature increase. As result, the most severe calcite scale deposition tends to occur from lower temperature geothermal fluids (below about 220°C to 240°C) and it is relatively unusual to find calcite scale at wells as hot as those 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. Because of this, 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 fluid and a shallower, cooler component. Both components would be calcite-saturated, but the mixture would be oversaturated and have a particularly high scaling potential upon flashing.

3.4 Studies of Field Wide Scaling.

Mercado et al., (1989), realized an analysis of the scaling in Cerro Prieto wells. Figures 2 and 3 show some of wells included in this work, in some cases the major scale problems were detected at pipe diameter changes, as a consequence of the boiling point.

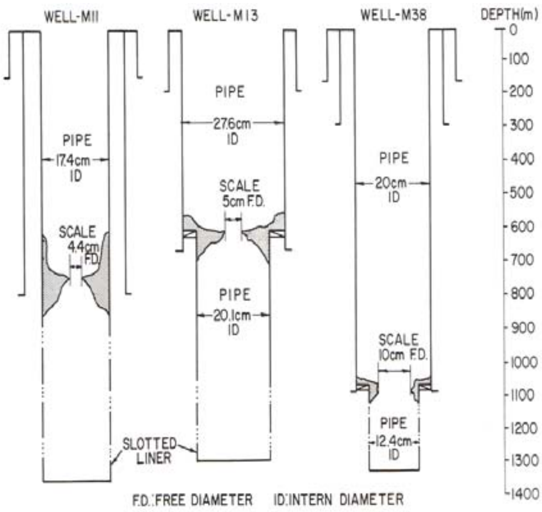

Figure 2. Scaling profiles in wells M-11, M-13, and M-38

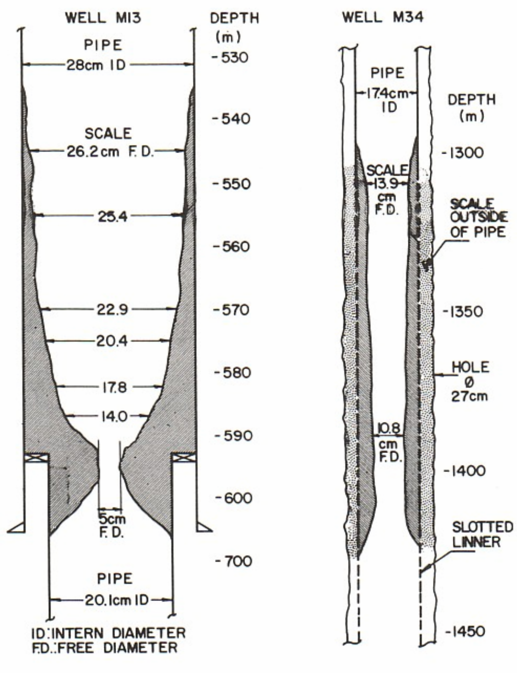

Figure 3. Scaling profiles in wells M-13, and M-34

CFE personnel at Cerro Prieto made statistical analysis of workovers between 1988-1991, the results pointed out that the steam percentage recovered 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. Arellano et al., (1991), developed a procedure to diagnose production abatement in Cerro Prieto wells, and found a silica deposition rate parameter (Rd) equal or greater than 10 kg/h. Gutierrez Puente, H. and Mendoza, M.A., (1995), pointed out that each year in Cerro Prieto geothermal field, 12 to 16 wells are repaired as a consequence silica scaling that had caused a production decrease. Ocampo and Pelayo, (1997) analysed 27 workovers of Cerro Prieto wells, from 1994 to 1997, and the results showed poor steam recovery in wells cleaned inside the production casing. The best results were obtained in wells that were deepened. Beal et al., (1997), estimated a range of the silica subsurface deposition between 0 to 120 pound per hour, in some CP2 and CP3 wells.

4. CORROSION IN GEOTHERMAL FIELDS

Corrosion attacks occur in many geothermal operations and these result in severe equipment damage. Production wells, steam and brine gathering systems, injection lines and wells are subject to the extreme corrosion tendencies of geothermal steam and brine. In many instances, steam turbines will also encounter stress corrosion cracking related to the chemical characteristics of geothermal steam. There are multiple mechanisms of corrosion attack contributing to the failure of pipe and equipment in these systems. These mechanisms involve the following types of contaminants and conditions in the steam and brine:

- Carbon Dioxide
- Hydrogen Sulfide
- Hydrogen Chloride
- Iron Sulfide
- Sulfuric Acid
- Oxygen
- Temperature
- Suspended Solids
- Flow Hydrodynamics

In liquid-dominated binary plant operation, the major species associated with corrosion attack is carbon dioxide. In the presence of carbon dioxide, the corrosion tendency of steel is controlled by the iron carbonate (siderite) corrosion product. Dense iron carbonate films prevail at higher temperature and more porous iron carbonate prevails at lower temperature. At higher temperature the denser iron carbonate is formed at the metal/brine interface and protects the steel substrate from attack. As temperature decreases, there is an abrupt transition to a more corrosive condition characterized by the formation of a more porous iron carbonate that does not effectively impede the corroding steel substrate. In flash plant operation, where steam and water rations vary, corrosion attack may include any or all of the contaminants listed previously. Hydrogen chloride and hydrogen sulfide attacks frequently occur in the production and steam/brine gathering systems. To further complicate things, corrosion by-products are generated and can react with silica and sulfide to form deposits in the systems.

4.1. Casing Corrosion in Cerro Prieto Wells.

To the present day, there have been more than 250 wells drilled in Cerro Prieto field, with different purposes: production, reinjection, exploration and observation, however the largest number have been production wells.

Dominguez et al., (1979, 1981) realized an analysis about cement degradation and casing corrosion in Cerro Prieto wells. In the group of wells M-3, M-5, M-7, M-8, M-45, M-46 and M-53, with exception of M-5 and M-8, corrosion problems have been detected. Figure 4, shows two wells with corrosion problems.

A careful analysis of these casing profiles shows that through time, different types of well completions have been used at Cerro Prieto. We observe different depths (according to the area), one or two casings, gun-perforated casings, hanging liners, and even slotted casings. Casings of grade J-55 are dominant, because they are less sensitive to chemical attack. Grade N-80 is considered to be more sensitive. However, it seems that the electrochemical action has been unmistakable and has damaged casings of grades J-55, K-55 and N-80.

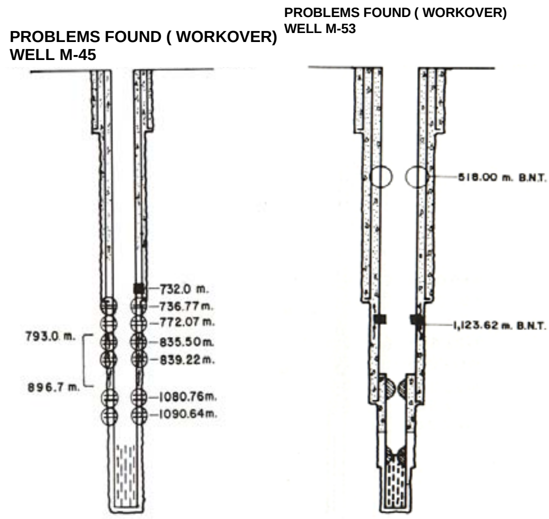

Figure 4. Wells M-45 and M-53 with corrosion problems.

After several years of production, some Cerro Prieto wells began to show problems which affect mostly the production casing, these were internal and external corrosion. The most severe of these problems was caused by electrochemical corrosion which produced the migration of the steel from the exterior of the casing into the formation. This phenomenon was associated with the transition zone in the reservoir, just above the hot zone (Dominguez, et al., (1981). After some time elapsed, due to the extent and gravity of the corrosion of the casing, some modifications were made in both the grade of steel and the thickness of the casing used. In many cases the corrosion problems affected the casing seriously, for example, in about two-and a half years after the well had been completed, the casing practically disappeared.

Before the start the commercial generation in the Cerro Prieto 2 and 3 power plants (1986), a lot of wells were drilled to feed these plants. However, after flowing some months and evaluating the discharge condition, several of the wells were choked until they stopped flowing. For some months these wells did not flow, until the power plants finished construction and the wells were reopened. At the beginning of the production, some wells showed problems due to corrosion mainly in the production casing. These events occurred during 1985-1986, and it was necessary to repair the wells in some cases by installing a casing of smaller diameter inside the damaged casing. The corrosion problems were caused as consequence of the mixture of air, gases and the static brine column in the well.

5. CONCLUDING REMARKS

1. The complex of chemical compounds contained in geothermal brine creates difficult production limitations in geothermal fields. The extreme scaling and corrosion characteristics of geothermal brine can cause severe damage and failures in wells and superficial installations

2. The following types of scale are found in Cerro Prieto wells: calcium carbonate (calcite), amorphous silica (SiO_2) and metallic sulfides (iron, and to a lesser extent lead and copper).

3. Mineral scale deposition occurred in almost all Cerro Prieto production wells.

4. Each year, Comision Federal de Electricidad realized about 12 workovers in wells affected by scaling both in pipes and in the reservoir.

5. The best alternative to working over the wells in Cerro Prieto field has been deepening the production zone.

6. During the first stage of commercial operation of Cerro Prieto Field an analysis of casing problems showed casing corrosion (internal and external corrosion). Electrochemical corrosion caused the damage in casing.

7. To avoid or minimise the corrosion problems, different casings grades have been used.

8. Also, the corrosion problem in pipes of production wells in Cerro Prieto has been correlated to reservoir steam zones with high amounts of H_2S gas.

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