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The Cerro Prieto IV Area: A Field Case Study

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ABSTRACT

Chemical composition of fluids produced by wells from Cerro Prieto IV (CP IV) area of the Cerro Prieto Geothermal Field have different features among them. Since Cerro Prieto Geothermal Field is a liquid-dominant system, most of the wells from CP IV produce a mixture of fluids from a zone deeper than wells from other parts of the field.

The chemistry of liquid samples is characteristic of a neutral and of the sodium chloride geothermal brine type. Recently, liquid samples from few wells from CP IV has shown pH below neutral; as well as changes in their chemistry. These changes in composition may be indicative of processes that are occurring in the system.

According to production and chemical data at least two groups of wells may be differentiated and probably are associated to geologic features in the field.

Introduction

The Cerro Prieto Geothermal Field (CPGF) is a liquid-dominant field, located in the northwest part of Mexico close to the United States border (Figure 1). It is the largest producing field within Mexico and has 720 MWe of installed capacity. It is the second largest producer in the world. At present more than 300 wells have been drilled not all of them are in use.

For administrative purposes the entire field has been divided into four areas known as CP-I, CP-II, CP-III and CP IV; being CP IV the shortest in productive life.

Two reservoirs have been inferred (Lippmann et al., 1991). The Alpha reservoir in the west part of the field is the shallowest and was the first to be exploited. It is found at depths between 1000 and 1500 m (Cerro Prieto I). The deeper Beta reservoir extends underneath the entire area of the Cerro Prieto at depths between 1500 and 2800 m with temperatures higher than those in Alpha reservoir.

The Beta reservoir is located in high porosity, permeable sandstones underlying a low porosity, relatively impermeable brown shale unit.

In the year 2000, the condensing type 100 MWe CP IV power plant enter on line to increase to 720 MWe the total power plant CP II mounted on line in 1981.

Figure 1. Location of wells and power plants in the Cerro Prieto geothermal field; CP IV roughly corresponds to the northeastern part of the field. Distances given in meters.
installed capacity in the field (Gutiérrez-Negrín and Quijano-León, 2005).

A particular feature is that compared to the whole field, the CP IV area has the highest average production enthalpy (Rodríguez M, 2003).

**Geological Setting**

The sediments at Cerro Prieto were deposited mainly in alluvial, deltaic, estuarine and shallow-marine environments during Pliocene to middle Pleistocene (Halfman et al., 1984).

The hydrological model developed by Halfman et al. (1984, 1986) for the entire field indicates that the geothermal fluids circulate horizontally through permeable stratum from east to west and vertically through faults.

Recently, Lira (2005) has identified five lithological units: The first (oldest) unit is the basement, represented by metamorphic and granitic rocks. The gray shale is the second unit, formed by intercalated shales and sandstones; average thickness: 3000 m. The thickness of sandstone in the gray shale varies from a few meters to 300 m; it has been called the silica epidote mineralized zone (SEMZ) and it is considered as the production zone.

The third unit is known as the brown shale. The top is found at 600 m to the west and at 2500 m to the east (well M-205). The fourth is the siltstone unit. It has a random distribution mainly in CP IV. It is found mainly to the east of the field. Layers of sandstone are also found in it.

Non-consolidated clastic sediments conform the fifth unit that is composed of sand, gravel, silt and clay. It is of variable thickness, thin at the west and thicker to the east.

Izquierdo et al. (2000, 2001) carried out mineralogical studies of cutting samples from the producing strata from wells of CP IV. Hydrothermal mineralogy is the common found in other geothermal systems. It reflects interaction with neutral to alkaline pH fluids.

**Cerro Prieto IV**

The Cerro Prieto IV area is located at the north east of the Cerro Prieto geothermal field. At present 31 wells have been drilled in this area; some of them from different reason are not on line. Figure 2 shows CP IV wells as well as main faults in the area. Drilling in CP IV started in 1985 with few wells (E-48, E-49, M-192, M-197, M-198 and NL-1); most of the wells were drilled from 1998 to 2005. So the operation of CP IV and information related to production is limited to a few years.

Four 25-MWe single flash units had been installed in CP IV; raising to 720 MWe the total installed capacity in the field (Gutiérrez-Negrín and Quijano León, 2005).

In CP IV the lithological units are deeper than in the west part of the field. At the west of the field, the top of the gray shale (SEMZ) is at a depth of 398 m; in CP IV it is found on average at 2000 m deep. The brown shale; which has been considered as an impermeable strata, is a narrow layer overlaying the gray shale (i.e. the productive zone) is very thin in CP IV. The non-consolidated clastic sediments also have variable thickness being thicker at the east in CP IV. The siltstone unit is found at the east of the field mainly in CP IV, where it has a variable thickness and a random distribution.

Using epidote as a marker, the top of the SEMZ is found at different levels deeper at the east of CP IV. It has an average of 1750 m at the west and 2100 m to the east. So all of the wells in CP IV have been drilled to depth greater than 2100 m.

Recharge of the beta reservoir has been considered to occur laterally along the edges of the geothermal reservoir (Truesdell and Lippmann, 1990), there is also evidences of inflow of descending cooler groundwaters. The hydrological model of Cerro Prieto developed by Halfman et al. (1984) describes the circulation of fluids from east to west as well as the ascension of hot fluids though faults. From the distribution of hydrothermal minerals Elders et al. (1984) also developed the same direction of fluids circulation pattern and suggested that the heat source was located to the east of the field.

Being a liquid dominated reservoir, the CP-IV wells produce a mixture of steam and liquid at the wellhead. The liquid fraction has a chemical composition characteristic of geothermal brine. According to the Piper classification, the CP-IV brine can be defined as of sodium-chloride type. The content of potassium and calcium are high, while that of lithium, boron and sulfate is very low. The salt concentration in the wellhead brine varies depending on the water/steam ratio, and of course by recharge.

Stable isotopic composition ($\delta^{18}O$ and $\delta^D$) for wellhead fluids are in the range of $-89.8\%$ to $-96.7\%$ for deuterium and $-7.3\%$ to $-9.4\%$ for oxygen-18. The stable isotopes indicate that the natural recharge to the reservoir consists of groundwater from the alluvial aquifer located in the western part of CP-IV area. The main gases for CP-IV are CO$_2$ (91 wt. %), H$_2$S (4 wt.%) and CH$_4$ (3 wt. %); i.e. represent over

![Figure 2. Location of wells and main inferred faults (solid lines) in CP IV. Distances given in meters.](image-url)
98 wt % (dry basis) of the non condensable gases (Portugal et al., 2005).

Respect to hydrothermal mineralogy, petrographic and X-ray analysis of samples from the production zone (SEMZ) CP IV wells revealed the occurrence of: Na-smectite, Ca-smectite, illite, chlorite and scarce interstratified minerals (Izquierdo et al., 2000, 2001). Calcite, quartz, epidote, illite, chlorite, smectite, wairakite, pyrite, amphiboles and scarce biotite were recognized under the microscope. These minerals occur in active hydrothermal systems where neutral to alkaline pH sodium-chloride fluids are present.

Optically, rock alteration was estimated to be close to 40 % in the cutting samples; it was defined as high rank and moderate intensity. In most of the samples, the rocks are terrigenous being shale more abundant than sandstone. According to minerals assemblages, the temperature in the SEMZ is in the range of 150 to 300 °C and higher when amphiboles are present.

**Fluid Production in CP IV**

According to the data provided by the Comisión Federal de Electricidad, the wells in CP IV have produced about 150 million tons of fluids (77 million tons of steam and 73 million tons of liquid) between the date each well started to produce to October 2005. In that part of the field, the best of the liquid producers under wellhead conditions are wells 406, 407, M-192 and 414 (Figure 3), while wells 423, 403, 424 and 425 (Figure 4) are the best of the steam producers.

Table 1 shows the main chemical components in the brine produced by the best CP IV liquid and steam producers. Some of the liquid producers have different chemical characteristics. For example, wells M-192 and 414 present higher values for all ions than wells 406 and 407, indicating the effects in the borehole, such as entrance of fluids from different strata.

The chemical composition of the brine sampled from the main steam producers also show differences (Table 1). Apparently steam production in well 403 occurs under a mechanism different than in wells 423, 424 and 425. This may be related to the location of 403 in the field. The particular chemistry of well 425 may reflect the effects of condensation; the brine collected has very low salinity. Its relative high B concentration may indicate deep fluid recharge; since B tends to be transported by deep high-temperature fluids. The relative high values of Mn and Fe in the brine may be related to the corrosion of the well casing.

Truesdell et al. (1992) associated the difference in several well parameters, like inlet vapor fraction, temperature, isotopes and Cl concentration, observed at CPII and CPIII to the location of the wells with respect to the dowthrown and upthrown blocks of the beta reservoir. At CP IV these two fault blocks are not so evident; however where the top of the
SEMZ is slightly displaced may indicate the location of the Fault H that limits these blocks. Using data provided by the Comisión Federal de Electricidad, several geological sections across CP IV were prepared, which showed slight offsets of the lithological units. The offset between NW wells (e.g. 403) and SE wells (e.g. 423) is between 150 m and 250 m.

Black circles in Figure 2 correspond to wells which have shown brines of low salinity. Most are located from southwest to south-east in direction to north-east close to branches of Fault H which was considered as a source of hot fluids (Halfman et al., 1984). So, it is possible that deep hot fluids are ascending through Fault H and reach the productive zone. Considering the two fault blocks mentioned by Truesdell et al. (1992) the difference in well fluid chemistry seems to reflect structural effects. For example, well 423 – the best steam producer and one of the deepest (2991m) in the southern part of CP IV – is located SE of Fault H (Figure 2), possibly in the downdropped block.

Casing corrosion has been observed in well 423. The recharging deep hot fluids might be corrosive or become corrosive on their way to the surface. Other possibility is that because of lack of fluid recharge the liquid remaining in the reservoir becomes concentrated forming a high-salinity brine. As the concentration of chemical species rises (e.g. of Cl) the aggressivity of the fluid increases, leading to the corrosion of the steel pipes. Physical and chemical characteristics of the CP IV steam wells suggest that condensation of very high-temperature steam may occur in the reservoir (Truesdell et al., 1992) or as it flows up the borehole toward the surface.

Recently, some of the CP IV wells have shown corrosion effects in their casings; also some black solids have been recovered from fluids sampled at the wellhead. X-ray diffraction analysis of these solids shows that they are mainly magnetite with minor amounts of halite and calcite.

The pH measured in samples collected from the wellhead does not show low values (Portugal et al., 2006). However the effects of corrosive fluids and most of the differences found in fluid chemistry of CP IV wells may be associated to the processes occurring in the reservoir in response to exploitation of the field or be related to different sources of fluid recharge; which may be controlled by geologic structures in the geothermal system, like Fault H.

**Conclusions**

From the production and chemical composition of fluids, in CP IV there are at least two groups of wells. The main difference between them seems to be the fluid recharge from different strata...

Also this recharge may feed aquifers located in the wide column of non consolidated elastic solids; and because of its permeability may recharge vertically to some wells and do no reach others.

The two groups of wells have a different chemical composition of the produced brines. They are located close to the main fault system; so the fractures may be conduits of a deep steam flow recharge.

Fluids with a pH below neutral are forming in wells located at the south of CP IV.

Corrosion effects in surface pipelines may be due to formation of acidic brines by the movement of deep hot fluid or because of the lack of recharge. A good example is well 425. Work has to be done in order to understand the processes occurring in the reservoir.

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