EFECTS OF COLD WATER RECHARGE ON DOWNHOLE TEMPERATURE WELLS OF CERRO PRIETO UNO AREA IN CERRO PRIETO FIELD MEXICO

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ABSTRACT

The first area under exploitation in Cerro Prieto geothermal field in México was Cerro Prieto I, this area of 12 km^2 is located in the west part of the geothermal field; it started the commercial production in 1973. Two reservoirs have been identified in CPI area, the shallow alpha and the deeper beta reservoir, which extends over the entire field. Through 30 years under exploitation the old field of Cerro Prieto I have been produced around 800 millions of tons of water-steam mixture; this geothermal area has been showing several reservoir changes in their chemical and thermodynamics properties. This part of the Cerro Prieto geothermal systems is strongly influenced by nearby groundwater aquifers; cooler water readily recharges the reservoir. In response to exploitation, the natural influx of cold water into the shallower alpha reservoir is mainly from the west and possibly from down fault named L, whiles the recharge to the deeper beta reservoir in this part of the field, and seems to be only lateral, from the west and possible south. As consequence of the cooler recharge some production wells in this area show a temperatures higher than 50 °C, and other show reversal temperatures in the downhole. This paper analysed and discusses the downhole temperatures evolution in this old area of the Cerro Prieto geothermal system with more than 30 years of commercial exploitation.

INTRODUCTION

The Cerro Prieto geothermal field, located in the northern Baja California, Mexico, about 35 km south of the US-Mexico border, is developed in the deltaic sands and shales. Extensive drilling by the Comisión Federal de Electricidad, has provided fairly detailed information concerning lithology and temperatures from about 800 to 3500 m depth approximately. Geothermal exploration in Cerro Prieto geothermal field started in the lathe 1950s and lead to drilling the first deep exploration wells in 1960-1961 (Lippman et al., 1999). The Comisión Federal de Electricidad of Mexico, which operates and manages Cerro Prieto began power commercial production in 1973 with 75 MWe; 1979, capacity was 150 MWe and by 1981, 180 MWe. At the end of 1986, by extending the production area to E and completing two 220-MWe plants, the total installed capacity reached 620 MWe, finally during 2000 was added two 100 MWe units more. Thus present day the total capacity at Cerro Prieto is 720 MWe.

Since started the reservoir develop, more than 250 wells have been drilled in Cerro Prieto, some of them are exploration wells, other injection wells, reservoir monitoring wells, and the highest percentage correspond to production wells. Approximating 150 wells are supplying steam to four power plants. Cerro Prieto is a largest liquid-dominated geothermal system under exploitation, these wells producing about 12,000 tons per hour of mixture of steam-water. The geothermal field has been divided in four areas CI, CPII, CPIII and CP IV (Fig 1).

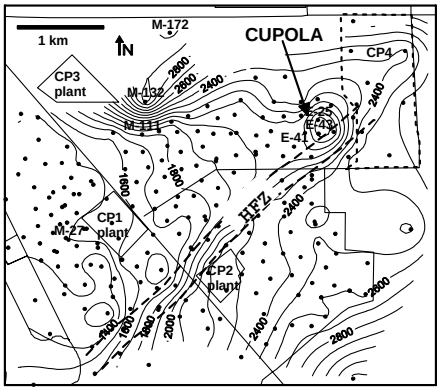

Figure 1.- Cerro Prieto Production areas

CERRO PRIETO RESERVOIR

The Cerro Prieto geothermal field is limited mainly by two important structures, the Cerro Prieto Fault at W and Imperial fault at NE. The top of the production zone have been defined by the silica-epidote zone. The Cerro Prieto wells produce from three major aquifer, the α (alpa) it

is the shallower reservoir located in the W of the field (CP I field), β (beta) it exist along of entire field underlying the alpa reservoir (CP I, II and III), and the deeper γ (gamma reservoir) to E of the field.

According to Halfman et al., Cerro Prieto Model (1984, 1986), the hot fluids originates at great depths in the eastern portion of the field flowing through the deepest reservoir identified like γ (gamma reservoir) and then the fluids rises along fault "H", flow westward through the sandstone into β (beta) reservoir, then ascending to sandy gap in shale and flowing westward through a sandy shale layer, corresponding to the α (alpa) reservoir, then rise up fault L , and flow westward trough the shallower sandstone.

However, the rock matrix permeability and porosity conditions dominated the intergranular fluid distribution in the reservoir, (Mahendra et al., 999, Ocampo et al, 2000). The Cerro Prieto wells produce from three major aquifer, the α (alpa) it is the shallower reservoir located in the W of the field (CP I field), β (beta) it exist along of entire field underlying the alpa reservoir (CP I, II and III), and the deeper γ (gamma reservoir) to E of the field.

Halfman et al. (1984, 1986) and Lippman et al. (1989) have described the natural state hydrology of Cerro Prieto. These descriptions are based on lithologic and temperatures logs and on modelling of heat and fluids flows. The general pattern of circulation in each of the Cerro Prieto reservoirs is similar

It has been suggested from geochemical arguments, that the deep recharge to the Cerro Prieto systems is formed from hypersaline brines of marines origin that mix with Colorado Rivers water in several stages (Truesdell et al., 1981). This mixing was the major process for cooling the Cerro Prieto brines in the natural state. The hot brines (at 350 ºC where first encountered) flow up normal faults H and enter the deep g (gamma) y b (beta) reservoir and then flows through part of the b (beta) reservoirs to the shallow α (alpha) reservoir. Each of these reservoirs has complex connection through more or less permeable interbedded sandstones and shales to the hot brines and in most parts to cooler water. The g (gamma) reservoir has been found only SE of fault H at depths greater than 3300 m. Very few wells produce from this aquifer. The entry of hot water suggests connection and flow to cold aquifers to maintain temperatures. The b (beta) reservoir is the largest in the exploited field. It underlies the entire α (alpha) reservoir and extends to the NE. The depth to this reservoir is around 1500 m in the W to more than 2700 m in the E. It is divided by SE dipping fault H into upthrown and downthrown blocks. Fluids ascending along fault H flow NW and SE into these two parts of the b (beta) reservoir (Fig. 2).

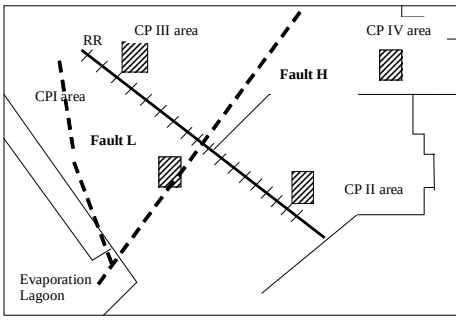

Figure 2.- Cerro Prieto Faults

CERRO PRIETO I FEATURES

The Cerro Prieto I area is located in west part of the field, (Figs. 1 and 2). This was first exploited area in Cerro Prieto geothermal field. This area presents two geothermal production zones, the shallow (at 1000 to 1500 m depth) named alpha reservoir and the deeper (below 1500 m depth) named beta reservoir (Sánchez and de la Peña, 1981). Previous fluid flow models of the Cerro Prieto were mainly based on the analysis of lithologic and temperature logs (e.g., Halfman et al., 1982, 1986; Lippmann et al., 1991). Rodriguez et al., (2000), have been classified CP I reservoir into five zones as to shows de table 1:

Table 1, Cerro Prieto I reservoirs subdivision

No.	Zone	Name	Depth average (m)
1	α_N	Alpha north	1500
2	β_N	Beta north	1600
3	α_S	Alpha south	1650
4	β_S	Beta south	1700
5	β_{SW}	Beta southwest	1800

Table 1, Cerro Prieto I reservoirs subdivision

In about 1977, some four year after the first power plant came on line, the geochemistry of the fluids produced by many Cerro Prieto I wells began reflecting an encroachment of cold water into the shallower alpha reservoir (Truesdell et al., 1979, 1989). With time, additional data confirmed that more-dilute

groundwater were recharging the geothermal systems and that heat was being swept by the colder water as they moved toward the producing wells (Grant et al., 1984). Initial fluids production began from the shallower alpha reservoir located only in the western part of the Cerro Prieto Field, this zones of the field is named CP I. As consequence of large-scale production from the deeper beta reservoir which extend over the entire field

Lipmman et all., (1989), realized an analysis of five wells located in Cerro Prieto I, in alpha and beta reservoir, using geochemical data (geothermometer and chloride concentrations), the table 2 shows de temperature decreasing calculated from this data using the NaKCa and Silica temperatures.

Well	Reservoir	Production	ΔT (°C)
M-42	Alpha	1976-1989	20
E-4	Beta	1981-1989	35
M-35	Alpha	1974-1989	70
M-31	Alpha	1971-1983	25

Table 2, Cerro Prieto I wells downhole temperatures

Between 1973 and 1980 most of the fluid produced at Cerro Prieto came from alpha reservoir. Present exploitation of the alpha reservoir continues but on a smaller scale as a reduce production enthalpy (i.e. steam /water ratio). As consequence of production, the pressure in the alpha reservoir has dropped resulting in an increasing of influx of colder, less saline water (Grant et al, 1984, Truesdell et al., 1984). The beta reservoir has been discovered in 1974 in the eastern part of the field with the drilling of well M-53. Some CPI deeper wells like E-1 are located in this reservoir.

Rodriguez, et al., (2002), realized an analysis of the dowhole temperatures in some Cerro Prieto I wells, using static temperature logs, the main comments obtained from it, are included in table 3:

Well	Time space	ΔT (°C)	Depth (m)
E-9	1984-1989	50 C	1700
M-143	1989-1987	50 C	1800
E-63	1989-1997	50	1700
M-48	1978-1989	90**	1200

** decreased compared with well E-57

Table 3, Temperature decreased observed in Cerro Prieto I wells

Rodriguez et al., (2000), realized the following observations:

- E-9 well, showed temperature decreased of 20 ° C in the αN reservoir upper 1450 m, and decreased of 50 °C in the βN reservoir below of 1450 m; similar temperatures were.

- Wells E-63, showed similar behaviour of well E-9.

- Well 143, drilled in 1998, shows a temperature reversal below of 1800 m.

- The temperature decreased observed in $\beta_1 S$ y en αS reservoirs were evaluated with static temperature logs in wells M-48, E-57, M-84 y M-84A, realized in different years; these point out a temperature decreasing of 80 °C in αS reservoir and les than 80 °C in $\beta_1 S$.

CERRO PRIETO I RECHARGE

As consequence of the continues exploitation through 30 years, Cerro Prieto I reservoirs have been producing more than 800 millions of tons of mixture water-steam, the pressure drawdown is causing the influx of cool water toward the reservoir, several authors (Grant et al., 1984, Truesdell et al., 1975, Mercado, 1975) have been indicated the influx of cool water from the west part of the CP I area (Fig. 3). Besides a considerable amount of cool water from aquifer located in southwest of the field is feeding the CP I reservoir (Truesdell et al., 1990, Mercado, 1975).

Mercado, 1975, pointed out a recharge observed in the earlier develop of this Cerro Prieto area, when only have a few production wells produced.

The α reservoir is connected to cold water aquifers laterally in the W and S and the top through fault L. providing a “leaky cap” (Grant and O´Sullivan, 1982).

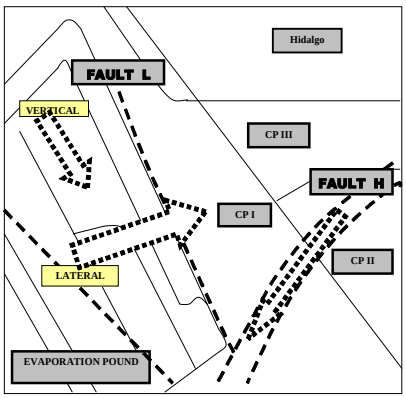

Figure 3 – Cerro Prieto I recharge inferred directions

The β reservoir also has lateral connection to cooler aquifer to the SW and SE (Grant et al., 1984).

Rodriguez, et al., (2000), realized the following observation related to present recharge direction:

- A cool water lateral recharge (low temperature) from west to Cerro Prieto I reservoirs, through α_N and upper zone of $\beta 1_N$.

- A cool water recharge (low temperature) from upper aquifer maybe induced by the high vertical permeability in the zones of fault Cerro Prieto and fault L.

CONCLUSION

Cerro Prieto I area, is the oldest zone more exploited in Cerro Prieto geothermal field, it started the commercial production in 1973, to present more than 800 million of mixture of water-steam have been extracted from this zone, it have been causing reservoir pressure drawdown and consequent influx of cool water.

The analysis of the geochemical and production data of Cerro Prieto I wells, showed during earlier exploitation stage a cool water recharge from west and southwest.

After 30 years of production static temperature logs realized in some wells located in alpha and beta reservoir showed temperature decreased about 50 °C approximately, it is a clear evidence of the influx of cool water to reservoir, this temperatures decreasing have been mentioned by several authors using geochemical data. If we considered this decreasing temperature value as representative of the CPI reservoir it corresponds to 1.67 ^{0}C/year of production.

The recharge of cool water toward the CP I reservoirs have been identified from west lateral and upper vertical.

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